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Federal Lands Highway

Project Development and Design Manual

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Federal Lands Highway

"Commitment to Excellence"

U.S. Department of Transportation
Federal Highway Administration

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1.1 GENERAL

This manual has been developed to provide information and guidance to engineering staffs involved with project development and design of highways. It will identify those standards, specifications, guides, and references approved for use in carrying out the highway and bridge design responsibilities in the Federal Lands Highway (FLH) Program.

One primary goal of the FLH Program is to design safe, cost effective, and environmentally sound highways and roads to serve our nation's Federal Lands. To assist in achieving this goal, the Project Development and Design Manual (PDDM) has been developed.

The manual supplements Federal laws and regulations relative to the development and design of highways. It is intended to be used with current engineering practices and procedures issued by the Federal Highway Administration (FHWA), the American Association of State Highway and Transportation Officials (AASHTO), State highway agencies, and Federal Land Management agencies.

A. Background. Approximately one-third of the total land area of the United States is owned or controlled by the Federal Government. One of the worlds largest highway networks has been constructed to serve these Federal lands.

Several Federal agencies are responsible for managing public lands and consequently are also responsible for managing a part of this vast network of Federal roads. The role of the Federal Highway Administration (FHWA) and its Federal Lands Highway Office (FLHO) in designing and constructing highway facilities on Federal lands is well defined in existing legislation and supplemental National interagency agreements.

In 1893, legislation established the *Office of Road Inquiry* within the Department of Agriculture. This office was not initially created to build highways but to provide the lead in research and development of new methods and techniques for road construction. Assistance and technical information were provided the local and State agencies responsible for road construction. However, short demonstration projects approximately 0.4 km in length and called *object lesson roads* were built by FLH forces to promote the most recent technology of the time for the construction of surfaced, all-weather roads.

In 1905 the *Office of Road Inquiry* became the *Office of Public Roads.* In 1918, the office became the *Bureau of Public Roads* and in 1967 became the *Federal Highway Administration.*

In 1982, the Surface Transportation Assistance Act (STAA) created the Federal Lands Highway Program. The STAA annually authorized, out of the Highway Trust Fund, $250 million in fiscal year (FY) 1983 and $300 million in each FY from 1984 through 1986. With the initiation of this program came increased responsibility upon the Federal Lands Highway Programs (FLH Program) to assist the Federal land managing agencies in the application of uniform policies for highway planning, design, construction, maintenance, and safety.

In 1987, the Surface Transportation and Uniform Relocation Assistance Act was enacted. It continued the Federal Lands Highway Program but reduced the FY authorizations from the previous $300 million to $235 million. This act provided funding for highways from FY 87 through FY 91. The Intermodal Surface Transportation Efficiency Act (ISTEA) of 1991 extended the Federal Lands Highway program through FY 97. The act authorized funding of $371 million in FY 92, $445 million in FY 93 through FY 95, and $447 million in FY 96 and FY 97. The Public Lands Highway category under the act incorporates the previous Forest Highway category. Within this manual, Forest Highways and Public Lands Highways are used interchangeably.

In 1986, the Department of Transportation (DOT) approved the reorganization of the *Office of Direct Federal Programs* within FHWA to become the *Federal Lands Highway Office (FLHO).* This office administers the Federal Lands Highway Program, the Emergency Relief Program on Federally owned roads, and the Defense Access Road Program. It also administers training and development programs and provides engineering services to other Federal and State agencies and foreign countries. See Exhibit 1.1 for a geographical breakdown of Federal Lands Highway division offices.
For more than 90 years, FLHO and its predecessor offices have offered their expertise to other Government agencies for the planning, location, design, and construction of highways, parkways, roads, and trails in the Federal domain. Many foreign countries have also been assisted in the development and construction of road systems.

B. Format. This manual consists of eleven chapters in electronic form. Generally each Chapter is located in a separate electronic file in a format compatible with WordPerfect 6.1 for Windows. (Note: Due to the large file space required by graphical Exhibits in Chapters 6 and 9, they are located separately in each Division's CADD system in MicroStation format. The initial distribution of these graphics outside FLH will be "hard copies.") Each chapter has its own table of contents and is subdivided into sections. The last section in each chapter has been reserved for special Division office supplemental procedures. Division procedures may be separate hard copy or electronic files.

C. Revisions. FLHO is responsible for maintaining the manual. Periodically, selected chapters will be reviewed for adequacy and to determine if there is need for revisions. Policy changes and new technology will also require chapters to be revised.

The following process shall be used for updating information in the manual:

1. The FLHO or a Division office may propose revisions at any time. Divisions shall submit their proposal to FLHO for consideration. If FLHO determines the manual should be revised, it will make the revisions, or work with the Divisions to have the preparatory work be done by consultant or one of the Division offices.

2. Once revised, the FLHO will distribute copies to each division, requesting comments. When appropriate, comments may also be requested from other FHWA offices and from private industry.

3. The FLHO will approve and issue revisions after resolving any comments. If revisions are minor or not controversial, FLHO may approve and issue revisions without distribution for comments.

4. All changes to the manual chapters and sections (except sections reserved for Division procedures) shall be issued by FLHO. Each revision shall be distributed by a sequentially numbered transmittal memorandum. Transmittal Memorandum Number 7 shall transmit the original metric version of manual Chapters 1 through 11.

1.1 General. (continued)

5. The revisions shall be distributed electronically. No hard copies will normally be included. Revisions shall be of a type style as the original manual. The revised file (generally an entire chapter) shall be identified by including the transmittal number and the revision date at the bottom of each page to the left of the page number. In addition a history of Transmittals will be attached as a separate file to insure users have received all previous revisions.

FLHO will be responsible for distribution to other FHWA offices and Partner agencies. Each FLHD office is responsible for the distribution of the manual and supplements within their jurisdiction.

The most efficient medium for distributing and updating the PDDM is exepected to change rapidly in the future. It is planned to send the initial copy on CD ROM to each Division and agency. Updates will likely be by E-mail or floppy disk in the near future. Eventually, it is proposed to update the PDDM by keeping the current files(s) available on the Internet. This should minimize distribution difficulties with outside users such as A/E firms and other Federal agencies.

A Record of Holders should be kept by each Division providing copies to others to insure updates are distributed. It is the responsibility of each Division to develop a process to insure receipt of revisions which need to be included in manuals being held by A/E firms working on active contracts.
Supplements added to the section reserved for Federal Lands Highway Division office procedures shall be issued by the appropriate office in a compatible format. The electronic versions should be identified by divisions reference at the bottom of each page as noted below:

- Eastern Federal Lands Highway Division - (EFLHD).

- Central Federal Lands Highway Division - (CFLHD).

- Western Federal Lands Highway Division - (WFLHD).

Informational electronic copies of Division supplements shall be distributed to the other Division offices and FLHO on a routine basis upon issuance.

Each user of this manual can contribute to its continuing improvement and is encouraged to submit suggestions to make it more useful and practical.

1.2 GUIDANCE AND REFERENCES

Applicable laws are set forth in Title 23, United States Code (U.S.C.) - Highways. The governing regulations are found in Title 23, Code of Federal Regulations (CFR). Policies and guidelines are contained in the *Federal-aid Policy Guide* , the *Federal Lands Highway Manual*, national and project interagency agreements, and AASHTO or other recognized publications.

A. Code of Federal Regulations (CFR). The *Code of Federal Regulations* is a codification of the general and permanent rules published in the *Federal Register* by agencies of the Federal Government. The code is divided into 50 titles representing broad areas of Federal regulations. Title 23 CFR, Highways, is the volume representing those current regulations applicable to the Federal Highway Administration and the FLH Program. The following are the parts of 23 CFR that are most relevant to the development and design of highways:

- Part 620, Subpart A. *Highway Improvements in the Vicinity of Airports.*
- Part 625. *Design Standards for Highways*.
- Part 630. *Preconstruction Procedures*.
- Part 650. *Bridges, Structures and Hydraulics*.
- Part 652. *Pedestrian and Bicycle Accommodations and Projects*.
- Part 655. *Traffic Operations*.
- Part 660. *Special Programs (Direct Federal) Forest Highways and Defense Access Roads*.
- Part 668, Subpart B. *Emergency Relief Program Procedures for Federal Agencies for Federal Roads*.
- Part 752. *Landscape and Roadside Development*.
- Part 771. *Environmental Impact and Related Procedures*.
- Part 772. *Procedures for Abatement of Highway Traffic Noise and Construction Noise*.

B. Federal-aid Policy Guide (FAPG). The FAPG consists of 2 volumes containing FHWA's current policies, procedures, standards, and guides relating to the Federal-Aid Highway Program. The manual also contains program directives relative to administration of the Federal Lands Highway program.

C. Federal Lands Highway Manual (FLHM). The manual is a one-volume book of documents developed by the Federal Lands Highway Office to consolidate all basic policies, directives, standards, and guides pertaining to the Federal Lands Highway operations into a single resource publication for ease of use and reference.

D. National Interagency and Project Agreements. Agency agreements are required whenever FHWA performs work for another agency or when work is performed by another agency with funds administered by FHWA. National agreements have been executed between FHWA and principal Federal land management agencies — National Park Service (NPS), Forest Service (FS), Bureau of Indian Affairs (BIA), Bureau of Land Management (BLM). Project agreements are executed between Division offices and another agency to detail project specifics that cannot be covered by a national agreement, such as project funding, length, geometrics, right-of-way acquisition, utility relocation, and construction and maintenance responsibilities. Agreements are discussed in Chapter 2.

E. American Association of State Highway and Transportation Officials (AASHTO) Policy and Guides. AASHTO was organized in 1914 and is composed of representatives from all 50 State highway transportation departments, the Commonwealth of Puerto Rico and the Northern Mariana Islands, the District of Columbia, 6 Canadian Provinces and 2 Territories, and the Federal Highway Administration.

The organization brought together Federal, State, and other highway engineers for discussion of problems, planning of concerted action and adoption of uniform practices. Its avowed objective is to foster the development, operation, and maintenance of a nationwide integrated system of highways to adequately serve the transportation needs of our country.

AASHTO publishes specifications, guides, and standards on highway design and construction that generally prescribe good practices or criteria considered adequate to provide safe and cost-effective highway facilities. These approved standards and guides as listed herein are to be used in conjunction with this manual. Design standards for highways are listed in Part 625 of 23 CFR.

F. Other Guides. Other acceptable guides and publications may be referenced in specific chapters. Publications referenced in this manual are available for use within in each Division office.

G. References. The publications listed in this section provided much of the fundamental source information used in the development of this manual. Additional reference documents may also be identified in individual chapters.

Standard Specifications for Construction of Roads and Bridges on Federal Highway Projects, (FP-96). DOT, FHWA. 1996.

Park Road Standards. U.S. Department of the Interior, National Park Service. 1984.

Standard Highway Alphabet. DOT, FHWA. 1977 metric edition.

Standard Highway Signs. DOT, FHWA. 1979.

Traffic Control Devices Handbook. DOT, FHWA. 1983.

Manual on Uniform Traffic Control Devices for Streets and Highways (MUTCD). DOT, FHWA. 1988.

A Policy on Geometric Design of Highways and Streets (generally called the Green Book). AASHTO. 1994.

Roadside Design Guide. AASHTO, 1989.

Designing Safer Roads, Practices for Resurfacing, Restoration, and Rehabilitation, Special Report 214, TRB, 1987.

Standard Specifications for Structural Supports for Highway Signs, Luminaires, and Traffic Signals. AASHTO. 1994

Materials Manual. Parts I and II. AASHTO. 1986.

A Guide to Standardized Highway Barrier Hardware. ARTBA Technical Bulletin No. 268B. American Road and Transportation Builders Association. 1995.

Erosion and Sediment Control on Highway Construction Projects, FHWA, 23 CFR Part 650, Subpart B, Pavement Design, FHWA, 23 CFR Part 626.

1.3 LAND MANAGEMENT AGENCIES

Land management agencies are Federal agencies established under laws and regulations and delegated the authority to administer and manage the vast national resources on federally owned or controlled lands within the United States and its territories. They have the responsibility for constructing and maintaining a public roads system within these lands.

The four principal land management agencies involved with the Federal Lands Highway Program are as follows:

- National Park Service
- Forest Service
- Bureau of Indian Affairs
- Bureau of Land Management

The FLHO also works, on a smaller scale, with other Federal and State government agencies upon request.

FLH's mission when working with these land management agencies usually entails all phases of project development and design. The legal authorization permitting the FLHO to design and construct highways serving Federal lands is contained in 23 U.S.C. 202, 204, and 308.

A. National Park Service (NPS). The NPS is an agency of the U.S. Department of Interior responsible for presiding over all national parklands, recreational areas, monuments, military parks, historical sites, seashores, lakeshores, and parkways.

The national park system encompasses more than 8.7 million hectares of Federal lands that are noted for their scenic beauty or historical significance. The system contains some 13 000 kilometers of park roads and parkways.

Under the authority prescribed in 23 U.S.C. 202, 204, 308 and in the Memorandum of Agreement between the NPS and the FHWA, the procedures are established defining responsibilities of each organization relative to the project development and construction of park roads and parkways. See FAPG G6090.13.

B. Forest Service (FS). The FS is an agency of the U.S. Department of Agriculture whose primary responsibility is the protection and multiple use management of land and resources within the National Forest System as set forth in the National Forest Management Act of 1976 (16 U.S.C. 1609).

The National Forest system contains approximately 39 000 kilometers miles of Forest Highways and 500 000 kilometers of Forest Development Roads (FDR) with some 48 000 kilometers of these FDR's maintained for public passenger car use.

Under the authority prescribed in 23 CFR 660 and in the Memorandum of Understanding executed between the FS and the FHWA, the procedures are established for coordinating project development applicable to Public Lands Highways.

Title 23 U.S.C. 308 establishes the foundation for FHWA's participation in the location, design and/or construction of forest development roads and trails when such activities are requested by the Forest Service.

C. Bureau of Indian Affairs (BIA). The BIA is an agency of the U.S. Department of the Interior with the primary responsibility for constructing and maintaining a system of public roads located within or providing access to an Indian reservation, Indian trust land, or restricted Indian land, which is not subject to fee title alienation without the approval of the Federal Government. The system includes approximately 39 000 kilometers of roads.

Under the authority prescribed in Title 23 U.S.C. 204, 308, and in the Memorandum of Agreement between the BIA and FHWA, the Federal Lands Highway Divisions may perform any or all phases of project development as set forth in individual project agreements executed between BIA and the appropriate division. See FAPG G6090.17.

D. Bureau of Land Management (BLM). The BLM is an agency in the U.S. Department of Interior. It was formally known as the Grazing Agency and until after the turn of the century was responsible for the management of all Federal lands. The BLM is still landlord of the largest domain of Federal land in the United States and has over 160 million hectares under its jurisdiction with a major portion of these lands located in the Western States.

The BLM is also responsible for the administration of revested Oregon and California (O&C) Railroad land grants, and reconveyed Coos Bay Wagon Road grant lands in Oregon. Under Public Law 759 dated September 6, 1950, the BLM is required to develop, construct, and maintain a system of timber access roads within or providing access to these 0&C lands. This road system at present contains some 48 000 kilometers of roads. The Division offices of FLHO are occasionally requested to provide engineering and technical services to assist in this road program.

This vast area contains approximately 106 000 kilometers of federally owned roads (including the O&C roads) which must be managed and maintained. Under the Authority prescribed in Title 23 U.S.C. 214 and 308, the FHWA and BLM cooperate in the design and construction of these public land development roads and trails.

E. Other Agencies. In addition to the primary land management agencies, FHWA, when requested, cooperates and works with other Federal agencies such as the Department of Defense, Federal Aviation Administration, Metropolitan Washington Airports Authority, Federal Railroad Administration, Corps of Engineers, Bonneville Power Administration, U.S. Fish and Wildlife, Immigration and Naturalization Service, and others.

FHWA also provides assistance to State agencies as well as to the FHWA-owned Turner Fairbank Highway Research facility in McLean, Virginia on an as-requested basis.

1.4 GLOSSARY

The following is a list of abbreviations and word/phrase definitions used throughout the manual. Additional acronyms and terms will be identified in individual chapters.

A. Abbreviations. Whenever these abbreviations are used, they will have the following meaning.

AA - Aluminum Association

AASHTO - American Association of State Highway and Transportation Officials

ACHP - Advisory Council on Historic Preservation

ACI - American Concrete Institute

ACSM - American Congress on Surveying and Mapping

ADT - Average Daily Traffic

AISI - American Iron and Steel Institute

APC - Action Plan Committee

ARTBA - American Road and Transportation Builders Association

ASA - American Standards Association

ASCE - American Society of Civil Engineers

ASLA - American Society of Landscape Architects

ASP - American Society of Photogrammetry

ASTM - American Society for Testing and Materials

AWPA - American Wood Preservative Association

AWS - American Welding Society

BIA - Bureau of Indian Affairs

BLM - Bureau of Land Management

BMPs - Best Management Practices

CADD - Computer Aided Design and Drafting

CE - Categorical Exclusion

CEQ - Council on Environmental Quality

CFLHD - Central Federal Lands Highway Division

CFR - Code of Federal Regulations

DHV - Design Hourly Volume

DOI - Department of the Interior

DOT - Department of Transportation

DTM - Digital Terrain Model

EA- Environmental Assessment

EDM - Electronic Distance Measuring

EFLHD - Eastern Federal Lands Highway Division

EIS - Environmental Impact Statement

EPA - Environmental Protection Agency

ERFO - Emergency Relief Federally Owned Programs

FAA - Federal Aviation Administration

FAR - Federal Acquisition Regulations

FEMA - Federal Emergency Management Agency

FHWA - Federal Highway Administration

FLHO - Federal Lands Highway Office

FONSI - Finding of No Significant Impact

FP-XX - Book of Standard Specifications for Construction of Roads and Bridges on Federal Highway Projects (The year of issuance 19XX or 20XX)

FS - Forest Service

FWS - Fish and Wildlife Service

GEOPAK - Software program for IHDS

HUD - Housing and Urban Development

IHDS - Interactive Highway Design System

IRR - Indian Reservation Road

MUTCD - Manual on Uniform Traffic Control Devices for Streets and Highways

MWAA - Metropolitan Washington Airports Authority

NBS - National Bureau of Standards

NCHRP - National Cooperative Highway Research Program

NEPA - National Environmental Policy Act

NGS - National Geodetic Survey

NHTSA - National Highway Traffic Safety Administration

NMFS - National Marine Fishery Service

NOAA - National Oceanic and Atmospheric Administration

NPS - National Park Service

NRCS - Natural Resources Conservation Service

OCZM - Office of Coastal Zone Management

OSHA - Occupational Safety and Health Administration

PCA - Portland Cement Association

PCI - Prestressed Concrete Institute

PRES - Parkwide Road Engineering Studies

PRMS - Program and Resource Management System

PS&E - Plans, Specifications and Estimates

RDG - Roadside Design Guide, AASHTO, 1988

RDS - Roadway Design System

ROD - Record of Decision

RRR - Resurfacing, Restoration, and Rehabilitation

SCS - Former Soil Conservation Service - now the Natural Resources Conservation Service

SEE - Social, Economic, and Environmental

SHA - State Highway Agency

SHPO - State Historic Preservation Office

SNRA - State Natural Resources Agency

SSPC - Steel Structures Painting Council

TAM - Department of Transportation Acquisition Manual

TAR - Department of Transportation Acquisition Regulations

TCP - Traffic Control Plan

U.S.C. - United States Code

UMTA - Urban Mass Transportation Administration

USACE - United States Army Corps of Engineers

USCG - United States Coast Guard

USDA - United States Department of Agriculture

VPH - Vehicles per Hour

WFLHD - Western Federal Lands Highway Division

B. Definitions. The following terms are used throughout this manual:

« A »

Acceleration Lane - A speed change lane to enable a vehicle entering a roadway to increase its speed to merge with through traffic.

Accuracy - The degree of agreement between a measured value and its established true value.

Aeolian Deposits - Wind deposited material such as dune sands and loess deposits.

Aesthetics - A branch of philosophy dealing with beauty and the beautiful and judgments of taste concerning them. In highway engineering, aesthetic judgments have to do primarily with the highway as a whole and the roadsides, and includes screening out unpleasant views.

Aggradation - General and progressive raising of the streambed by deposition of sediment.

Alkalinity - The degree of strength of an alkali. A liquid is said to be alkaline if it has a pH factor greater than seven.

Alluvial - Deposits of alluvium such as silts, sands, gravels or similar material that has been transported by running water.

Alternating Bars - Alternating bars tend to be distributed periodically along a channel, with alternate bars near opposite channel banks. Their lateral extent is significantly less than the channel width. Alternating bars move slowly downstream.

Anabranch - A diverging branch of a river which re-enters the main stream.

Angle of Internal Friction - The angle whose tangent is the ratio between the resistance offered to sliding along any plane in the soil and the component of the applied force acting normal to that plane. Values are given in degrees.

Angle of Repose - The angle between the horizontal and the maximum slope that a soil assumes through natural processes.

Anhydrous - Free from water.

Annual Flood - The highest peak discharge in a water year.

Arbitrary Coordinate System - A system of coordinates based upon an arbitrarily chosen origin. Used when established coordinate systems are not available. Sometimes called *assumed coordinate system*.

Architectural Features - As used in roadside enhancement, these may include stepped retaining walls to minimize the visual impact of massive walls, rock sculpturing to blend disturbed areas into the natural terrain, and special treatment of bridge abutments and culvert headwalls to blend them into the landscape.

Area-Capacity Curve - A graph showing the relation between the surface area of the water in a reservoir and the corresponding volume.

Auxiliary Lane - The portion of the roadway adjoining the traveled way for weaving, truck climbing, speed changing, or for other purposes supplementary to through-traffic movement.

Average Daily Traffic (ADT XXXX) - (1) The current or projected average two-way daily traffic for a specified year. (2) (ADT YY) The projected average two-way daily traffic for a specified future period, usually 20 years.

Average Discharge - In the annual series of the geological survey's reports on surface-water supply, the arithmetic average of all complete water years of record whether or not they are consecutive.

Average Highway Speed - The weighted average of the design speeds within a highway section when each subsection within the section is considered to have an individual design speed.

Average Initial Horizontal Illuminance - The average level of horizontal illuminance in the pavement area of a traveled way at the time the lighting system is installed, when lamps are new and luminaires are clean. This level is expressed in lux (lumens per square meter of horizontal surface).

« B »

Backfill - Material used to replace, or the act of replacing material removed during construction; also denotes material placed, or the act of placing material adjacent to structures.

Backslope - In cuts, the slope from the bottom of the ditch to the top of the cut.

Backwater - Water backed up or retarded in its course as compared with its normal or natural condition of flow. In stream gaging, a rise in stage produced by a temporary obstruction (such as ice or weeds) or by the flooding of the stream below. The difference between the observed stage and that which is indicated by the stage discharge relation is reported as backwater.

Bankfull Stage - Stage at which a stream first overflows its natural banks.

Bars - Bed forms having lengths of the same order as the channel width or greater, and heights comparable to the mean depth of the generating flow.

Bars, Transverse - Transverse bars occupy nearly the full channel width. They occur both as isolated and as periodic forms along a channel, and move slowly downstream.

Bars, Tributary - Tributary bars occur immediately downstream from points of lateral inflow into a channel. In longitudinal sections, bars are approximately triangular, with long gentle upstream slopes and short downstream slopes that are approximately the same as the angle of repose of the bed material. Bars generated by high flows frequently appear as small islands during low flows. Parts of the upstream slopes of bars are often covered with ripples or dunes.

Base Course - The layer, or layers, of specified or selected material of designed thickness placed on a subbase or a subgrade to support a surface course.

Base Discharge - In the Geological Survey's annual reports on surface-water supply, the discharge above which peak discharge data are published. The base discharge at each station is selected so that an average of about three peaks a year will be presented.

Base Runoff - Sustained or fair weather runoff. In most streams, base runoff is composed largely of ground-water effluent. The term *base flow* is often used in the same sense as base runoff.

Basic Capacity - The maximum number of passenger cars that can pass a given point on a lane or roadway during 1 hour under the most nearly ideal roadway and traffic conditions that can be attained.

Basic Hydrologic Data - Includes inventories of features of land and water that vary only from place to place (topographic and geologic map are examples), and records that vary with both place and time. (Records of precipitation, streamflow, groundwater, and quality-of-water analyses are examples.) Basic hydrologic information is a broader term that includes surveys of the water resources of particular areas and a study of their physical and related economic processes, interrelations, and mechanisms.

Bed Load - Sediment that moves by rolling, sliding, or skipping along the bed and is essentially in contact with the stream bed.

Bedrock - Rock of relatively great thickness and extent in situ.

Bench Mark - A temporary or permanent marker of known elevation with reference to a specific datum plane.

Bore (Hydraulic Bore) - A wave of water having a nearly vertical front, such as a tidal wave; a wave advancing downstream as the results of a cloudburst or the sudden release of a large volume of water as from a reservoir.

Braided Stream - A stream in which flow is divided as normal stage by small midchannel bars or small islands. This type of stream has the aspect of a single large channel within which there are subordinate channels.

Brake Reaction Distance - The distance traversed by the vehicle from the instant the driver sights an object necessitating a stop to the instant the brakes are applied.

Braking Distance - The distance required to stop the vehicle from the instant brake application begins.

Breakaway (Yielding) Supports - A support for a roadside device that yields or collapses readily when struck by a vehicle.

Bridge - A single or multiple span structure, including supports, erected over a depression or an obstruction, such as water, highway, or railway and having an opening measured along the center of the roadbed of more than 6 meters

Broken Back Curve - An arrangement of curves in which a short tangent separates two curves in the same direction.

Bypass - A highway that permits traffic to avoid part or all of an urban area.

« C »

Cadastral - Pertaining to extent, value, and ownership of land. Cadastral maps show property corners and property boundaries.

Cadastral Survey - A survey made to determine the lengths and directions of boundary lines and the area of land bounded by these lines. It may also be a survey made to establish these boundary lines on the ground. Also known as a Property Survey.

Calcareous - Material containing or similar to calcium carbonate or lime.

Calendar Day - Any day shown on the calendar, beginning and ending at midnight.

California Bearing Ratio (CBR) - The ratio of the force required to penetrate a soil mass with a circular piston to the force required to penetrate a mass of high quality crushed stone with the same piston. The rate of penetration in both cases is identical.

Camber - A slight arch designed or built into a structure to compensate for the natural deflection after loading.

Candela (cd) - The unit of luminous intensity.

Capillary Moisture - Moisture that clings to soil particles by surface tension and reaches the particles by surface tension either when free water passes through the soil or by capillary attraction from a wetter stratum. Within limits, it can move in any direction.

Centerline - For a two-lane highway the centerline is the middle of the traveled way, and for a divided highway the centerline may be the center of the median. For a divided highway with independent roadways, each roadway has its own centerline.

Channel (Watercourse) - An open conduit either naturally or artificially created which periodically or continuously contains moving water, or which forms a connecting link between two bodies of water. River, creek, run, branch, anabranch, and tributary are some of the terms used to describe natural channels. Natural channels may be single or braided. Canal and floodway are some of the terms used to described artificial channels.

Channel Stabilization - Protection of open channels from excessive erosion and scour by channel lining. Linings may be flexible, such as rock riprap and vegetation, or of rigid concrete.

Channel Storage - The volume of water at a given time in the channel or over the floodplain of the streams in a drainage basin or river reach. Channel storage is great during the progress of a flood event.

Channelization - The separation of traffic flow into definite paths, by means of traffic markings or islands.

Channelized Intersection - A grade intersection where traffic is directed into definite paths by islands.

Check-Dam - A structure usually made of sod, rock, or stone, and placed in a watercourse to retard water flow, thereby reducing erosion.

Chute - A steep, inclined open channel (flume).

Clay - A fine-textured soil, usually plastic and sticky when wet, which usually breaks into hard lumps when dry. When the moist soil is pinched between the thumb and finger, it will form a long, flexible ribbon.

Clear Zone - That area along the side of the traveled way *(including the shoulder)* that is available for recovery of an errant vehicle.

Climbing Lane - An additional traffic lane provided for slow moving vehicles on the up-grade side of a highway.

Coefficient of Utilization (CU) - The ratio of the luminous flux (lumens) from a luminaire received on the surface of the roadway to the lumens emitted by the luminaires' lamp(s) alone.

Cohesionless Soil - A soil that, when unconfined, has little or no strength when air dried, and little or no cohesion when submerged. Sand is an example of cohesionless soil.

Cohesive Soil - A soil that when unconfined has considerable strength when air dried and that has significant cohesion when submerged.

Composite Hydrograph - A plot of mean daily discharges for a number of years of record on a single year time base for the purpose of showing the occurrence of high and low flows.

Compressibility - The property of a material that enables it to remain compressed after compaction.

Compressive Stress - The stress produced in a member when the forces acting on it tend to push the particles together.

Concordant Flows - Flows at different points in a river system that have the same recurrence interval, or the same frequency of occurrence. This term is most often applied to flood-flows.

Conservation Storage - Storage of water for later release for useful purposes (such as municipal water supply, power, or irrigation) in contrast with storage capacity used for flood control.

Consistency - The degree of cohesiveness or resistance to movement of constituent particles in a mass of material. Some of the terms used to express consistency are firm, hard, friable (easily crumbled), sticky, or soft.

Construction Survey - A survey executed to locate or lay out engineering works. In highway construction applications, this survey is used to set grading elevation stakes, reference points, slope stakes, and other such controls.

Contour - A line that depicts equal elevation on a land surface. The line representing this on a map.

Contour Grading Plan - A drawing showing an arrangement of contours intended to integrate construction and topography, improve appearance, reduce erosion, and improve drainage.

Contour Interval - The elevation difference between adjacent contours.

Contract Document Hierarchy - There are five essential parts to a contract and a requirement occurring in one is as binding as if occurring in all. They are intended to be complementary and to describe and provide for a complete work. In case of discrepancy, numerical dimensions will prevail over scaled dimensions and the parts of the contract will prevail in the following order:

(1) Contract Clauses, 48 CFR, Chapters 1 and 12.
(2) Special Contract Requirements.
(3) Plans.
(4) Supplemental Specifications.
(5) Standard Specifications (FP-XX).

Contraction - The reduction of a cross sectional area of a stream channel.

Control - A section or reach of an open conduit or steam channel which maintains a stable relationship between stage and discharge.

Control Data - The horizontal and vertical values used to define the relative position of a control point.

Control Point - An established point on the ground with known horizontal and vertical positioning. In highway surveying, this point is generally of second order accuracy. This point is normally used as a basis for gathering field measurements and placing construction stakes.

Control Survey - A survey made to establish the horizontal and vertical positions of a series of control points. In highway applications, a control survey is generally the first survey performed on a project. Other aspects of the surveying process base their measurements on the control points established during the control survey.

Conveyance - A measure of the carrying capacity of a stream or channel.

Cooperator - A State or local government agency that has jurisdiction over and/or maintenance responsibility for forest highways. (FAPG 23 CFR 660 A)

Coordinates - A set of numbers used in describing the location of a point on a surface or in space.

Corridor - A strip of land between two termini within which traffic, topography, environment, and other characteristics are evaluated for transportation purposes.

Crash Cushion (Impact Attenuator) - A device placed in front of a fixed roadside object to absorb and dissipate collision energy.

Creep - The slow movement of a material under stress, usually imperceptible except to observations of long duration.

Crest Vertical Curve - A vertical curve having a convex shape in profile.

Critical Flow - That flow in open channels at which the energy content of the fluid is at a minimum. Also, that flow which has a Froude number of one.

Critical Length of Grade - That combination of gradient and length of grade that will cause a designated vehicle to operate at some predetermined minimum speed.

Critical Slope - The gradient of a channel that sustains a given discharge at a uniform and critical depth. A grade less than critical is called a mild grade or slope whereas a steeper than critical slope is called a steep slope.

Critical Velocity - The velocity in an open channel or a partially filled conduit where the velocity head equals one-half the hydraulic mean depth.

Cross Section - The transverse profile of a road showing horizontal and vertical dimensions.

Crosswalk - Any portion of a roadway at an intersection or elsewhere distinctly indicated for pedestrian crossing by signs and by lines or other markings on the surface.

Crossing Sight Distance - A distance along an intersection approach leg such that vehicle operators can see other vehicles on crossroads in time to avoid collision.

Crown - The highest point of the surface of a tangent traveled way in cross section.

Crushed Gravel - The product resulting from the crushing of ordinary gravel with substantially all fragments having one or more faces resulting from fracture.

Crushed Stone - The product resulting from the crushing of fragments of bedrock or large stones with all fragments having all faces resulting from fracture.

Cubic Meters Per Second (m^3/s) - A unit expressing rates of discharge. One cubic meter per second is equal to the discharge of a stream of rectangular cross section (1 meter wide by 1 meter deep) that is flowing water at 1 meter per second.

Culture or Cultural Features - General term used in mapping to describe manmade features.

Culvert - Any structure that provides an opening under the roadbed but does not meet the classification of a bridge.

Curb - A structure with a vertical or sloping face placed on roadways to form islands, gutters, etc. and to protect pavement edges.

Current Meter - An instrument for measuring the speed of flowing water.

Curve Widening - The widening of the highway traveled way on sharp curves to compensate for the fact that the rear wheels of a vehicle do not follow exactly in the track of the front wheels.

Curvilinear Alignment - A flowing alignment in which the majority of its length is composed of circular and spiral curves.

« D »

Data Collector - A recording device that electronically records surveying measurements and field notes. The information stored in these collectors is downloaded into a computer for later processing.

Datum Plane - A reference plane to which vertical measurements and elevations are referred. Usually the datum plane (elevation 0.000) used is mean sea level.

Dead Storage - The volume in a reservoir below the lowest controllable level.

Deadman - A buried object serving as an anchor, such as a cable-guardrail guy anchors.

Deceleration Lane - A speed-change lane that enables a vehicle to slow to a safe exit speed when making an exit turn.

Decibel (Db) - The unit for measuring the intensity of sound. When A-weighting is used, this unit is abbreviated as dBA.

Deciduous - Having leaves that are shed at the end of the growing season; opposite of evergreen.

Degradation - General and progressive lowering of the longitudinal profile of a channel by erosion.

Delineator - A visual device for defining the alignment of a roadway.

Dense Graded - A well-graded aggregate with sufficient fine material to nearly fill all voids.

Depletion - The progressive withdrawal of water from surface or ground-water reservoirs at a rate greater than that of replenishment. (See recession curve and streamflow depletion.)

Depression Storage - The volume of water contained in natural depressions in the land surface, such as puddles.

Design Capacity - The practical capacity or lesser value determined for use in designing the highway to accommodate the design volume.

Design Discharge - The discharge a culvert is designed to pass. This discharge depends on the recurrence interval of the design flood, which in turn depends on the importance of the road, and the characteristics of the watershed.

Design Headwater - The elevation of culvert inlet ponding above the culvert invert, for a given storm interval, culvert type, size, and discharge.

Design Hourly Volume (DHV) - The future two-way hourly traffic volume for use in design, usually the 30th highest hourly volume of the design year (30 HV).

Design Lane - The lane on which the greatest number of equivalent 80 kN , single-axle loads is expected. Normally, this will be either lane of a two-lane highway or the outside lane of a multilane highway.

Design Load - The loads that must be supported by a structure.

Design Noise Levels - The noise levels that represent the upper limit of acceptable traffic noise established for various activities or land uses. These levels are used to determine the degree of impact of traffic noise on human activities.

Design Speed - A speed selected for purposes of design and correlation of the geometric features of a highway and a measure of the quality of service offered by the highway. It is the highest continuous speed where individual vehicles can travel with safety upon a highway when weather conditions are favorable, traffic density is low and the geometric design features of the highway are the governing conditions for safe speed.

Design Thickness - The total thickness of the pavement structure determined from the thickness design charts as adequate for a given total 80 kN equivalent single axle loads soil strength value.

Design Vehicle Turning Radius - The turning radius of a Design Vehicle used primarily to determine the minimum radius used in the design of turning and intersecting roadways.

Design Year - The future year used to estimate the probable traffic volume for which a highway is designed. A time 10 to 20 years from the start of construction is usually used.

Dike - An embankment to confine or control water, especially one built along the banks of a river to prevent overflow of low lands or to deflect water away from a bank. Also called levee.

Dike, Finger - Relatively short embankments constructed normal to a larger embankment, such as an approach fill to a bridge. Their purpose is to impede flow and direct it away from the major embankment.

Dike, Spur - Relatively short embankments constructed at the upstream side of a bridge end for the purpose of aligning flow with the waterway opening and to move scour away from the bridge abutment.

Dike, Toe - Embankments constructed to prevent lateral flow from scouring the corner of the downstream side of an abutment embankment. Sometimes referred to as training dikes.

Dike, Training - Embankment constructed to provide a transition from the natural stream channel or floodplain, both to and from a constricting bridge crossing.

Dip (Low Water Crossing) - A road stream crossing designed to allow occasional flooding. The road grade is lowered to stream bed level from bank to bank.

Direct Runoff - The runoff entering stream channels promptly after rainfall or snowmelt. Superposed on base runoff, it forms the bulk of the hydrograph of a flood. See also surface runoff. The terms base runoff and direct runoff are time classifications of runoff. The terms ground-water runoff and surface runoff are classifications according to source.

Direct Shear Test - A shear test in which soil under an applied normal load is stressed to failure by moving one section of the soil container relative to the other section.

Discharge - The flow of water from a pipe, drain system or drainage basin.

Discharge Frequency - The runoff that can be expected to occur during the life of a highway. Design may be on a 10, 25, 50, or 100-year flood.

Discharge Rating Curve - See *stage-discharge relation*.

Diversion - The taking of water from a stream or other body of water into a canal, pipe, or other conduit.

Divided Highway - A highway with separated roadways for traffic in opposite directions.

Divisional Island - A longitudinal island to separate opposing traffic, to provide protection for left turn bays, and to channel traffic into the proper approach paths at skewed intersections.

Dormant Stage - The period in plant life when seasonal growth ceases.

Drainage Area - The drainage area of a stream at a specified location in that area, measured in a horizontal plane and enclosed by a drainage divide.

Drainage Basin - The part of the surface of the earth that is occupied by a drainage system consisting of (1) a surface stream or (2) a body of impounded surface water together with all tributary surface streams and bodies of impounded surface water.

Drainage Divide - The rim of a drainage basin.

Drawdown - The difference in elevation between the water surface elevation at a constriction in a stream or conduit and the elevation that would exist if the constriction were absent. Drawdown also occurs at changes from mild to steep channel slopes and at weirs or vertical spillways.

Driveways - Minor roadway connections that fall into three categories: private, commercial, and public.

Dune - A sand wave of approximately triangular cross section (in a vertical plane in the direction of flow) formed by moving water or wind, with gentle upstream slope and steep downstream slope. Dunes travel downstream by the movement of sediment on the upstream slope and deposition on the downstream slope.

Dynamic Equilibrium - That delicate balance of the many factors which must occur in a stream reach so that the channel is neither aggrading nor degrading.

« E »

Ecology - The branch of science concerned with the relationship of organisms and their environment.

Effluent - Sewage, water, or other liquid, partially or completely treated or in its natural state flowing out of a reservoir, basin or treatment plant.

Elastic Limit - The greatest stress that a material is capable of sustaining without any permanent deformation remaining upon complete release of the stress.

Elasticity - That property of a material that permits it to return approximately to its original dimensions upon the removal of an applied load.

Electronic Distance Measuring Instrument (EDM) - A device that transmits and receives a modulated microwave, infrared, or visible light signal and, by measuring phase differences between modulations of transmitted and reflected or retransmitted signals, computes the distance between the instrument and the reflector or retransmitter.

Elevation - The vertical distance of a point above mean sea level or above another datum.

Elongation - The increase in gage length of a tension test specimen, usually expressed as a percentage of the original gage length.

Embankment - A raised earth structure on which the roadway pavement structure is placed.

Embankment Foundation - The material below the original ground surface, the physical characteristics of which affect the support of the embankment.

Emergency Vehicle - (1) A vehicle belonging to the armed forces, civil defense, police. (2) Any ambulance rescue unit vehicle. (3) Any designated vehicle used for answering emergency calls for assistance.

Empirical - Developed from experience or observations without regard to science and theory.

Emulsified Asphalt - A mixture of asphalt cement and water mixed with an emulsifying agent.

Emulsified Asphalt Treated Base - A base consisting of a mixture of mineral aggregate and emulsified asphalt spread on a prepared surface to support a surface course.

Energy Dissipator - A riprap basin or concrete structure placed at the outlet end of a culvert to dissipate the stream energy and reduce scour and erosion.

Energy Grade Line - The line which represents the total energy gradient along the channel. It is established by adding together the potential energy (water surface elevation referenced to a datum) and the kinetic energy (usually expressed as velocity head) at points along the stream bed or channel floor.

Entrance Loss - The loss of energy at a culvert entrance due to the shape of the entrance.

Environment - The totality of man's surroundings -- social, physical, natural, and manmade.

Environmental Design - The location and design of a highway that includes consideration of the impact of the facility on the community or region based on aesthetic, ecological, cultural, sociological, economic, historical, conservation, and other factors.

Equivalent Single-Axle Load (EAL) - The effect on pavement performance of any combination of axle loads of varying magnitude, equated to the number of reference single-axle loads required to produce an equivalent number of repetitions of an 80 kN single axle.

Erosion - A slow wearing away of the surface by natural action of wind or water.

Estuary - That portion of a river channel occupied at times or in part by both sea and river flow in appreciable quantities. The water usually has brackish characteristics.

Euthrophic - A body of water rich in nutrients and characterized by a large quantity of planktonic algae.

Evapotranspiration - Water withdrawn from a land area by evaporation from water surfaces and moist soil and plant transpiration.

Excavation - (1) The act of taking out material. (2) The materials taken out. (3) The cavity remaining after materials have been removed.

Expressway - A multilane, divided highway designed to move large volumes of traffic at high speeds under free-flow conditions. Expressways have full control of access with grade-separated interchanges.

Expropriation - Acquisition of property for highway purposes by the right of eminent domain.

« F »

Federal Lands Highway Division - A Federal Lands Highway field office, responsible for the administration of the Federal Lands Highway program within a predetermined geographic area. See Exhibit 1.1.

- EFLHD - The Eastern Federal Lands Highway Division office headquartered in Sterling , Virginia.
- CFLHD - The Central Federal Lands Highway Division office headquartered in Denver, Colorado.
- WFLHD - The Western Federal Lands Highway Division office headquartered in Vancouver, Washington.

Federal Lands Highway Office (FLHO) - A FHWA headquarters office located in Washington, D.C. with the responsibility for the direct Federal program that is administered through division field offices.

Flexible Base - A base with low resistance to bending, enabling it to stay in contact with the underlying structure. This type of base distributes loads to the subbase. Examples are dense-graded aggregate bases and asphalt-treated bases.

Flexible Pavement - A pavement structure that maintains intimate contact with and distributes loads to the subgrade, and depends on aggregate intergranular particle friction, and cohesion for stability.

Flood - (1) An overflow or inundation that comes from a river or other body of water and causes or threatens damage. (2) A relatively high streamflow overtopping the natural or artificial banks in any reach of a stream. (3) A relatively high flow as measured by either gage height or discharge quantity.

Flood Exceedance Probability - Probability that a random event will exceed a specified magnitude in a given time period, usually 1 year unless otherwise indicated.

Flood Frequency - The average interval of time, based on the period of record, between floods equal to or greater than a specified discharge or height. Generally, this frequency is expressed in years.

Flood, Maximum Probable - The largest flood for which there is any reasonable expectancy in a given climatic era.

Flood Peak - The highest value of the stage or discharge attained by a flood; thus, *peak stage* or *peak discharge*. Flood crest has nearly the same meaning, but since it connotes the top of the flood wave, it is properly used only in referring to stage; thus, crest stage, but not crest discharge.

Flood Plain - Normally dry land areas that are adjacent to a natural stream or watercourse and that are temporarily inundated during floods.

Flood Routing - The process of determining progressively the timing and shape of a flood wave at successive points along the river.

Flood Wave - A distinct rise in stage culminating in a crest and followed by recession to lower stages.

Flood Zone - The land bordering a stream which is subject to floods of about equal frequency.

Floodway - (1) A part of the floodplain, otherwise leveed, reserved for emergency diversion of water during floods. (2) A part of the floodplain which, to facilitate the passage of floodwater, is kept clear of encumbrances.

Flow Line - The bottom of a streambed, culvert, ditch, or other watercourse.

Flow-Duration Curve - A cumulative frequency curve that shows the percentage of time that specified discharges are equaled or exceeded.

Flow Regime - The system or order characteristic of streamflow with respect to velocity, depth and specific energy.

Footing - Portion of the foundation of a structure that transmits loads directly to the soil.

Foreslope - The slope from the edge of the surfaced shoulder to the top of the subgrade, or the bottom of the ditch in cuts.

Foundation - Lower part of a structure that transmits loads directly to the soil.

Free Water - Water that can move through the soil by force of gravity.

Freeboard - The vertical distance between the level of the water surface at design flow and a specified point such as a bridge beam, levee top, or location on a highway grade.

Friable Soil - A soil that can be easily broken and crushed by moderate finger pressure.

Frontage Road - A road contiguous to a controlled access highway, so designed as to (1) intercept, collect, and distribute traffic desiring to cross, enter, or leave the controlled access highway and, (2) furnish access to adjacent property.

Froude Number (F_r) - A dimensionless expression of the ratio of inertia forces to gravity forces, used as an index to characterize the type of flow in a hydraulic structure in which gravity is the force producing motion and inertia the resisting force.

The Froude number for critical flow is one. Values greater than one indicate supercritical flow. Values less than one indicate subcritical flow.

$$F_r = \frac{V}{\sqrt{9.81y}} = \frac{V}{V_c}$$

where:

where:	V	=	mean, surface, or maximum flow velocity (m/s)
	V_c	=	critical velocity for channel and discharge (m/s)
	y	=	a characteristic dimension in meters, such as diameter or depth

Functional Classification - The grouping of individual roads in a road system according to their purpose and the type of traffic they serve.

« G »

Gage Height - The water-surface elevation referred to by some arbitrary gage datum. Gage height is often used interchangeably with the more general term stage, although gage height is more appropriate when used with a reading on a gage.

Gaging Station - A location on a stream where measurements of stage or discharge are customarily made.

Geodetic Control - Monument points of known horizontal and/or vertical position established by other agencies and published by NGS.

Geometric Design - The arrangement of the visible elements of a road, such as alignment, grades, sight distance, widths, slopes, etc.

Geotechnical Engineering - The application of scientific methods and engineering principles to the acquisition, interpretation, and evaluation of subsurface data to predict the behavior of the materials of the earth's crust. It encompasses the fields of soil mechanics, rock mechanics, geological engineering, geophysics, and related fields, such as pavement design.

Glare - The sensation produced by luminance within the visual field that is sufficiently greater than the luminance to which the eyes are adapted, thereby causing discomfort, or loss of visibility.

Global Positioning System (GPS) - A system of satellites which are used with accurate receiving equipment to determine survey coordinates.

Gradation - A general term used to describe the composition of an aggregate, soil, or other granular material. Gradation is usually expressed as the proportions (percents) of the aggregate that will pass each of several sieves of different sizes.

Grade - (1) The profile of the center of the roadway, or its rate of ascent or descent. (2) To shape or reshape an earth road by means of cutting or filling. (3) To arrange according to size. (4) Elevation.

Grade Contour - The trace of a predetermined grade plotted on a topographic map or traced on the ground by an Abney Level Line. For example, if the contour interval is 2 meters and the gradient 5 percent, the grade contour intersections with successive contours would be 40 meters apart.

Grade-Controlled Location - A section of highway where the highway route is controlled by the maximum allowable gradient and the difference in elevation between termini.

Grade Intersection - An intersection where all roadways join or cross at the same level.

Grade Separation - A structure that provides for highway traffic to pass over or under another highway or the tracks of a railroad.

Gradient - The rate of rise or fall with respect to the horizontal distance.

Grading - (1) Construction of the earthwork portion of the Highway. (2) Planing or smoothing the surface of various parts of a roadbed.

Gradually Varied Flow - Flow in which changes in depth and velocity take place slowly over large distances, resistance to flow dominates and acceleration forces are neglected.

Gravel - Aggregate composed of hard, durable stones or pebbles, crushed or uncrushed, often intermixed with sand.

Ground Control - An accurate ground survey of targets, or other features visible in aerial photographs, to ensure the accuracy of photogrammetric mapping.

Ground Cover - Herbaceous vegetation and low-growing woody plants that form an earth cover.

Ground Water - Free water contained in the zone below the water table. The source of water in wells, springs, etc.

Grout - Mortar, composed of sand, cement, and water, of such consistency that it can be easily worked.

Guardrail - A protective cable or rail device placed along the roadway edge for the purpose of redirecting vehicles that have left the roadway at a point of hazard.

Gunite - A type of portland cement mortar blown into place by compressed air. The materials are mixed while being forced through a nozzle.

Gutter - A paved and generally shallow waterway provided for carrying surface drainage.

« H »

Hardpan - A layer of extremely dense soil.

Head - The energy, either kinetic or potential, possessed by each unit mass of a liquid expressed as the vertical height through which a unit mass would have to fall to release the average energy possessed.

Headcutting - Progressive scouring and degrading of a stream bed at a relatively rapid rate in the upstream direction -- usually characterized by one or a series of vertical falls.

Headwall - A wall or structure constructed at the end of a culvert to prevent earth from spilling into the channel.

Headwater Depth - Culverts constrict the natural stream flow and cause a rise in the water surface at the culvert entrance. Headwater depth is the total flow depth from the inlet invert of the culvert to the water surface at the inlet.

Herbaceous - Vegetation that is nonwoody.

Hinge Point - Point where the slope rate changes.

Horizon (Soils) - One of the layers (strata) of the soil profile, distinguished principally by its texture, color, structure, and chemical contents.

Horizontal Curve - A circular curve or transitional by means of which a highway can change direction to the right or left.

Hot Mix - A general term used for hot plant mixed asphalt concrete mixtures manufactured and laid at temperatures ranging from $95^\circ C$ to $160^\circ C$.

Humidity (Relative) - The amount of moisture in the air compared with the amount that the air could hold if saturated at that temperature.

Humus - A brown or black material formed by the partial decomposition of vegetable or animal matter; the organic portion of soil.

Hydrated Lime - A dry powder obtained by treating quick-lime with enough water to satisfy its chemical affinity for water under the conditions of its hydration.

Hydrograph - A graph showing stage, flow, velocity, or other property of water with respect to time.

Hydrologic Cycle - (1) A convenient term to denote the circulation of water from the sea, through the atmosphere, to the land; and thence, with many delays, back to the sea by overland and subterranean routes, and in part by way of the atmosphere. (2) The many short circuits of the water that is returned to the atmosphere without reaching the sea.

Hydrology - (1) The science encompassing the behavior of water as it occurs in the atmosphere, on the surface of the ground, and underground. (2) The scientific study of the properties, distribution, and effects of water on the earth's surface, in the soil and underlying rocks, and in the atmosphere.

« I »

Igneous Rock - Those rocks formed by the cooling and consolidation of complex silicious solutions (magma) newly risen from some deeper level.

Illuminance - The density of the luminous flux incident on a surface; it is the quotient of the luminous flux divided by the area of the surface when the latter is uniformly illuminated.

Illuminance (Lux) Meter - An instrument for measuring the illuminance on a plane. The instrument is comprised of some form of photodetector, with or without a filter, driving a digital or analog readout through appropriate circuitry.

Impact Attenuator - A device placed in front of a fixed roadside object to absorb and dissipate collision energy.

Impervious - Resistant to the penetration of a liquid or gas.

Incised Channel - Those channels that have been cut relatively deep into underlying formations by natural processes. Characteristics include relatively straight alignment and high, steep banks such that overflow rarely occurs, if ever.

Independent Alignments - Each roadway of a divided highway is designed and located to take full advantage of the terrain. The median need not be of uniform width, and the two roadways need not be at the same level.

Indigenous - Produced, growing, or living naturally in a particular region or environment.

Infiltration - The flow of a fluid into a substance through pores or small openings. It connotes flow into a substance in contradistinction to the word percolation, which connotes flow through a porous substance.

Inlet Control - A culvert operates under inlet control when the flow capacity is controlled by headwater depth, culvert cross section, and inlet edge configuration.

Interchange - A system of interconnecting roadways in conjunction with one or more grade separations, providing for the movement of traffic between two or more roadways on different levels.

Internal Friction - The resistance to sliding within the soil mass.

Intersection - The area common to two or more highways that come together at an angle.

Intersection Angle - The angle between two intersection legs.

Inundate - To cover or fill, as with a flood.

Invert - The lowest point of the internal cross section of a closed conduit or channel.

Isolux Line - A line plotted on any appropriate coordinates to show all the points on a surface where the illuminance is the same. For a complete exploration, the line is a closed curve. A series of such lines for various illuminance values is called an isolux diagram.

« J K »

Karst Topography - Irregular topography characterized by sink holes, streamless valleys, and streams that disappear into the underground, all developed by the action of surface and underground water in soluble rock such as limestone.

« L »

Landscaping - Enhancing the natural features of the land through the design and use of vegetation and other materials.

Lane - A portion of the traveled way providing for a single line of traffic in one direction.

Left-Turn Lane - A traffic lane within the normal surfaced width of a roadway, or an auxiliary lane adjacent to or within a median, reserved for left-turning vehicles at an intersection.

Leveling Course - The layer of material placed on an existing surface to eliminate irregularities prior to placing an overlaying course.

Lime - A general term that includes the various chemical and physical forms of quicklime, hydrated lime, and hydraulic lime used for any purpose.

Lithology - A geological term dealing with the physical properties of rocks and their structure.

Loam - A mixture of sand, silt or clay, or a combination of any of these with organic matter. It is sometimes called topsoil in contrast to the subsoils that contain little or no organic matter.

Loess - A uniform windblown deposit of silty material having an open structure and relatively high cohesion due to cementation of clay or calcareous material at grain contacts.

Luminaire - A complete lighting unit consisting of a lamp or lamps together with the parts designed to distribute the light, to position and protect the lamps, and to connect the lamps to the power supply.

Luminance (L) - Luminance is the luminous intensity of any surface in a given direction per unit of projected area of the surface as viewed from that direction expressed in candelas per square meter (cd/m^2) .

« **M** »

Mannings Equation - An equation normally used to express the velocity of a uniform flow of water in a natural or manmade channel (i.e. culvert). See Appendix B in HDS publication No. 5 for Mannings equation and listing of commonly used roughness values.

Matting - Material used as a surface protector in conjunction with seeding that protects the surface until vegetation becomes established.

Meander - In connection with streams, a winding channel usually in an erodible, alluvial valley. A reverse of an S-shaped curve or series formed by erosion of the concave bank, especially at the downstream end, characterized by curved flow and alternating shoals and bank erosion. (Meandering is a stage in the migratory movement of the channel as a whole down a valley.)

Meander Plugs (Clay Plugs) - Deposits of cohesive materials in old channel bendways. These plugs are sufficiently resistant to erosion to serve as essentially semi-permanent geological controls to advancing channel migrations.

Meander Scroll - Markings resembling a partly unrolled sheet of paper or having a spiral or coiled form, which have been left on a floodplain as a result of the historic migratory movement of the channel.

Median - The portion of a divided highway separating the traveled ways for traffic in opposite directions.

Median Barrier - A longitudinal system used to prevent an errant vehicle from crossing the median of a divided highway.

Median Lane - A speed-change lane within the median to accommodate left-turning vehicles.

Microfilm - A photographic process by which plans, specifications, and other printed materials are greatly reduced in size for permanent storage, usually at a ratio of 24 to 1.

Mineral Filler - A fine inert mineral matter such as limestone dust or portland cement, used in asphalt concrete mixtures.

Minimum Turning Path - The path of a designated point on a vehicle making its sharpest turn.

Minimum Turning Radius - The radius of the path of the outer front wheel of a vehicle making its sharpest turn.

Modulus of Elasticity - The ratio of stress to strain for a material under given loading conditions.

Modulus of Rupture - A measure of the strength of concrete when it is broken by bending.

Moisture Content - The percentage, by mass, of water contained in soil or other material, usually based on the dry mass .

Monument or Reference Point - A permanent or semipermanent reference point set during the survey or construction of a highway so that the survey can be reestablished later.

Mortar - A mixture of cement, sand, lime/fly ash, and water.

Mountable Curb - One that can be readily traversed by a moving vehicle.

Muck - An organic soil of very soft consistency.

Mudflow - A well-mixed mass of water and alluvium which, because of its high viscosity and low fluidity as compared with water, moves at a much slower rate, usually piling up and spreading over the fan like a sheet of wet mortar or concrete.

Mulch - Material placed on exposed earth to provide more desirable moisture and temperature relationships for plant growth. It is also used to control the occurrence of unwanted vegetation.

« N »

National Geodetic Vertical Datum of 1929 -The average of the heights of the surface of the sea at all stages of the tides.

Noise Barrier - A barrier of earth, stone, concrete, or wood placed adjacent to the highway to reduce the noise level on abutting property.

Noise Level - The sound level obtained through the use of A-weighting according to ANSI Standard 1.4. The unit of measure is the decibel (dB), commonly referred to as DBA when A-weighting is used.

Nonuniform Flow - A flow in which the velocities vary from point to point along the stream or conduit, due to variations in cross section, slope, etc.

Normal Water Surface (Natural Water Surface) **-** The free surface associated with flow in natural streams.

Nutrient - Material that nourishes and promotes plant growth.

« O »

Open Channel - A natural or manmade path in which water flows with a free surface.

Open Channel Flow - Open channel flow may be uniform or nonuniform, steady or unsteady, and subcritical or critical. Of these, nonuniform, unsteady, and subcritical flow is the most common type of flow in open channels. However, to facilitate hydraulic computations, steady, uniform or gradually varied flow is generally assumed.

Open-Graded Aggregate - A graded aggregate, containing little or no fines, with a high percentage of aggregate voids.

Operating Speed - The highest overall speed, exclusive of stops, at which a driver can travel on a given highway under prevailing conditions without at any time exceeding the design speed.

Optimum - The best quantity, number, or condition.

Outlet Velocity - The speed of flow measured at the downstream end of a culvert and is usually higher than the maximum natural stream velocity.

Overburden - The mass of soil that overlies a source of rock, gravel, or other road material. This material is removed before the materials are quarried to avoid contamination.

Overland Flow - The flow of rainwater or snowmelt over the land surface toward stream channels. After it enters a stream, it becomes runoff.

Overlaying Course (Overlay) - An asphalt surface course, either plant mixed or road mixed.

Overlook (Scenic Overlook) - A roadside area provided for motorists to stop their vehicles primarily for viewing the scenery.

Overpass - A grade separation where the highway passes over an intersecting highway or railroad.

« P »

Parcel - A tract of private or public land of variable size required for the right-of-way for a highway.

Passing Opportunity - A section of two-lane highway where the clear passing sight distance allows a safe passing maneuver to be performed.

Passing Sight Distance - Minimum sight distance on 2-lane highways that must be available to enable the driver of one vehicle to pass another safely and comfortably, without interfering with the speed of an oncoming vehicle traveling at the design speed should it come into view after the overtaking maneuver is started.

Passive Pressure on Walls - The horizontal pressure exerted on the front of a wall by the earth load, or water, if present. Passive pressure opposes active pressure.

Pavement Structure - The combination of subbase, base course, and surface course placed on a subgrade to support the traffic load and distribute it to the roadbed.

Peat - A fibrous mass of organic matter in various stages of decomposition.

Pedestrian Crossing (Crosswalk) - An area reserved and clearly marked for the passage of pedestrians at street junctions or other locations where drivers must yield the right-of-way by stopping to enable pedestrians to cross safely.

Pedestrian Overpass (Underpass) - A facility for pedestrian crossings justified by the following: pedestrian crossing volumes, type of highway to be crossed, location of adjacent crossing facilities, and predominating type and age of persons who will utilize the facility.

Perception Time - The time required by a driver to perceive that a speed change or stop is necessary.

Permeability - The property of soils that permits the passage of any fluid and depends on grain size, void ratio, shape, and arrangement of pores.

Permissible Velocity - In stream flow, the greatest velocity that will not cause excessive erosion.

Pervious - A layer of material, through which water will move under ordinary hydrostatic pressure.

pH - A scale of numbers from 0 to 14 that indicate the acidity or alkalinity of a solution. Numbers below seven indicate acidity and numbers above seven alkalinity.

Phase - A part of a signal cycle during which a specific traffic movement (and concurrent nonconflicting movements) receives the right-of-way. It includes the change and clearance intervals associated with those movements.

Photoelectric Device - Where detection is accomplished by the vehicle passing between a source of light and a photocell that is capable of distinguishing between light and lack of light.

Photogrammetry - The science and art of obtaining reliable measurements by use of photographs. It produces dimensional data for mapping, cadastral purposes, design, and computation of quantities.

Physiographic Region - A geographic area whose pattern of landforms differ significantly from that of adjacent regions.

Pigment - Any substance used to impart color; specifically, an insoluble, dry coloring matter that, when mixed with a suitable medium, forms a paint.

Pipe, Clay - Pipe made of shale and fired clay; unglazed, or glazed and vitrified; with or without bell; used for field drains, edge drains, culverts, sewers, etc.

Pipe, Concrete - Pipe made of concrete with or without steel reinforcement; used for culverts, sewers, etc.

Pipe, Corrugated Metal - Pipe fabricated from corrugated metal sheets, generally steel or aluminum alloy stock; used for culverts.

Pipe, Corrugated Plastic - Pipe fabricated from corrugated plastic, generally Polyethylene (PE) or polyvinylchloride (PVC), and used for culverts.

Pipe, Perforated - Pipe fabricated from metal, plastic, or concrete with holes or slots on approximately one-half of the periphery and used as underdrains to drain off water trapped in the soil.

Pipe, Smooth-Wall Plastic - Pipe fabricated from plastic, generally Polyvinyl Chloride (PVC) or Acrylonitrile-Butadiene-Styrene (ABS) and without corrugations and used for underdrains, downdrains, etc.

Piping - The action of water passing through or under an embankment and carrying some of the finer material with it to the surface of the downstream face.

Plane Coordinate System - A cartographic projection that, by accepting small variations of scale, permits describing the position of points on the surface of the earth by their plane coordinates on a cylindrical or conical surface.

Planimetric Map - A map that presents horizontal but not vertical data for the features represented. Drainages, coastlines, cover, and culture are usually shown.

Planimetrics - All features both manmade and natural of significant value to the design of a proposed highway.

Plans (Drawings) - The approved plans (drawings), profiles, typical cross sections, working drawings, and supplemental drawings, or exact reproductions thereof that show the location, character, dimensions, and details of the work.

Point Bars - Points bars are deposits of sediment that occur on the convex side or inside of channel bends. Their shape may vary with changing flow conditions, but they do not move relative to the bends.

Poised Stream (also Graded Stream) **-** A term used by river engineers as applying to a stream that over a period of time is neither degrading nor aggrading its channel. A stream nearly in equilibrium as to sediment transport and supply.

Pollution - Contamination of any component of the total environment by harmful substances, sounds, smells, or sights degrading or injurious to humans and other living organisms.

Pool - A small and rather deep body of quiescent water, as a pool in a stream.

Porous - Having many small openings, through which liquids may pass.

Portable Traffic Control Signal - A signal that is designed to be moved as a unit to the site and be operated for a limited time. (It normally consists of the necessary signal faces on poles attached to moveable bases, a control unit, the necessary electrical cables, and a power supply).

Portland Cement - A hydraulic cement consisting of compounds of silica, lime, and alumina; so called from its resemblance in color, when set, to the Portland stone of England.

Precision - The variance of repeated measurements of a characteristic from their average.

Prestressed Concrete (Pretensioned) - Reinforced concrete in which base, wires, or cables are held in a stretched condition during placing of the plastic concrete until the concrete has hardened. Then as the tension on the reinforcing steel is released, it compresses the concrete.

Prestressed Concrete (Post-tensioned) - Reinforced concrete in which the prestressing wires or tendons are placed in tubes before the concrete is cast. After the concrete has hardened, the wires or tendons are stretched to a predetermined tension by jacking and are wedged in this position. The tubes may also be pressure-grouted.

Prime Coat - An asphalt material applied to an absorbent surface, preparatory to any subsequent treatment, for the purpose of hardening or toughening the surface and promoting adhesion between it and the superimposed construction.

Profile - A longitudinal section of a highway, drainage course, etc.

Profile grade - The trace of a vertical plane intersecting a particular surface of the proposed road construction located as shown on the plans; usually along the longitudinal centerline of the roadbed. Profile grade means either elevation or gradient of such trace according to the context.

« Q R »

Radial Survey - A method of ground surveying in which the instrument is placed on a point of known horizontal and vertical position and all required features are located by direction, distance, and elevation difference from the instrument point.

Railroad Grade Crossing - The intersection of a highway and a railroad at the same elevation.

Rapidly Varied Flow - Flow in which changes in depth and velocity take place over short distances, acceleration forces dominate, and energy loss due to friction is minor.

Reach - A length of a stream channel or shore.

Reaction Time - The time required for a driver to apply foot pressure to the brake after perception that a stop must be made.

Reclamation - The restoration of borrow and aggregate pits to a natural form that may include replacement of topsoil and vegetation (seeding).

Recurrence Interval (Return Period) - The average interval of time within which the given flood will be equaled or exceeded once.

Refuge Island - (1) An island in a wide inter-section to provide refuge for pedestrians. (2) A place for transit passengers to load and unload from a bus.

Regime - The system or order characteristic of a stream; its behavior with respect to velocity and volume, form of and changes in channel, capacity to transport sediment, amount of material supplied for transportation, etc.

Regional Factor - A numerical factor expressed as a summation of the values assigned for precipitation, elevation, and drainage. This factor is used to adjust the structural number.

Reinforced Concrete - Concrete where steel reinforcement is embedded so that the steel and concrete act together in resisting stress.

Residential Area - That portion of a municipality, or an area within the influence of a municipality in which the dominant land use is residential development, but where small business areas may be included.

Rest Area - A roadside area with parking facilities separated from the roadway providing motorists with opportunities to stop and rest for short periods.

Resurfacing - The placing of one or more new courses on an existing surface.

Reverse Curve - A curve consisting of two arcs of the same or different radii curving in opposite directions and having a common tangent or transition curve at their point of junction

Riffle-Pool Ratio - The sum of the riffle lengths divided by the sum of the pool lengths expressed in percent for a given reach. These lengths are usually measured at a relatively low stage.

Right-of-Way (R/W) - (1) Land generally publicly owned, acquired for and devoted to transportation purposes. (2) The privilege of the immediate use of the highway. The right of one vehicle or pedestrian to proceed in a lawful manner in preference to another vehicle or pedestrian.

Right-Turn Lane - An auxiliary lane or designated lane provided at grade intersections for right-turn movements.

Riparian - Pertaining to the banks of a stream.

Ripple - (1) The light fretting or ruffling of the water surface caused by a freeze. (2) Undulating ridges and furrows or crests and troughs formed by action of the flow.

Riprap - A protective covering of graded stones, with or without mortar, to prevent erosion.

Road (Highway) - A general term denoting a public way for purposes of vehicular travel including the entire area within the right-of-way.

Road Approaches - Rural and suburban minor connections to a highway or frontage road from adjoining properties. These approaches can be private, public, or commercial.

Roadbed - The graded portion of a road or highway (usually considered as the area between the intersection of top and side slopes) upon which the base course, surface course, shoulders, and median are constructed; the top of the subgrade.

Road Mix - A method of combining surfacing materials (such as mineral aggregate combined with liquid asphalt) in which the materials are mixed on the road using discs, harrows, blades, or other approved means.

Roadside - That portion of the right-of-way outside the roadway.

Roadside Barrier - A longitudinal system used to shield vehicles from hazards on the roadside.

Roadside Development (Roadside Enhancement) - Treatment of the roadside to (1) conserve, enhance, and effectively display the natural beauty of the landscape through which the highway passes; (2) provide safety, utility, economy, and highway-related recreation facilities by means of proper location, design, construction, and maintenance of highways.

Roadside Hazards - The following are all potential roadside hazards for out-of-control vehicles: embankments , ditches, and rock cut slopes; fixed objects such as trees, boulders, drainage structures, signs, bridge parapets and barrier ends, and poles; side road intersections; and narrow medians.

Roadway - The portion of a highway, including shoulders, for vehicular use. (A divided highway has two or more roadways.)

Roughness Coefficient (n) **-** A coefficient used in Manning's formula to estimate the time it will take for rainwater to flow overland to the nearest watercourse. A low roughness coefficient for a watershed results in a rapid concentration of water from that watershed.

Rounding - The removal of the angle where cut and fill slopes intersect the natural ground, and the substitution of a gradual transition, or rounded surface.

Rumble Strip - A rough textured surface, constructed for the purpose of causing the tires of a motor vehicle driven over it to vibrate audibly as a warning to the drivers.

Runoff - That part of the precipitation that appears in surface streams. It is the same as stream flow unaffected by artificial diversions, storage, or other works of man in or on the stream channels.

« **S** »

Sag Vertical Curve - A vertical curve having a concave shape in profile.

Scale - The ratio of the size of the image or representation of an object on a map or photograph to its true size. Scale may be expressed as a representative fraction (1/10 000), or ratio (1:10 000), or as the number of meters on the ground represented by one meter of the map or photograph (1 meter to 1000 meters, or 1:1000) .

Scour - The result of erosive action of running water primarily in streams, excavating and carrying away material from the bed and banks.

Scour, General - The removal of material from the bed and banks across all or most of the width of a channel, as a result of a flow contraction which causes increased velocities and bed shear stress. Also known as Contraction Scour.

Scour, Local - Removal of material from the channel bed or banks which is restricted to a minor part of the width of a channel. This scour occurs around piers and embankments and is caused by the actions of vortex systems induced by the obstructions to the flow.

Scour, Natural - Removal of material from the channel bed or banks which occurs in streams with the migration of bed forms, shifting of the thalweg, and at bends and natural contractions.

Screening - The use of trees, shrubs, fences, or other materials to obscure an objectionable view or to reduce an objectionable sound.

Seal Coat - An asphalt coating, sometimes with cover aggregate, applied to the surface of a pavement for the purpose of waterproofing and preserving the surface, altering the surface texture of the pavement, or providing resistance to traffic abrasion.

Sediment - Fragmentary material that originates from weathering of rocks and is transported by, suspended in, or deposited by water.

Sedimentation - The action or process of depositing particles of waterborne or windborne soil, rock, or other materials.

Sediment Discharge - The rate at which dry mass of sediment passes a section of a stream or is the quantity of sediment, as measured by dry mass or by volume, that is discharged in a given time.

Seiche - An oscillation of the water surface of a lake or other large landlocked body of water due to unequal atmospheric pressure, wind, landslides, earthquakes, or other causes, which sets the surface in vibration. Also associated with hurricanes on waters which are not landlocked.

Seismic Wave - A gravity wave caused by an earthquake.

Service Road - A road, generally unimproved, used to transport personnel, materials, or equipment for the operation or maintenance of utilities located on a highway right-of-way.

Serviceability - A concept where pavements are judged on their ability to serve traffic. Longitudinal smoothness is a primary factor in this judgment.

Shoaling - Deposition of alluvial material resulting in areas with relatively shallow depth.

Shoulder - The portion of the roadway contiguous to the traveled way for accommodation of stopped vehicles, for emergency use, and for lateral support of base and surface courses.

Shrub - A small, woody, multi-stemmed plant.

Side Slopes - Slopes along the side of the roadway identified by their distance from the traveled way, their slope rate, and their height.

Sidewalk - That portion of a street or highway between the curb line or edge of the roadway, and the adjacent right-of-way line constructed specifically for pedestrians.

Sight Distance - The length of roadway ahead, visible to the driver.

Signal System - A system of visual signals used to control the movement of traffic, usually on city streets.

Silt - Material passing a 75 μm sieve that is nonplastic or very slightly plastic, and exhibits little or no strength when air dried.

Site Map - A large scale map of a specific small area, such as a bridge site.

Skew - Oblique, not at right angles.

Skew Angle - The complement of the acute angle between two centerlines that cross.

Sliver Fill - A thin embankment slope that is roughly parallel to the natural slope of the hillside. Sliver fills that are very high in proportion to their thickness, are difficult to compact and should be avoided.

Slope - Any ground whose surface makes an angle with the plane of the horizon.

Slope Rate - The steepness of the slope--usually the ratio of the vertical change divided by the horizontal distance.

Slump - The measure of the consistency of portland cement concrete by consolidating in a slump cone, removing the cone, and allowing the concrete to settle under its own mass.

Soil - Sediments or other unconsolidated accumulation of solid particles produced by the natural physical and chemical disintegration of rocks, and which may or may not contain organic matter.

Soil Classification - The arrangement of soils into classes according to their physical properties.

Soil Stabilization - Measures taken to eliminate or minimize the erosion of soil, or to improve its supporting capacity.

Spalling - Chipping along the edges, as at joints in concrete pavement and structures.

Specific Energy - The energy contained in a stream of water, expressed in terms of head, referring to the bed of a stream. lt is equal to the mean depth of water plus the velocity head of the mean velocity.

Specifications - The compilation of provisions and requirements for the performance of the prescribed work.

- *Standard Specifications*. The book of Standard specifications for construction of roads and bridges on Federal Highway projects issued periodically and designated FP-XX, e.g., FP-96 .
- *Supplemental Specifications*. Approved additions and revisions to the Standard specifications issued by the Federal Lands Highway Office (FLHO).
- *Special Contract Requirements (SCR)*. Additions and revisions to the Standard specifications and Supplemental specifications applicable to individual projects and generally issued by the applicable Federal Lands Highway Division offices.

Spillway - A surface apron or trough for conducting water down a relatively steep slope.

Stabilization - Modification of soils or aggregates by incorporating materials that will increase load-bearing capacity, firmness, and resistance to weathering or displacement.

Stage - The height of a water surface above an established datum plane; also *gage height*.

Stage Construction - The construction of a highway by stages or increments.

Stage-Discharge Curve (Rating Curve) - A graph showing the relation between the gage height (usually plotted as ordinate) and the amount of water flowing in a channel (expressed as volume per unit of time, and plotted as abscissa).

Standard - Something having recognized and usually permanent values and established as a model or criteria.

Standard Drawings - Drawings issued by the Federal Lands Highway Office and approved for repetitive use.

Standing Wave - A term which when used to describe the upper flow regime in alluvial channels means a vertical oscillation of the water surface between fixed nodes without appreciable progression in either an upstream or downstream direction. To maintain the fixed position, the wave must have a celerity (velocity) equal to the approach velocity in the channel, but in the opposite direction.

Station - (1) A measure of distance used for highways and railroads. A station is equal to 1 kilometer . (2) A precise location along a survey line.

Steady Flow - A flow in which the flow rate or quantity of fluid passing a given point per unit of time remains constant.

Stereoplotter - A photogrammetric instrument (often simply called a plotter) used for measuring and mapping from aerial photographs. The instrument provides analogical solutions for object point positions from their corresponding image positions on overlapping pairs of photographs. The primary use of stereoplotters is in the compilation of topographic maps and digital terrain models.

Stockpass - A culvert of a size large enough for the passage of domestic and wild animals.

Stone - Rock material produced from a quarry, i.e., nongravel material.

Stop Line - A white line placed transversely on the pavement (at an intersection) to indicate where the vehicle must stop when obeying a traffic signal or stop sign.

Stopping Sight Distance - The distance required by a driver of a vehicle, traveling at a given speed, to bring the vehicle to a stop after an object on the roadway becomes visible. It includes the distance traveled during the perception and reaction times, as well as the vehicle braking distance.

Storage - (1) Water artificially impounded in surface or underground reservoirs for future use. The term *regulation* refers to the action of this storage in modifying stream flow. See also *conservation storage* and *dead storage*. (2) Water naturally detained in a drainage basin, such as groundwater, channel storage, and depression storage. The term *drainage basin storage* or simply *basin storage* is sometimes used to refer collectively to the amount of water in natural storage in a drainage basin.

Storm Drain - A system of catch basins and underground conduits for collecting, concentrating, and conveying water to a disposal point.

Stratigraphy - The study of rock strata, generally by analyzing rock outcrops or drill cores.

Stream - A general term for a body of flowing water. In hydrology the term is generally applied to the water flowing in a natural channel as distinct from a canal. More generally as in the term stream gaging, it is applied to the water flowing in any channel, whether natural or artificial. Streams in natural channels may be classified as follows:

<u>Relation to Time</u>

- *Perennial*. One that flows continuously.
- *Intermittent or Seasonal*. One that flows only at certain times of the year when it receives water from springs or from some surface source, such as melting snow in mountainous areas.
- *Ephemeral*. One that flows only in direct response to precipitation, and whose channel is at all times above the water table.

<u>Relation to Space</u>

- *Continuous*. One that does not have interruptions in space.
- *Interrupted*. One which contains alternating reaches that are either perennial, intermittent, or ephemeral.

<u>Relation to Ground water</u>

- *Gaining* . A stream or reach of a stream that receives water from the zone of saturation.
- *Losing*. A stream or reach of a stream that contributes water to the zone of saturation.
- *Insulated.* A stream or reach of a stream that neither contributes water to the zone of saturation nor receives water from it. It is separated from the zones of saturation by an impermeable bed.
- *Perched.* A perched stream is either a losing stream or an insulated stream that is separated from the underlying groundwater by a zone of aeration.

Stream-Gaging Station - A gaging station where a record of discharge of a stream is obtained. Within the Geological Survey this term is used only for those gaging stations where a continuous record of discharge is obtained.

Stream Order - A method of numbering streams as part of a drainage basin network. The smallest unbranched mapped tributary is called first order, the stream receiving the tributary is called second order, and so on. It is usually necessary to specify the scale of the map used. A first-order stream on a 1:62 500 map, may be a third-order stream on a 1:12 000 1 map. Tributaries which have no branches are designated as of the first order; streams which receive only first-order tributaries are of the second order; large branches which receive only first-order and second-order tributaries are designated third order; and so on, with the main stream being always of the highest order.

Stream Power - An expression used in predicting bed forms and hence bed load transport in alluvial channels; the product of the mean velocity, the specific weight of the water sediment mixture, the normal depth of flow, and the slope.

Stream Response - Changes in the dynamic equilibrium of a stream by one, or a combination of various causes.

Stress-Strain Diagram - A diagram where corresponding values of the stress and strain are plotted.

Subbase - The layer or layers of specified or selected material of designed thickness placed on a subgrade to support a base course.

Subcritical Flow - Flow with a Froude number less than one. In this state, the role played by gravity forces is more pronounced, so the flow has low velocity and is often described as tranquil and streaming.

Supercritical Flow - Flow with a Froude number greater than one. In this state, the inertia forces become dominant, so the flow has a high velocity and is usually described as rapid, shooting, and torrential.

Superelevation - The elevation of the outside edge of a curve to partially offset the centrifugal force generated when a vehicle rounds the curve.

Superelevation (Water) - The increase in water surface elevation at the outside of open channel bends.

Superelevation Runoff - The transition distance between normal crown and fully superelevated roadway.

Surface Course - One or more layers of a pavement structure designed to accommodate the traffic load, the top layer of which resists skidding, traffic abrasion, and the disintegrating effects of climate. The top layer is sometimes called *wearing course*.

Surface Treatment - An application of asphalt material and cover aggregate.

Suspended Load - Sediment that is supported by the upward components of turbulent currents in a stream and that stays in suspension for an appreciable length of time.

Sustained Grade - A continuous highway grade of appreciable length and consistent, or nearly consistent, gradient.

« T »

Tack Coat - An application of asphalt material to an existing surface to provide bond with a superimposed course.

Tailwater Depth - This is the flow depth in the downstream channel measured from the invert at the culvert outlet to the water surface.

Target (Aerial) - A contrasting symmetrical pattern centered around a point on the ground to facilitate locating and measuring to the image of the point in a photograph.

Terrace - A berm, or discontinuous segments of a berm, in a valley at some height above the flood plain, and representing a former abandoned flood plain of the stream.

Terrain - The physical features of a tract of land, geographic area, or territory.

Thalweg - The line following the lowest part of a valley, whether under water or not. Usually the line following the deepest part of the bed or channel of a river.

Time of Concentration - The time required for water to flow from the farthest point on the watershed to the gaging station.

Toe of Slope - The intersection of a roadway embankment side slope with the original ground surface.

Topographic Map - A planimetric map with an added expression of topography, usually contours.

Topographic Survey - A survey conducted to determine the configuration of the ground.

Topsoil - A surface soil that is predominately a loose, friable, free draining sandy loam, which is free of subsoil, refuse, stamps, roots, and rocks larger than 50 millimeters in diameter, but containing some organic matter.

Tortuous Channel - A winding channel that is not free of shift in its alignment.

Total Station - A vertical and horizontal angle-measuring theodolite with an electronic distance measuring instrument attached to or integral with the theodolite's telescope. The theodolite generally has the ability to convert angular measurements into a digital form. Such theodolites display the slope and horizontal distance as well as the elevation difference between the instrument point and a remote point. Some models are able to retain horizontal coordinates. Often a data recording device is offered as optional equipment.

Traffic Actuated Signal - A type of traffic control signal in which the length of most intervals and the cycle, and in some types the sequence of phasing, are varied by the demands of traffic.

Traffic Barriers - Roadside barriers, median barriers, crash cushions, and bridge parapets intended to guide or protect traffic from roadside hazards, including collision with other vehicles.

Traffic Control Devices - Signs, signals, markings, and devices placed or erected for the purpose of regulating, warning, or guiding traffic.

Traffic Island - An island provided in the roadway to separate or direct streams of traffic; includes both divisional and channelizing islands.

Traffic Lane - That portion of the traveled way for the movement of a single line of vehicles.

Traffic Markings - A traffic control device consisting of lines, patterns, words, symbols, or colors on the pavement.

Traffic Noise Impacts - Impacts that occur when the predicted traffic noise levels approach or exceed the design noise levels, or when the predicted traffic noise levels substantially exceed the existing noise levels.

Traffic Volume - The number of vehicles passing a given point during a specific period of time.

Transition - A section of variable pavement width required when changing from one width of traveled way to a greater or lesser width.

Transition Curve (Spiral) - A curve of variable radius intended to effect a smooth transition from tangent to curved alignment.

Transverse - At right angle to the longitudinal direction.

Traveled way - The portion of the roadway for the movement of vehicles, exclusive of shoulders.

Traverse - In surveying, a series of interconnected straight lines. The lengths of the lines and the angles of deviation between them are measured as the traverse develops.

Triaxial Shear Test - A test in which a cylindrical specimen of soil, encased in an impervious membrane, is subject to a confining pressure and then loaded axially to failure.

Trigonometric Leveling - Determining elevation difference by measuring the slope distance, vertical angle, and difference in instrument heights between two points.

Turning Track Width - The radial distance between the turning paths of the outside of the outer front tire and the outside of the rear tire that is nearest the center of the turn.

« U »

Underdrain - Porous or perforated pipe, or graded aggregate installed under a roadway or shoulder to provide subsurface drainage.

Underpass - A grade separation where the highway passes under an intersecting highway or railroad.

Uniform Flow - Flow in which the velocities are the same in both magnitude and direction from point to point along the stream or conduit, all stream lines being parallel.

Unit Hydrograph - (1) The hydrograph of direct runoff from a storm uniformly distributed over the drainage basin during a specified unit of time; the hydrograph is reduced in vertical scale to correspond to a volume of runoff of 25 millimeters from the drainage basin. (2) The hydrograph of surface runoff (not including groundwater runoff) on a given basin due to an effective rain falling for a unit of time.

Unsteady Flow - A flow in which the velocity changes with respect to both space and time.

« V »

Vertical Curve - A curve on the longitudinal profile of a road to provide for change of gradient.

Vista - A distant view seen from a highway. A *moving vista* is a view observed from a moving vehicle. A *stationary vista* is a view seen from a fixed place or location such as from a rest area or scenic overlook.

« W »

Washload - That part of the total sediment discharge which is composed of particle sizes finer than those found in appreciable quantities in the bed material.

Water-Cement Ratio - The ratio of the mass of water, exclusive only of that absorbed by the aggregates, to the mass of cement in a concrete or mortar mixture.

Water Course - A natural or artificial channel in which a flow of water occurs, either continuously or intermittently. Natural water courses may be either on the surface or underground.

Water Table - The top of the zone of permanent soil saturation. The water table may rise or fall seasonally, or it may be drawn down by removal of water.

Water Year - In Geological Survey reports dealing with surface-water supply, the 12- month period October 1 through September 30. The water year is designated by the calendar year in which it ends and which includes 9 of the 12 months. Thus the water year ending on September 30, 1959, is called 1959 water year.

Watershed - In the past, the term watershed was used to mean the divide separating one drainage basin from another. However, over the years, use of the term to signify drainage basin or catchment area has come to predominate, although drainage basin is preferred. Drainage divide, or just divide, is used to denote the boundary between one drainage area and another. Used alone, the term "watershed" is ambiguous and should not be used unless the intended meaning is made clear.

Weathering - The decomposition of rock, shale, etc., resulting from any chemical or mechanical process caused by exposure to weather.

Weephole - A hole through an abutment or retaining wall to relieve hydrostatic pressure.

Working Drawings - Stress sheets, shop drawings, erection plans, falsework plans, framework plans, cofferdam plans, bending diagrams for reinforcing steel, or any other supplementary plans or similar data.

« X Y Z »

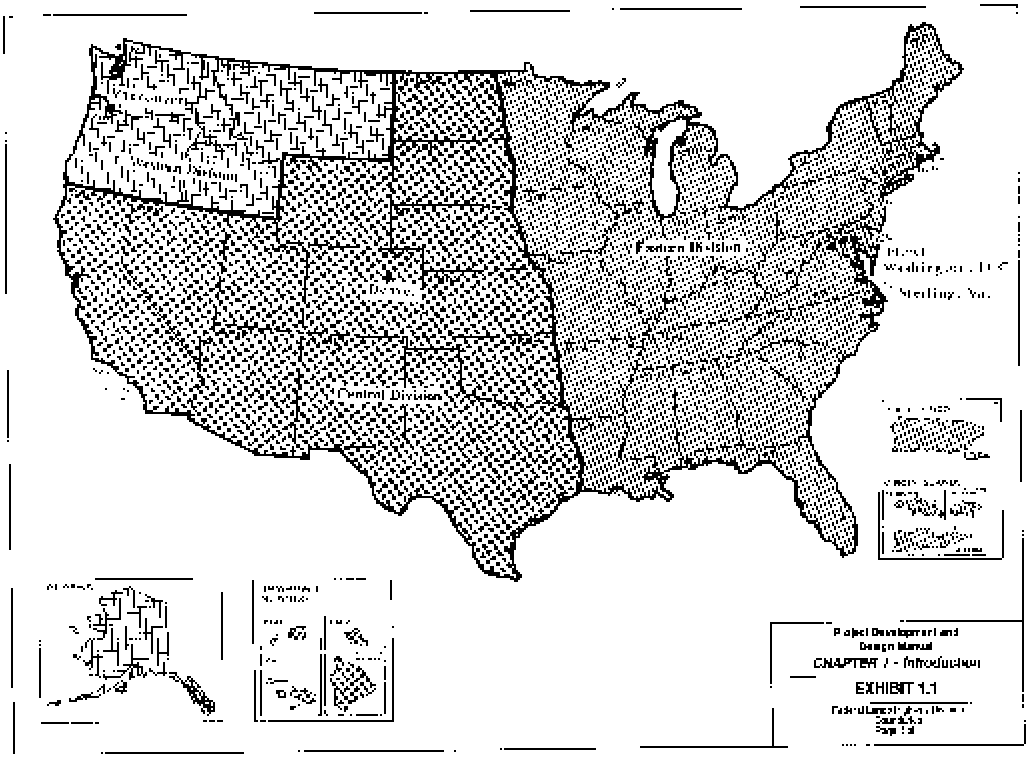
1.5 (RESERVED)

1.6 (RESERVED)

1.7 DIVISION PROCEDURES.

Reserved for Federal Lands Highway Division office use in supplementing the policy and guidelines set forth in this chapter with appropriate Division procedures and direction.

LIST OF EXHIBITS


Central Division
Project Development and
Design Manual
EXHIBIT 1.1

CHAPTER 2 - PLANNING AND PROGRAMMING

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CHAPTER 2 - PLANNING AND PROGRAMMING

2.1 GENERAL

The planning and programming process provides the designer with the program of projects and the funds available so that each specific project may be properly scheduled for design.

Planning with respect to the FLH program involves periodic monitoring of the highway system (network) to carry out the following:

- Identify functional, structural, or safety deficiencies.
- Identify the scope of a project and its respective limits.
- Develop preliminary cost estimates for various improvement alternatives for use by the owner agency to balance capital improvements, RRR projects, and maintenance programs.

Programming consists of scheduling of those identified highway improvements on Federal roads both within the FLHP and within the respective programs of the cooperating agencies. Funding requirements, personnel resources, and the relative need for the projects are all considered when programming them in a long range schedule.

The Federal roads associated with the FLHP consist of the following:

- Public lands highways are public roads within or serving Federal areas.
- The park roads and parkway (PR&P) system administered by the National Park Service (NPS).
- Designated forest highways (FH) on roads owned and maintained by State or local governments.
- The Indian reservation roads (IRR) system administered by the BIA.

Other roads that the FLH Divisions provides design and construction services for include forest development roads administered by the Forest Service (FS), public lands development roads administered by the Bureau of Land Management (BLM), Federal Aviation Administration (FAA), Metropolitan Washington Airports Authority (MWAA) owned roads, and various defense access roads off military reservations that are under the jurisdiction of a State or local government. In addition to the FLHP, funds may also be provided for National Park Service and Bureau of Indian Affairs owned roads through other appropriations.

2.2 GUIDANCE AND REFERENCES

There are many policy references (See Chapter 1 for definitions) on FLH programs and systems. The following are frequently used:

- **23 United States Code (U.S.C.)**

Section 101 Definitions and Declarations of Policy
Section 125 Emergency Relief
Section 201 Authorizations
Section 202 Allocations
Section 203 Availability of Funds
Section 204 FLH Program
Section 205 Forest Development Roads and Trails
Section 210 Defense Access Roads
Section 214 Public Land Development Roads and Trails

- **23 Code of Federal Regulations (CFR)**

Section 660A	Forest Highways
Section 660E	Defense Access Roads
Section 667	Public Lands Highway Funds
Section 668	Emergency Relief Program

- **Federal-Aid Highway Program Manual**

FAPG 23CFR 660A	FH Administration (includes 23 CFR 660A)
FAPG 23 CFR 667	Public Lands Funds (includes 23 CFR 667)
FAPG 23 CFR 660E	Defense Access Roads (includes 23 CFR 660E)
FAPG 6090.13	Preliminary Engineering and Construction for Other Federal Agencies
FAPG 23 CFR 668B	Emergency Relief Program Procedures for Federal Agencies for Federal Roads (contains 23 CFR 668B)
FAPG 6090.17	Indian Reservation Roads

- **Federal Lands Highway Program Manual**

Chapter 2 - Planning and Coordination

- **National Interagency Agreements**

  Forest Service, effective May 11, 1981 (Exhibit 2.1)

  Bureau of Land Management, Feb. 26, 1982 (Exhibit 2.2)

  Bureau of Indian Affairs, May 24, 1983 (Exhibit 2.3)

  National Park Service, May 19, 1983 (Exhibit 2.4)

2.3 PROGRAMS

FLHO is involved in several programs, including the Federal Lands Highway Program and other Federal agency road programs.

A. Federal Lands Highway Program (FLHP). The Surface Transportation Assistance Act of 1982 established the FLHP. This allowed Federal Highway Trust Funds to be spent on park roads and parkways and IRR roads that were previously not eligible for Trust Fund financing. Additionally, the FH and FLH programs that were previously financed by Trust Funds were brought under the umbrella of the FLHP.

The programs that come under the FLHP legislation are, public lands highways (includes the forest highway system), park roads and parkways, and Indian reservation roads.

1. Public Lands Highways. The Public Land Highway category incorporates the old Forest Highway and Public Lands Highway category, with a fixed percentage of the total category funding going to each subcategory.

a. Forest Highways (FH). Forest highways are forest roads that are (1) wholly or partly within or adjacent to and serving the National Forest System, (2) under the jurisdiction of and maintained by a public authority, and open to public travel. Forest highways are designated from the eligible forest roads by the FHWA in consultation with the FS and the appropriate State highway agency.

FH route designation is delegated to the FLH Division Engineer. Either the FS or the State can nominate a route, but it must adhere to the following criteria:

- The route is under the jurisdiction of a State or local government agency (cooperator) and open to the public.

- The route provides a connection between a safe public road and the renewable resources of the National Forest System that are essential to the local, regional, or national economy, and/or the communities, shipping points, or markets that depend upon those renewable resources.

- The route serves other local needs such as schools, mail delivery, commercial supply, and access to private property within the National Forest System; serves high-volume traffic, which is generated by use of the National Forest System and its resources; or serves National Forest System-generated traffic volumes that have a substantial impact on roadway design and construction.

FH funds are allocated by formula by FS region and by State area in States having national forest lands. Since the allocations are made for each State, project costs must fit within the available funds. FH funds may be borrowed from another State with unobligated monies provided such funds are returned by the end of the current highway authorization period. Project cost records are managed in the FLH Division offices, but obligation limitation is controlled at Headquarters.

Project selections for the FH program are made at annual program conferences. A conference is held in each State; projects are discussed and programs are developed. The meetings are attended by representatives of the State highway agency, the FS, the FHWA, and other interested agencies.

FH Projects are selected based on the following criteria:

- The development, utilization, protection, and administration of the National Forest System and its renewable resources.

- The enhancement of economic development at the local, regional, and national level.

- The continuity of the transportation network serving the National Forest System and its dependent communities.

- The mobility of the users of the transportation network and the goods and services provided.

- The improvement of the transportation network for economy of operation and maintenance and for the safety of its users.

- The protection and enhancement of the rural environment associated with the National Forest System and its renewable resources.

The objective of the program conferences is to reach agreements on a minimum 5 year FH program that can be feasibly accomplished within the requirements and restraints of each agency.

b. Public Lands Highways (PLH). PLH are those main public highways through unappropriated or unreserved public land, non-taxable Indian lands, or other Federal reservations.

The funds for PLH are administered by the Office of Engineering; Federal-Aid Program Branch (HNG-12). Annually each State with eligible highways will submit candidate PLH projects for funding under this program. The FLHO is to work with Federal agencies and the Federal-aid Divisions to coordinate their involvement in the PLH program although the overall responsibility for the PLH program rests with HNG-12. Fund allocation is made on a project-by-project basis for an approved scope of work. Increases above the approved amount must be authorized by HNG-12. The increases are submitted through the appropriate SHA.

Preference is given to States containing at least three percent of the total public lands in the Nation, and additional preference is given to those projects that significantly benefit or improve Federal land and resource management, regardless of the type of Federal lands involved. All candidate projects submitted are reviewed by FHWA Headquarters, and a priority of need is determined on the basis of supporting information as submitted with the application dealing with the following considerations:

- Relationship to Federal land and resource management plans and activities including traffic carrying capacity and other effects on land use and resource development.

- Current status and adequacy of the present road with regard to route continuity, capacity, safety, and Federal and State agency transportation plans.

- Relationship of proposed improvement to the adequate development of a complete highway section.

- Schedule for physical construction, particularly how soon physical construction will begin.

After reviewing the applications and based on the above criteria, the FHWA will also give some consideration to the equitable distribution to States of available funds.

2. Park Roads and Parkways (PR&P). Park roads are those public roads that are located within or provide access to an area in the National Park System with title and maintenance responsibility vested in the United States. Parkways are those roads authorized by an Act of Congress on lands to which title is vested in the United States. Eligible projects also include bridges that are primarily for pedestrian use, but with capacity to handle emergency vehicles.

Funds for PR&P are allocated based on a priority program of projects developed by the NPS and approved by the FHWA. When additional funds are required for a specific project, requests must be made simultaneously to the NPS Region and FLHO for approval and a new allocation is then developed. Generally, the allocations are very specific as to the use of the funds. For instance, the allocations will specify the amount for preliminary engineering, construction engineering, and construction. Since funds are allocated to specific projects for a specific scope of work, there is no flexibility to transfer from one account to another unless FLHO approval is granted.

Annually, each park submits to its Regional office a list of improvement priorities. Regional priorities are developed using the park requests. The Regional Directors then cooperatively develop a list of service-wide priorities (SWP). Each FLHD meets periodically with appropriate NPS Regions to establish a program of projects to be funded 5 to 10 years into the future. This program considers the SWP as well as resurfacing, restoration, and rehabilitation (RRR) and other miscellaneous projects that need improvements within the relative priority and availability of funds. This program of projects is then submitted to NPS Headquarters for coordination and consolidation to a nationwide PR&P program that NPS Headquarters (WASO) then submits to FLHO for approval.

Routes on the PR&P system are those designated with a functional classification I, II, III, VII, and VIII. (See pages 3, 4, and 5 in the NPS *Road Standards*.) There is no formal approval required for roads in this system.

3. Indian Reservation Roads (IRR). Indian reservation roads are public roads (consisting of BIA system roads as well as State and local roads), including those on the Federal-aid system, that are located within or provide access to either of the following:

(1) An Indian reservation or Indian trust land or restricted Indian land which is not subject to fee title alienation without the approval of the Federal Government,

(2) Indian and Alaska native villages, groups, or communities in which Indian and Alaskan natives reside whom the Secretary of the Interior has determined are eligible for services generally available to Indians under Federal laws specifically applicable to Indians.

Funds are distributed to the 12 BIA areas based on a relative needs formula. The formula takes into consideration land area served, Indian population, and road mileage with an adjustment for road surface. After the annual IRR priority program of projects is reviewed and approved by the FLHO, funds are transferred to the BIA for those projects being administered by the BIA. Funds are allocated to the respective Division offices for those projects for which FLHD has administrative responsibility.

The IRR annual priority program of projects is developed by the BIA areas, with input from the Tribes. The program of projects, which is based upon relative need, is submitted to the BIA Headquarters for review and approval. FLHO reviews the priority program of projects for eligibility and issues a concurrence/approval letter.

Routes on the IRR system are designated by the BIA after nomination by the Tribal governing body. The FLHO reviews and concurs in the selection of the various routes.

B. Other Federal Agency Highway Programs. Other Federal agencies have jurisdiction or responsibility over road systems. From time to time, FHWA will perform work for these agencies.

The FS has jurisdiction over the forest transportation system. The forest transportation system includes forest development roads which are (1) forest roads under the jurisdiction of the FS, (2) wholly or partly within or adjacent to and serving the National Forest System, and (3) necessary for the protection, administration, use, and development of FS resources.

Some NPS and BIA projects on which FLHDs are asked to provide engineering services are funded through agency appropriations with special funding rather than through the FLHP. These include major special interest projects, cyclic maintenance projects, and projects with special features. In addition, the NPS and BIA also have road programs for non-public type roads within their jurisdictional boundaries which are not open to the public (such as administrative, maintenance, fire control, or other service roads).

The BLM has jurisdiction over public lands development roads and trails which are the public roads determined by the Department of the Interior to be of primary importance for the development, protection, administration, and utilization of public lands and resources.

The BLM also has jurisdiction over forest access roads on and to the O & C lands (revested Oregon and California Railroad and reconveyed Coos Bay Wagon Road grant lands) in Oregon.

Department of Defense (DOD) access roads are roads designated by the DOD as important to the Military defense because they access military reservations, defense industry sites, and sources of raw materials. These roads are generally owned by State or local governments and are not within the boundaries of military reservations. Also meeting the criteria of DOD access roads are highways and highway connections that are shut off from general public use by closures or restrictions at military reservations or defense industry sites.

In addition to working on highways under the jurisdiction of the above Federal agencies, FLHO may provide engineering services for the improvement of highways for other Federal agencies, cooperating foreign countries, and cooperating State agencies on a reimbursement basis.

C. Emergency Relief Federally Owned Programs (ERFO). When Federal roads have suffered serious damage, the Secretary of Transportation may rule that Highway Trust funds can be used to repair the damage. This damage could have been the result of

- natural disasters over a wide area (such as floods, hurricanes, tidal waves, earthquakes, severe storms, landslides) or
- catastrophic failures from any external cause.

For ERFO purposes, 23 U.S.C. 125 © defines Federal roads as follows:

> *Forest highways, forest development roads, park roads, parkways, public lands highways, public lands development roads, and Indian reservation roads.*

The administrative procedures for this program are outlined in the *Emergency Relief for Federally Owned Roads, Disaster Assistance Manual.* FHWA-FL-90-008. September 1990

2.4 PLANNING AND PROGRAM COORDINATION

There are many program planning and coordination vehicles, including interagency, State and local, and other miscellaneous project agreements. Additionally, there are standing agreements with several agencies (including the FS, BLM, BIA, and NPS) that cover the standard procedures for coordinating the respective programs. (See Exhibits 2.1 through 2.4)

A. Interagency Agreements. Whenever FLHO performs work for other agencies or other agencies perform work for FLHO, an interagency agreement is executed between the organizations. The agreement must spell out the responsibilities and the method of payment for the services rendered. This agreement may cover a continuing program or cover an individual project.

B. Federal/State Forest Highway Cooperative Agreements. Each State participating in the FH program is asked to enter into an agreement setting forth the terms by which FH projects will be planned, programmed, designed, constructed, and maintained. (See Exhibit 2.5.)

C. Federal/County Forest Highway Cooperative Agreements. Each county participating in the FH program is asked to enter into an agreement similar to the State agreements. (See Exhibit 2.6.)

D. Forest Highway Project Agreements. Every project constructed under the FH program should have a project agreement implementing the FH cooperative agreement. (See Exhibit 2.7.) However, the FH regulations require a project agreement only when the following conditions exist:

- A cooperator's funds are to be made available to the FHWA for the project or any portion of the project.
- Federal funds are to be made available to a cooperator for any work.
- Special circumstances exist that make a project agreement necessary for payment purposes or to clarify any aspect of the project.

E. Miscellaneous Agreements. In addition to the above agreements, the FLH Divisions use agreements with utilities, railroads, other Federal agencies, State agencies, and local governments to perform specific tasks such as utility removal, railroad crossing protection, signing and markings, materials testing or investigation, and special project design or construction management activities.

2.5 PLANNING STUDIES AND REPORTS

It is necessary to have complete, concise and accurate data for management to make an informed and judicious decision on needs, priorities and cost of projects.

FLHO and owner agencies conduct studies to assist in this decision-making process; these include road and bridge inventory programs, unit-wide evaluation studies, and special function studies. These studies are for identifying needs, costs, and alternatives, and for establishing relative priorities for improvements.

Route and location studies are outlined in Chapter 4. Special feature studies are evaluations of specific engineering problems and are usually conducted by the appropriate engineering staff specialist.

Unit-wide engineering studies are investigations (through data collection and evaluation) to identify and access various alternative courses of action and make pre-design recommendations to restore, resurface, rehabilitate, or reconstruct roads and bridges with the most reasonable and cost effective design.

Such studies can include the following:

- Parkwide road engineering studies (PRES).
- Project planning reports.
- Traffic forecasting and analysis.
- Other similar studies.

These studies discuss alternatives, identify needs, estimate costs, and set priorities for implementation of an improvement program.

The Bridge Inspection Program (BIP) and Road Inventory Program (RIP) consist of a periodic rating and assessment of the condition of the road and/or bridge. A BIP is required for all bridges open to public traffic. Bridges are inspected on a 2-year cycle. The inspections are used to monitor and identify structural conditions that may lead to a catastrophic failure of the bridge. The RIP is planned for a 3-year cycle for paved roads.

Unit-wide engineering studies are intended to provide direction and scope of the alternative courses of action for improvements identified in RIP/BIP or other planning processes for preparation of detailed designs.

These studies should provide important decisions for preparing long-range programs and project design or development activities. The studies should be completed in most areas where FLHO involvement is continuous and significant road construction improvements are anticipated.

Supplemental or special feature engineering studies may also be needed for traffic engineering, traffic safety, geotechnical, pavement design, and similar activities.

The types of engineering studies to be conducted should be determined on a case-by-case basis that would gain the most from each study. The selection process must always be inclusive of those studies that identify, evaluate, and compare impacts of each alternative; establish design flexibility; define commitments to protect and preserve the environment; and provide long-term planning guidance.

The scope and extent of the data gathering, analysis, and reporting will vary for each study. Engineering studies should be in sufficient detail to support alternative engineering solutions, estimates, and schedules. A recommended alternative should be identified. These studies may incorporate extensive engineering, economic, traffic, and environmental data collection and analysis to support the recommendations.

In other instances the study may be less exhaustive and analytical depending upon the circumstances. Engineering studies will be used for budgeting and programming purposes to form the basis for initial cost estimates. In most instances, further in-depth field investigations and engineering analyses will be required during design stages.

A diligent effort should be made to complete these types of studies at the earliest possible time to assist in developing a program of projects. Coordination is needed to ensure that decisions and tasks accomplished in the engineering studies will be compatible with the owner-agency management plans and functional classification to minimize the risk of significant changes after the studies are completed.

All studies should be scheduled so as to provide proper timing of input into the various engineering activities.

A. Park Roads and Parkway Studies. There are a variety of studies performed under the PR&P program.

1. Road Inventory Program (RIP). An inventory and condition rating has been completed on all NPS roads and is now being maintained by FLHO. During the initial RIP, the entire PR&P system was photo logged and roadway data collected. Subsequent photo logging and data collection is done as major changes to the roads are made. A RIP report is available for each of the NPS units.

2. Bridge Inspection Program (BIP). The FLHO has inventoried and rated all NPS bridges and tunnels and a biannual inspection is conducted under the national BIP. A BIP report is available for all NPS bridges and tunnels in the Structures unit.

3. Parkwide Road Engineering Studies (PRES). PRES are complete evaluations of individual parkwide road systems. The studies include evaluations of the condition, safety, and signing of a park's road system with a recommended program for upgrading deficiencies.

The PRES evaluations and recommendations are used by the NPS when considering the overall goals and objectives of a park's General Management Plan (GMP) relative to the park road system.

4. Road System Evaluation Reports. These reports are evaluations of the existing roadways conducted by the NPS. The reports make recommendations for needed maintenance or reconstruction.

5. Safety and Traffic Accident Studies. These NPS studies evaluate the safety aspects of a park system and evaluate accident data. Safety improvements are recommended when needed.

To support these studies, the NPS has developed a system-wide traffic counting program and a service-wide traffic accident reporting system (STARS). This data is collected by the NPS, Denver Service Center, Transportation staff and is available for input in FLHD project planning and development.

B. Forest Highway Studies. Studies are conducted on all FH routes as directed by FLH Headquarters. The information taken includes ADT, FS related traffic, physical data, and estimated cost of improvements. This data is maintained in a national data base in FLHO.

C. IRR Studies. The FLHO assisted the BIA in an inventory of its road system. FLHO also provides, on an as-requested basis, bridge inventory and inspection services.

D. Other Studies. FLHO also conducts special engineering studies for other agencies as requested, such as the defense access roads studies. Other location and engineering studies are discussed in Chapter 4.

2.6 PROJECT IDENTIFICATION AND ACCOUNTING

Formal fiscal procedures have been developed for allocating funds, establishing accounts and account numbers, recording obligations, producing project cost reports, and closing out project accounts. Procedures have also been adopted for using a standardized project numbering system.

A. Project Numbering System. The use of a formal numbering system assists in tracking and identifying the type, location, and source of funding for a particular project.

A uniform project numbering system has been adopted for projects being administered by the FLH. See Table 2-1.

Table 2-1
Project Identification Numbers

Source of Funding	Preferred Prefix[10]	Optional Prefix	Route Number	Section or Sequence Number
Direct/Highway Trust Funded				
Park Road Parkway[1]	PRA	PR	2	6
Forest Highway	PFH	FH	3	6
Indian Reservation Roads	IRR	IR	4	6
Public Lands Highways[7]	PLH	PL	4	6
Emergency Relief Federal Lands[8]	ERFO	ER	4	6
Allocations/Transfer (Other Federal Agencies)				
National Park Service[1]	NPS		2	6
Forest Service	FS	FDR	4	6
Bureau of Indian Affairs	BIA		4	6
Bureau of Land Management[9]	BLM		4	6
Department of Army	AAD		5	6
Department of Navy	NAD		5	6
Department of Air Force	RAD		5	6
Department of Air Force (O&M)	OMAD		5	6

Note:
[1]On Park Road projects use official NPS Park Abbreviations. (See Planning and Coordination Unit.)
[2]Use road inventory program number.
[3]Use designated FH route number.
[4]Use official system route number.
[5]Headquarters, HFL-10, coordinates route and section number.
[6]Section and sequence numbers as agreed upon with appropriate Federal or State agency.
[7]SHA may designate route number.
[8]Project number may need coordination with appropriate Federal-aid Division.
[9]BLM will generally provide the numbers.
[10]Other prefixes may be warranted for special legislative requirements.

Project reports such as the Advertise and Award schedule that contain the following information should be submitted in all uppercase letters using the following format to permit FLH-wide compilation of data:

Project No. and Common Name: For example - **PRA BIBE 15(5), ROSS MAXWELL ROAD**

State: Use uppercase two letter designation. If multiple states, list the one with the predominate work.

Description: Begin with work category (See Table 2-2 for examples), then list length or No. of Bridges if a Bridge project, and finally list major items of work.
For example - **REC, 1.2 km, GR, DR, BS, PAVE**

Engineers Estimate: (Include estimated incentives).

Date Planned/Actually Advertised: Use actual date, not an estimated quarter.

Set Asides: Use an X under each category heading, SB, LS, 8a

Date Planned/Actually Awarded: Use actual date, not an estimated quarter.

Award Amount: (Include obligated incentives)

Number of Bids Received: Include only the number of responsive bids.

Table 2-2
Description of Work

Description of Work	Abbreviation
Work Category	
New	NEW
Reconstruction	REC
Rehabilitation	REH
Resurfacing	RES
Major Items of Work	
Grading	GR
Drainage	DR
Base	BS
Graveling	GRVL
Paving	PAVE
Bituminous Surface Treatment	BST
Slide Repair	SLIDE REP
Bridge	BR

B. Accounting Procedures. The FLH has adopted a standardized alpha work code to be used in the last digit of the account number. The work code allows the FLHD(s) to develop several project cost reports for work performed by the various organizational units. The standardized work codes are shown in Table 2-2 and are to be used on all advanced planning, preliminary engineering, and construction engineering activities.

Preliminary engineering accounts are programmed in the amount estimated by the project manager to be expended in the fiscal year and are adjusted as required. At the end of the fiscal year, the account is balanced and then funds must requested at the start of the next fiscal year at a new estimated amount.

Construction accounts are established prior to advertisement with an amount matching engineer' estimate or the initial contract bid amount, plus incentives, and adjusted during the life of the contract as necessary to reflect project costs. The accounts are kept open until the project is complete and the final voucher is paid.

Construction engineering accounts are programmed in the amount estimated to be expended by the construction engineer within the fiscal year. These accounts are adjusted as required so that they balance at the end of the fiscal year.

Other accounts, such as utility, R/W, planning and archeology accounts, are handled differently depending on how the work is being handled. If the work is under contract or a formal interagency agreement, then it is programmed and handled like a construction contract. If the work is done in-house, then the procedures for construction engineering and preliminary engineering accounts apply.

Account numbers are assigned to each facet of work in each project.

Account numbers shall be established prior to expenditures being incurred. The DAFIS accounting system requires a lengthy account string for each projects, activity and workcode.
A typical account number would look like this:

X180-050-14-0 180051 150420 D^^2041234567AD

where:

X180-050-14-0	=	Funding source
180051	=	Activity (051 = PE, etc.)
150420	=	Location (Region/State/Park)
D^^2	=	Federal Lands
04	=	State (AL)
1234567	=	Specific project
A	=	Activity associated with project (A=PE, C=CE, H=Construction)
D	=	Work code (See Table 2-2)

This accounting string is required for all expenditures.

Table 2-3
FLH Activity Codes

Code	Activity Code Title
A	51 (PE)
B	51, 95 (CTIP)
C	52 (CE)
D	51, 59 (RIP)
E	53 (RR, AGM)
G	53 (ARC, AGM)
H	54 (CNT, CNST)
I	55 (MAINT)
J	56 (PST, CNST)
K	57 (LNDSCP)
L	59 (ADV PL)
M	NOT USED
P	33 (RC CST/O)
Q	IC (DEMO PJT)
R	NOT USED
S	
T	NOT USED
U	53, 58 (UTIL AGM)
V	40 (EQ DPT)
W	13 (DEMO PRJT)
X	NOT USED
Y	4Y (DEMO PJT)
Z	

Table 2-4
FLH Work Codes

Work Code	Work Code Title
A	ADP/CADD
B	Bridge
C	Contract Administration (Construction and A/E Contracts)
D	Highway Design
E	Environment/Public Involvement/Permits
G	Geotechnical
H	Hydraulics
I	Construction Inspection
J	A/E Procurement (Work on A/E proposals, Work Order, etc.)
K	ERFO (Disaster and Damage Assessments)
L	Location
M	Materials (Testing)
P	P&C, Procurement, Coordinate PS&E, & Advertise
Q	TQM Branch
R	Right of Way
S	Survey/Mapping
T	Technical/Engineering Contract Services (A/E Contracts)
U	Utilities
V	
W	
X	
Y	
Z	

2.7 DIVISION PROCEDURES

Reserved for Federal Lands Highway Division office use in supplementing the policy and guidelines set forth in this chapter with appropriate Division procedures and direction.

LIST OF EXHIBITS

Note: All Memoranda of Understanding and Agreements with our Partner Federal Lands Agencies are undergoing revision. The agreements are not included here, and Exhibits 2.1 through 2.4 are reserved for the revised documents.

FOREST HIGHWAY COOPERATIVE AGREEMENT

Parties to Agreement: Federal Highway Administration, U.S. Department of Transportation, hereinafter called "FHWA," and Department of Highways, State of ______________________________ hereinafter called the "Cooperator. "

• **Purpose.** The purpose of this agreement is to set forth the general terms and conditions, mutually acceptable to the parties hereto, for the cooperative planning, programming, survey, design, construction, and maintenance of Forest Highways in the State of ________________________ pursuant to the provisions of Title 23 U.S.C. 204 and Title 23 CFR 660.

The Congress has, from time to time, authorized and appropriated funds for highways within, adjoining, or adjacent to and serving the national forests that are of primary importance to the State, counties, or communities. Recognizing that substantial benefits will accrue to the State and to the Nation from the construction and maintenance of such Forest Highways, and from their integration into the State or local road system over which the Cooperator has jurisdiction, and further that the Cooperator has systems planning, maintenance, right-of-way acquisition, and interdisciplinary facilities available to assist in the accomplishment of the work, it is accordingly deemed fitting and desirable to the parties hereto to express by this instrument, the general terms of their mutual cooperation in that regard with the object of achieving maximum benefits therefrom in the public interest.

It is recognized that where Forest Highway programs exist, separate memorandums of understanding setting forth procedures for administering the Forest Highway program are in effect between the Forest Service and the Cooperator.

• **Forest Highway Routes.** This agreement shall cover the Forest Highway routes, previously approved for inclusion in the Forest Highway system and approved amendments thereof. This list of such approved routes may be varied from time to time by mutual agreement between the Cooperator and FHWA either by adding routes thereto, or removing routes therefrom, or by altering the description of any route to give it proper identity. Each such action shall be indicated by: (I) a revised list; or (2) a revised page or pages bearing the signatures of the parties together with a showing of the effective date of the revision.

• **System Planning.** It is recognized that Forest Highways are an integral part of the Federal-Aid System of roads in any State. Systems planning is then a function that will be performed by the Cooperator who will work with the Forest Service and FHWA on long-range planning activities of mutual concern. The Cooperator agrees that in performing these functions, the Cooperator's Action Plan approved by the FHWA will be adhered to.

• **Programs.** Programming will be in accordance with Title 23 U.S.C. and Title 23 CFR 660 paragraph 109.

• **Project Agreement.** A Forest Highway project agreement is to be entered into between the parties hereto whenever: (1) the survey, construction, acquisition of rights-of-way, or maintenance in connection with a project included in an approved Forest Highway program is to be accomplished in a different manner from that set forth in the Forest Highway Cooperative Agreement; (2) Federal funds are to be made available to the Cooperator for the work; or (3) Cooperative funds are to be made available to FHWA for the project. Project agreements are to be executed in duplicate, one executed copy being for the Cooperator and one for FHWA. Additional copies (conformed) will be available for the Regional Forester of the Forest Service, and for offices of the Cooperator or FHWA as may be desired. Functions performed by FHWA with its own organization with 100 percent Federal funding will not require a project agreement.

• **Compliance With Federal-Aid Procedures and Action Plans In Project Development.** Where survey, design, and construction are performed by the Cooperator, Federal-Aid procedures and the Cooperator's approved social, economic, and environmental action plan shall apply. Unless otherwise provided in the project agreement for the specified project, phases of project development performed by FHWA from program conferences through construction, FHWA will adhere to the Nationwide Direct Federal Action Plan prepared by FHWA under the guidelines established under 23 U.S.C. Section 1O9(h). This Action Plan requires that a Social, Economic, and Environmental (SEE) Study Team be formed to insure that SEE effects of each project are identified in conjunction with all its objectives outlined in the FHWA Action Plan. The Cooperator agrees to assign, on a project basis, a member or members to the SEE Study Team from within the Cooperator's force. This team member shall be given authority by the Cooperator to make decisions necessary to insure that the SEE Study Team can meet its objectives as outlined in the FHWA Action Plan. The Cooperator also agrees to furnish to the team whatever interdisciplinary capabilities their team member may request insofar as such capability is already available within the Cooperator's in-house staff. The FHWA agrees that the Cooperator's SEE Study Team member has the authority to insure that during project development the public and other agencies are given the same opportunity for input that they would have under the Cooperator's approved Action Plan.

• **Federal Funds.** When any proposed work provided for in an approved Forest Highway program is to be performed by the Cooperator, and financed in whole or in pan with Federal funds, such circumstances shall be set forth in the project agreement together with a statement of the amount of Federal funds and cooperative funds. If it appears that the project cost may exceed the estimate and additional Federal funds may be needed, no obligation shall arise against the Federal Government with respect to the increased cost except by modification of the project agreement prior to incurring amy commitment.

As the work progresses, or upon its completion, the Cooperator shall submit vouchers to FHWA for payment of the United States pro rata share of the cost of the work. Usual Federal-aid procedures are to be followed when submitting billings.

• **Cooperative Funds.** If cooperative funds are provided on an advance basis, they shall be deposited in the Treasury of the United States to the credit of cooperative work, Forrest Highways, Federal Highway Administration. Payments for work performed shall be made out of the funds provided by the Cooperator, and by FHWA, in equal amounts until either fund is exhausted, and then from the remaining fund until the project is completed or all funds are exhausted. Any unused balance of cooperative funds will be returned to the Cooperator after completion of the project.

If FHWA is constructing the work and cooperative funds are to be made available on a reimbursement basis as the work progresses or upon its completion, FHWA shall submit to the Cooperator periodic billings, but not more often than monthly, or a final billing as the case may be, showing the total amounts expended for work accomplished and the amount owing to FHWA from the Cooperator. The amount of cooperative funds as set forth in the project agreement shall be the maximum commitment of the Cooperator to the project, unless changed by a modification of the project agreement duly executed by the parties hereto.

• **Construction of Projects.** Construction by the Cooperator of Forest Highway projects on the listed Forest Highway routes will be accomplished in accordance with the project agreement and the approved Forest Highway program. Construction shall be in compliance with plans, specifications, and estimates approved for the project, and in conformity with the Forest Highway Regulations. If the construction is to be accomplished by FHWA without cooperative funds, no project agreement is necessary.

The project shall be undertaken as promptly as possible after funds are made available, and shall be carried to completion with all reasonable speed. Minor changes in grade, alignment, surface course, or structures made necessary by unforeseen contingencies or deemed desirable by conditions developing during the progress of the work may be made by the constructing agency without the prior or separate approval of the other. It is incumbent upon the constructing agency to insure that any such changes are not in conflict with any of the SEE considerations developed during project implementation.

All work is to be performed by contract entered into by competitive bids unless some other method is mutually deemed to be more advantageous to the public interest.

For any publicly-owned equipment furnished for the work, the charge therefor, including items for depreciation and repairs, shall be in accordance with procedures established by the constructing agency.

• **Cost of Project.** Whenever FHWA performs the work and cooperative funds are involved, FHWA shall furnish to the Cooperator a summary statement of the cost of the project. When no cooperative funds are involved, a statement of the cost of the project will be available upon request.

• **Rights-of-Way.** Rights-of-way or other interests in property acquired by the Cooperator are to be at the Cooperator's expense unless otherwise provided in the project agreement. In the event the project agreement provides that reimbursement from Federal funds be made to the Cooperator for the cost of right-of-way, the procedure to be used and the submission of supporting papers shall follow current Federal-Aid practice.

The FHWA will cooperate in the procurement of rights-of-way, over or upon Federal lands or other lands under the jurisdiction of the United States, required for any project included in an approved Forest Highway program and will furnish the Cooperator copies of survey notes, maps, and other records.

Pending the execution and recording of deeds or other instruments for the rights-of-way over private lands, the Cooperator guarantees right of entry thereon for construction purposes.

When contract administration is performed by FHWA and the approved plans for the construction of the project provides for obtaining local material from designated quarries, gravel pits, or borrow pits situated on private lands, the FHWA may request the Cooperator to negotiate and enter into all necessary agreements for the right to remove such material, and enter into necessary agreements with the owner of the land for the price to be paid for material removed. Such agreements are to be made sufficiently in advance of construction to assure they can be fully set forth in the invitation for bids.

• **Maintenance.** Upon the completion and acceptance of Forest Highway projects constructed pursuant to an approved Forest Highway program, the Cooperator agrees to assume and continue the maintenance thereof at the Cooperator's expense. Maintenance shall include the preserving and keeping of each roadway, road structure, and road facility as nearly as possible in its original condition as constructed, or as subsequently improved, to provide satisfactory and safe highway service.

In the event it is determined that conditions on a project under maintenance require extraordinary repairs, removal of unusually extensive slides, or similar work outside the scope of ordinary highway maintenance, the performance thereof may be accomplished as a Forest Highway project, subject to regular Forest Highway program procedures. The cost of such work shall be eligible for payment from Federal funds, and if the work is to be performed by the Cooperator or if cooperative funds are involved, it shall be covered by a project agreement.

A Forest Highway project shall be deemed in maintenance status when: (I) all construction work has been completed in accordance with the approved plans and specifications as documented by the separate approvals of FHWA and the Cooperator; and (2) the clearing and disposal of refuse has been approved by the Regional Forester of the United States Forest Service.

- **Amendments to Forest Highway Cooperative Agreements.** It is the intention that this Cooperative Agreement shall exist and continue as the formal instrument expressing the terms of the mutual cooperation entered into by the parties hereto for accomplishing the systems planning, programming, survey, design, construction, and maintenance of projects on the Forest Highway routes. It is the further understanding and desire of said parties that this Cooperative Agreement shall be and is subject to modification by advance notice of 60 days from either party to the other. Otherwise, the cooperative arrangements set forth herein shall continue from the effective date hereof.

This agreement shall be effective as of the _______________ day of ________________________________, ___________, and shall supersede all prior existing cooperative agreements for the same routes entered into pursuant to 23 U.S.C. 204 and 23 CFR 660 except those involving a commitment of funds or arrangement for the performance of construction work on projects underway but not yet completed and final settlement made.

_______________ DEPARTMENT OF HIGHWAYS	DEPARTMENT OF TRANSPORTATION FEDERAL HIGHWAY ADMINISTRATION
By: ____	By: ____
____	____
(Title)	(Title)

FOREST HIGHWAY AGREEMENT

Parties to Agreement: Federal Highway Administration, U.S. Department of Transportation, hereinafter called "FHWA," and the County of ____________________________________, State of ___________________________, hereinafter called the "County."

- **Purpose.** The purpose of this agreement is to set forth the general terms and conditions, mutually acceptable to the parties hereto, for the project selection, project agreements, survey, design, construction, rights-of-way acquisition, and maintenance of forest highways in _______________________________ County, ____, pursuant to the provisions of Title 23 U.S.C. 204 and Title 23 CFR 660 Subpart A.

- **Project Selection.** Projects will be selected by mutual agreement of the FHWA, the Forest Service (FS), and the State Highway agency (acting on behalf of the County) in accordance with Title 23 CFR Part 660.109.

- **Project Agreement.** In addition to this Forest Highway Agreement, a project agreement shall be entered into between the FHWA and the County for each project prior to the expenditure of Federal funds. The purpose of the project agreement is to spell out the project specifics that cannot be covered in this general agreement, including project length, geometrics, rights-of-way requirements, and utility relocation requirements.

The project agreement shall set forth the procedure between FHWA and the County when (1) the survey, construction, acquisition of right-of-way, or maintenance in connection with a project included in an approved Forest Highway program is to be accomplished in a different manner from that set forth in this Forest Highway Agreement; (2) Federal funds are to be made available to the County for the project; or (3) County funds are to be made available FHWA for the project. Project agreements are to be executed in triplicate, one executed copy being for the County, one for the Forest Service, and one for FHWA.

- **Survey, Design, and Construction.** The FHWA will administer the survey, design, and construction of each Forest Highway project unless otherwise provided for in a project agreement. The location of the survey and the general design will be accomplished to the mutual satisfaction of the County, the FS, and the FHWA. The County is encouraged to provide input in the project development phase during the action plan process.

The project will be constructed as promptly as possible after funds are made available. Minor changes in grade, alignment, surface course, or structures made necessary by unforeseen contingencies or deemed desirable by conditions developing during the progress of the work may be made by the FHWA without the prior or separate approval of the County. The FHWA will, to the extent practicable, insure that any such changes are not in conflict with any of the Social, Economic, and Environmental (SEE) considerations developed during the action plan process.

EXHIBIT 2.6 Sample Cooperative Agreement with a County

All work will be performed by contract entered into by competitive bids unless some method is mutually deemed to be in the public interest.

No construction shall be undertaken on any Forest Highway project until plans, specifications, and estimates have been concurred in by the County and the FS and approved by the FHWA.

- **Compliance with Federal-aid Procedures and the Direct Federal Nationwide Action Plan in Project Development.** Projects or phases of projects administered by the County will be developed in accordance with applicable Federal-aid procedures, including appropriate environmental procedures as set out in Title 23, CFR. Projects or phases of projects administered by FHWA will be developed in accordance with 23 CFR Parts 660 and 771 and with the Nationwide Action Plan for the Direct Federal Program. This action plan requires that a SEE Study Team be formed for projects that require the preparation of an environmental assessment or impact statement to insure that SEE effects of each project are identified and considered.

The County will assign a representative(s) to the SEE Study Team for each such project. The County representative(s) shall be given authority by the County to make decisions necessary to insure that the SEE Study Team can meet its objectives as outlined in the Nationwide Direct Federal Action Plan. The County also agrees to furnish to the team whatever interdisciplinary capabilities it is able to provide within its existing staff.

- **Rights-of-Way and Utilities:** Right-of-way or other interests in property needed for a project will be acquired by the County or their agent in the name of the County. The cost of such right-of-way or other interest in property will be at the County's expense unless otherwise provided in the project agreement. Federal-aid procedures (Title 23, CFR, Part 712) shall be used for rights-of-way acquisition.

The FHWA will cooperate in the procurement of rights-of-way over or upon Federal lands or other lands under the jurisdiction of the United States Government that is required for any project and will furnish the County copies of survey notes, maps, and other records unless otherwise provided for in a project agreement.

Pending the execution and recording of deeds or other instruments for the rights-of-way over private lands, the County shall obtain right-of-entry thereon for construction purposes. Utilities which are located within the construction limits of the proposed rights-of-way shall be relocated at the expense of the County prior to awarding the construction contract. Utilities may be accommodated on the rights-of-way when such utilities do not interfere with the free and safe flow of traffic or otherwise impair the highway or its visual quality.

- **Maintenance.** After construction of Forest Highway projects, the County agrees to operate and maintain the highway at the County's expense. Maintenance is the preservation of the entire highway, including surface, shoulders, roadside, structures, and such traffic-control devices as are necessary for its safe and efficient utilization .

During construction, the contractor shall bear all expense of maintaining traffic over the project other than during the period of winter suspension. If the facility is to remain open for public use during the winter suspension, the County agrees to provide routine maintenance, including all snow removal, as necessary.

A Forest Highway project shall be accepted by the County for operation and maintenance when all construction work has been completed in substantial conformity with the approved plans and specifications and the project has been inspected by the County, the FS, and the FHWA.

• **Amendments to Forest Highway Agreements.** This Forest Highway Agreement may be modified by mutual agreement of the parties. Either party may prepare a modification by giving notification at least 60 days in advance of the proposed effective date of the modification.

This agreement shall be effective as of the ________________ day of_________________________________, and shall supersede all prior existing cooperative agreements for the same routes entered into pursuant to 23 U.S.C. Section 204 and 23 CFR Part 660, Subpart A except those involving a commitment of funds or arrangement for the performance of the construction work on projects underway but not yet completed and final settlement made.

_______________ County, _______________

By: ________________________________

____
(Title)

By: ________________________________

____
(Title)

By: ________________________________

____
(Title)

Department of Transportation
Federal Highway Administration
________________ Federal Lands Highway Division

By: ________________________________

Division Engineer

U . S . DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION
CENTRAL FEDERAL LANDS HIGHWAY DIVISION

FOREST HIGHWAY PROJECT AGREEMENT

State: Colorado | Forest: Flatland

County: Clark | Forest Highway Route No.: FH Route 75, Glasgow to Opheim

Project No.: FH75-2(1) | Project Length (km): 2.1 ± | Terrain: Mountainous

This Agreement is entered into between the undersigned parties pursuant to the provision of 23 U.S.C. 204, and the Forest Highway Regulations issued thereunder jointly by the Secretary of Transportation and the Secretary of Agriculture, and in accordance with the terms of the Forest Highway Agreement dated July 14, 1988.

Project Location: The bridge over Willow Creek located about S miles southwest of Opheim, Colorado, on Clark County Route No. 236.

Description of Work: The replacement of Willow Creek bridge and reconstruction of the approaches.

Funding: The cost of preliminary engineering, construction engineering, and physical construction will be the responsibility of the Federal Highway Administration (FHWA). The cost of rights-of-way, utility relocation, and maintenance after completion of the project will be the responsibility of Clark County.

Responsibility for the Survey, Design, and Construction: The FHWA will administer the survey, design, and construction as stipulated in the Forest Highway Agreement. Additionally, the FHWA will obtain all the necessary environmental clearances, Section 404 fill permits, materials source permits, and other Federal or State required permits.

Design Standards: The project will be designed in accordance with the AASHTO Policy on Geometric Design of Highways and Streets, 1994 edition.

Structures will be designed in accordance with the AASHTO Standard Specifications for Highway Bridges, Fifteenth Edition, 1982, as supplemented.

The following general criteria will be applied for this project:

Design speed: 50 km/h | Roadway surface: Asphalt concrete

Design volume: Less than 400 ADT | Roadway width: 7.3 meters

Design loading: MS 18 | Bridge width: 8.5 meters

EXHIBIT 2.7 Sample Project Agreement with a Country

Rights-of-Way: Rights-of-way needed for this project will be acquired by the County or their agent in the name of the County.

The FHWA will prepare rights-of-way plans and legal descriptions of the necessary property needed for the project.

Pending the execution and recording of deeds or other instruments for the rights-of-way over private lands, the County shall obtain right-of-entry thereon for construction purposes.

Utility Relocation: Utilities which are located within the construction limits of the proposed rights-of-way shall be relocated at the expense of the County prior to awarding the construction contract. Utilities may be accommodated on the rights-of-way when such utilities do not interfere with the free and safe flow of traffic or otherwise impair the highway or its visual quality.

Construction: As soon as practical after the plans are complete and as soon as funds are available, the FHWA will either advertise for or negotiate with a contractor to construct the project in accordance with the Federal Acquisition Regulations (48 CFR 1) and the Transportation Acquisition Regulations (48 CFR 12). During the construction phase, FHWA will provide a project engineer to oversee and inspect the work to assure a quality product. The construction will be governed by the plans supported by the *Standard Specifications for Construction of Roads and Bridges on Federal Highway Projects* (FP 96). The project engineer is the designated FHWA contact for the County and the Forest Service during the construction phase.

Maintenance: After construction, the County shall operate and maintain the highway at the County's expense. Maintenance is the preservation of the entire highway, including surface, shoulders, roadside, structures, and such traffic-control devices as are necessary for its safe and efficient utilization.

During construction, the contractor shall bear all expense of maintaining traffic over the project other than during the period of winter suspension. If the facility is to remain open for public use during the winter suspension, the County shall provide routine maintenance, including all snow removal, as necessary.

Amendments to the Project Agreement: This Project Agreement may be modified by mutual agreement of the parties. This Agreement shall be effective as of the 30th day of September, 1996.

CLARK COUNTY, COLORADO

By: ______________________________

____
(Title)

By: ______________________________

____

By: ______________________________

____
(Title)

DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION
CENTRAL FEDERAL LANDS HIGHWAY DIVISION

By: ______________________________

____

DEPARTMENT OF AGRICULTURE
FOREST SERVICE
ROCKY MOUNTAIN REGION

By: ______________________________

Regional Engineer

CHAPTER 3 - ENVIRONMENT

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CHAPTER 3 - ENVIRONMENT

3.1 GENERAL

The purpose of this chapter is to provide guidance on the process and reporting requirements to comply with Federal statutes, executive orders, and regulations concerning Social, Economic, and Environmental (SEE) aspects introduced into the highway program during the past 4 decades. The 1950's emphasized public hearings concerning highway bypasses and impacts on local economics and wildlife resources. The emphasis of the 1960's was for highway projects to be compatible with local planning and to consider their impacts on civil rights, parklands, archeology, and history. The 1970's involved more specific identification and balancing of impacts on the natural and human environment.

The environmental process (as defined by the operational procedures contained herein) is based on the Federal Lands Highway (FLH) Divisions' efforts to meet the requirements of the Council on Environmental Quality (CEQ) and DOT Order 5610 1C and 23 CFR 771. The implementing procedures that have been developed ensure that proper considerations are given to SEE impacts during the development of highways. The Direct Federal Nationwide Action Plan was developed to meet these requirements.

Although an integral part of the conceptual studies stage (see Chapter 4) during development of highway improvements, the environmental process continues throughout the entire spectrum of highway planning, design, and construction activities.

Depending upon the magnitude of the highway improvement and its location, the environmental process may range from a minimal effort to a major effort using substantial resources and time, with public and interagency involvement.

The SEE effects of alternatives are identified and compared. Resultant decisions may be to proceed with a build alternative (with agreed upon mitigation measures), to recycle the proposal for further study and/or additional public involvement, or to abandon the proposal (no-build).

Environmental clearance of a proposal constitutes approval of the general highway location (corridor) and approval to begin detail design.

The environmental procedures outlined herein apply to projects that come under the decision making responsibilities of the FLH Divisions. These environmental procedures apply to such projects as forest highways, defense access highways, Indian reservation roads, emergency relief (ERFO) projects, and public lands highways when Direct Federal is the lead agency unless other environmental procedures are specified in the project agreement. The State environmental procedures apply for those projects where the FLH Divisions serve basically as consultants to a State highway agency.

Unless otherwise stipulated in a project agreement, when the land management agency maintains lead agency responsibility (other than the FLH Division or the State highway agency) neither the State environmental procedures nor the Direct Federal procedures will apply. For such projects, the rules and procedures of the principal land management agency are applicable and the FLH Division basically performs as a consultant.

With the completion of the environmental process, the highway designer is given the scope of the project including the approved alternative, preliminary design standards, corridor location, and environmental mitigation commitments. These elements provide substantial input and direction into the subsequent design phase.

A. National Environmental Policy Act (NEPA). NEPA, enacted in 1969, is the basic national charter for protection of the environment. It establishes policy, sets goals, and provides means for carrying out the policy. NEPA is the most sweeping of all pieces of environmental legislation since it deals with the total impact on the natural and human environment. NEPA applies to every Federal agency. On major Federal actions it requires a systematic, interdisciplinary approach in planning, decision making, and consultation with other Federal, State, and local agencies. Public involvement is an integral part of the environmental/conceptual studies design process that ensures adequate opportunity for citizen and/or agency input and an exchange of views. Many States have also passed environmental policy acts similar to NEPA and these may require separate attention.

Since NEPA is a broad based statute, it has been necessary to enact numerous other statutes and executive orders to provide specific directions and procedures to protect all important environmental concerns. Section 3.5 contains a list of legislation, orders, and actions or approvals required from other agencies.

B. Section 4(f). Section 4(f) is an enacted DOT regulation, originally contained in the 1966 Transportation Act and now codified in 23 U.S.C. 138 and 49 U.S.C. 303, which substantially restricts the use of publicly owned special purpose land for transportation facilities. The regulation states that the Secretary shall not approve any program or project that requires the use of publicly owned land from public parks, recreational areas, wildlife and waterfowl refuges, and historic sites of national, State, or local significance for a highway *unless* there is no feasible and prudent alternative to the use of such land and the program includes all possible planning to minimize harm to said lands resulting from highway usage.

Section 4(f) preceded NEPA by several years and resulted in several significant court decisions requiring extraordinary measures to be taken to avoid or minimize harm to Section 4(f) lands.

Procedures to protect Section 4(f) sites are included in DOT Order 5610.1C, 23 CFR 771, and the Direct Federal Nationwide Action Plan. Documentation and reporting criteria is included in FHWA Technical Advisory T6640.8A.

3.2 GUIDANCE AND REFERENCES

Numerous guidance, advisory, and regulatory procedures have been written to assist in carrying out NEPA and other environmental statutes and orders. Copies of these procedures (addressed in the following discussions) are available in the Environmental Planning unit in each FLH Division.

A. Council on Environmental Quality (CEQ) Regulations. The Council on Environmental Quality (CEQ) was established in the Executive Branch by NEPA to advise the President about environmental matters and to guide Federal agencies in complying with the procedures and goals of NEPA. These directions are included in the CEQ Regulations (40 CFR 1500-1508) for implementing the provisions of NEPA. The CEQ regulations also include the pertinent requirements of separate statutes and executive orders on the protection and enhancement of environmental quality.

The CEQ regulations require Federal agencies to develop supplementary procedures applicable to each agency's programs and responsibilities.

B. Procedures for Considering Environmental Impacts (DOT Order 5610.1C). This order implements the provisions of Section 102(2) of NEPA, the CEQ regulations, and the statutes and executive orders for Federal Highways.

The order also implements the following:

- Section 4(f) regulations
- Clean Air Act
- Historic Preservation Act
- Coastal Zone Management Regulations
- Fish and Wildlife Act
- Endangered Species Act
- Water Pollution Control Regulations

The DOT order includes procedures relative to environmental impacts in decision making and directs that information of proposed DOT agency actions be made available to public officials and the general public through appropriate documents. This order also requires DOT agencies, such as FHWA and UMPTA, to develop supplementary implementing procedures.

C. Environmental Impact and Related Procedures. (23 CFR 771). FHWA/UMPTA regulations. These regulations incorporate the requirements of the CEQ regulations and DOT Order 5610.1C. They also set forth procedures for complying with other environmental statutes, principally Section 4(f) of the DOT Act of 1966 and Section 136(b) of the 1970 Federal-aid Highway Act. These regulations are cross-referenced in 49 CFR 622. None of the above three regulations (CEQ, DOT Order 5610.1C and 23 CFR 771) are all inclusive; all three must be consulted to satisfy all environmental requirements.

D. Direct Federal Nationwide Action Plan. Section 136(b) of the 1970 Federal-aid Highway Act (23 USC 109(h)) directed the Secretary of Transportation to promulgate guidelines designed to assure that possible adverse Social, Economic, and Environmental (SEE) effects of Federal-aid highway projects are fully considered and that final decisions are made in the best overall public interest.

These requirements were set forth in State and Direct Federal Action Plans that included organizational responsibilities and procedures for achieving the following objectives:

- Increased involvement of the public, groups, and other agencies in the planning and development of projects.
- Use of a systematic interdisciplinary approach.
- Identification of SEE effects.
- Consideration of other courses of action that would include alternative types and varying magnitudes of highway improvements, other transportation modes, or no action.

The Direct Federal Nationwide Action Plan incorporates those requirements and facilitates compliance with other environmental requirements.

FHWA no longer requires highway agencies to document their procedures through action plans. If action plans are not used, however, agencies must substitute other documentation of their procedures. These procedures shall be acceptable to FHWA and shall be understandable and accessible to the public. FLHD offices shall continue to use the Direct Federal Nationwide Action Plan.

A national committee was established and given the responsibility for updating and keeping the action plan current. The committee is composed of representatives from the following offices:

- Federal Lands Highway Office
- Office of Environmental Policy
- Federal Lands Highway Division offices
- Federal Land Management Agency offices

An action plan committee was also formed in each of the Federal Lands Highway Division offices with the following responsibilities:

- Assist in the implementation of the action plan.
- Make reviews, provide guidance, and determine direction during a project development stage.
- Assure commitments are incorporated into the project design and construction.

E. Guidance for the Preparation and Processing of Environmental and Related Documents (FHWA Technical Advisory T6640.8A (1987)). This advisory provides guidance in the preparation of environmental documents relevant to NEPA and Section 4(f). It addresses CE and EA/FONSI determinations, EIS's, supplemental EIS's, reevaluations, and Section 4(f) evaluations.

The advisory also provides the guidance required by 23 U.S.C. 109(h) to assure that possible adverse social, economic, and environmental effects of proposed actions are evaluated. Consideration of these factors satisfies the reporting requirements of 23 U.S.C. 128. Technical Advisory T 6640.8A is not regulatory.

3.3 INFORMATION GATHERING AND COORDINATION

Information gathering is continuous through-out the stages of planning and programming, conceptual studies, and design. Reference is made to Section 3.4 for a complete understanding of important engineering and SEE information that must be gathered and assessed to satisfy specific needs or requirements.

The process of identifying needs for project selection (during planning and programming and conceptual studies) is based on engineering and reconnaissance studies describing the physical conditions, current deficiencies, future road needs, and estimates of needed improvements and costs.

Engineering and SEE information gathered during environmental/conceptual studies for a proposed project is more specific than reconnaissance studies since reasonable engineering alternatives and their relative costs or impacts must be considered using an interdisciplinary approach, involving other agencies having special expertise or jurisdictional authority, special interest groups and the public.

Interagency and interdisciplinary involvement continues into the design stage where engineering and SEE information may be even more specific as important design elements are refined. At this stage, sound engineering principles should be applied to minimize adverse impacts while maximizing benefits for important SEE aspects.

A. Information Gathering. Information is gathered and disseminated in a number of ways, such as by the following:

- Issuing a letter of intent or a questionnaire describing the scope of proposals to newspapers; other agencies; and to groups, persons, or organizations asking for comments.
- Establishing contact with cooperating agencies (those having jurisdiction on some aspect of the proposal).
- Conducting public and interagency meetings and hearings to explain the proposal and provide a forum for an open exchange of views.
- Undertaking studies or research by specialists in various disciplines in FHWA, other agencies, or consultants.
- Forming a task force composed of in-house and other agency specialists during project development activities.
- Establishing a SEE Study Team.

B. Project Coordination. The many facets of environmental/public involvement require detailed and continuous coordination throughout conceptual studies and design. The Environmental Planning Engineer, assisted as needed by location and/or design engineers, develops and performs the following:

- Coordinates the public involvement process.
- Prepares environmental documents to comply with environmental laws and regulations.

- Initiates and coordinates SEE activities with Federal, State, and local agencies; citizen groups; and individuals.
- Engages consultants for needed expertise.
- Collects data and performs environmental studies.
- Identifies and analyzes SEE effects.
- Recommends measures to mitigate adverse effects for reasonable engineering alternatives as well as the no-action alternative.
- Monitors construction of selected projects to provide feedback concerning environmental information to be used in the development of future projects and to accumulate actual *as-constructed* environmental data.
- Reviews selected completed projects to determine if they were constructed in conformance with the environmental commitments and if mitigation measures were effective.

C. SEE Study Team. A SEE study team also assists environmental planning and engineering offices in coordinating major proposals during conceptual studies and design.

The team is composed of representatives from the applicable land management agency, Federal Lands Highway Division office, and highway agency with support help from other agencies as needed.

The SEE Study Team performs as follows:

- Acts as a steering team for project development activities, such as public involvement events, field and office reviews, and interagency meetings.
- Correlates SEE impacts and engineering needs.
- Represents and advises its agency of any consequences of alternative highway locations and designs.

The SEE Study Team members have authority to do as follows:

- Make commitments concerning alternatives.
- Call on needed and available disciplines within the agency. (Natural, social, and technical services and environmental design graphics, as needed, are represented depending on the type of project and impacts foreseen).

3.4 ENVIRONMENTAL ANALYSIS AND PUBLIC INVOLVEMENT

The environmental analysis and public involvement phases use the early information and coordination data to further define and develop the appropriate environmental processes. The various aspects of the proposed improvements are evaluated to determine the scope and nature of subsequent actions required for the environmental clearances and other project development processes. The many factors and alternatives that may be involved require continuing coordination and input from a variety of sources.

The analyses of important environmental aspects during the conceptual studies and design phase should have sufficient scientific and analytical substance to provide a basis for evaluating the alternatives. Include in the analyses, any information, issues, values, or other ongoing or planned activities that may have an impact on the evaluation and selection of an alternative. Photographs, illustrations, and other graphics may provide a clear understanding of the impacted area. Identify significant SEE effects and make an assessment of the estimated costs (financial and otherwise) of eliminating or minimizing anticipated adverse effects.

The *reconnaissance report* will include the results of engineering and SEE aspect studies and recommendations. (See Chapter 4 and/or the appropriate environmental document addressed in this chapter.)

The disciplines of the highway, land management, and resource agencies (also consultants if needed) are used in the environmental analyses. (See Section 4 of the Direct Federal Nationwide Action Plan.)

A. Environmental Considerations. Full consideration of favorable or adverse SEE effects and decisions to be made in the best overall public interest, require a careful analysis of reasonable alternatives. There is no absolute scale on which a project's desirability can be measured, and only by assessing the SEE effects of all reasonable alternatives can sound judgments be reached. One alternative that must be considered is not to construct the project. While this alternative may highlight adverse effects, it also provides a basis for presenting the needs for, and benefits of, the proposed project and the harmful effects of delay or abandonment.

The environmental process requires significant determinations and mitigation measures concerning important aspects affected by a proposal:

- Social aspects include the total effects on the quality of living.
- Economic aspects include the total effects on the material needs of people.
- Environmental aspects include the total effects on the human and natural environment.

Consideration of reasonable alternatives should include possible effects on a broad range of SEE aspects. However, the consideration given to each aspect will vary with the characteristics of the area traversed. SEE aspects that are determined relatively unimportant or minimally affected should be eliminated early in conceptual studies, while important SEE aspects should be studied (and if necessary) mitigated during the conceptual studies and design phases in consultation with land management, natural resource agencies, environmental and special interest organizations, the concerned public, and agencies having jurisdiction by statute.

Consideration is given to the consequences and impacts of the proposal on the following typical environmental and potentially significant features:

- Land use.
- Farmlands.
- Social/economic changes.
- Pedestrians/bicyclists.
- Air/noise/energy.
- Water quality.
- Stream modification.
- Floodplains/wetlands/riparian vegetation.
- Wild and scenic rivers.
- Coastal zones.
- Threatened/endangered species.
- Historical/archeological preservation.
- Hazardous waste sites.
- Visual/recreational/vegetation.
- Construction.
- Cumulative impacts.
- Relationship of local short-term uses versus long-term productivity.
- Irreversible and irretrievable commitment of resources.
- Environmental Justice

Some environmental aspects requiring special considerations or procedures are as follows:

- Flood plains and wetlands that cannot be avoided may require preparation of a formal Only (flood plains) or No (wetlands) Practicable Alternative Finding.

- If a threatened or endangered species may be affected, a formal biological assessment is written and consultation achieved with the U.S. Fish and Wildlife Service concerning mitigation measures. Biological evaluations are required if a Forest Service designated sensitive species may be affected.

- A survey of the proposed corridor must be made concerning possible cultural resources. When sites are found, a determination of eligibility to the Federal register of Historic Places is made. Consultation and/or agreement shall be reached with the applicable State Historic Preservation Officer and Advisory Council on Historic Preservation concerning disposition of any significant sites (see Section 3.6.C.4).

- Extraordinary measures must be taken to avoid and/or minimize harm to Section 4(f) lands (see sections 3.1.B and 3.6.B).

A sample of a SEE checklist is shown in Exhibit 3.1. The use of such a checklist is encouraged to assist one in tracking the numerous SEE aspects and to provide a method of documenting any need for additional action on specific subjects. The FHWA Technical Advisory T6640.8A also addresses SEE considerations.

B. Project Classification. Projects are classified into one of three categories that prescribe the level of activity and type of documentation required for the environmental clearance process (23 CFR 771). The numerical designation assigned to a project indicates the type of project, its degree of complexity, and the extent of SEE study needed.

During the first steps of the environmental/ conceptual studies analysis, the Action Plan Committee (APC) assigns the classification of the proposal that indicates the type of environmental document to be prepared. The committee may be guided by the SEE study team and environmental planning recommendations, as well as other financial, engineering, traffic, and safety considerations, including comments received from agencies and the public.

The project categories are defined below:

Class I

Actions that significantly effect the environment (EIS).

Class II

Actions that do not individually or cumulative have a significant environmental effect (CE).

Class III

Actions in which the significance of the environmental impact are not clearly established (EA).

The minimum level of activities required for each classification are shown in Table 3-1. Section 5 of the Direct Federal Nationwide Action Plan illustrates each step in the project development process and highlights interagency and public involvement in both written and flow chart form. The flow charts are shown in Exhibit 3.2.

The APC takes one of the following possible actions:

- Assigns the project to the Class I category because of identified significant SEE impacts or an environmentally controversial proposal. A full EIS process is required.
- Assigns the project to the Class II category for approval as a CE by the Division Engineer. This decision may be deferred until appropriate SEE studies are completed.
- Assigns the project to the Class III category requiring preparation of an EA to determine the significance of the environmental impacts.

This early classification may be changed by the APC as the SEE study team and the environmental planning office evaluate the input from early coordination, analyze the SEE effects, and recommend a different category.

C. Scoping. Scoping is a process for determining the range of issues to be considered in evaluating the environmental impact of a proposal. The scoping process stresses early coordination among agencies involved with or affected by the proposal as well as early public involvement.

The purpose of scoping is to do the following:

- Determine the scope of a proposal's impact limits, its range of alternatives, and the significant issues to be analyzed; and to evaluate mitigation measures.
- Identify and eliminate from the detailed study the issues that are not significant or that have been covered by prior environmental documents. The discussion of these issues should be narrowed to a brief presentation of why they will not have a significant effect on the human environment.
- Identify other environmental review consultation requirements so analyses and studies can be integrated.

Scoping will generally consist of joint meetings with all concerned agencies, but can also be accomplished through appropriate public involvement and other mechanisms, such as letters and individual meetings. It is FHWA's responsibility, when acting as lead agency, to evaluate the input from scoping and in coordination with other agencies and the public to determine the scope of the environmental document.

Cooperating and interested agencies, such as the land management agency or the permit agencies, are encouraged to assist in preparing environmental documents in order to maximize the joint efforts, minimize duplication, and improve the time frame for project development.

Table 3-1
Minimum Level of Activity by Project Category [1]

Level of Activity	Class I	Class II	Class III	
Environmental Studies	Yes	Yes	Yes	
Significant Impacts	Yes	No	Yes	No
Opportunity for Public Meeting	As Appropriate	No[2]	As Appropriate[3]	As Appropriate
Opportunity for Public Hearing	Yes	As Appropriate	Yes[3]	As Appropriate
Final Environmental Documentation	EIS	CE	EIS[3]	EA
Results	ROD	CE	ROD[3]	FONSI

[1] 3.4.B and 23 CFR 771 for project category classifications.
[2] For minor projects (such as surfacing, reconstruction and widening existing lanes and/or adding auxiliary lanes where little or no additional right-of-way is required, installing traffic controls, etc.), public hearings are not required and public meetings are generally not requested by the public.
[3] Projects initially classified as Class III but later determined to have significant impacts will be considered to be in the Class I category and treated accordingly.

D. Public Involvement. Public involvement is an integral part of the environmental, conceptual studies and design processes that ensure adequate opportunity for citizen and/or agency input and an exchange of views.

Highlights of public involvement are as follows:

- Agencies, groups, or individuals are asked for input and placed on a mailing list.
- Outside agencies and interested groups are consulted during the early coordination process.
- Public meetings are held during conceptual studies and design phases.
- The environmental document is available for review and comment.
- Location/design public hearings are conducted.
- Wide exposure is obtained through public notices.
- Cooperating agencies are determined and their involvement is encouraged at this time.

An effective public involvement program can gain public support, assist the project development process through early identification and resolution of issues, and remove potential barriers caused by poor dissemination of information.

Public involvement includes the participation of officials of local governments and other State and Federal agencies, citizens, special interest groups, adjacent residences and businesses, community groups, minority groups, and any others expressing interest or knowingly affected by a project.

Local governments, which are often active sponsors of proposed projects, can effectively assist in developing and conducting public participation programs. They, along with State and Federal agencies, should be contacted early in the public involvement process, and be kept informed of project progress.

Effective public involvement needs to be flexible, innovative, and continuous. Many methods can and should be considered.

The following are intended as a source of ideas from which to develop an effective public involvement effort. Each Division office should respond to changes, as appropriate, in order to keep the affected community informed about project actions.

1. Public Meetings. Meetings are generally more informal and use a less traditional format than hearings. Public meetings range from the large informational and workshop meetings to the small group and one-on-one meetings with individual citizens.

Drop-in centers where the public may leisurely visit to review project displays and interact with FHWA personnel have been very successful in gaining public involvement in a relaxed atmosphere. Small meetings are also very useful for gaining information from special interest and neighborhood groups. Workshop formats, where large groups are organized into small discussion groups, serve to maximize participation while discouraging domination of the meeting by a few individuals. Presentations at regularly scheduled meetings of chambers of commerce, city councils, and other interested groups should also be considered. Each Division needs to evaluate what end product is desired from the meeting, then plan accordingly to achieve that product.

Since public meetings or hearings are frequently the Government's principal community exposure, it is important that the person conducting the meeting conveys the people image. For additional information, see the FHWA publication, *Improving the Effectiveness of Public Meetings and Hearings*, 3rd edition 1981.

When the meeting is well-planned and the meeting moderator is sensitive to the needs of the audience and objective about the needs of the project, public meetings are usually productive public involvement efforts.

Public meetings are to be documented in a report that should be sent to all participants, as well as other interested parties as appropriate.

2. Notification Techniques. Develop notification techniques to attract a cross section of the public interested in the project. Special notices should be provided to those directly affected. All notifications should catch the public's attention and encourage people to attend the meeting or become involved. The following techniques should be considered:

- News releases - TV or newsletters
- Billboard advertisements near project
- Fliers
- Newsletters
- Posters
- Local bulletin board announcements
- Paid advertisements
- Personal contacts
- Radio announcements
- On-site tours

Notices prepared for the public frequently make effective handouts. A well-designed and informative handout can serve as an ongoing link between FHWA and the community.

Handouts have no set format. They should be as clear, relevant, up-to-date, as self-explanatory as possible, and written in a style that is easily understood. Handouts in appropriate foreign languages, such as those below, should be used when necessary:

- Special project newspapers
- Pamphlets, brochures, booklets (for large, complicated projects)
- Fliers (for small, simple projects)
- Charts, tables, graphs
- Project maps (such as aerial photographs or line drawings)
- Project development schedules
- Summary project reports
- Right-of-way brochures (or other general information)
- Questionnaires (surveys)

Normally, graphics or visual aids are used to present project information to the public. Clear, attractive, and self-explanatory audiovisuals can create a baseline of common interest and understanding. Traveling slide shows or graphic exhibits to inform civic groups, community groups, coffee klatches, local officials, etc., on specific projects have been successfully used. These presentations need to be informal, responsive to questions and concerns, and presented by people with the same qualifications as those conducting meetings.

Suggested presentation techniques include the following:

- Slides, slide-tape presentations
- Models
- Maps (should be large and simple)
- Artist's renderings
- Videotapes
- Photomontages
- Aerial photograph exhibits

3. Follow-up Procedures. Even though effective public involvement is on-going, at significant points in the process the Division Public Information Officer should follow up public input with general information about the project. Responsive follow-up assures the public that information gained is appropriately considered in the final decision. Follow-up information needs to convey as accurately as possible how public input was used or not used to develop the project.

Follow-up procedures should be tailored to the needs of the project. On long, complex projects, it may be necessary to provide followup information two or three times to maintain an exchange of information and on-going credibility with the community. Follow-up on larger projects may include newsletters, summary reports, individual contacts, or other types of information prepared and disseminated in context with the public's contribution to the project. Follow-up on smaller projects or specific comments may simply be a timely response to individual requests for specific answers or information.

4. Public Hearing Procedures. The statutory requirements for affording the opportunity for public hearings are contained in 23 U.S.C. 128. At the time this requirement was instituted, public hearings were extremely formal. In the interim, increased emphasis on other involvement mechanisms and major attention to SEE effects have changed the public hearing format. In many cases, a public hearing is structured very differently than in the past. Experience gained in the last several years indicates that a hearing is more effective if it is less formal.

While perhaps the most displayed aspect of an agency's involvement program for certain projects, hearings are only one means of obtaining data on the public's interests, concerns, priorities, and perceptions. Consider combining hearings with informal involvement procedures such as open houses or recesses after the presentations to afford the public the opportunity to review displays and ask one-on-one questions. Holding informal meetings to clarify issues and concerns and to provide prehearing information should be considered in order to reduce misunderstandings and conflicts that might arise at the hearing.

a. Public Hearings. During the environmental/conceptual studies process, a public hearing must be scheduled or the opportunity offered in order to discuss projects that fall into the following categories:

- Are on new location.
- Require the acquisition of significant amounts of right-of-way.
- Substantially change the layout or function of connecting roads or streets or of the facility being improved.
- Have a significant adverse impact upon abutting real property or otherwise have a significant social, economic, or environmental effect.
- Have been determined by FHWA that the project is in the public interest.

Table 3-1 summarizes the application of this hearing criteria by project category. For Class I projects, a public hearing will be scheduled or an opportunity offered for a public hearing. Projects classified as Class II, under 23 CFR 771.117(d), may require public hearings or the opportunity for a public hearing offered. On Class III proposals, either a public meeting and/or an opportunity for a public hearing is the appropriate action(s) to inform the public and get their input.

Public hearings provide a forum for an open exchange of views concerning the need for the project, alternate locations, alternate major design features, and the related potential social, economic, and environmental effects. These features most generally can be covered during Conceptual Studies in a combined corridor and design hearing. However, for a difficult or controversial project, it may be expedient to hold separate corridor and design hearings.

The alternatives presented at each hearing will be developed to comparable levels of detail, and hearings will be held and comments evaluated before final determination of design parameters for an alternative. For example, when a combined hearing is held, some major design features may have been developed. The comments received at the hearing will be considered before either the location or design alternatives are approved.

During a reevaluation of a project, the following criteria for additional hearing(s) or meeting(s) shall be considered when there has been any of the following:

- A substantial change in the proposal.
- A substantial unanticipated development in the area affected by the proposal.
- An unusually long lapse of time since the last hearing.
- Significant social, economic, or environmental effects identified that were not previously considered at earlier hearings or meetings.

When a substantial amount of right-of-way has already been acquired, alternate locations should be discussed at the hearings/meetings in order to inform the public of the project history, but the main discussion will center on major design features.

All required hearings should be timed to follow the circulation of the environmental document for the project.

b. Public Hearing Notices. Those interested in or affected by proposed projects (such as property owners) must be notified of the opportunity for a public hearing and of a scheduled public hearing. At least two notices of the hearing opportunity or the scheduled hearing shall be published in newspapers having general circulation in the vicinity of the proposed project and in any newspaper having substantial circulation in the area concerned, such as foreign language and local newspapers.

At the discretion of the Division engineer, one of the following notice procedures shall be followed:

(1) The first notice is published from 30 to 40 days in advance of the deadline for requesting a hearing or of the scheduled hearing. The second notice is published 5 to 12 days in advance of the deadline for requesting a hearing or of the scheduled hearing.

(2) The notices are published for 2 consecutive weeks, with the last notice at least 10 days prior to the deadline for requesting a hearing or of the scheduled hearing.

Each notice shall be sent to appropriate news media; the State's resource, recreation, and planning agencies; and appropriate Federal agencies, such as the Departments of Agriculture, Interior, and Housing and Urban Development.

Copies should be sent to local public officials, public advisory groups and agencies who have requested notice of hearing, and other groups or agencies who (by nature of their function, interest, or responsibility) are known to be interested in or affected by the proposal.

Under normal circumstances, each Division maintains a list upon which any Federal agency, local public official, public advisory group or agency, civic association, or other community group can enroll to receive notices in any area specified by them.

The notice of a hearing opportunity will explain the procedures to use for requesting a hearing and explain that the hearing will either be scheduled or a mutually agreeable meeting will be arranged with those requesting one. The notices also indicate the date, time, and place of a scheduled hearing; contain a description of the proposal; and announce the availability of the environmental document. The notices include the procedures for submitting written statements and exhibits at or after the hearing. The public hearing notice indicates that relocation assistance programs, as appropriate, will be discussed at the hearing. Notices for design hearings should also indicate that tentative schedules for right-of-way acquisition and construction will be discussed. Notices also include information such as significant flood plain encroachments to comply with other applicable laws, executive orders, or regulations.

The notice should also specify that maps, drawings, and other pertinent information developed by the Government, and written views received, are available for public inspection and copying. Generally this inspection will be held at the nearest FHWA, land management agency, or highway agency offices, or at some other convenient location in the vicinity of the project.

Following a public hearing or opportunity for a hearing, a notice shall be published in the news media concerning the decision made on the final environmental document and/or the action taken on the location and major design features for Class I and III projects, as well as some Class II projects as appropriate. See Exhibit 3.3 for an example of a typical hearing notice.

c. Conducting Public Hearings. Hearings are to be held at a place and time convenient for persons affected by the proposed undertaking and are to be accessible to the handicapped. Responsible officials from the highway agency and FHWA, or other qualified individuals, will be present to conduct the hearings and will respond to questions that arise. The FHWA staff will be available prior to the hearings to receive the public and respond to their questions.

The hearing moderator and participants should be responsive to all reasonable and proper questions. The hearing moderator should control the tone of the hearing and should not allow any person to be harassed or subjected to unreasonable cross-examination.

Formal presentations by the program agencies should be accomplished first, in a reasonable time frame that should last no more than 45 minutes. Questions should not be accepted during this time.

There should then be a brief break, at which time the public may view the exhibits and visit with the program agency participants.

The time after the break is for the public. The agenda should allow for acceptance of written and/or oral presentations by the public in an orderly manner and in an appropriate time frame.

The moderator may decide to have those wishing to speak sign in as speakers, or the moderator may decide to randomly select the speakers from the audience. It may be necessary that the moderator limit each speaker's allowed time to accommodate a large number wanting to speak. A random selection of speakers may be more appropriate for smaller groups.

Speakers should be asked to state their names and who they represent so they can be readily identified with their presentations in the hearing transcript.

Responses by the program agency participants may follow each presentation by the public or may be held until later, during a question and answer period.

There should be a question and answer period following the formal presentations by the public. Program agency participants should provide informative responses to questions asked. Should information to respond not be available, a verbal commitment may be made to provide such information to the questioner when it is available.

Prior to adjourning the hearing, the moderator or Division office participant may summarize the important information received at the hearing and relate what procedures, schedules, or actions will follow the review, based on the hearing information and comments received on the environmental document.

d. Public Hearing Agenda. Public hearings are generally more successful and gain more public participation when an informal agenda is used to learn the public's views and opinions in a casual and personal way.

The hearing agenda and/or presentations should be prepared to do the following:

- Explain the purpose of the hearing, the need for the project, and the history of project development (including a synopsis of public and interagency involvement activities).

- Provide an appropriate brochure, pamphlet, the Federal, State, and county highway agency relationship in the Federal-aid highway program.

- Provide a method of recording attendance, and informing the attendees that anyone wishing to receive written notice of FHWA's action resulting from this environmental hearing process should list their name and mailing address on the sign in sheet.

- Provide information on all reasonable location alternatives studied, on the no action alternative, and on their significant SEE effects at corridor hearings. At corridor/design hearings, discuss all reasonable location /design alternates, the no action alternative, and significant SEE effects.

- Present preferred alternatives. However, it should be stressed that the alternatives are subject to reevaluation and/or revision based upon public input at the hearing, additional studies, comments made on the environmental document, or other information that may become available.

- Explain, as appropriate, right-of-way acquisition procedures, cost estimates, and construction schedules including any critical activities that may involve or affect the public.

- Discuss the relocation assistance program and explain what assistance payments are available. Distribute a relocation assistance brochure, pamphlet, or similar type of handout.

  In the event that the project requires no relocation, the relocation assistance discussion may be omitted and a simple statement made that *relocation assistance is provided when needed but that no relocation is required by the project under discussion*.

  However, right-of-way personnel should still be in attendance and the relocation assistance handout made available to the public.

- Explain that all information developed in support of the proposed location or design will be available upon request for public inspection and copying.

The information presented for inspection and copying should be available in the locality of the project. A project office, a state transportation facility, a local government office, or other Federal offices are logical and sometimes convenient sites for the presentation of the information.

- Explain the requirements for public submission of written statements and exhibits at or within 10 days after a hearing. The procedures for making submissions should be described in the notice and at the hearing.

e. Documenting Public Hearings. The following documents shall be prepared and made available to interested parties:

(1) A verbatim written transcript of the oral proceedings, together with copies of all written statements or exhibits used or filed in connection with the hearing assembled into one document. The document shall also contain or reference all information made available to the public before the hearing.

(2) A certification stating that the hearing has been held or that the opportunity for the hearing has been afforded. A further certification is prepared stating that the SEE effects of the proposed project have been considered and, where appropriate, the project is consistent with the goals and objectives of such urban planning as has been set forth by the community.

(3) Appropriate environmental documents which indicate the consideration given to the social, economic, environmental, and other effects of the plan or highway location or design and the various alternatives that were raised during the hearing or which were otherwise considered.

The transcript and all other relevant data assembled shall be made available for public inspection and copying at the locations listed in the public hearing notice.

After the Division Engineer has selected the design to be constructed, the public should be advised. Two effective methods of notification are sending a newsletter or an environmental document to those on the interest list or publishing a notice in the local newspapers.

3.5 APPROVALS

Numerous approvals needed as a proposal advances through the project development process are addressed in the following Sections.

A. Actions By Other Agencies. The following list briefly describes various statutes and regulations that require consultation and/or approval actions by other agencies having jurisdictional authority for some aspect of the proposal. Depending on the location of the project and its impact on the surrounding area, additional statutes and regulations may apply.

Many of these actions are common occurrences on most proposals while others are infrequent occurrences. Although some do not require formal approval actions, several regulations have the same time-consuming effect: they involve difficult consultation and agreement on mitigation measures before the environmental document can be completed and the proposal advanced to detailed design.

Environmental legislation requiring consultation, coordination and/or permits, certification, clearance, concurrence, or otherwise approvals from other agencies is as follows:

ISTEA

- All Federal Lands Highway Projects are required to be included in an approved State Transportation Improvement Plan (STIP).

River and Harbor Act of 1899:

- Consult and coordinate with EPA, USACE, AND USCG.
- Obtain navigation permit from USCG.
- Obtain Fill Permit (Section 10) from USACE.

Clean Water Act of 1977:

- Consult and coordinate with EPA, USACE, and State water agency.
- Obtain water Quality Certification (401) from State Water Agency.
- Obtain fill Permit (404) from USACE.

Fish and Wildlife Coordination Act of 1958:

- Consult and coordinate with FWS and State fish and game authorities.
- Obtain certification from State fish and game authorities pursuant to some State acts.

Wild and Scenic Rivers Act:

- Consult and coordinate with USFS and NPS.

Clean Air Act of 1970 (amended 1990):

- FHWA and State Air agency will determine if the project is consistent with a State implementation plan.
- Consult and coordinate with EPA.

National Historic Preservation Act of 1966 (Section 106) (amended 1992):

- Consult and coordinate with SHPO and DOI.
- Obtain clearance from SHPO.

Archeological and Historic Preservation Act of 1974:

- Consult and coordinate with SHPO and DOI.
- Obtain clearance from SHPO.

DOT Act of 1966, Section 4(f):

- Consult and coordinate with HUD, USDA and DOI.

Land and Water Conservation Fund Act, Section 6(f):

- Consult, coordinate, and obtain approval from DOI if such lands are taken.

Wilderness Act of 1964:

- Consult and coordinate with FS, FWS, NPS, BLM, and appropriate State agencies.

Endangered Species Act of 1973 (Amended 1978):

- Memorandum of Understanding between USDA, DOD, USACE, NMFS, DOI, DOT, EPA, dated September 1994.
- Consult and coordinate with FWS, State fish and game authorities and NMFS (marine species only).

Intergovernmental Cooperation Act of 1968 (EO 12372):

- Submit notification(s) to State's Single Point of contact.

Safe Drinking Water Act of 1974:

- Consult and coordinate with EPA, and State health agency.

National Flood Insurance Act of 1968:

- Consult and coordinate with HUD relative to areas threatened by flood hazard.

36 CFR Parts 215 and 217: Procedures for National Forest System Projects and Activities. Appeal of Regional Guides and National Forest Land and Resource Management Plans.

- Consult and coordinate with Forest Service
- Environmental Justice, Executive Order 12898

Evaluation of Flood Hazards, Executive Order 11296:

- Consult and coordinate with USACE.

Protection of Flood Plains, Executive Order 11988:

- Consult and coordinate with USACE and FEMA.

Migratory Bird Conservation Act:

- Consult and coordinate with DOI and State agencies relative to sanctuaries or wildlife areas.

Anadromous Fish Conservation Act:

- Consult and coordinate with FWS, NMFS, and State fish and game authorities.

Protection of American Antiquities (Monuments and Memorials):

- Consult and coordinate with NPS and the land management agency.

National Park Service General Authorities Act of 1970: Section 8, National Natural Landmarks

- Coordinate with NPS.

Protection of Wetlands, Executive Order 11990:

- Consult and coordinate with FWS, USACE, and State fish and game authorities.

National Trails System Act:

- Consult and coordinate with NPS and FS.

Highway Improvements in the Vicinity of Airports. (23 CFR 620, Subpart A):

- Submit design to FAA for approval.

Farmland Protection Policy Act of 1981. (7 CFR 658):

- Coordinate with SCS.

Coastal Zone Management Act of 1972. (15 CFR 923 and 930):

- Coordinate with State Coastal Zone Management agency and the U.S. Department of Commerce (OCZM).

When applicable, the following actions must occur during the environmental analysis and be documented in the environmental report prior to its completion and approval:

- Make a floodplain/wetland determination.
- Make a clean air consistency determination.
- Obtain a cultural resource clearance.
- Perform an endangered species biological analysis.
- Make an airport/highway conflict determination.

Although coordination for action is initiated early in the environmental analysis, the following actions are to be undertaken during the detailed design phase, following approval of the environmental report:

- Obtain a fill permit.
- Obtain a navigational permit.
- Obtain a water quality certification.
- Obtain a streambed alteration certification (pursuant to some State acts).
- Obtain State and/or local permits for material sources.
- Obtain FAA approval of highway design in vicinity of airports.
- Obtain NPDES permit.
- Obtain State permits for sediment and erosion control during construction.
- Obtain State permit for stormwater management.
- Obtain State permit for wetland encroachment.
- Obtain State permit for upland mitigation.

B. Actions by Federal Highway Administration. The environmental process involves numerous approval actions (in consultation with land management agencies) during conceptual studies at various levels of authority in FHWA. See Table 3-2.

Table 3-2*
Approval Actions

Action	Authority
Initial project classification	Action Plan Committee
Final project classification	Action Plan Committee
CE	Division Engineer
FONSI	Division Engineer
Draft EIS	Division Engineer
Final EIS	FHWA Regional Office
Section 4(f) Statement	FHWA Regional Office
ROD	FHWA Regional Office

Note:
1. Approval of the CE, FONSI, or ROD constitutes approval of the general highway location and to begin detailed design.
2. Final EIS approval may require prior concurrence of FHWA Headquarters.

* Table applicable when FHWA is the lead agency.

3.6 REPORTING

The environmental document formally reports the process of collecting, researching, summarizing and analyzing the facts concerning alternatives, focusing on the important impacts and issues.

Underlying scientific theory, assumptions, rationale and findings presented in the environmental document should be clear, concise and to the point. They may be supported by visual aids and evidence that the necessary analyses have been made and understood by the reviewer.

A. Environmental Documents. The SEE study team and the environmental planning engineers consider for inclusion in the appropriate environmental report: the important engineering and SEE aspects of the proposal; the effects of no-build and reasonable engineering alternatives; and determine measures to minimize adverse impacts. The environmental document promotes the policies and goals of NEPA and other environmental statutes in Federal programs and actions.

The engineering information and descriptions of the improvement alternatives contained in the environmental documents are summarized from the conceptual study reports. (See Section 4.6.B in Chapter 4.) Dual units (metric and imperial) should be used for all documents that are subjected to public review and comment. Since the final location approval decisions are a product of the environmental process, it is imperative that environmental documents present the engineering data in an accurate, complete, and understandable fashion.

FHWA concurs with the CEQ philosophy that the goal of the NEPA process is *better decisions*. The length of an environmental assessment should range from 10 to 15 pages and the length of an environmental impact statement should not normally exceed 150 pages.

The primary environmental documents (environmental actions) are as follows:

1. Environmental Assessment (EA). A public document developed by a Federal agency to provide evidence and supporting analysis for determining whether there is a significant impact and if there is a need to prepare an EIS or a FONSI. An EA is also used to substantiate compliance with NEPA when no EIS statement is necessary.

This document should include discussions of the need for the proposal, of the environmental impacts of the preferred action, no-build and other reasonable alternatives and a listing of agencies and persons consulted.

2. Finding of No Significant Impact (FONSI). A document by a Federal agency briefly presenting the reasons why an action, not otherwise excluded, will not have a significant effect on the human environment and that therefore an EIS will not be prepared. The FONSI includes the EA or a summary of it and notes any other environmental documents related to it. If the EA is included, the FONSI need not repeat any of the discussion in the EA but may incorporate it by reference.

3. Environmental Impact Statement (EIS). A detailed, written statement containing an assessment of the anticipated significant, beneficial, and detrimental effects that a proposed major FHWA action, no-build, or other alternatives may have upon the quality of the human environment.

4. Record of Decision (ROD). A decision document that follows the final EIS and sets forth the reasons for the project decision, based on material in the EIS. While cross referencing and incorporation by reference of material in the final EIS or other documents is appropriate, the ROD completely and clearly explains the basis for the project decision.

5. Categorical Exclusion (CE). A statement on an action that does not individually or cumulatively have a significant effect on the human environment and has no effect on procedures adopted by a Federal agency in implementing the CEQ regulations. Neither an EA nor an EIS is required. Examples of projects complying with these regulations are highway improvement projects such as resurfacing, reconstruction and widening existing lanes, and adding auxiliary lanes.

Although CE proposals do not require a formal environmental document pursuant to NEPA, coordination and documentation is still required for other applicable environmental statutes and regulations.

6. Section 4(f) Evaluations/Approvals. The FHWA Technical Advisory T 6640.8A provides detailed information on format and content requirements for documenting and reporting evaluations or approvals on projects proposing to use Section 4(f) lands.

A no-build decision and each reasonable engineering alternative that uses Section 4(f) lands should be addressed. For a complex 4(f) involvement, include the analysis in a separate part of the EIS, EA, or FONSI document. For projects processed as a CE, the evaluations or determinations may be in a separate document.

The Section 4(f) approval is incorporated into the final EIS, ROD, or FONSI document. For projects processed as a CE, the approvals should be in a separate document.

B. Permits/Clearance Documentation. As discussed in Section 3.5 and in other chapters, numerous permits/clearances or other similar actions or documentation are required before projects may be advanced to construction.

1. Fill Permits pursuant to Section 404. During the USACE review of Section 404, fill permit applications (pursuant to the Clean Water Act), the USACE will consider earlier public meetings or hearings and consultations with the Water Quality and Natural Resource agencies and the Fish and Wildlife Service.

Satisfactory processing of fill permit applications is dependent upon a well written environmental report, use of procedures detailed in the FHWA/USACE memorandum of agreement, and the providing of evidence of public and interagency involvement.

The environmental report should give the general location of fill activity, approximate quantities of fill material, general construction grades, proposed mitigation measures and evidence of public and interagency involvement.

The application to the USACE for a fill permit generally occurs during the design phase of the proposal and uses Standard Form 4345. The proposed fill activity, its purpose, and intended use must be described in detail. A sample of a completed application form is shown in Exhibit 3.4.

General or Nationwide permits are issued by USACE for any category of activity on a State, regional, or national basis if the activities are similar in nature, will cause only minimal adverse environmental effects when performed separately and will have only minimal cumulative adverse environmental effects.

2. Other Clearances (Sections 401 and 402 of Clean Water Act). Certifications are required from the State water quality agency pursuant to Sections 401 (water quality) and 402 (point discharges) of the Clean Water Act. Consultation with the Environmental Protection Agency concerning point discharges is also required. National Pollution Discharge Elimination System (NPDES) permits are also required for many projects.

Modifications of streambeds may also require a permit from the State natural resources agency pursuant to State statutes.

These actions are byproducts of the USACE and Coast Guard permit procedures.

3. Navigation Permit (Section 10 of the Rivers and Harbors Act of 1899). Corp of Engineer permits are required whenever proposals involve building any obstruction in navigable waters or waters subject to tidal influence. Coast Guard permits are required under Section 9 of the Rivers and Harbors Act of 1899 and Section 502(b) of the General Bridge Act of 1946.

The USACE, Fish and Wildlife Service, and State water quality and natural resource agencies are also involved because Sections 401, 402, and 404 of the Clean Water Act and State streambed alteration statutes are applicable.

Consultation is similar to Section 3.6.C.1 above, but with the Coast Guard and other waterway agencies involved. Specific responsibilities are included in the FHWA/Coast Guard Memorandum of Understanding. Should a proposal affect a historic bridge that is eligible for the National Register of Historic Places, coordination with the Coast Guard is necessary to ensure they will accept the environmental document and/or programmatic Section 4(f) approach.

The navigational and engineering needs, environmental resources and effects, and mitigation measures should be discussed and agreed upon and documented in the appropriate FHWA environmental report. There may be instances where the Coast Guard will process a FHWA Categorical Exclusion with a Coast Guard FONSI.

4. Cultural Resource Clearance. Studies and consultations concerning cultural resources are performed together with alternative studies and other environmental aspects to minimize or mitigate the effects of proposals and assure timely clearance.

Cultural Resource Analyses:

- Consult with the SHPO, historical societies and groups, and management agencies.
- Conduct historical/archeological surveys.
- Identify properties included in or eligible for inclusion in the National Register of Historic Places.
- Evaluate the effect of the proposed action.

Documentation in the EA or draft EIS:

- Resources and survey information.

- Coordination with SHPO.
- Determination of effect on eligible sites by FHWA.
- Proposed mitigation measures (avoidance, data recovery, etc.).
- Unresolved issues

Documentation in the FONSI or Final EIS:

- Coordination with the SHPO.
- Coordination with the Advisory Council on Historic Preservation (ACHP) if there is an effect.
- Determination of no adverse effect (with or without conditions).
- Memorandum of Agreement with the ACHP/FHWA/SHPO if there is an adverse effect.
- Unresolved issues.

Some Categorical Exclusion proposals may involve cultural resources that will be documented in the project files.

5. Airport Clearance. Reconstruction or relocation of any highway located within a 3.2-kilometer radius of an airport facility shall be coordinated with the appropriate FAA authority to ensure that airway-highway clearances are adequate for the safe movement of air and highway traffic. See 23 CFR 620 Subpart A and FHPM 6-1-1-2.

6. Other approvals and/or certifications. If a proposed project is located within a coastal management zone, a consistency statement concerning the local coastal zone management program may be required by the FLH Division Engineer.

Plans for the construction, operation, or maintenance of any structure affecting navigation or flood control across, along, or in the Tennessee River and its tributaries must be approved by the Tennessee Valley Authority (TVA) pursuant to Section 26a of the Tennessee Valley Authority Act. The TVA may require an EA before approving the proposal.

7. Standard Forms. Standard forms are sometimes used by other agencies in order to obtain data needed to apply for a permit or clearance for the portion of a project for which they are responsible.

The most recurring use of a standard form is for applications to the USACE for a fill permit (ENG. FORM 4345). (See Exhibit 3.4.)

3.7 DIVISION PROCEDURES

Reserved for Federal Lands Highway Division office use in supplementing the policy and guidelines set forth in this chapter with appropriate Division procedures and directions.

LIST OF EXHIBITS

SOCIAL, ECONOMIC, AND ENVIRONMENTAL CHECKLIST

Project Identification: ______________________________

Checklist prepared by: ______________________ Date: ________, ________ ____

Instructions: Complete Column A by checking appropriate action response to questions. If action response is Yes, check proper response in Column B. Place a check mark in Column C on those issues considered important and requiring additional discussion or documentation.

	A		B		C	
	SEE ACTION		**Important Issue or Concern?**		**Additional Discussion Required?**	
PHYSICAL. Will the proposal either directly or indirectly	**Yes**	**No**	**Yes**	**No**	**Yes**	**No**
1. Change the topography or ground surface relief features?						
2. Destroy, cover, or modify any unique geologic or physical features?						
3. Result in unstable earth surfaces or exposure of people or property to seismic or geologic hazards?						
4. Result in or be affected by soil erosion or siltation whether by water or wind?						
5. Result in a change in the rate of use of any natural resource? (Include energy fuels.)						
6. Result in substantial depletion of any nonrenewable natural resource?						
7. Benefit or hinder mining, well drilling, timber production, grazing, or other natural resource activity?						
8. Result in solid waste or litter control problem?						
9. Modify the channel or change the water currents of a river or stream or the bed of the ocean or any bay, inlet, or lake?						
10. Affect any “Wild and Scenic River's” natural, cultural and recreational value?						
11. Cause or be affected by flooding, floodwaters, or tidal waves?						
12. Cause or be affected by flooding, floodwaters, or tidal waves?						

SOCIAL, ECONOMIC, AND ENVIRONMENTAL CHECKLIST

	A		B		C	
	SEE ACTION		Important Issue or Concern?		Additional Discussion Required?	
	Yes	No	Yes	No	Yes	No
PHYSICAL. Will the proposal either directly or indirectly (Continued)						
13. Affect surface water, groundwater, public water supply, or sole source aquifer?						
14. Adversely affect water quality?						
15. Change the absorption rates, drainage patterns, or rate and amount of surface water runoff?						
16. Result in substantial air emissions or adverse effects on or deterioration of ambient air quality?						
17. Be consistent with the State Implementation Plan for air quality?						
18. Result in noise levels that are inconsistent with Federal, State, or local noise standards?						
BIOLOGICAL. Will the proposal either directly or indirectly						
19. Result in change in the diversity of species or number of any species of plant (including trees, shrubs, grass, crops, microflora, and aquatic plants)?						
20. Effect critical habitat of any unique, rare, threatened, or endangered species of plant?						
21. Result in reduction in area of any agricultural crop?						
22. Result in removal or deterioration of existing fish or wildlife habitat?						
23. Change the diversity of species or number of any species of animal (birds, land animals including reptiles, fish and shellfish, benthic organisms, insects, or microfauna)?						
24. Reduce the number of any unique, rare, threatened, or endangered species of animal?						
25. Take area wildlife or waterfowl refuges?						
26. Take wetland area						
27. Result in the formation of new wetland?						
SOCIAL AND ECONOMIC. Will the proposal directly or indirectly						
28. Be inconsistent with any elements of adopted community plans, policies, and goals, e.g., land use plans, management goals?						

SOCIAL, ECONOMIC, AND ENVIRONMENTAL CHECKLIST

SOCIAL & ECONOMIC. Will the proposal directly or indirectly (Continued)

	A SEE ACTION		B Important Issue or Concern?		C Additional Discussion Required?	
	Yes	**No**	**Yes**	**No**	**Yes**	**No**
29. Affect the location, distribution, density, or growth rate of the human population of an area?						
30. Affect life styles or neighborhood character or disrupt an established community?						
31. Affect minority, elderly, handicapped, or other specific interest groups?						
32. Affect existing housing, require the displacement of people, or create a demand for additional' housing?						
33. Affect employment, industry, or commerce, or require the displacement of business or farms?						
34. Result in the reduction of area of any prime or unique farmland?						
35. Result in the reduction of area of any prime or unique farmland?						
35. Affect property values or the local tax base?						
36. Affect any community facilities (including medical, educational, scientific, recreational, pedestrian and cultural or religious institutions, ceremonial sites or sacred shrines)?						
37. Affect public utilities or police, fire, emergency, or other public services?						
38. Have substantial impact on existing transportation systems or alter present patterns of circulation or movement of people and/or goods?						
39. Affect vehicular movements or generate additional traffic?						
40. Affect or be affected by existing parking facilities or result in demand for new parking?						
41. Increase traffic hazard to motor vehicles, bicyclists, or pedestrians?						
42. Involve a substantial risk of an explosion or the release of hazardous substances in the event of an accident or upset condition?						
43. Affect public health, expose people to potential health hazards, or create a real or potential health hazard?						
44. Affect a significant archeological, historical, or cultural site, structure, object, or building?						
45. Affect natural landmarks or manmade resources?						

SOCIAL, ECONOMIC, AND ENVIRONMENTAL CHECKLIST

	A		B		C	
	SEE ACTION		**Important Issue or Concern?**		**Additional Discussion Required?**	
SOCIAL & ECONOMIC. Will the proposal directly or indirectly (Continued)	**Yes**	**No**	**Yes**	**No**	**Yes**	**No**
46. Affect publicly-owner parklands or recreational areas?						
47. Result in increased demand on existing sources of energy?						
OTHER ENVIRONMENTAL CONSIDERATIONS: Will the proposal directly or indirectly						
48. Affect any scenic resources or result in the obstruction of any scenic vista or view open to the public, or create an aesthetically offensive site open to public view?						
49. Result in impacts associated with construction activities (e.g., noise, dust, temporary drainage, traffic detours, and temporary access, etc.)?						
50. Does the project have the potential to achieve short-term, to the disadvantage of long-term, environmental goals.[1]						
51. Does the project have environmental effects that are limited individually, but cumulatively considerable?[2]						
52. ______________________						
53. ______________________						

[1] A short-term impact on the environment is one that occurs in a relatively brief, definitive period of time while long-term impacts will ensure well into the future.
[2] Cumulatively considerable means that the incremental effects of an individual project are considerable when viewed in connection with the effects of past projects, current projects, and probable future projects. It includes the effects of other projects which interact with this project, and together, would be considerable.

LEGEND:

APC	Action Plan Committee	**EPU**	Environmental Planning Unit	**HA**	Highway Agency
DEIS	Draft Environmental Impact Statement	**FEIS**	Final Environmental Impact Statement	**LMA**	Land Management Agency
EA	Environmental Assessment	**FHWA**	Federal Highway Administration	**SEE**	Social, Economic, and Environmental
EIS	Environmental Impact Statement	**FLHD**	Federal Lands Highway Division	**SNRA**	State Natural Resources Agency
EPA	Environmental Protection Agency	**FONSI**	Finding of No Significant Impact	**SPOC**	Single Point of Contact

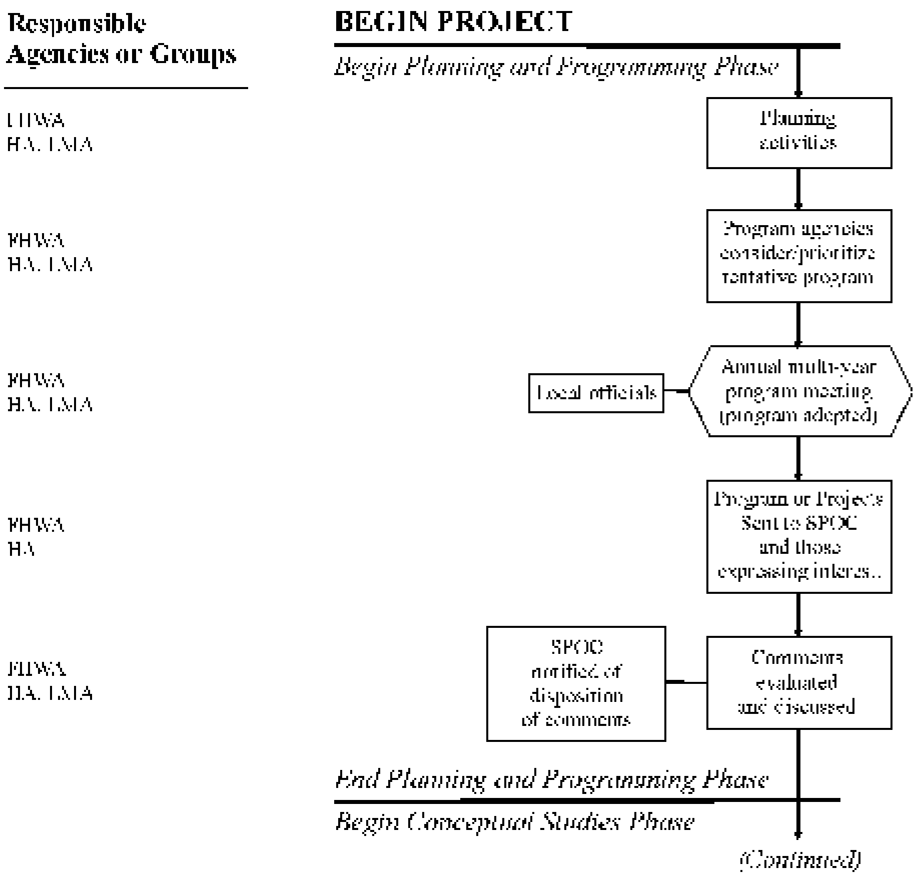

EXHIBIT 3.2 Flow Chart Project Development Process

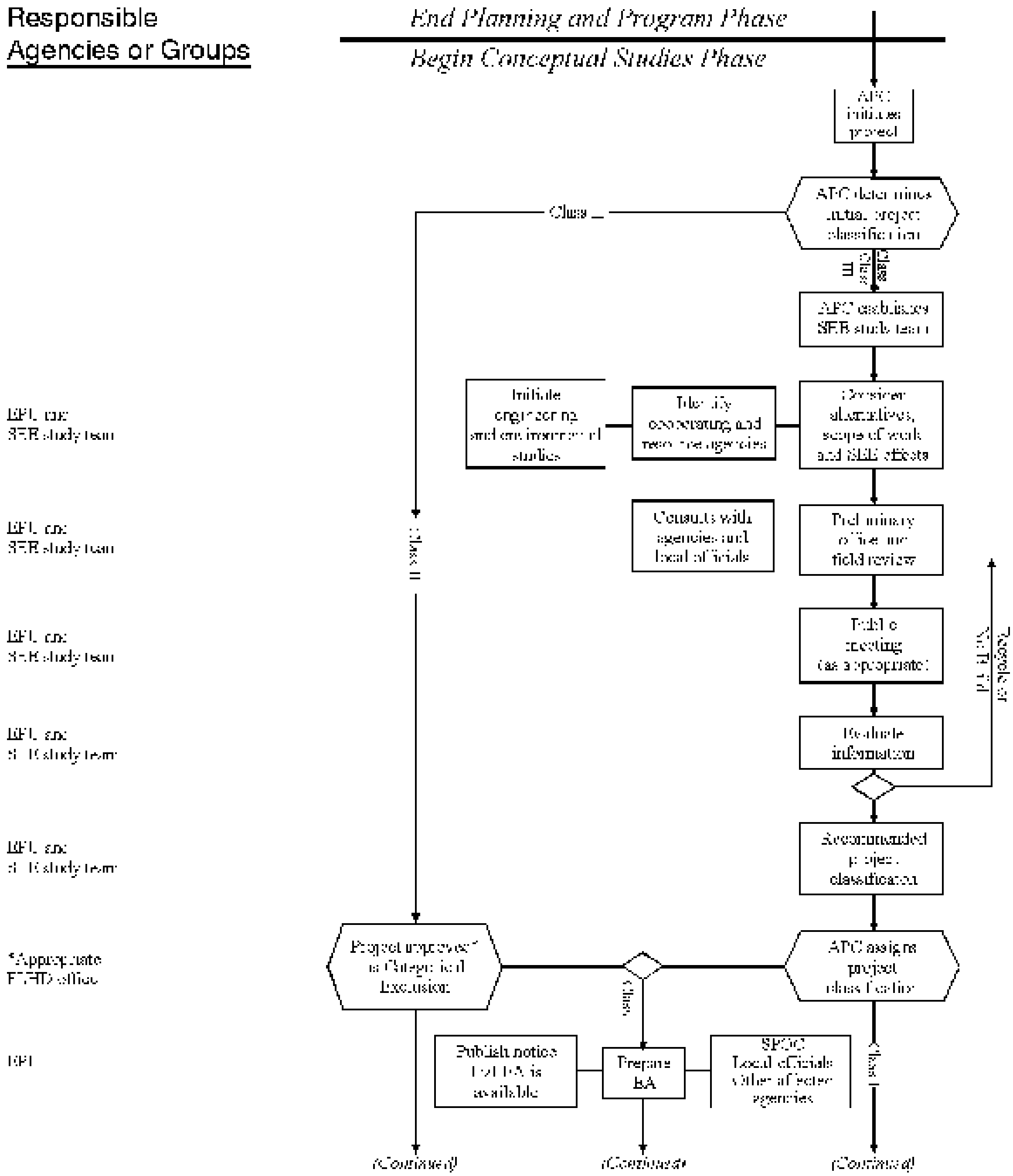

EXHIBIT 3.2 (continued)

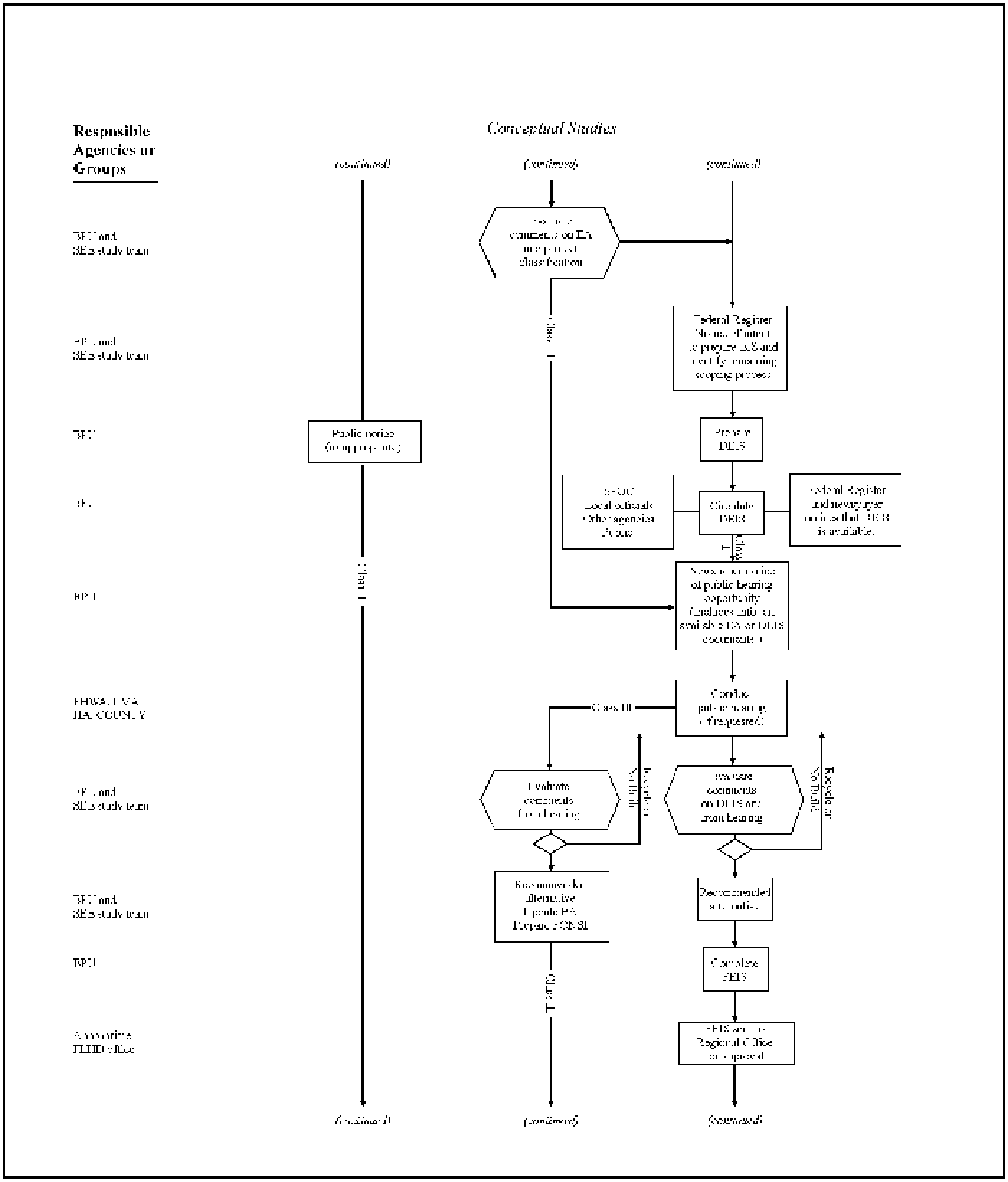

EXHIBIT 3.2 (continued)
Page 3 of 5

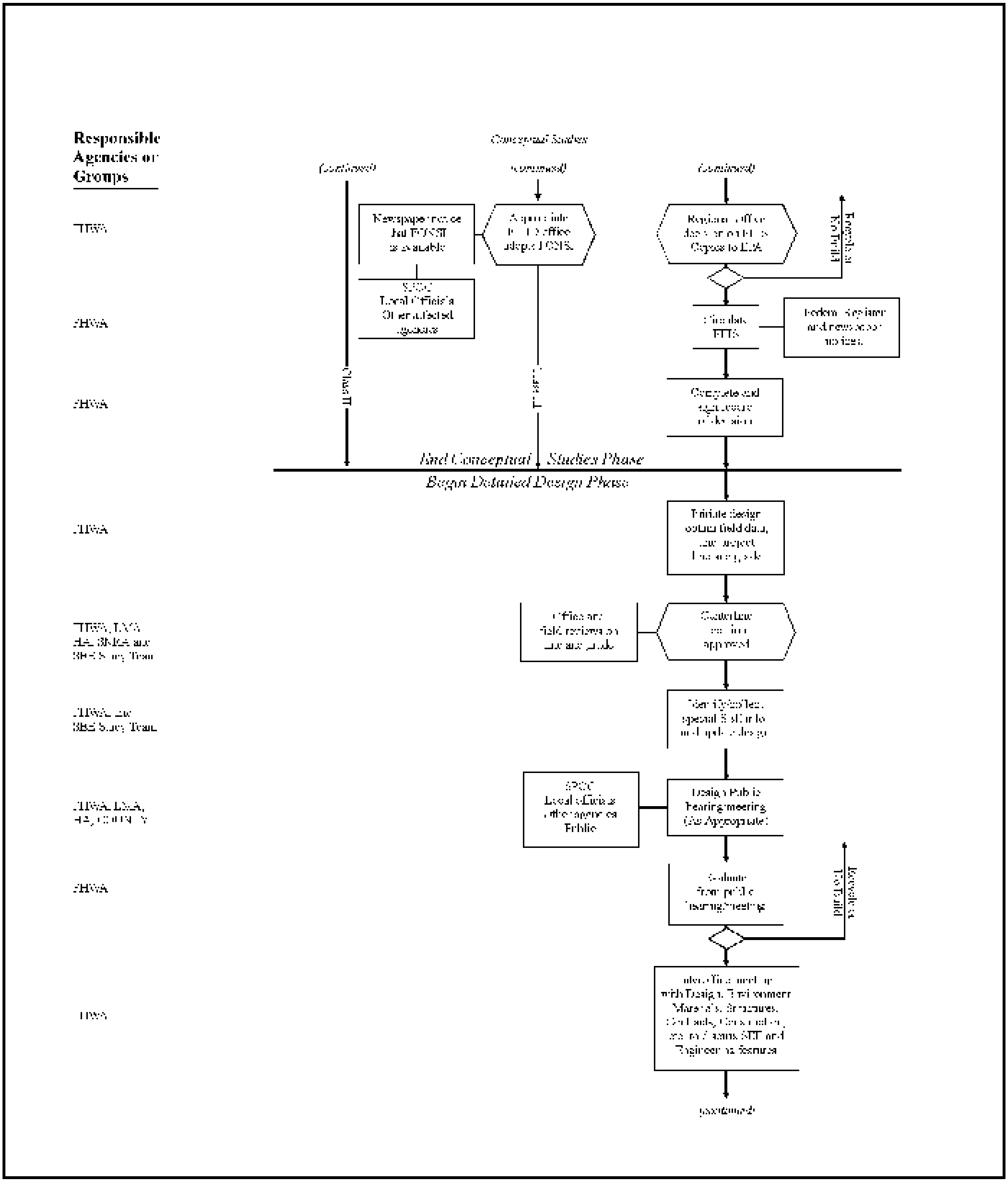

EXHIBIT 3.2 (continued)

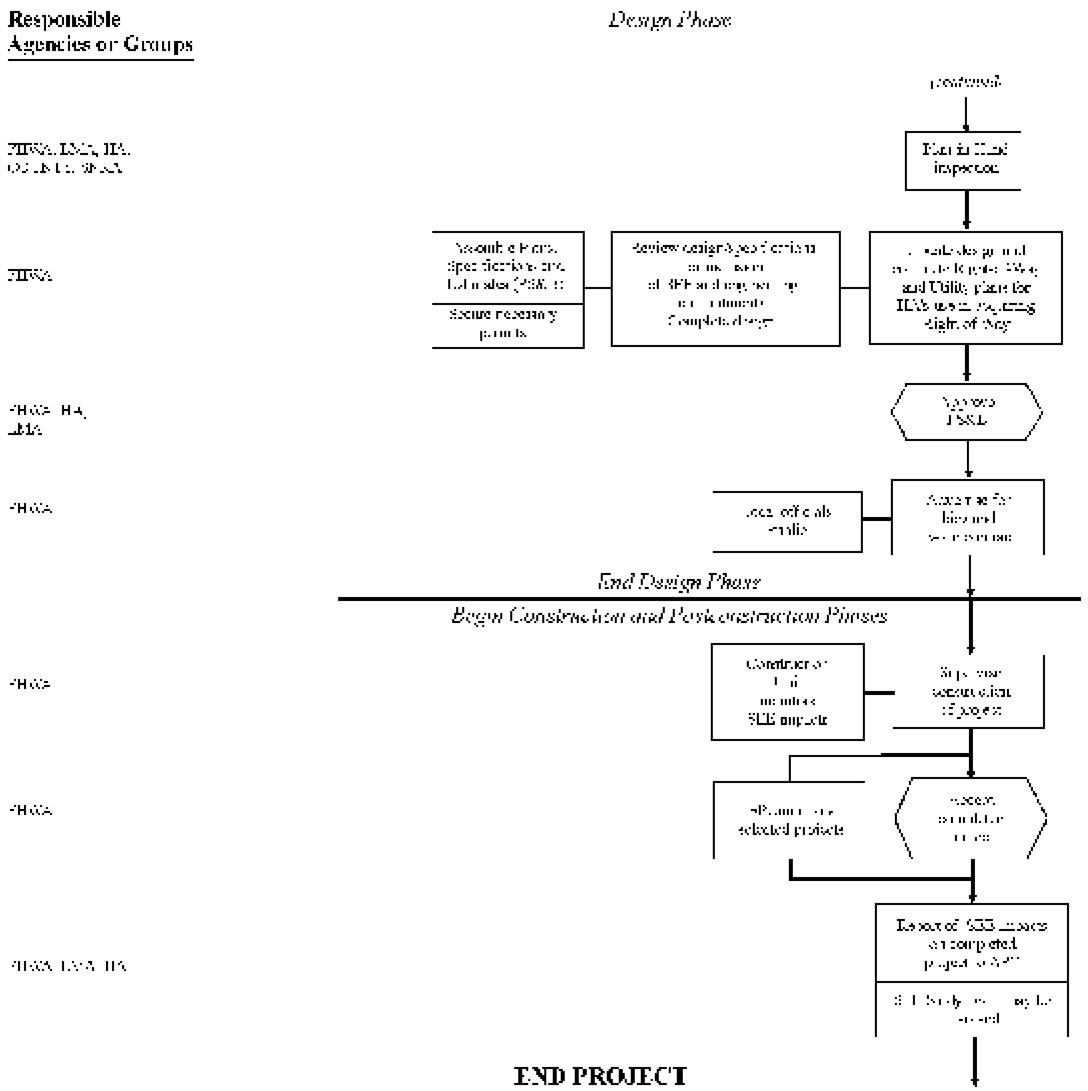

EXHIBIT 3.2 (continued)

The Federal Highway Administration, together with the Forest Service, Wayne County, Sevier County, and the Utah Department of Transportation, will hold a public hearing concerning the reconstruction of a portion of Forest Highway 42. The portion to be reconstructed begins at State Highway 72, about 4.3 kilometers (2.7 miles) northeast of the town of Fremont, then proceeds up the Fremont River valley to Johnson Valley reservoir ending at the recently improved highway on the west side of the reservoir.

The proposed reconstruction will generally follow the existing road. Work will include improving the horizontal and vertical alignment, improving drainage structures, widening the travel lanes to 3.3 meters (11 feet), and adding 0.6-meter (2-foot) shoulders. The travel lanes and shoulders will be surfaced with a hot asphaltic concrete pavement.

An environmental assessment document has been prepared and is available for examination at the Forest Service offices in Richfield and Loa, at the Utah Department of Transportation district office in Richfield, and at the Federal Highway Administration offices in Salt Lake City, Utah and Denver, Colorado. A limited number of copies are available upon request from the Federal Highway Administration address given below. A draft Section 4(f) evaluation report for the 3.2-km (1.97-mile) section of this improvement that lies within the Fish Lake/Johnson Valley Recreation Area has been included.

The proposed improvement will encroach upon the 100-year flood plains of the Fremont River, Sevenmile Creek, and UM Creek. The proposal will affect wetlands along the Fremont River and Johnson Valley Reservoir, and at the UM Creek and Sevenmile Creek crossings. Corps of Engineers Section 404 permits will be required for the Sevenmile Creek, Fremont River (two), and UM Creek crossings. It is also likely that Section 404 permits will be required at several locations along the Fremont River where riprap will be used to stabilize the bank. Concerns relating to these permits should be expressed at this hearing.

The public hearing will be held on Wednesday, April 2, 1996 beginning at 7 p.m. in the Loa Community Center, Loa, Utah. The hearing is being held to provide an opportunity for citizens to learn more about the proposal and to present oral and written comments.

All written comments that are to be included in the public hearing record must be received at the Federal Highway Administration, PO Box 25246, Denver, Colorado 80225, no later than April 14, 1996.

NOTICE OF PUBLIC HEARING
For the Improvement of
Utah Forest Highway 42
The Fish Lake - Fremont River Road

EXHIBIT 3.3 Sample Notice for a Public Hearing

EXHIBIT 3.4

Application for a Department
of the Army Fill Permit

APPLICATION FOR DEPARTMENT OF THE ARMY PERMIT *(33 CFR 325)*	***OMB APPROVAL NO.0702-0036*** ***Expires 30 June 1992***

Public reporting burden for this collection of information is estimated to average 5 hours per response for the majority of cases, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Applications for larger or more complex projects, or those in ecologically sensitive areas, will take longer. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302; and to the Office of information and Regulatory Affairs, Office of Management and Budget, Washington DC 20503.

The Department of the Army permit program is authorized by Section 10 of the Rivers and Harbors Act of 1899, Section 404 of the Clean Water Act and Section 103 of the Marine, Protection, Research and Sanctuaries Act. These laws require permits authorizing activities in or affecting navigable waters of the United States, the discharge of dredged or fill material into waters of the United States, and the transportation of dredged material for the purpose of dumping it into ocean waters. Information provided on this form will be used in evaluating the application for a permit. Information in this application is made a matter of public record through issuance of a public notice. Disclosure of the information requested is voluntary; however, the data requested are necessary in order to communicate with the applicant and to evaluate the permit application. If necessary information is not provided, the permit application cannot be processed nor can a permit be issued.

One set of original drawings or good reproducible copies which show the location and character of the proposed activity must be attached to this application *(see sample drawings and instructions)* and be submitted to the District Engineer having jurisdiction over the location of the proposed activity. An application that is not completed in full will be returned.

1. APPLICATION NUMBER *(To be assigned by Corps)*

2. NAME AND ADDRESS OF APPLICANT

Telephone no. during business hours)
A/C ( ) ____________________ (Residence)
A/C ( ) ____________________ (Office)

3. NAME, ADDRESS, AND TITLE OF AUTHORIZED AGENT

Telephone no. during business hours
A/C ( ) ____________________ (Residence)
A/C ( ) ____________________ (Office)

Statement of Authorization: I hereby designate and authorize ________________ ____________ to act in my behalf as my agent in the processing of this permit application and to furnish, upon request, supplemental information in support of the application.

SIGNATURE **DATE**

4. DETAILED DESCRIPTION OF PROPOSED ACTIVITY

4a. ACTIVITY

4b. PURPOSE

4c. DISCHARGE OF DREDGED OR FILL MATERIAL

5. NAMES AND ADDRESSES OF ADJOINING PROPERTY OWNERS, LESSEES, ETC., WHOSE PROPERTY ALSO ADJOINS THE WATERWAY

6. WATERBODY AND LOCATION ON WATERBODY WHERE ACTIVITY EXISTS OR IS PROPOSED

7. LOCATION ON LAND WHERE ACTIVITY EXISTS OR IS PROPOSED

ADDRESS:

STREET, ROAD, ROUTE OR OTHER DESCRIPTIVE LOCATION

COUNTY STATE ZIP CODE

LOCAL GOVERNING BODY WITH JURISDICTION OVERSITE

8. Is any portion of the activity for which authorization is sought now complete? YES NO
If answer is "yes" give reasons, month and year the activity was completed. Indicate the existing work on the drawings.

9. List all approvals or certificates and denials received from other federal, interstate, state or local agencies for any structures, construction, discharges or other activities described in this application.

ISSUING AGENCY	TYPE APPROVAL	IDENTIFICATION NO.	DATE OF APPLICATION	DATE OF APPROVAL	DATE OF DENIAL

10. Application is hereby made for a permit or permits to authorize the activities described herein. I certify that I am familiar with the information contained in the application, and that to the best of my knowledge and belief such information is true, complete, and accurate. I further certify that I possess the authority to undertake the proposed activities or I am acting as the duly authorized agent of the applicant.

SIGNATURE OF APPLICANT **DATE** **SIGNATURE OF AGENT** **DATE**

The application must be signed by the person who desires to undertake the proposed activity (applicant) or it may be signed by a duly authorized agent if the statement in block 3 has been filled out and signed.

18 U.S.C. Section 1001 provides that: Whoever, in any manner within the jurisdiction of any department or agency of The United States knowingly and willfully falsifies, conceals, or covers up by any trick, scheme, or device a material fact or makes any false, fictitious or fraudulent statements or representations or makes or uses any false writing or document knowing same to contain any false, fictitious or fraudulent statement or entry, shall be fined not more than $10,000 or imprisoned not more than five years, or both.

U.S. GOVERNMENT PRINTING OFFICE: 1989 0--941-358

CHAPTER 4 - CONCEPTUAL STUDIES

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CHAPTER 4 - CONCEPTUAL STUDIES

4.1 GENERAL

The formal project development process begins with a conceptual studies phase. The conceptual studies phase identifies and evaluates alternative courses of action (i.e., engineering concepts) to address the highway's transportation needs and deficiencies. This phase advances a project listed in the multi-year program to a point where it is sufficiently described, defined, and located to allow the actual design phase to begin. Conceptual studies are closely related to the environmental process outlined in Chapter 3. The environmental reports normally summarize the engineering results of the conceptual studies.

The overall objectives of the conceptual studies are as follows:

- To fully identify and quantify a highway's transportation needs and deficiencies.
- To develop a general course of corrective action.
- To identify and evaluate with engineering analyses the feasible and reasonable solutions (alternatives) to these needs and deficiencies.

A preferred alternative is selected after the options have been jointly evaluated in the environmental phase. Assuming the preferred solution involves some form of highway upgrading, the conceptual study phase concludes with the selection of a preferred alternative with the scope of work defined by a category of improvement, geographical corridor, and preliminary highway design standards. The formal identification of the preferred alternative occurs in the final approved environmental document, and this constitutes *location approval*.

4.2 GUIDANCE AND REFERENCES

The regulations, policies, guides, and references that provide the background for implementing conceptual studies are listed in Chapter 1, Section 1.2.

For additional references on specific subjects, refer to the guidance and reference section in the appropriate chapters of this manual. The listings are not all inclusive and other documents may contain useful information in special situations.

4.3 INFORMATION GATHERING

Data collection is an integral step in the conceptual study process. The following subjects are the most common areas where comprehensive information must be gathered for highway location analysis.

A. Needs Studies (Planning Reports and Inventories). These documents provide system-wide highway information on the physical condition, current deficiencies, and future needs of routes on a system. General types of needed improvements and approximate construction cost estimates are also reported and can be used to develop a priority list of projects.

While this information is primarily used to show revenue needs or assists the priority setting/programming process, it can provide a good starting data base for conceptual studies. Usually needs studies are general in nature and must be expanded and refined into specific project data, issues, and details.

The NPS *Road Inventory and Needs Study* and 1983 *Forest Highway Inventory and Improvement Study* are examples of studies conducted by FHWA's Federal Lands Highway Divisions. Federal-Aid Divisions and State transportation agencies routinely conduct other *needs* studies, which may be useful on Federal Lands Highway projects.

B. General Design Criteria. General design criteria are used to describe and evaluate highway improvement alternatives in conventional engineering terms, so that a highway's physical, structural, safety, and operational characteristics can be readily understood. While many elements of design (e.g., stopping sight distances, grades, horizontal/vertical alignment and superelevations, etc., as described in the AASHTO Green Book), must be established to conduct a detailed highway design, only a few elements are usually essential at the conceptual stage. Roadway width (lanes and shoulders), design speed, surfacing type, and corridor location are the main criteria for studying highway alternatives. Other features like side slopes, ditch widths, and clearing limits should also be identified if the total width of project disturbance appears to be a critical consideration. (See Figure 4-1.).

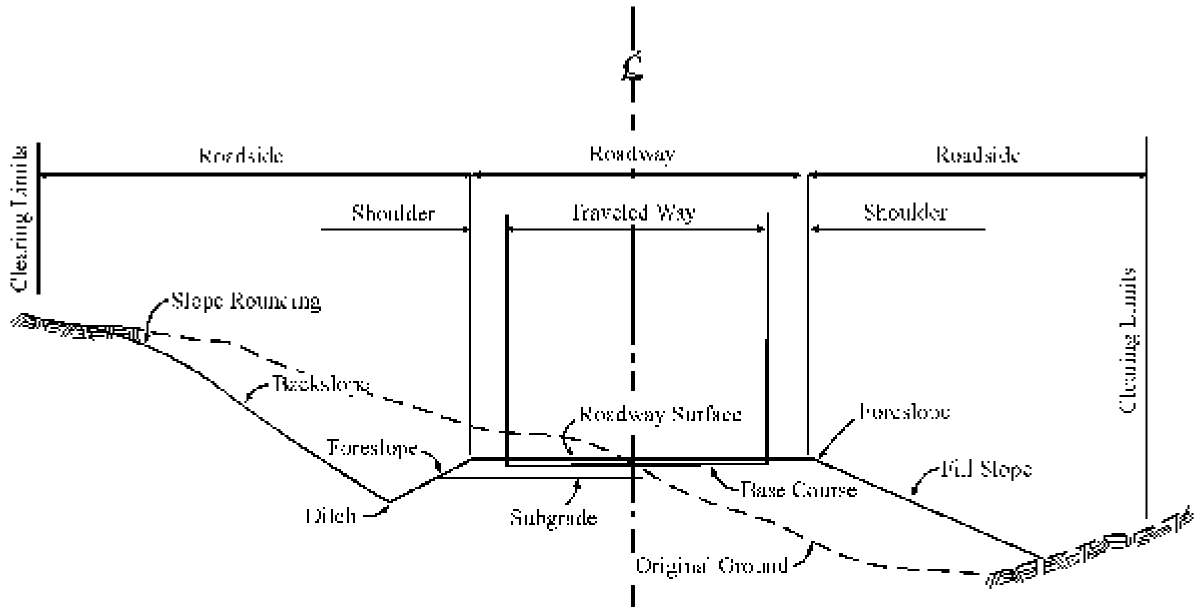


Figure 4-1
Typical Road Cross Section Elements

C. Traffic Characteristics. Traffic plays a major role in establishing the concept and design of a highway. Traffic indicates the type of service for which the improvement is being made and directly affects the geometric features of design such as widths, alignment, and grades.

General traffic data (average daily traffic and vehicle classification) is collected on almost a continuous basis by most highway departments and some land management agencies. This information can be readily obtained and provides a benchmark for traffic data in the study area. When traffic data is not present, it must be developed by special counts or by calculating the number of vehicles from related information such as National Park visitations, cubic meters of timber hauled, and recreational visitor days.

The AASHTO Green Book provides an excellent description of traffic characteristics, such as volume, directional distribution, composition of traffic projections, and speeds. While much of this information has a more direct bearing on design details, conceptual studies and associated alternative analyses are also dependent on overall traffic data. Sometimes traffic data such as operating speeds, travel time and delay, and occupancy rates are needed to address a special issue. If this data is unavailable, traffic studies as described in ITE's *Transportation and Traffic Engineering Handbook* should be conducted to provide such information.

D. Accident Data. Vehicular accident data can provide excellent guidance in determining a road's past problems. These statistics are usually maintained and readily available at the highway department, land management agency, and/or the law enforcement office responsible for that highway facility. When such data is not immediately available, a short term avoidance study or an assessment of accident potential should be conducted.

Figures for accident rates are currently shown in accidents per million vehicle miles traveled. Figures for fatality rates are currently shown in fatalities per one hundred million vehicle miles. FHWA plans to keep this figure for at least several more years, but will supplement it with fatalities per one hundred million vehicle kilometers beginning with the 1994 Highway Statistics Report. Chapter 8 describes in detail how accident rates fit into the safety analyses of highways.

E. Environmental Considerations. A highway has wide-ranging effects beyond that of providing traffic service to its users. It is essential that the highway be considered as an element of the total environment. The highway can and should be located and designed to complement its environment and serve as a catalyst to environmental improvement.

Conceptual studies are conducted concurrently with the environmental process and each has a major effect on the other. As outlined in Chapter 3, close coordination is important to ensure the range of improvement alternatives is established in recognition of overall environmental factors. This allows for an orderly, complete evaluation when determining the preferred improvement alternative. Also, design of the preferred alternative must reflect the mitigation commitments identified in the environmental phase.

F. Reconnaissance Study. The reconnaissance study or survey is a traditional term given to the engineering process now called *conceptual studies.* Originally, it was associated more with the investigation and evaluation of road corridors on new alignment. In contemporary terms, the field inspections and engineering involved with identifying and quantifying a highway's deficiencies and needs, developing a course of action with improvement alternatives, and conducting engineering analyses that result in a preferred alternative are collectively called a *reconnaissance study*. Project planning study, route study, feasibility study, and preliminary engineering study are all terms used by different agencies and offices to mean some form of reconnaissance activity that falls within the conceptual study phase.

G. Aerial Photography and Mapping. Aerial photography and mapping (described in Chapter 5) generally provide very valuable and essential data in the study and illustration of highways, roadside features, and proposed highway improvements. Detail maps and sometimes mosaic photo composites developed specifically for the highway in the study area are needed in the conceptual study stages when improvements include new corridors or substantial widening and/or curve flattening. Many times USGS quadrangle maps or aerial photographs from other agencies can be obtained to suffice or assist in the conceptual studies, especially when more minor improvements are being investigated.

Oblique and terrestrial photography can be quite helpful to study proposed improvement corridors and can be enhanced by photomontage techniques to illustrate future highway improvements. Such techniques require a preliminary design (cross section, earthwork, etc.), a time consuming and labor intensive program.

H. Geotechnical Reconnaissance. Preliminary geotechnical information should be obtained early in conceptual studies by specialists in this field of engineering. This will assist in determining the cause for instability or pavement problems on the existing highway and provide information on potential problems for constructing the alternatives under consideration. Subsurface investigations in the study area may be required if existing information is inadequate and/or incomplete.

Typically, a geotechnical reconnaissance report addresses the following:

- Geology of the study area.
- Existing and/or potential unstable soil conditions.
- Location of possible sources or sites for base, surfacing, and topsoil materials.
- Estimated surfacing requirements.

More *in depth* investigations are conducted later on in the project development process as described in Chapter 6.

I. Hydraulic Information. Where water resources affect the road corridor (i.e., flood plains, erosion, drainage, water quality, etc.), hydraulic information should be obtained for the conceptual studies by specialists. This data aids in determining the cause of some road problems and, more importantly, provides guidance to determine feasibility, location, or size of hydraulic structures for the alternatives under consideration. This data is needed more to address environmental concerns and establish a datum than to resolve engineering design problems, which are addressed in the design phase. See Chapter 7 for obtaining detailed information about hydraulic data and procedures.

J. Public Involvement. Public involvement is a formal environmental process requirement as shown in Chapter 3, it does provide necessary input and benefit during conceptual studies. As outlined in Chapter 3, it is important to publicly announce the beginning of the conceptual studies phase especially for the larger scale projects. This can help in identifying the *local* perspective on what are the major highway problems and driving difficulties along the route. Once alternatives have been developed, public input can be obtained through the environmental review process for the proposed improvement alternatives and their respective scopes of work.

4.4 LOCATION ANALYSIS

The location analysis combines preliminary investigations by nearly all the transportation engineering disciplines, (such as traffic engineering, survey/mapping, geotechnical, hydraulics, structural engineering, and roadway design) into a coordinated comprehensive assessment of a highway's transportation problems and a feasibility study of possible solutions. The analyses involve evaluating diverse field data, yet the analyses are preliminary or general in nature. A higher degree of technical detail is necessary in the design phase.

The types and sequence of steps in the conceptual study process are described in the following subsections. The technical analyses are not always presented in depth, but references are given to the other chapters where the preliminary and detail design requirements are discussed.

A. Course of Action. Depending on the degree of investigation and analysis in the planning phase, a project's course of action, as it enters the conceptual study stage, could vary greatly, from a simple description of study area limits to a specific course of action, (e.g., replacement of a particular bridge, etc.). To fully develop a complete, specific course of action, the overall highway deficiencies and transportation needs must be well identified, quantified, and evaluated in the conceptual studies.

The first step is data collection. This consists principally of an inventory of the physical and operational features of the existing highway. Most of this information is available from the highway agencies (highway departments or Federal land management agencies), road monitoring reports, and planning/reconnaissance studies. One should determine and verify with field inspections the road's length, width, surfacing type, traffic control devices, and roadside features along with their current condition. In addition, the road's maintenance condition and recurrent problems are important and should be documented. Also, general traffic data and operational characteristics including seasonal variations, peak use, vehicle types, and their volume percentages should be obtained. Travel information like running speeds, congestion periods, or any irregularities should be determined. Usually the maintenance forces have many observations to offer. The amount of other road users, such as bicyclists and pedestrians, must also be established.

Do not overlook winter driving conditions including problems of removing snow and ice. Rural farming areas may also present unique problems of moving farm machinery on the highway.

The current traffic accident statistics for the route should be obtained. This must be supplemented with field identification of potential accident sites that may not be discernible from the past data.

After gathering the data, compare the existing road and its current functional classification, geometric standards, physical condition, and present travel demand with the highway agency's road standards. The Green Book's Geometric Standards are broad enough to address most types of roads if there are no other standards that apply. A listing of the road's current deficiencies, both physical and operational, and relative importance of each should be prepared to indicate where the road is substandard and not functioning properly. Exercise care when determining the major contributing factors of a defective road facility. Do not automatically assume an existing substandard road feature is the problem.

Next, the long-term needs of the highway must be determined. Usually this is based on projections of how land use activities in an area are going to change along with their associated transportation requirements. Longterm transportation needs are commonly described by a forecasted 20 year ADT and percentages of vehicle types, (e.g., trucks, buses, recreation vehicles, etc.), in the travel stream. Other factors like urbanization of the roadside and functional classification changes also directly affect future needs.

The land management agencies through their planning offices and area-wide comprehensive planning documents (e.g., NPS General Management Plan, NPS Development Concept Plans, and FS Forest and Resources Management Plans) can provide some information and assistance in determining future travel demands on highways. Comparing the current highway facility with the geometric standards of a road that is sized to accommodate its future traffic volumes and travel conditions will usually indicate what upgrading may be necessary to address the long-range transportation needs.

To establish a course of action, one must recognize the existing road, its deficiencies and future needs, and then describe the type of improvement required to create a highway that meets objectives. Usually the objectives are to provide the highway user a facility that fulfills the following:

- Meets the convenience and safety standards for that system of highways.
- Is cost effective to build.
- Avoids or minimizes environmental impacts.
- Minimizes maintenance costs.

A typical course of action addresses the road's width, alignment, surfacing, major structures, and the general types of construction items needed to implement such improvements. The following is an example of a typical course of action.

> *Route 1 is to be upgraded between A and B by widening to provide two continuous traffic lanes and shoulders. The horizontal and vertical alignment will also be flattened and corrected to provide a uniform design speed. The road will be stabilized, paved, and delineated with standard traffic control devices. The bridge over Clear Creek at Kilometer 198 will be replaced. The principal items of work consist of clearing, grading, drainage, base, asphalt surfacing, signing, striping, and bridge construction.*

The intent is to generally describe the type of improvements to be done, but leave flexibility so various alternatives can be considered that will accomplish, to one degree or another, the proposed course of action.

B. Alternatives. Once the course of action is established, the next step is to identify all reasonable alternatives that can implement the work. These should be practical engineering solutions to the road's problems, e.g., current deficiencies and future needs, within the overall limits of the course of action.

Initially, alternatives might cover quite a range or scale of improvements, but they should be condensed to three or four succinct alternatives for which further engineering analyses can be applied. Otherwise, the details, data, and description become too cumbersome to handle. The basic categories of alternatives to be considered on most road upgrading include the following.

1. No action. The no action alternative would only continue the routine maintenance of the facility and does not include any upgrading that would change the road's operation or extend its service life.

2. Transportation System Management (TSM). This alternative should always be considered when upgrading a road. It consists of travel controls and/or limited construction to maximize the operation and efficiency of the existing facility without major reconstruction or new construction. Sometimes these controls might include one of the following:

- Accommodating the existing traffic on other routes or with different types of vehicles.
- Posting vehicle restrictions and load limits.
- Providing an alternate, more attractive mode of transportation.

Usually, this form of TSM alternative is only marginally effective for Federal Lands Highway Programs because of the outdated, rural highway systems, and automobile dependency present in most FLHP situations.

Resurfacing, restoration, or rehabilitation (RRR) projects are TSM alternatives with limited construction efforts that can be very cost effective measures. The objective is to preserve and extend the service life of the existing highway and enhance safety without substantial costs, construction impacts, or major right-of-way takings. Generally RRR projects are not reconstructed to full geometric standards.

RRR work is undertaken to preserve and extend the service life of an existing highway and enhance highway safety. This may include placement of additional base and surface material and/or other work necessary to return an existing roadway to a condition of structural or functional adequacy. The RRR work is generally done on existing alignment. This salvages a substantial amount of the existing surfacing, but may include some upgrading of geometric features, such as minor roadway widening, flattening curves, or improving sight distances.

RRR projects are customized for individual situations and may result in exceptions to conventional standards. The improvements, whether only at spot locations or continuous, should adequately meet existing and hopefully future (10-20 year) traffic needs and conditions in a manner conducive to safety, durability, and economy of maintenance. Usually, the upgrading only addresses the most critical deficiencies of the highway so the resultant condition may still have some problem areas/ substandard features.

Any substandard design elements require approval as design exceptions as set forth in Chapter 9.

3. Reconstruction. This is an improvement alternative that rebuilds a highway essentially along the same alignment and when the retention of the pavement structure is not a primary objective.

Reconstruction work normally involves a substantial construction effort to rebuild the existing highway to at or near full geometric/safety standards.

The complete spectrum of design deficiencies and functional obsolescence of the roadway, as well as future transportation needs, should be addressed by this level of upgrading. The work normally includes activities such as widening, realignment, and replacement of bridges. While reconstruction, by nature, follows an existing road corridor, it may deviate significantly in width and alignment from the present road to obtain its full geometric standards.

4. New construction. This is an improvement alternative to build a road and/or bridge on completely new alignment, or substantially upgrade a highway facility along an existing alignment providing new access to or through an area.

Usually the highway is built on new alignment in a virgin corridor. It normally is constructed to full geometric standards to fulfill both the current as well as longterm transportation needs of the area.

a. Preliminary Design Standards. Proposed highway improvement alternatives are principally described by preliminary design standards. The design standards listed in FLHM 3-C-1 can be supplemented or substituted with approved highway design standards from owner agencies. These substitutions must be consistent with the highway program legislation, regulations, and interagency agreements discussed in Chapter 2.

While the categories of alternatives indicate the overall level of upgrading, more specific terms must be used to describe an alternative beyond the general course of action to evaluate its operational, safety, and structural characteristics. The roadway width, design speed, and surface type are the main elements of the general design criteria used to describe an alternative's preliminary design standards. Other elements (like the full typical roadway cross section, preliminary line and grade, grading/clearing limits, auxiliary lanes/tapers, and right-of-way widths) are sometimes included when the environmental analysis requires more specific information to evaluate roadside impacts.

The intent of conceptual studies is not to develop the design of the project, but to provide direction and scale of the improvement. Given this direction, the designer should develop the most cost-effective design of the preferred alternative.

Thus a good conceptual study should do the following:

- Identify, evaluate, and compare impacts of each alternative.

- Establish design flexibility.

- Define commitments to protect and preserve the environment.

- Provide long-term planning guidance.

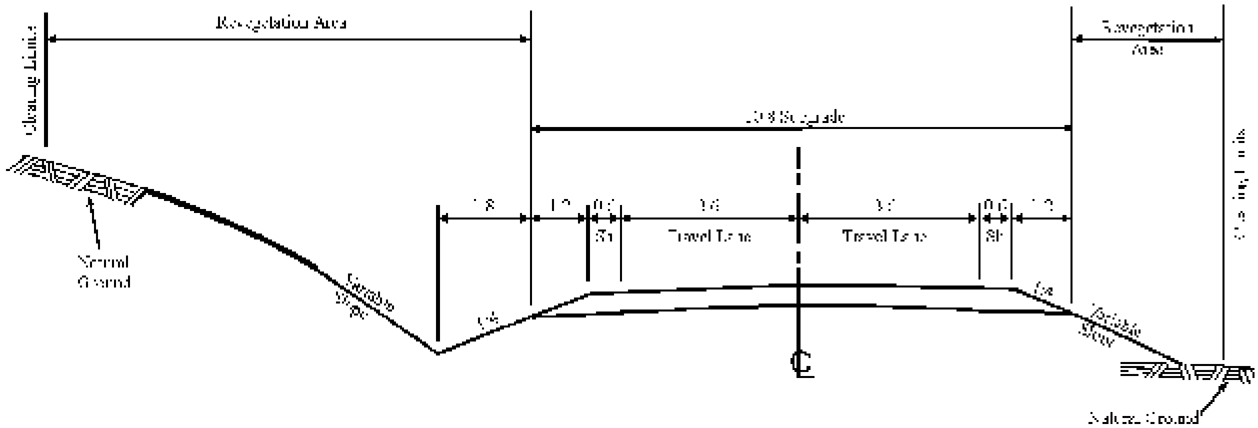
Preliminary concept studies define the project by line and grade, right-of-way limits, construction quantities and roadway geometrics in general terms based on projected traffic volumes, terrain, and other special features. During the design phase of the project, these activities will be addressed in more specific detail. See Chapter 9.

To establish the preliminary geometric design standards of roadway width and design speed, it is necessary to know the road corridor's predominate terrain (level, rolling, and mountainous), the functional classification of the route, and the traffic volumes (current/future ADT) on the highway.

While in many cases the minimum AASHTO geometric standards will provide the most appropriate level of safety, convenience, and operational efficiency, alternatives with different standards must also be considered to address any special factors (e.g., economic, environmental, or operational, etc.) that affect the road. Gathering and evaluating diverse land use, transportation, environmental, and economic data, together with applied engineering judgment and analysis, will aid in formulating practical improvement alternatives above and/or below the minimum full standards.

The preliminary design standards used to describe the alternatives provide guidance for establishing other criteria to be used in the design process. Many of these other elements are functions of the ADT, design speed, or roadway width and are set during the design activities. The preliminary design standards, as well as the other design standards and criteria, become the final adopted project standards when the design approval is issued (see Chapter 9).

Figure 4-2 is an example of how to show and describe an alternative and its preliminary design standards. This information should also be supplemented with a map depicting the location of the alternative as discussed in the next subsection. When comparing numerous alternatives, it can also be rather effective to display them together in a conceptual setting.



ALTERNATIVE A

Note: This alternative for the reconstruction of 105 km of Flat Mountain Road by widening and adding bituminous surfacing to obtain a 8.4 meters wide roadway consisting of two 3.6 meters paved lanes and two 0.6 meters paved shoulders. Roadside features such as 1:4 foreslopes, variable ditch widths, and backslopes with minimum selective clearing are included to provide a reduces, but adequate, cross section with standard sight distances and roadside safety.

The horizontal and vertical alignment of the existing road will be adjusted by curve flattening, grade raises, and short relocations to provide a minimum 60 km/h design speed. Necessary widening will be provided with the least effect on natural features and private property. Generally, widening will be made on the roadside away from the river or other sensitive features such as wetlands.

The bridge over Deep Creek at km 20.1 is to be replaced in approximately the same location. The existing right-of-way can be used in constructing much of this alternative. Partial takings from parcels along the existing roadway totaling approximately 0.93 ha will be required for widening, improving the sight distance, and reducing the severity of curves.

The proposed improvement of FH 72 begins at km 20.8 which is the northern terminus of previous improvements, and generally follows the existing road to the vicinity of Dutch Road, about km 20.4. At this point an alignment shift is proposed 60± meters to the east of the existing road. This approximately 600-meter long relocation would avoid a congested area formed by residences and commercial property bordering the east side of the existing road and a historic mine site bordering the west side. The proposed improvement connects with the existing road at about km 20.9 and generally follows it northerly to its terminus at an intersection with US 22 (km 30.2).

Figure 4-2
Typical Presentation of an Alternative

b. Highway Corridor. When formulating improvement alternatives, it occasionally becomes apparent that a highway should be considered on new alignment in a corridor outside of the existing road. In fact, there may not even be a road connecting the termini, although this situation is not common.

New highway corridors are usually identified and evaluated separately from an alternative's preliminary design standards although they must be compatible with all the components that make up the alternatives. A highway corridor can be defined as a linear strip of ground that connects termini and has sufficient width and variable positioning on the terrain to allow a road with its preliminary design standards to be built within its borders.

Depending on length and terrain, most corridors are between 30 to 120 meters wide. Its position on the topography is tied to existing land forms and sometimes defined in relation to a survey traverse line (see Chapter 5).

Highway corridors are normally established with three general objectives in mind:

(1) The corridor must be broad enough to allow the highway centerline to be positioned or shifted in conformance to the geometric standards and to achieve reasonable cost effectiveness.

(2) The geographical and geophysical features should be stable and compatible with the construction, operational, and maintenance requirements of the highway.

(3) The environmental impacts should be minimized and aesthetics maximized.

In the past, the whole process of investigating new highways and corridors has been called a location survey or reconnaissance study; now, much of the process is covered in the environmental analysis and documentation.

The basic procedures in establishing feasible highway corridors are still valid and are described in the following paragraphs.

A thorough initial investigation is essential in making effective corridor determinations. If the most feasible, serviceable, and economical corridor is not determined at this stage, no amount of engineering effort can overcome the inherent deficiencies that will exist. When presenting corridor evaluations, it is imperative that the same basic data and methods of investigation be used for each corridor studied.

Most corridor reconnaissance work is done using photogrammetric or other topographic maps supplemented with field data. On occasion, ground reconnaissance surveys are made as a substitute for or supplement to the topographic mapping.

Before beginning the study, the reconnaissance engineer should review all available maps and photographs to determine what additional data and mapping are needed for conducting the study.

The following information will usually be pertinent to corridor studies:

- Land use, population, and density.
- Geophysical and geological formations.
- Potential of the area for future industrial, residential, farm, or recreational development (land use changes).

- Frequency, condition, and type of existing roads and highways serving the area.
- Existing utilities and facilities, planned and potential, such as transportation (other than highways), dams, power lines, gas and water lines, and recreational areas.
- Photographs of controlling features.

Photogrammetric maps, topographic maps, and aerial photographs of the area are good references and may be obtained from the following sources:

- Previous surveys and reports.
- Maps by Federal, State, county, and municipal agencies.
- Quadrangle maps by U.S. Geological Survey (USGS),U.S. Coast and Geodetic Survey, and Civil Aeronautics Board.
- Hydrographic surveys of rivers and river and harbor surveys by the USACE.
- Tideland maps by the State land department.
- Surveys by the Bureau of Reclamation, NPS, and BIA.
- Highway right-of-way maps by FHWA, State, and county agencies.
- Township maps by the BLM.
- Maps by Forest Service (transportation maps, firemen's maps, topographic maps, etc.).
- Stereophotographs from private sources and government agencies, particularly the USGS and the Department of Agriculture.
- Geological reports and bulletins.
- Railway maps and profiles.
- Maps made by the State planning divisions (county maps showing county road systems and roadside culture and city maps which include the immediate surrounding area).

(1) Mapping Requirements. The type and scale of mapping required for the advance planning study are dictated by the terrain and land use intensity of the route corridor area and the level of preliminary design analysis to be conducted. The maps must be complete, current, and give full details of topography and physical features.

Mosaic reproductions or photographic prints may be used to show routes or portions of routes. The route plan should be made to the same scale as the mosaic copies. If oblique photographs are used, they should show the route in contrasting lines and should be delineated legibly. The date of photography should appear on the maps.

Mapping for areas of moderate to intensive land use should be to a scale of 1:1000 or 1:2000 with a 2 or 4 meter contour interval. In areas of limited or homogeneous land use and in mountainous or heavily timbered areas, a map scale of 1:5000 with 4 meter contour intervals will suffice. If only broad reconnaissance is to be done, existing USGS quadrangle maps with their 1:24 000 scale may also be adequate.

The photogrammetric mapping may be used where feasible and where its use is cost effective. Further mapping discussions are contained in Chapter 5.

(2) Photographs. Ground photographs or oblique aerial photographs should be taken of controlling elements in the field to supplement the mapping. These can be used in analysis, report illustration, and for exhibits in the public involvement process.

(3) Corridor Selection. Specific procedures should be followed in the selection of route corridors for comparative evaluation. Common points of termini for all routes to be studied should be identified in addition to any constraints that may limit alignment, grade, and route location.

Typical constraints include the following:

- Limitations imposed by design standards such as maximum allowable grades and curvature.

- Physiographic controls, such as land form and watercourse gradients, shorelines, property or jurisdictional boundaries, preemption of lands for other (usually higher) use, and the avoidance of known problem areas such as unstable or highly erosive land forms.

- Economic controls, including encroachment on high cost lands or improvements, and alternatives involving features of excessively high construction cost.

- Mandated points of contact. For example, intersection with a limited access facility where the access point is predetermined, or access to a major point of interest that has a fixed location.

- Environmental controls, some of which are mandated by law, govern the avoidance of wetlands, prime and unique farm lands, habitat for endangered species, historical and archaeological sites, and park lands.

(4) Aesthetic Elements. Weigh the aesthetic qualities of the corridors under investigation as carefully as those that contribute to traffic safety, highway efficiency, and structural adequacy. Gentle curves, easy grades, and lanes with adequate clearance between passing vehicles contribute both to pleasant and safe driving. Both horizontal and vertical alignments should be coordinated to create a total roadway alignment that complements rather than disrupts the natural land form.

Pleasing appearance can usually be achieved at little extra cost if the road is located with these aesthetic elements in mind from the start. Further, roadside development (viewpoint, fisherman stopping areas, etc.), erosion control, flattening and rounding slopes, seeding, and revegetation contribute significantly to roadway beauty and safety as well as reduce maintenance cost.

When the merits of competing locations are nearly equal, scenic quality may be a deciding factor.

To ensure aesthetics in highway design, do the following:

- Direct the highway toward worthwhile scenic features within reasonable range.

- Locate the highway so that scenic features are large (mountains, lakes, etc.) and directly ahead of the driver's line of vision.

- Make maximum use of independent horizontal and vertical alignment on divided highways to blend the roadways into the terrain and reduce harsh effects and unnecessary construction scars.

- Coordinate vertical and horizontal curvature. The best appearance is achieved when vertical and horizontal curves coincide or horizontal curvature leads vertical curvature slightly.

- Avoid short, abrupt horizontal and vertical curves, especially if the central angle is small.

- Avoid long tangents in rolling country. Roller coaster profiles are visually distressing.

- Ensure that sufficient right-of-way area can be provided at ends of tangents and on the inside of curves to permit ample clearing and to prevent erection of buildings or structures that could impair perspective or horizontal sight distance.

- Avoid unsightly obstacles by adjusting the alignment away from the obstacle before it is within the driver's view.

(5) Map and Photograph Study. Use a large scale map that shows only the major topographic features (rivers, mountains, roads, cities, and towns, etc.), to show the various alternative corridors between the termini. By studying this map, select the more representative alternatives. The most feasible alternatives to be evaluated in detail may then be chosen through a process of elimination.

Next, the locator should intensively study and analyze the collected material before going into the field. If good photographic and map coverage is available, much of the hard work of reconnaissance can be done by stereo analysis and map study. Impractical locations can logically be eliminated, freeing the locator to concentrate on the more promising alternatives during the field investigation. Further refinement or elimination of alternatives may occur following the field investigation.

(a) Map Study. Study of the topography between assigned termini will reveal *avenues* through the terrain that may be followed for a road location, and barriers that must be avoided. Ridges or watersheds are often good avenues, and where there are long regular ridges leading in the right direction, the locator is indeed fortunate. Valleys are also excellent avenues if they lead in the right direction. The most difficult locations are those that cut across the natural avenues or those that lie in confusing terrain where the ridges and streams have no continuous well-defined direction.

Each possible avenue should be examined, though some may be immediately discarded as impracticable. Each practical route should be sketched on the map using different colors or line symbols. Where the gradient might be controlling, the grade contour should be stepped out on the map with a bow divider to make sure the route grade is within acceptable limits. Points where curvature may be critical should also be checked.

(b) Stereo Analysis. A reasonably good study can be made by stereo examination of aerial photos. It is possible to check gradients using only the stereoscope and an engineer's scale. Possible lines may be sketched on the photos and compared with map locations. Stereo examination will yield information that may not be shown on a map, so if both the map and photos are available, both should be used.

A thorough map or stereo study should investigate all possible routes within a band that is 40 to 60 percent as wide as the distance between termini. If adequate photo and map coverages are not available, the locator should view the terrain from a light plane or helicopter before going into the field. Under some conditions it is desirable to have air photos of the route made for use in the reconnaissance.

The time required for the field work of reconnaissance depends on the effectiveness of the preliminary office studies, and the accessibility of the route, weather, etc., and might vary from a day to weeks. The field investigation can be made by any means available, such as by vehicle, horseback, or on foot. During this investigation, the locator observes and keeps notes on the forest cover, drainage, bridge sites, the nature and classification of the soil, rock outcrops, land use, and anything else that might affect the location.

(6) Major Considerations and Physical Controls. The termini is the major control of the route. From a strict user's standpoint, the most economical route is a straight line between the termini, both horizontal and vertical.

However, the practical economic location and the environmentally acceptable locations are based upon a compromise between construction cost, user's cost, and environmental impacts.

Physical controls affect the construction costs-bridge sites, rock areas, valley and mountain sides, built-up areas, lakes and drainages, etc.

(7) Information to be Obtained. On each corridor studied, the following information should be known:

(a) Termini. Common study termini should be used even though some routes may use portions of existing facilities that already conform to standards.

(b) Traffic Data. Assembly of data on traffic and projected roadway use requires a thorough research effort. Primary source agencies are Federal, State, and local road administration and planning agencies. In some instances it may be necessary to conduct special traffic studies as a part of the corridor study.

Research and collect all available data on the following subjects. Items 7, 8, and 9 are optional depending on specific project requirements.

1. Traffic data on existing facilities.

   - Average daily traffic.
   - Seasonal average daily traffic.
   - Peak hourly volumes.
   - Design hourly volumes.

2. Traffic trends, past and projected.

3. Classification of vehicles (percent passenger vehicles, percent trucks and buses, and percent recreation vehicles).

4. Accident data.

   - Route segments.
   - Spot high hazard locations.

5. Directional split.

6. Turning movements at major intersections.

7. Traffic desire lines.

8. Speed and delay data.

9. Conflict study data.

(c) Right-of-Way. Describe the property affected and the nature of damages, estimate of right-of-way cost, and any special right-of-way problems. If all or part of route crosses government land, identify the agency controlling the land.

(d) Geology. Give the geology of the general area. Use a geologic map if one is available.

Interpret and show the relationship of the geology to the proposed route. Include location and extent of the following features:

- Landslide areas.
- Solid rock.
- Unconsolidated material.
- Ground water and surface water conditions.
- Availability of road construction materials (type of deposits, quantity, and quality).

Make recommendations for type of materials to be used, e.g., borrow, waste sites, contractor staging areas, etc.

(e) Controlling Factors. Describe all controlling features involved in route selection, such as the following:

- Railroad crossings.
- Bridges and other structures.
- High voltage power line crossings (record elevation of low point in cable and air temperature).
- Problems involving terrain and/or access.
- Utilities and/or special services.

(f) Design. Describe range of proposed preliminary roadway design standards, especially alignment and grades, roadway sections, type and cost of structures, and other preliminary design elements being considered. Many of these are illustrated in a roadway cross section.

(g) Construction Materials. Describe all construction materials available in the area. Identify pit sites by location and pit number, if known, and give names and addresses of local construction materials' suppliers.

Depending on the detail and accuracy being required, a preliminary design line may have to be developed through the corridor to approximate and represent the alignment and construction cost parameters. The procedures for developing the line and grade projection/ information is found in Chapter 8, Section 8.4.

Cost estimates for constructing a road in the corridor are developed using quantities and unit prices for the major items such as the following:

- Clearing and grubbing per hectare.
- Unclassified roadway excavation per cubic meter.
- Minor drainage per kilometer.
- Surfacing and base per kilometer.
- Paving (type) per kilometer.
- Revegetation and landscaping per kilometer.
- Major structures per each (identify).
- Right-of-way cost estimate per hectare.
- Miscellaneous. (Include construction traffic control, guardrail, guide posts, fences, etc.).
- An estimate of the user's cost both per kilometer and from termini to termini.

(8) Corridor Study Report. Extensive corridor analyses are sometimes documented in a formal corridor study report that then can be considered a Conceptual Study Report. More frequently, though, this information is kept informal. In either case, corridor analyses are summarized in the major environmental documents, e.g., Environmental Assessment and Environmental Impact Statements. The corridor study reports not only contain the results of the corridor analyses but also summarize the preliminary design standards under consideration. In addition to the engineering information, the social, environmental, and economic features of the alternatives (separate corridors) used in the analyses are presented at least in a general fashion.

The final study report should contain the following items:

(a) Introduction. Describe the authority and purpose of the study.

(b) Organization. Identify all sources of information, maps, and data obtained for the study.

(c) Climate, Physiography, and Geology. Provide a description of the climate, significant geographic features, land uses, and geology of the area.

(d) Preliminary Design Standards. This section should include all traffic data and design criteria for the study.

(e) Corridor Descriptions. Provide a detailed description of each corridor studied.

(f) Comparative Evaluation. This section should contain a comparative evaluation of routes studied. Include a dissertation of the related SEE impacts (such as changes in land uses, displacement of residences, disruption of communities, environmental mitigation measures, construction costs, road user costs, secondary economic factors, etc.).

(g) Benefit Cost Analysis. An optional section that may be used to provide a benefit cost analysis for each corridor and the basis for them.

(h) Exhibits. Use exhibits to include route maps or aerial mosaics depicting the location of the corridors, typical roadway sections, vicinity maps, route profiles, physical characteristics outlined on reconnaissance study form, and detailed cost estimates of alternatives.

4.5 APPROVALS

At the conclusion of conceptual studies, a decision must be made identifying which alternative is going to be advanced into the design phase.

A. Conceptual Engineering Studies. Since the results of the location analysis provide the critical engineering and/or reconnaissance information, array of alternatives, and in some cases the preferred alternative to be contained in the public environmental document; these findings should be reviewed and concurred in by the appropriate Division staff who are responsible for the clearance of environmental documents. In addition, land management agencies should also review and concur in the engineering findings regardless of whether they have been documented by informal analyses or in complete, formal conceptual (corridor) study reports. This will ensure the environmental process is evaluating alternatives that the agency is comfortable with. Concurrence of the report or informal findings does not constitute official approval of a specific alternative or issue authority to commence design activities.

B. Location Approval. Formal approval of the preferred alternative, traditionally referred to as *location approval*, occurs when the project's environmental clearance document is approved as described in Chapter 3. This also completes the conceptual study phase and advances the project into the design phase and subsequent PS&E preparation.

The description of the preferred alternative contained in the environmental decision making documents, e.g., categorical exclusion, finding of no significant impact, and record of decision, should include preliminary design standards and corridor information to ensure the project will be designed to implement the approved *concept*.

4.6 REPORTING

Conceptual studies provide findings and recommendations that are reviewed and commented on by various agencies and parties. This information can be reported to the agencies in various ways or combined in other documents.

A. Conceptual Engineering Study Reports. The results of the location analysis can be contained in a separate conceptual study report, (e.g., corridor study report) or more commonly be documented in a less formal manner. Memorandums, trip reports, or even semi-formal checklists can be used to record the conceptual study results. In any case, this information should be documented to ensure the findings and/or recommendations, as well as existing conditions, objectives, facts, assumptions, and analyses can be reviewed and understood by all interested and affected parties. All improvement alternatives should be readily supportable from an engineering position, which is contained in these study documents.

If separate formal reports are prepared, they can be in different formats or detail and should be only as formal as appropriate for that scale of project.

B. Environmental Documents. The engineering information and descriptions of the improvement alternatives contained in the environmental documents are summarized from the conceptual studies. Since the final location approval decisions are a product of the environmental process, it is imperative that environmental documents present the engineering data in an accurate, complete, and understandable fashion. The content of environmental documents are described in Chapter 3.

4.7 DIVISION PROCEDURES

Reserved for Federal Lands Highway Division office use in supplementing the policy and guidelines set forth in this chapter with appropriate Division procedures and direction.

CHAPTER 5 - SURVEYING AND MAPPING

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CHAPTER 5 - SURVEYING AND MAPPING

5.1 GENERAL

This chapter provides guidelines to engineers and technicians who are responsible for surveying and/or mapping. A definition of data required and the sources of such data is provided in this chapter as well as guidelines for gathering, processing and documenting the data. Suggested note formats for both conventional and automated surveys with references to mapping standards are provided.

This chapter presents many of the established surveying and mapping methods along with some of the modern techniques now in use. It is not the purpose of this chapter to be all inclusive. Specific information concerning techniques, theory, and methodology can be obtained from the list of reference materials contained in Section 5.2.

Surveying for highway engineering involves the gathering of field information and measurements for use in locating, designing, and constructing highways and other related features. Field data is collected by ground surveys, aerial surveys, or by a combination of these two methods. Establishing controls for construction is generally done by ground surveying techniques.

The safety of field crews and the traveling public is a high priority. The road or bridge construction work environment often presents potential hazards that must be evaluated on a project by project basis. Surveying activities are not to be attempted on or adjacent to a traveled roadway until appropriate traffic warning and/or control measures have been implemented. Traffic control devices shall conform to standards in the MUTCD.

There are generally four stages of survey activities in the progression of a highway project from start to finish. These are:

*Reconnaissance
*Preliminary
*Location
*Construction

A. Reconnaissance. The reconnaissance survey is normally performed in connection with early scoping activities on a project.

A reconnaissance survey of an area is the examination of a large area to determine feasible highway corridors or alternate locations within a corridor between designated termini. The evaluation of feasible alternatives is a comparison of these corridors or alternative locations in sufficient detail to select the corridor or alternative locations deserving further study.

Aerial photography, Geological Survey quadrangle maps, and Forest Service mapping are often useful for reconnaissance purposes.

B. Preliminary. Preliminary surveys are normally performed during the environmental planning and conceptional study phases of project development.

The following are considered preliminary surveys:

Aerial Control Surveys
Ground Control Surveys
Topographic Surveys
Planimetric Surveys
Bridge Site Surveys
Cadastral Surveys
Preliminary Alignment Surveys
Special Surveys (for retaining walls, drainage structures, borrow pits, quarry sites, etc.)

Preliminary surveys provide the necessary data to be used in environmental planning, conceptional studies, bridge design, and highway design. Typically, the direct derivatives of preliminary surveys are topographic and planimetric maps, digital terrain data, and survey monumentation.

Aerial surveying is the process of obtaining ground measurements from photographs rather than from field techniques. Where visibility permits, this method of surveying provides substantial savings in manpower for information gathering, and mapping.

C. Location. Location surveys involve establishing previously designed data on the ground. In many ways, location surveys are the inverse of preliminary surveys. Preliminary surveys are used to extract and collect field data. Location surveys normally disseminate data back to the field. Location surveys always include the establishment of the highway centerline and reference points, and may include setting construction slope stake reference hubs and other preconstruction controls as required.

D. Construction. Construction surveys include establishing points in addition to those placed during the location survey. These include slope stakes, grade stakes, and culvert and bridge control stakes.

5.2 GUIDANCE AND REFERENCES

The publications listed in this section provided much of the fundamental source information used in the development of this chapter. This list is not all inclusive and there are numerous manuals, technical documents, and journals that explain the techniques and formulas required to perform proper and accurate surveying and mapping.

Abbett. *American Civil Engineering Practice.* Volume I. New York. McGraw Hill. 1978.

Bouchard, H. and Moffitt, F.H. *Surveying.* 6th ed. Scranton, PA. International Textbook Company. 1982.

Hickerson, Thomas F. *Route Location and Design.* New York. McGraw Hill. 1972.

Rubey, H. *Route Surveys*. New York. The MacMillan Company. 1951.

Wolf, P.R. *Elements of Photogrammetry*. New York. McGraw Hill. 1974.

Geodetic and Topographic Surveying, Manual of Photogrammetry. American Society of Photogrammetry. Volumes I and II. 3rd ed. 1966.

Manual of Surveying Instructions. Technical Bulletin No. 6. Department of the Interior, Bureau of Land Management. 1973.

Reference Guide Outline, Specifications for Aerial Surveys and Mapping by Photogrammetric Methods for Highways. Department of Commerce, Bureau of Public Roads. 1958. (Out of print).

Surveying and Mapping Manual. DOT, FHWA. 1985.

Metric Practice Guide for Surveying and Mapping, ACSM, 1992

Refer to the glossary in Chapter 1 for definitions of the most common terms used. If a more detailed definition on a specific subject is desired, consult the glossaries in the reference manuals listed.

5.3 INFORMATION GATHERING

Information gathering, as it relates to surveying, actually consists of two parts:

(1) An examination of existing information about the project.

(2) The physical gathering of the ground information.

Both information gathering actions are of equal importance. Careful attention to detail during this process can often result in substantial savings in time and effort. The surveyor should use as much of the existing information as practical to reduce the time spent gathering actual field data.

A. Existing Sources. Before any type of survey occurs, perform a search for existing information. For the most part, the information described below can be obtained from other government agencies. However, do not limit the search to these agencies. Much valuable information may be available from private consulting engineering firms that have worked near a specific highway project.

Sources of information that are helpful during the course of a survey include the following:

- Survey control data.
- As-constructed plans.
- Existing photography (both aerial and ground).
- Existing maps.
- Legal property descriptions.
- Local land owners.
- Agency contacts.

1. Survey Control Data. Horizontal and vertical control is crucial to performing an accurate and correct survey. Whenever practical, base the survey on horizontal coordinates and vertical elevations from established National Geodetic Survey (NGS) first order or second order control points.

The horizontal and vertical control information can be obtained by writing to:

Director, National Geodetic Survey Division
1315 East-West Highway, Room 9535
Silver Spring, MD 20910-3282

Each FLHD office should establish and maintain a file of the control data for their respective areas. Make arrangements with the agencies mentioned above to receive the periodic information concerning existing control points and the location of new points. For a small fee, NGS will provide horizontal and vertical control data on floppy disks for individual counties or on CD-ROM's for entire regions of the country.

a. Horizontal Control. The NGS publishes a map showing the status of the horizontal control that exists in the United States. Triangulation maps are also available for each State. These triangulation maps show the monumented points and their general location throughout the State. The names and index numbers for these monuments are given, along with their line of observed triangulation.

Upon request, NGS furnishes the following information for each monument:

- Monument name.
- Location (State, county, etc.).
- Year the monument was established.
- Geodetic latitude and longitude.
- Order of accuracy.
- Elevation.
- State plane coordinates in meters (NAD83 datum).
- Geoid height and scale factor (NAD83 datum).
- Monument description and historic data.
- Azimuths and distances to neighboring monuments.
- Station recovery/condition notes.

b. Vertical Control. The NGS publishes an index map for control leveling that covers each State. This index map shows the level circuits that exist in the State. These circuits are generally located along existing highways or railroad right-of-ways. The index map numbers the circuits for filing purposes. The degree of accuracy of each level line is also indicated on the index map.

Using the numbers assigned to a particular level line, the surveyor is able to obtain detailed information on each Bench Mark (BM) along the circuit. The BM information is on the following items:

- BM type and Identification Code. (The ID code is generally stamped on the monument cap).
- Location (including State, county, and nearest town or community).
- Elevation (meters and feet).
- Accuracy.
- Date established and by whom.
- Station recovery/condition notes.

When an elevation is stamped on a bench mark, it is usually to the nearest foot. If needed, the actual documentation will provide further accuracy, and the elevations may have already converted to metric units.

2. As-Constructed Plans. Since the majority of highway construction activity concerns the rehabilitation and/or reconstruction of existing highway facilities, as-constructed plans can be an excellent source of preliminary information. Depending on the composition of the construction plans, a surveyor may obtain the position and condition of existing control points, right-of-way monuments, bench marks, and construction monuments.

If it is desirable to use the existing centerline stationing and location, the center-line control points (such as PC, PT, POT) can be obtained from the as-constructed plans. The horizontal alignment information is also often obtained from these plans.

Other information available from the as-constructed plans includes the types and locations of drainage systems, structures and special features, property descriptions, and boundary lines.

Along with as-constructed plans, often times the original survey notes still exist and can be obtained. The information contained in these original survey notes can be very helpful to the surveyor.

It is also recommended that the as-constructed plans from adjoining projects be used to achieve consistency between projects. Use of adjacent plans allows for the continuity of stationing and control throughout an entire route.

In addition to the as-constructed plans pertaining to existing bridge projects, the surveyor also should make use of the information contained in the bridge inspection report. As these reports are generally made biannually, the information is usually more useful and reliable than the original construction plans.

As-constructed plans, original survey notes, and bridge inspection plans can be obtained from the agency responsible for that particular section of highway. Records on projects originally constructed by FLH may be obtained from the applicable Federal Records Center. The data in as-constructed plans will frequently be in English units and will have to be converted to the metric system of units before use.

3. Photography. The use of photography as a source of preliminary surveying information is somewhat limited. General project layouts can usually be obtained from readily available maps rather than from photographs. On the other hand, existing aerial photographs for a current project can often be used by the photogrammetric engineer. If the control points that are referenced in the photographs can be reestablished by a ground survey and the physical topography of the route has not been altered, the photographs may be usable.

Sometimes routes or portions of routes have been photologged for maintenance or planning purposes. When available, a photolog can be a source of valuable data. The existence of old aerial photographs often indicates the presence of aerial maps. Final construction reports may also be a source of helpful photographs. The surveyor should check into these possible sources for information.

Aerial photographs are usually available from highway agencies, appropriate Federal agencies, or private consulting firms.

4. Existing Maps. Generally 7-1/2 minute or 15 minute quadrangle (topographic) maps are available covering the desired project limits. These quadrangle maps are available from both the U.S. Geological Survey offices and from many private vendors for a minimal fee. They provide a wide variety of control and terrain information.

For most types of survey projects there exists a variety of available maps. By using these maps, much of the field gathering of information can be reduced.

A list of agencies that provide maps containing survey information follows:

- **U.S. Geological Survey (USGS), Department of the Interior**

  Quadrangle, topographic, and index maps.
  Bench mark locations, level data and tables of elevations.
  Stream flow data.
  Water resources.
  Geologic maps.
  Horizontal control data.
  Monument locations.

- **National Geodetic Survey (NGS), Department of Commerce**

  Topographic maps.
  Coastline charts.
  Topographic and hydrographic studies of inland lakes and reservoirs.
  Bench mark locations, level data, and tables of elevations.
  Horizontal control data.
  State plane coordinate tables for Lambert and transverse Mercator projections.
  Tide and current tables.
  Coast pilots information.
  Seismological studies.
  Magnetic studies.
  Aeronautical charts.
  Charts of the Great Lakes and connecting waters.

- **Bureau of Land Management (BLM), Department of the Interior**

  Township plots, showing land divisions.
  State maps showing public lands and reservations.
  Survey progress map of the United States showing the progress of public land surveys.

- **Defense Mapping Agency, Aerospace Center, Department of Defense**

  Topographic maps and charts.
  Nautical charts, navigational manuals.
  Aeronautical charts.

- **Corps of Engineers, Department of Defense**

  Topographic maps and charts.
  Nautical charts, navigational manuals.
  Aeronautical charts.

- **Board of Engineers for Rivers and Harbors**

Maps and charts of ports and harbors.
Permits for construction of structures other than bridges in navigable rivers and harbors.
Beach erosion data.

- **Coast Guard, Department of Transportation**

Permits for bridges in navigable water.
Designation of special anchorage areas.
Regulations for drawbridges and obstructive bridges.

- **Mississippi River Commission, Department of the Army**

Hydraulic studies and flood control information.

- **Natural Resources Conservation Service, (NRCS) Department of Agriculture**

Soil charts, maps, and indexes.

- **Forest Service (FS), Department of Agriculture**

Forest resource maps including topography, culture, and vegetation classification.

- **U.S. Postal Service**

Rural free delivery maps by counties showing roads, streams, etc.

- **International Boundary Commission, United States, Alaska and Canada**

Topographic maps for 0.5 to 4 km on either side of the United States-Canadian boundary.

- **Local Governments: State, county, city**

Street and zoning maps.
Drainage and utility maps.
Horizontal and vertical control data.

The maps and related coordinate data in will frequently be in English units and will have to be converted to the metric system of units before use.

5. Property Descriptions. One of the oldest forms of property descriptions available in the Public Land states are the Government Land Office (GLO) plats. These plats are available from the Bureau of Land Management (BLM). Besides the plats, which depict the original bearings and distances of land corners, many of the original field notes are available. This information is stored by the BLM on microfilm. The BLM sells enlargements of these slides for a minimal charge.

These property descriptions provide information concerning the identity and location of property corners. The surveyor shall make ties to the property corners during the cadastral survey portion of the field work. This data is used by the designer and right-of-way engineer in acquiring additional property for highway projects. Outside Public Land states, property description information is found in the property records of the local jurisdiction where the property is located.

6. Agency Contacts. Before any surveying activity begins on a project, contact the local representatives of any concerned agency. The purpose of this contact is to inform the agency that a survey is about to be performed. Briefly describe the surveying activities at this time. Special restrictions desired by these agencies, such as fire restrictions, recreational uses, scenic routes, limitations on cutting vegetation, and noise requirements, should be discussed. The agency contact will often provide additional information about availability of existing survey data and the type of ground survey desired. The names of specific agency contacts are usually identified in the reconnaissance report or in the scoping document.

Affected property owners should also be contacted. A letter to the property owner asking permission to make the survey across their property and/or personal contact with the owner is suggested. Retain any signed documents in the project files. Where contact cannot be made or permission granted, the surveyor should contact an immediate supervisor rather than trespass.

B. Surveys. The type of information gathered during preliminary surveys can be broken down into three different categories: planimetric, topographic, and cadastral.

1. Planimetric. Planimetric data consists of natural and political boundaries, natural vegetation, and cultural items such as sign posts, trees, buildings, etc. Using ground surveying techniques, these items are located relative to control survey monuments. Specific items are located with side shot measurements taken from these control points. Only the horizontal positioning (coordinates) for each point is required to plot the item on a planimetric map. However, when using total station surveying equipment, it is recommended that the elevation of each point be obtained. This additional data aids the plotting of contour intervals during the topographic mapping process.

2. Topographic. Topographic information gathering begins where planimetric information leaves off and consists of obtaining horizontal coordinates and vertical elevations of ground points. The intent of topographic data gathering is to obtain enough ground points to accurately describe the general relief of a specific area.

There are three general methods of canvassing a given area with topographic shots. The first is to use a *preliminary alignment and cross sections*. The preliminary line is usually a straight line connecting the ground control points. The survey crew then establishes points at given intervals, usually 20 m, and topographic breaks along this preliminary line. The spacing of these points is based on the type of land features and relief along the route. Cross sections are taken perpendicular to the preliminary line at these regular intervals. The points along the cross section lines essentially form a grid of coordinates that are used to construct the contour map.

The second method used to obtain topographic information is the use of *radial surveying*. The instrument is set up on a point with known elevation, and coordinates and readings are taken in a radial pattern around the instrument. Major breaks in the terrain (such as edges of shoulders, catch points, and drainages) are usually strung together in a series of sequential shots. These data points are called discontinuities and are treated differently from other random shots. The intent is to obtain a general description of the terrain, using a digital terrain model (DTM) to build an accurate contour map.

The third method is the use of *aerial photography* to plot topographic data. Viewing a given section of the project, the operator locates the discontinuities in a photograph with a series of shots.

The lines that connect these discontinuities divide the area to be mapped into segments. These segments are then digitized with a series of topographic shots taken along uniformly spaced scan lines. This process effectively covers the area with a grid of topographic points for use by the DTM.

3. Cadastral. A cadastral survey is used to locate property boundaries and monuments and determine the respective coordinates. This information may be obtained disregarding elevation. Since property and right-of-way documents are often based on the actual location of cadastral monuments, the engineer should verify these points by running traverses through them or by using the mean of two independent side shots.

5.4 APPLICATIONS

The process of surveying a highway project involves many small individual tasks (i.e. measurements of distances) that when combined into an established format (i.e. bridge surveys) produce an accurate description of the area under consideration. For simplicity, these small individual surveying tasks have been combined into a category called *general surveying procedures*. These procedures are discussed in more detail in the following section. A brief description of the mapping procedures used by both the photogrammetrist and the field surveyor are also contained within this chapter.

A. General Surveying Procedures. The techniques presented herein can be found in most standard surveying textbooks. The discussions are general in nature and are intended to provide a basic guideline for the entry level field surveyor. The following are some of the covered topics:

- Measurement of horizontal distances.
- Leveling procedures.
- Measurement of angles.
- Traverse surveys and computations.
- Horizontal and vertical curves.
- Coordinate systems.
- Topographic surveys.
- Photogrammetry.
- Global positioning satellite systems (GPS).

The recording and documentation required by each of these particular surveying operations is discussed in Section 5.5.

1. Measurement of Horizontal Distances. One of the basic operations of surveying is determining the horizontal distance between two points on the surface of the earth. The distance between two points at different elevations is obtained either by computing the horizontal distance from a measured slope distance or by direct horizontal measurement. Distances may be measured by pacing, odometer, stadia, taping, light waves, radio waves, infrared waves, or *GPS*.

Where approximate results are satisfactory, distances can be obtained by *pacing*. The length of a person's pace can be determined by walking over a line of known length several times, while maintaining a natural walking stride. When available, a measuring wheel can be used to obtain more accurate distances. Regular vehicle odometers will give fairly reliable distances along highways, provided the odometer is periodically checked against a known distance. For more accuracy, high quality electronic odometers can be installed and used for location and photologging purposes.

Another method of determining the distance between two points is to use stadia. Since the use of stadia has essentially been replaced by electronic distance measuring (EDM) devices, the stadia method of determining distances will not be discussed. Details of this method may be found in any standard surveying textbook.

Taping a distance with either a steel or a cloth tape is one method of obtaining the distance between two points. Where high accuracy is not required, cloth tapes are recommended. Cloth tapes are likely to change length with age, moisture condition, and use. Better accuracies can be obtained with steel tapes if proper taping techniques and corrections are applied for temperature, sag, and tension errors.

Most Government land surveys recorded distances in chain measurements. Two kinds of chains were formally used in surveying--the 100-foot [30.48-meter] engineer's chain and the 66-foot [20.12-meter] Gunther's chain.

Both were divided into 100 links. A link of an engineer's chain is therefore 1-foot [304.8-millimeter] long, and a link of a Gunther's chain is only 0.66 feet long [201.2 millimeters]. Typically when a distance was recorded in chains, the implied chain is the 66-foot Gunther's chain.

Most distances are now measured using electronic distance measurement (EDM) devices. These machines use light, radio, micro, or infrared waves to determine the distances between two points. The systems typically consist of a transmitter/receiver unit and a reflector device. The reflector generally is a glass prism. These EDMs are capable of high accuracies over both short and long distances. The operation and limitations of these instruments should be understood before incorporating their use into daily practice.

2. Leveling Procedures. Leveling is the surveying operation performed to determine elevations of points, to determine differences in elevations between points, and to control grades and roadway templates in construction surveys. The traditional instrument used is a spirit level that establishes a horizontal line of sight by a telescope fitted with a set of cross hairs and a level bubble. Other instruments used for determining vertical distances are the *transit, total station, aneroid barometer, and hand level*. *GPS* may also provides sufficiently accurate elevations for many purposes.

When differences of elevation are determined either trigonometrically or by using a level and a rod, the effects of curvature and refraction must be considered. This is particularly true when the horizontal distances are long and when a high degree of precision is required. The curvature error results from measuring distances horizontally (flat) instead of measuring them along the arc or curvature of the earth. Refraction errors occur because the earth's atmosphere bends light waves from the horizontal towards the earth's surface.

The combined effects of curvature and refraction may be negated in differential leveling by balancing the foresights and backsights. They may also be negated by using the mean of the vertical angles looking both ahead and back when using trigonometric leveling. Should the occasion arise where negating curvature and refraction is not practical, formulae for the corrections may be found in any standard surveying textbook.

The traditional method of determining differences of elevation is with the spirit level and a rod. By placing the level between the two points and recording the rod readings from both points, the elevation from one point can be used to determine the elevation of the other point. This method of leveling is called *differential leveling*. *Three-wire leveling*, also referred to as *precise leveling*, is a process of direct leveling where three cross hairs are read and recorded rather than the single cross hair.

The difference in elevation between two points can also be determined by measuring the vertical angle of the line from one point to the other and then computing the difference in elevation. Use either the slope distance or the horizontal distance between the two points. This method is called *trigonometric leveling*. The difference between the height of instrument and height of target has to be considered to obtain a true elevation difference between the points occupied.

Stadia leveling combines features of trigonometric leveling with those of direct differential leveling. Again, consult a standard surveying textbook before undertaking this method.

Leveling with a *total station* is the fastest and simplest method of determining elevation differences. A total station includes an electronic transit/theodolite combined with an EDM. The EDM measures the slope distance to the point in question and uses the vertical angle from the transit/theodolite to reduce the slope distance to horizontal distance and vertical difference.

Atmospheric pressure decreases as the altitude increases, enabling the engineer to use an *aneroid barometer* to determine rough elevations. Aneroid barometers produce results within 2 to 3 meters from actual measurements. Where accurate beginning elevations are not required (i.e., reconnaissance work), the aneroid barometer provides an alternative to a level loop.

The *hand level* consists of a short metal or plastic tube with a small level bubble mounted on the top. A prism on the inside of the main tube enables the user to tell when the level is being held horizontally. The hand level is used where accuracy is not critical, such as in taping to determine when the tape is being held horizontally.

A bench mark may be established by the engineer or surveyor at predetermined intervals along the survey. A good bench mark is a bronze disk set either in the top of a concrete post or in the foundation wall of a structure. Other locations for bench marks are the top of a culvert headwall, the top of an anchor bolt, or the top of a spike driven into the base of a tree. The elevations of bench marks are determined to varying degrees of accuracy by the particular field operation.

Profile leveling is used to determine the elevations of the ground surface along a given line. In highway applications, profile levels are often performed on centerline stations and on cross section reference points. The elevations at these points are crucial to the construction of the highway.

3. Measurement of Angles. A horizontal angle is the angle formed by two intersecting vertical planes. The vertical planes intersect along a vertical line which contains the vertex of the angle. In surveying, an instrument for measuring angles occupies this vertex. A horizontal angle in surveying has a direction. That is, it is measured to the right or to the left, or it is considered clockwise or counter-clockwise. Angles measured to the left are considered to be negative. The common methods of measuring horizontal angles are by the total station and transit/theodolite.

A transit (a deflection angle instrument) or a theodolite (a single directional instrument) have horizontal and vertical circles that are graduated into fractions of minutes and/or seconds. Electronic theodolites display the angular readings and their differences, eliminating interpolation errors.

The number of times an angle must be measured and the required accuracy of the instrument will vary depending on the type of survey. The requirements of surveying accuracies for various types of survey projects are listed in Section 5.4.C.

4. Traverse Surveys and Computations. A traverse is a series of connected lines of known length and course direction. The lengths of the lines are determined by direct measurement of horizontal distances, by slope measurements, or by other methods as described in section 5.4.A.1. The angles at the traverse stations between the lines of the traverse are measured with either a transit, a theodolite or a total station instrument. The angles can be either deflection angles or angles to the right.

The results of field measurements related to a traverse will be a series of connected lines whose lengths and azimuths or bearings are known. The course directions may be azimuths from North or South or bearings. Either may be true, grid, magnetic, or assumed.

Some of the many purposes for which traverse surveys are made are listed below:

- To determine the boundaries of individual property.
- To determine the position of arbitrary points from which data may be obtained for preparing various types of maps.
- To establish ground control for photogrammetric mapping.
- To establish control for gathering data regarding earthwork quantities for highway construction.
- To establish control for locating highway projects.

In general, traverses may be of two classes. The first class is an *open traverse*. It starts either at a point of known horizontal position with respect to a horizontal datum or at an assumed horizontal position, and ends at an unknown horizontal position. The second type of traverse is known as a *closed traverse*. A closed traverse starts at an assumed or known horizontal position and ends at either the same point, or at another known horizontal position. A known horizontal position is defined by one or more of the following:

- Geographic latitude and longitude.
- X and Y coordinates on a grid system.
- Location on or in relation to a fixed boundary.

To make an open traverse more reliable, several techniques may be employed:
(1) Each distance can be remeasured; (2) The measurements of the angles at the stations can be repeated; (3) The directions of the lines can be checked by magnetic bearings or solar/polaris observations.

Use care in running an open traverse because it contains no checks for mistakes or errors.

A traverse that closes on itself affords a check on the accuracy of the measured angles, as well as an indication of the consistency of measuring distances.

A closed traverse that starts at one known position and closes on another is the most reliable, because the position of the final point checks both the linear and angular measurements of the traverse. A point of known position must have been located by procedures at least as accurate as those used in the traverse being executed.

There are several different methods employed in running a given traverse. Each method has a specific set of guidelines that govern their execution. Traverse methods include interior-angle, deflection-angle, angle-to-the-right, azimuth, and compass traverse. The deflection-angle, angle-to-the-right, and compass traverse are most often used by highway engineers.

Two methods of traverse adjustment are normally used in highway surveying. The *compass method,* assumes that both distance and angular measurements are of equal precision. The method of *least squares adjustment,* allows weights to be applied to any measurement. The compass adjustment is the easiest to use and generally provides acceptable results. There are many forms of the least squares adjustment and care must be exercised when using them so error is not introduced to the traverse through a misunderstanding. Consult a standard surveying textbook before using either of the adjustment procedures.

5. Horizontal and Vertical Curves. The horizontal alignment of a highway consists of a series of curves connected with straight lines. The grade line on a profile is likewise made up of straight lines and curves. These curves may be arcs of circles, parabolas, or spiral curves. The parabola is generally used as a vertical curve on grade lines, while the circle and/or the spiral curves are used as horizontal curves. On many highways, the horizontal curves are made up of circles with transition spiral curves at the two ends. See Chapter 9 for the notations and formulas commonly used to describe circular curves.

6. Coordinate Systems. Computations of traverse point locations are reduced to a series of X and Y coordinate pairs. Often a point of origin is assumed and the traverse points referenced to this point. This use of an assumed coordinate system works quite well on small survey projects but a problem arises when the engineer attempts to relate the points from one survey project to those of another. The Y-axis of the plane coordinate system for each of the two surveys is assumed to be parallel to the true meridian. Meridians converge as one moves toward the poles and are not parallel. Assuming that meridians are parallel may result in major coordinate differences.

The solution to this problem lies within the methods of *geodetic surveying techniques.* In geodetic surveying, distances are reduced to a common reference surface conforming closely to sea-level. Angles in geodetic surveys are considered spherical angles. The coordinate systems developed using geodetic surveying techniques are referenced to parallels of latitude and meridians of longitude by using angles computed near the center of the earth. Geodetic surveying is more precise over long distances without suffering the limitations of plane surveying methods.

Use caution when applying a State plane coordinate system to projects where either elevation or scale factors would make an appreciable difference in ground and grid distances. When this occurs, use a "modified" plane coordinate system to allow field measurements to be taken directly from map calculations.

For more than a century, the National Geodetic Survey, has established horizontal control monuments throughout the country. These stations have been located by geodetic surveys. All the points throughout the country bear a relationship to each other. State *plane coordinate systems* are a result of this network.

When practical, convert the highway survey to the State plane coordinate system. The following are advantages of using the State coordinate system:

- A traverse of relatively low accuracy run between a pair of control points is actually raised in accuracy after an adjustment between the control points is made.

- The use of well-established control points in a traverse eliminates many serious mistakes often made in measuring both distances and angles.

- A point whose X- and Y- coordinates have been determined can, if lost, always be replaced with the degree of precision with which it was originally established.

- Maps that have been controlled by coordinated points will always conform when joined, no matter how unrelated the projects which necessitated the maps.

- The use of a common reference system for surveys reduces or eliminates costly duplication in the way of many control surveys over the same area by various engineers and surveyors.

- The use of the State coordinate system permits surveys to be carried over statewide distances by using plane surveying methods with results which approach those obtained by geodetic methods.

- State coordinate definitions may be required for ROW deeds.

- Photogrammetric mapping can be conducted at much less expense when all control points in the area to be mapped are on the same system.

When using a plane coordinate system, elevations and scales will be slightly different than ground and grid distances. These differences can be computed and their significance determined.

Where an assumed datum of coordinate system is used, all field note books and any maps or plans compiled from the data should have a note so stating. Assumed vertical elevations shall be at least 100 meters different from the true elevation beginning with even hundreds. Assumed coordinates shall be at least 100 000 meters different from the true coordinates shall be at least 100 000 meters different from the true coordinate positions beginning with even hundred thousands. Azimuths shall be determined from astronomical observations to third order accuracy.

7. Topographic Surveys. Topographic surveying is the process of determining the positions of the natural and artificial features of a given locality as well as determining the configuration of the terrain. The horizontal location of the features is referred to as planimetry and the configuration of the ground is referred to as topography. The purpose of the survey is to gather data necessary for the construction of a topographic map. Such a map shows both the horizontal scales of the features and their elevations above a given datum. Often the type and limits of vegetation are also shown on topographic maps.

Contour lines are typically used to represent relief on a topographic map. A contour line is a line that passes through points having the same elevation. The contour interval for a series of contour lines is the constant vertical distance between adjacent contour lines. Contour lines on a map are drawn in their true horizontal positions with respect to the ground surface. A topographic map containing contour lines shows not only the elevations of points on the ground, but also the shapes of the various topographic features, such as hills, valleys, escarpments, and ridges.

The area to be mapped for highway location and design is usually a strip of land varying in width from one hundred meters to one thousand meters. The *cross section* method is usually used to obtain topography on ground surveys with heavy vegetation and/or rugged terrain. A base line is established from the control points, usually in the form of a traverse with intermediate points established at 20- to 30-meter intervals. The intermediate points are identified by elevation and distance (called stations) from the traverse points. These points also are the centerline points of the cross section which is measured normal to the traverse line. When an area of limited extent is moderately rolling and has many constant slopes, points forming a grid are located on the ground and the elevations of the grid points are determined. This is the *grid method* of obtaining topography. Another approach, *radial topography*, may also be used. In radial topography the instrument is placed over one of the control points and ground elevations are obtained radially around the control point.

Topography measurements can be obtained by total station, theodolite and EDM, level and tape, arc and tape, or any other method of measuring elevation and distance. The choice of equipment is usually based on the degree of accuracy desired.

In compiling topography, the positions of all planimetric features (such as buildings, fences, and streams) are located with respect to the control line. These items are also plotted on the topographic map. Often these items are located by azimuth angle and distance techniques (radial survey methods).

The grid method of obtaining topography may be used in areas of limited extent where the topography is fairly regular. Either a theodolite with EDM or a level may be employed. The area to be mapped is usually bound by a traverse and a grid of squares or rectangles inside the area to be laid out. The dimensions of these divisions depend on the required accuracy and the regularity of the topography. The elevations of all the gridpoints are recorded, and the points are used to generate the contour map.

In radial topographic surveys, the instrument is placed relative to the control points and topographic shots are taken in a radial pattern around the point. Take care to cover the area with sufficient points to obtain an accurate representation of the relief. By using this method, the engineer is able to obtain a concentrated number of points in an area where the terrain rapidly changes and fewer points where the terrain is fairly regular. Radial surveys also allow for local *discontinuities* to be outlined on the ground by a series of topographic points. Discontinuities are terrain features that reflect breaks in contour intervals. The bottom of draws and the edges of ridge lines are two such examples.

8. Photogrammetry. Photogrammetry is the science of making measurements on photographs. Terrestrial photogrammetry applies to the measurement of photographs that are taken from a known ground station, while aerial photogrammetry applies to the measurement of photographs taken from the air. Aerial photogrammetry is most often used in highway design applications and terrestrial photogrammetry finds uses in structural and land deformation. The science of aerial photogrammetry has come to include all operations, processes, and products using aerial photographs. Among these are included the measurement of horizontal distances, the determination of elevations, and the compilation of planimetric and topographic maps.

For a discussion of the exact processes involved in aerial photogrammetry the engineer should consult a standard photogrammetry textbook. These manuals describe in detail the types and uses of aerial cameras, the types of required photographs, the associated scaling factors, the principals behind measuring relief, and the operating procedures for various stereoplotting equipment.

In order that aerial photographs may be used for making simple measurements of distance and elevations, some ground control is necessary to fix the scale of the map and to establish a vertical datum with which to establish contour lines on the map.

Usually a system of control points and special points called wing points are located on the ground and then targeted so they can be identified in the aerial photographs. A traverse is run through these points and their coordinates and elevations determined.

Positively identify wing points between the photograph and the ground. They must be sharp and well defined as seen on the photograph under magnification.

The location of the wing points is usually predetermined by the engineer to avoid having a point fall near the edge of a photograph. These points should be reasonably accessible from the ground to keep the expense of the ground control survey to a minimum. Typical targeting is described in the photogrammetry reference materials.

The main advantages to compiling topographic maps by using aerial photographs over ground methods are as follows:

- Expandable map widths.
- Reduced compilation time.
- Reduced control surveying time.
- Highly accurate location of planimetric features.
- No interference by adverse weather and inaccessible terrain.
- Uniform accuracy throughout the map.

By the proper selection of flying heights, focal lengths, plotting instruments, and placement of ground controls, photogrammetric mapping can be designed for any map scale ranging from 1:100 to 1:20 000 and smaller. Contour intervals can also range down to 0.2 meters.

Among the disadvantages of mapping using aerial photographs are the following:

- Difficulty plotting areas containing heavy ground cover, such as high grass, timber, and underbrush.
- High cost per hectare to map areas of 2 hectare or less.
- Difficulty locating positions of contour lines on flat terrain
- Difficulty scheduling photographic flights (most jobs can not be flown in winter or summer).

Supplemental ground survey is required where the ground cannot be seen in the spatial model because of ground cover and where such planimetric features as overhead and underground utility lines must be located on the map. Editing is necessary to include road classification; property boundary lines not shown on the photography; drainage classification; and names of places, roads, and other map features.

9. Global Positioning Satellite System. Global positioning satellite (GPS) systems are the methods and equipment used to determine the three-dimensional coordinates of any point within the spherical world using satellite technology. The system consists of NAVSTAR satellites that transmit signals toward the earth. Special receivers record these signals and using computer programs interpret the signals and determine the coordinates and elevation of the location of the antenna receiver. There are a wide variety of receivers and data processing programs now available.

At present there are 21 satellites transmitting signals back to the earth. This coverage means that a receiver is able to record the signals from at least four satellites at the same time. The more satellites a receiver processes, the higher the accuracies and the less time spent recording data.

Using GPS systems for establishing ground control is currently cost effective for the majority of FLH projects. In areas where geodetic control is difficult and costly to use, GPS surveying should be considered.

B. Instrument Care and Adjustments. As surveying equipment becomes increasingly complex and expensive, care and maintenance becomes more imperative. Place total station, theodolites, levels, data collectors, EDMs, and all other equipment in their protective cases when not in service. Always place instruments in their cases when being transported. During wet periods, store the instruments in a dry place and in their cases, but with the case lid left open. This will allow moisture trapped within the instruments to escape.

Similarly, keep tripods, rods, and range poles clean and stored in either carrying cases or bins built into the survey vehicles. To avoid swelling of the wooden parts of these pieces, wipe them dry after exposure to moisture. Place the top plate covers on the tripods when not in use.

Inspect, axes, saws, machetes, and other metal equipment daily for condition. When being stored for extended periods, wipe them with an oiled cloth and store in a dry place.

All of the electronic surveying equipment will require periodic adjustments to ensure their accuracy. Manuals that describe how to calibrate and make minor adjustments to the instruments are provided by the manufacturer. Keep these manuals with the instruments in their field cases. Make an accuracy check on the instrument before initial use on a project and on a weekly basis thereafter. Check the equipment anytime accuracy is suspect. In addition to their regular maintenance, total station, theodolites and EDMs should have a manufacturer's cleaning and lubrication at least every 2 years.

C. Classification and Accuracy. Surveys are classified into order and class on the basis of the accuracy and precision used in the survey. See Table 5-1. Accuracy and precision is dependent on the quality of the instruments and equipment employed, the methods and procedures used, the repeatability of measurements, and the ability and experience of the personnel.

The following sections identify the standards for the classification of geodetic control as recommended by the Department of Commerce, National Geodetic Survey.

Surveys are accepted or rejected on the basis of the accuracy attained. Accuracy is the degree of conformity to a true standard or the degree of perfection obtained. This degree of conformity is shown by the computed survey closure.

Traverses qualifying for a specific classification on the basis of the precision used will ordinarily not only meet the accuracy requirements for that classification, but will generally provide closures for about one-third of that specified. If closures exceed one-half the closure specified, a review of equipment, measurements, and procedures shall be made. For example, a Third Order Class I traverse is acceptable if its closure error does not exceed 1 part in 10 000. A closure error of 1 part in 30 000 should be expected. If the closure error is more than 1 part in 20 000, perform a search for possible errors.

Table 5-1
Survey Standards

Item	First Order Surveys	Second Order Surveys		Third Order Surveys	
	Horizontal Controls				
Relative accuracy between directly connected adjacent points (at least)		Class I	Class II	Class I	Class II
	1 part in 100 000	1 part in 50 000	1 part in 20 000	1 part in 10 000	1 part in 5000
	Vertical Controls				
Relative accuracy between directly connected points or benchmarks (standard error)	Class I / Class II	Class I	Class II		
	$4mm\sqrt{k}$ / $mm\sqrt{}$	$6mm\sqrt{k}$	$8mm\sqrt{k}$	$12mm\sqrt{k}$	
	Traverse Controls				
		Class I	Class II	Class I	Class II
Recommended spacing of principal stations	Network stations 10-15 km. Other surveys seldom less than 3 km.	4 km	2 km	1 km	1 km
Smallest reading of horizontal circle on instrument	0.2 second	0.2 second	0.2 second	1.0 second	1.0 second
Number of horizontal observations	16	8	6	4	2
Rejection limit from mean	4 seconds	4 seconds	4 seconds	5 seconds	5 seconds
Number of and spread between vertical angle observations	3 D/R 10 seconds	3 D/R 10 seconds	2 D/R 10 seconds	2 D/R 10 seconds	2 D/R 10 seconds
Number of angle points	5 or 6	10 to 12	15 to 20	20 to 25	30 to 40
Angular closure not to exceed	1.0" per km station or $2''\sqrt{n}$	1.5" per km station or $3''\sqrt{n}$	2.0" per km station or $6''\sqrt{n}$	3.0" per km station or $10''\sqrt{n}$	8.0" per km station or $30''\sqrt{n}$

Note: k = distance in kilometers.n = number of angle points. "D" = Direct and "R" = Inverted

D. Specific Survey Procedures. By using the methods discussed in the previous section, the engineer can perform the more common highway surveying assignments. Typical highway surveying projects include the following:

- Control surveys for both ground and aerial projects.
- Reconnaissance surveys.
- Preliminary surveys.
- Location surveys.
- Property surveys.
- Construction surveys.
- Bridge surveys.
- Sundry surveys.

1. Control Surveys. Control surveying is the process of establishing a line or grid of points throughout the project limits. These points are the traverse points on a traverse line running between two or more points of known geodetic position. This traverse line contains the points from which all measurements within the project are made. Since the entire project will be relative to these points, give extra care to their accuracy and location.

Depending on whether the project will be measured by ground methods or by aerial photogrammetry, different requirements exist for the frequency and location of the traverse points. The next two sections describe in more detail the specific procedures to be followed when placing control survey points.

a. Ground Control. Begin and end the control survey on a first or second order geodetic monument. The coordinates for the monuments should be on the State plane coordinate system. When this is not practical, run a circuit from the end of the survey back to the point of beginning to achieve a closure or establish beginning and ending coordinates using GPS systems.

When placing supplemental points for an aerial survey or when establishing centerline, the circuits shall be closed traverses of the same accuracy as the primary control circuit.

Reference control lines with approved permanent type monuments at a recommended maximum spacing of three kilometers. Set monuments to prevent water from ponding above the caps and to ensure visibility to other control line monuments, triangulation points, or monumented azimuth markers. The monuments shall have their field locations referenced with approved witness type markers. It is recommended that these witness markers be a steel post with an aluminum identification plaque attached. The documentation should also describe bearings and distances from the monument to at least two other objects. See Exhibit 5.1 for an example of monument documentation.

When necessary to set semi-permanent points between monuments, place the monuments far enough below ground to be safe from ordinary maintenance operations. Use magnetic markers such as a 10M steel reinforcing bar capped with a yellow plastic cap. This permits locating the markers with metal detectors. Identification plaques need not be posted on semi-permanent points, but reference the points with an approved marker and record their locations.

Control surveys shall be performed with Second Order, Class II accuracy. See Section 5.4.C. As stated in that section, surveys shall close within an error of 1 in 20 000 before adjustment. On long traverses, use eccentric points or check circuit points to secure an azimuth check on every 20 angles or less. The closure at any azimuth check shall not exceed 2 seconds per angle or 6 seconds times the square root of the number of angles, whichever is less. Before computing coordinates, adjust the angles to effect a flat closure. The above values are minimum figures. With the equipment now in use, expect much higher accuracies without loss of production.

Number all monumented control survey points consecutively from the beginning to the end of the route. The monument designation will consist of the route number followed by a number or a number and/or a letter. All monuments set by the survey crew shall be identified by a primary number. Identify all supplemental points set by a number and a letter. All points set outside the control circuit by the survey crew shall be identified with a primary number and a parenthesized number.

Identify all existing points incorporated in the control circuit by a description. Identify all the check-circuit points with an eccentric number. See Figure 5-1.

b. Aerial Control. Control for aerial surveys shall consist of both horizontal and vertical control, targeted on the ground and visible from the air.

Horizontal control shall conform to the requirements of Section 5.4.D.1.a and usually will be the primary project control with no supplemental control required. In all cases involving aerial photography, those points required to control the mapping shall be placed in accordance with the furnished flight strip map. Give special attention to their location in relation to the flight line to ensure they are not obscured by shadows or other objects. (See Figures 5-2 and 5-3.)

Targets must not be placed on steep slopes since elevation orientation on a photogrammetric instrument becomes difficult and many times inaccurate.

Vertical control shall conform in all respects to the requirements outlined in Section 5.4.C. Those points that are required for vertical control shall be placed in accordance with the requirements of the horizontal control points to ensure that they too are visible on the photographs.

There are two types of targets, designated primary and supplemental control targets, used to identify ground control points in aerial photographs. Primary control targets are used to identify the main coordinate references from the photographs. Supplemental control targets are used to provide additional coordinate control and to serve as backup to the primary targets.

See Figures 5-4, 5-5, and 5-6. Prepare a sketch showing the location of all targets to ensure accurate photographic identification later. Target composition and size shall be determined by background and photo scale.

If preprinted targets are not practical or available, an appropriate white cross or wye shall be used with overall dimensions equal to those in the figures.

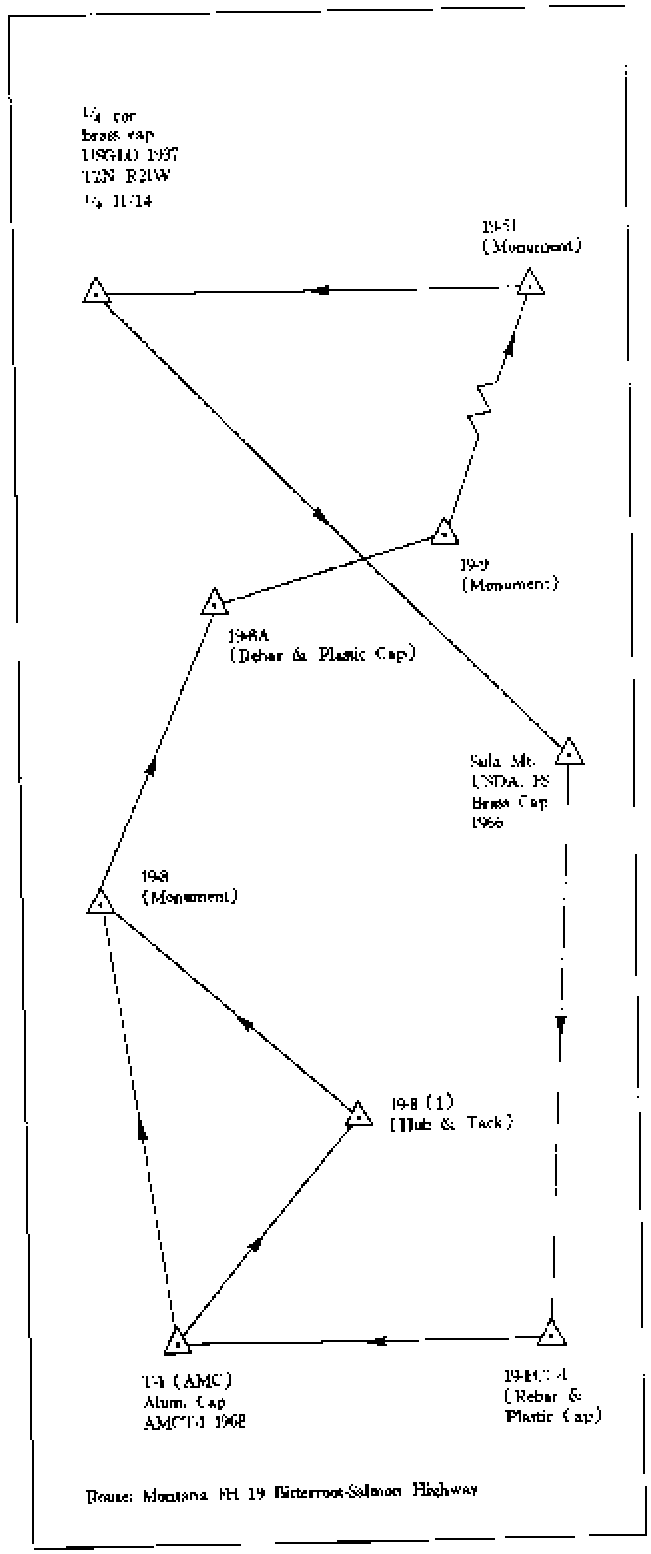
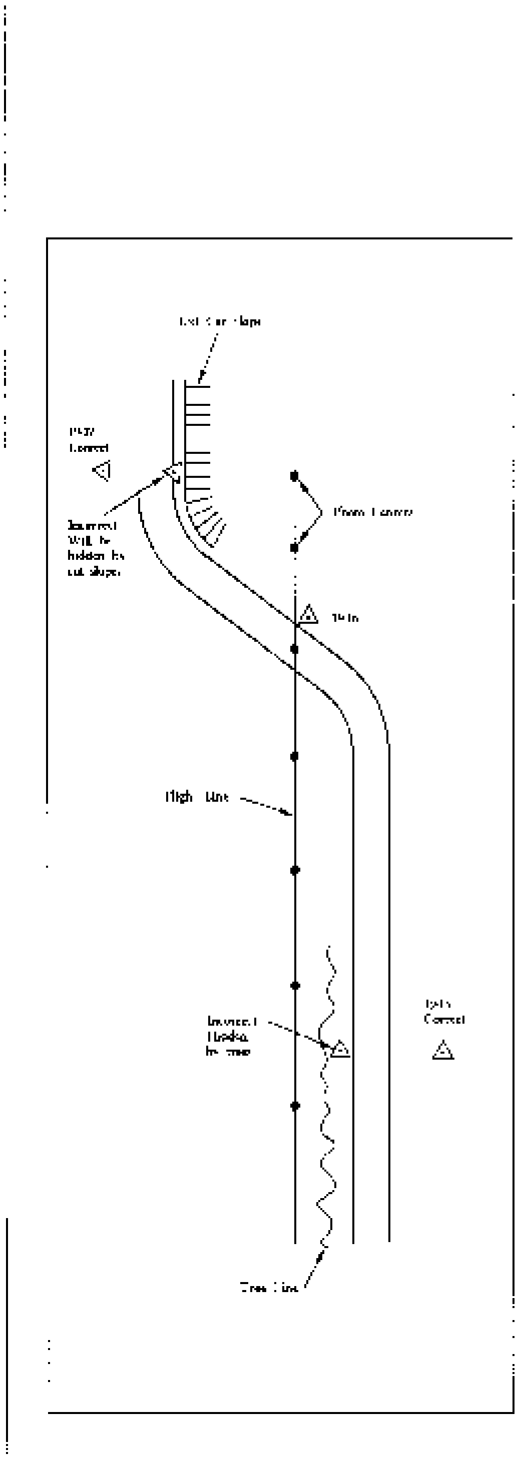
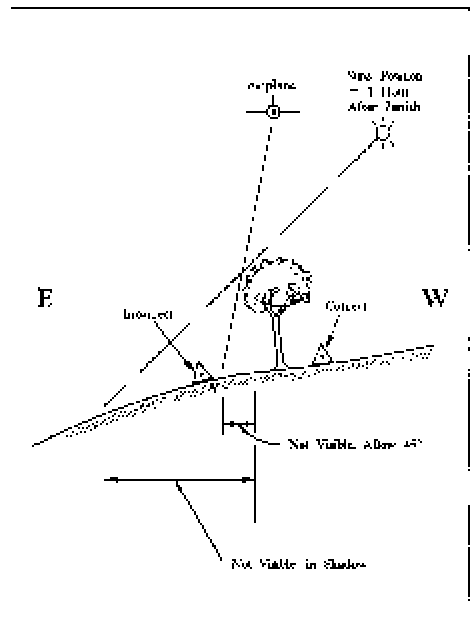
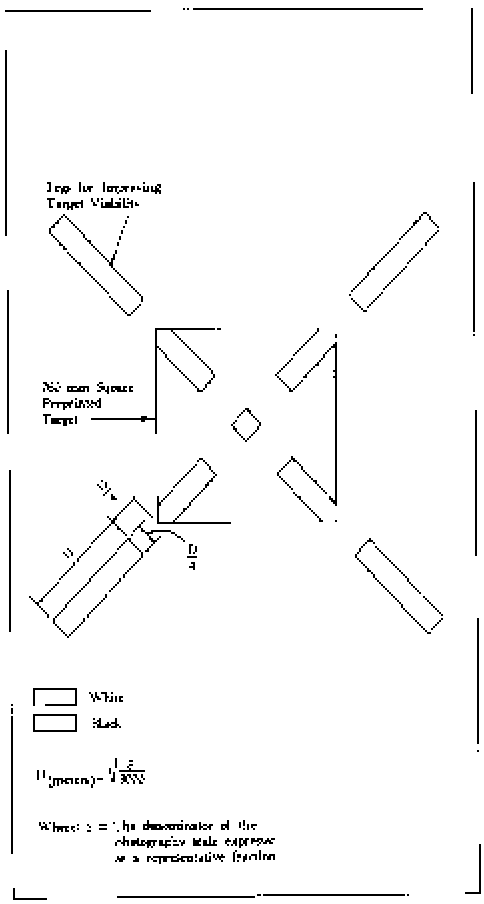


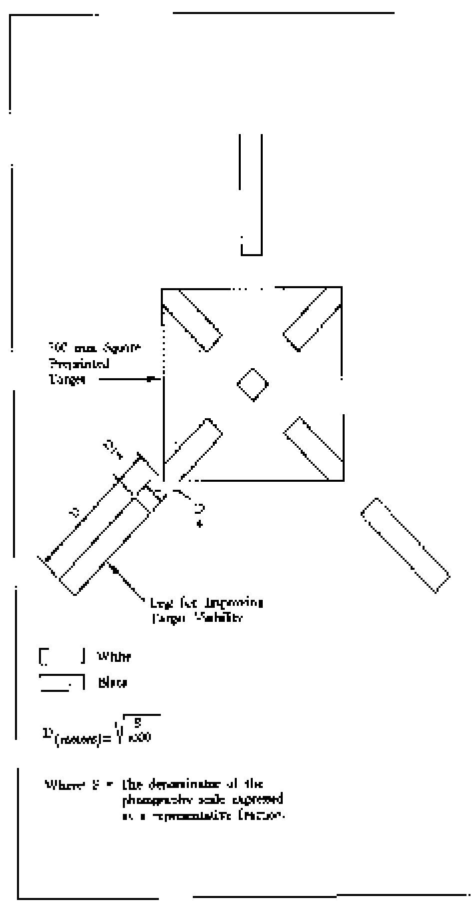
FIGURE 5-1
Exmple of a Monument Numbering System





FIGURES 5-2 AND 5-3
Monument Positioning





FIGURES 5-4 AND 5-5
Control Targets

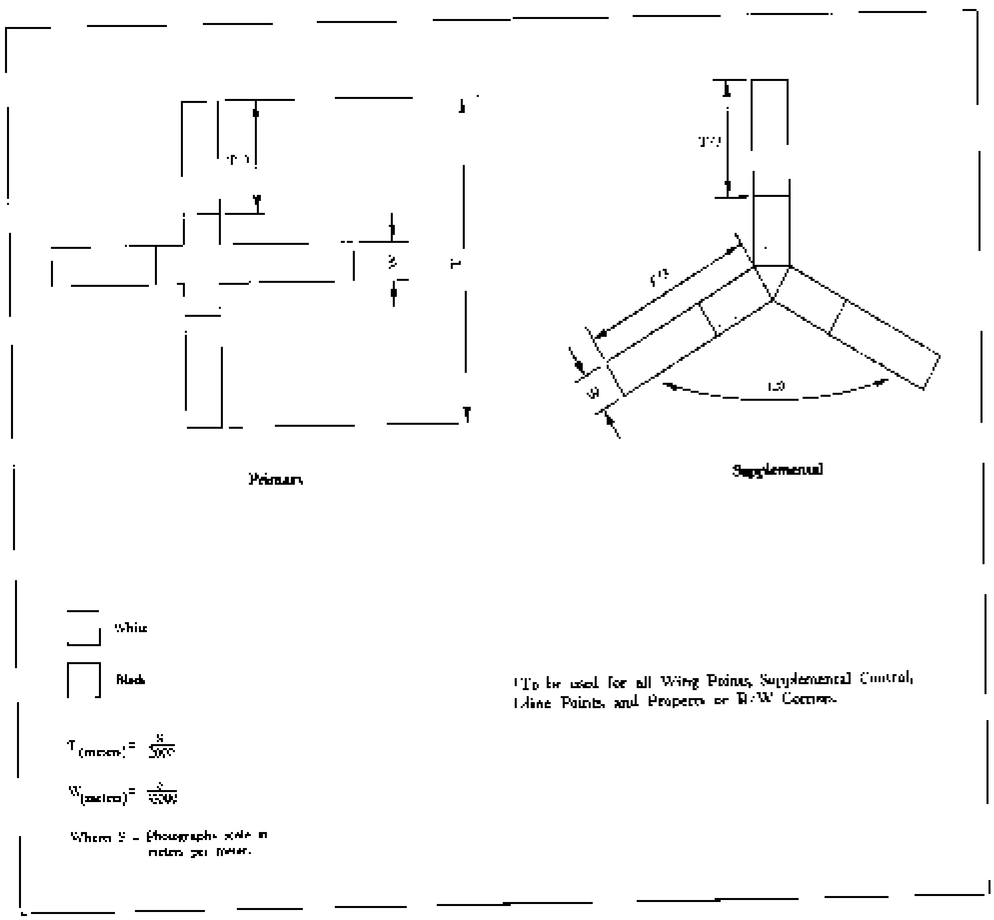


FIGURE 5-6
Alternate Targets

2. Reconnaissance Surveys. Reconnaissance surveys are divided into two parts, a survey of the area and an evaluation of feasible route alternatives.

For scoping purposes, horizontal and vertical information about the area is needed as well as information about cover and culture. This information can be obtained by field surveys; from existing maps or maps compiled specifically for the project; or it can be extracted from aerial photographs which is probably the most efficient method. Vertical aerial photographs represent the ground surface with sufficient accuracy to determine a feasible corridor.

Topography, geology, land use, ecology, and other features are immediately evident or readily interpreted by stereoscopic examination of the photographs. Elevations are easily derived from parallax measurements on the photographs. Horizontal distances measured on the photographs are converted to ground distances using local scales determined by parallax measurements. If topographic maps of the area are available, elevations and distances may by taken from them.

3. Preliminary Surveys. Preliminary surveys generally are line traverses (P-line) placed in the field in close proximity to where the final alignment of the future road or highway is to be placed. The points established by this survey serve as a base for locating the proposed road. These surveys are necessary to obtain all the field information needed to design the highway. The surveys are also used to locate and define private property, establish the relationship between natural and physical topography, and provide vertical and horizontal control. The control is derived from established control points placed during a previous control survey.

a. Accuracy. Preliminary surveys are normally third order, class II traverses and are tied to the control surveys. The points established shall be measured as specified in Table 5-1.

b. Monumentation Guidelines. A reinforcing steel bar, usually a 10M or 15M, with a plastic or aluminum cap shall be used. Return traverse points shall consist of hubs with tacks or nails driven into the roadway surface. Both double guard stakes and a lath shall be used to mark the angle points.

P-line stakes should be at least 600 millimeters in length and identified by the color red. The stake shall face ahead on line and be labeled with the station or appropriate section number. The section method for identifying preliminary survey sections is preferred over the more traditional stationing method. Angle points are designated in numerical sequence (P1, P2, P3, etc.). Intermediate points are designated with a slash (P2/1, P2/2, P2/3, etc.). The number following the slash corresponds to the number of the intermediate ahead of the angle point. Should an additional section be required after staking, it can be added by using a decimal (P4/6.1 means a section was added between the sixth and seventh section between angle points 4 and 5). The section method allows traverse adjustments to be made without changing the value of the station. It also enables the crew to positively identify the point prior to determining the true stationing.

Offset stakes shall be used when there is a good possibility that the centerline stakes maybe lost. The offset stakes shall contain either the station or the section number, with the offset distance circled and facing the centerline point. When offset stakes are set, some other means of identifying the centerline point shall be used (nails, small wooden pegs, etc.).

On preliminary surveys, a minimum of one tangent every 2 kilometers should be referenced on both ends using the double-point method with semi-permanent monuments. These reference points shall contain both horizontal and vertical values. Each angle point not referenced under the above guidelines shall be referenced using a double-swing tie to a standard aluminum tag. Both horizontal distances and the magnetic bearings, or azimuths, shall be recorded on the tag.

4. Location Surveys. A location survey is the placement of the final alignment of the highway (often called L-line) as it is to be constructed. Typically, during a location survey, the engineer will establish the following items along the project route. Other actions may be included in the location survey process.

- Centerline (L-line) of the roadway alignment.
- Right-of-way (R/W) limits.
- Reference points (RP).
- Project control points.

Often, other actions are included in the location survey process. These include the marking of the clearing limits, the movement of temporary bench marks from inside to outside the construction limits, and the running of profile and RP levels.

The centerline is marked with either a small wooden peg or a nail to indicate the point. In addition to the cross section centerline points, the alignment control points (i.e., PC, PT) may be staked and marked.

If required, the R/W line is designated with a stake placed along the cross section or at intervisible limits. Major breaks in the R/W line are marked with a lath and a small wooden peg.

When the clearing limits are set, they are marked by a lath. Bench marks are reset as indicated in the earlier section on leveling.

Discrepancies between the design and the actual ground can be determined by comparing the centerline and RP elevations. Re-cross sectioning may be required where the values vary more than an acceptable amount. Sometimes this resurveying is brought about by changes in the design alignment.

Additional control points placed outside the construction limits provide an extra layer of control coverage. Rather than running a long traverse to replace points disturbed by construction activities, they can easily be reestablished from these additional control points.

5. Property Surveys. A property survey is a means by which the ownership boundaries along the route can be represented on the various survey maps. If property lines can be determined in the field, they shall be tied to the traverse line. The methods used to tie property markers will be of an accuracy that is equal to that of the traverse.

a. Land Corners. Locate and tie the nearest section corners or quarter corners on both sides of the route (Public Land states only). To aid in the search of these corners, copies of the original land survey notes and township plats are available for all surveyed lands. These documents are available through the Bureau of Land Management. The local government agencies that have jurisdiction over land through which the project passes shall be contacted for additional information they may have on the location and condition of section corners.

Upon beginning a survey that involves much private property, a property search along the proposed route shall be performed. The county courthouse can provide the names, addresses and property descriptions of the land owners involved. If the task is substantial, the option of contracting the property search to a title company may be desirable. The search for section corners can sometimes be aided by contacting the appropriate land owner.

Refer to the *Manual of Instructions*, 1973, Department of Interior, BLM for detailed information regarding public land surveys.

b. Lot Corners and Subdivisions. Ties shall be made to all existing property corners necessary to establish property boundaries. These ties will include tract subdivisions, 1/16 corners, centers of sections, and monuments, when available. Mutually agreed to fence corners or fence lines should also be tied in the absence of monuments.

Most all tract subdivisions of later dates are platted and approved by county officials before lot sale and occupancy. These official plats are on record at the assessor's office in the local county courthouse and are available upon request. Copies of these plats can be used as an aid in defining the property and locating the corners within the subdivision.

c. Right-of-Way Monuments. Accurately tie existing right-of-way monuments. The monuments were originally set to define the right-of-way of the existing roadway, so they are actually property corners. Ties to right-of-way monuments should be consistent with other property ties.

d. Records. Submit copies of all records and agreements obtained during the preliminary survey to the Division survey staff upon the completion of the survey. The following are typical documents:

- Copies of the original government field notes for Township, subdivision, government land survey plats, etc., and homestead entry surveys.
- Prints of any subdivision plats and replats within the area.
- Prints of the county assessor's maps covering the general area.
- Copies of any Records of Survey made in the general area and filed in the county.
- Copies of surveys by various organizations (such as railroad companies; counties and cities; irrigation, water and drainage districts; power companies; gas and telephone companies; Federal agencies, etc).
- Copies of any deeds obtained.
- County court orders dedicating roads or establishing right-of-way widths.
- Copies of boundary line agreements.

e. Miscellaneous Monuments. Ties will be made to all monuments, memorials, and objects of antiquity of a permanent or semi-permanent nature found within the general area of the preliminary line. These monuments may also include cadastral survey references, government survey stations, bench marks, azimuth marks, or other similar items. These ties shall be made even though the monuments will not be destroyed by the alignment of the proposed highway.

f. Political Boundaries. Tie State, county, and city boundary lines where they cross the preliminary survey line. Also locate boundary lines for national forests and parks, State and county parks, and other such boundaries.

6. Construction Surveys. A construction survey is the process by which construction stakes are placed on the ground that allow the contractor to begin building the roadway template. These points include slope stakes, blue tops, red tops, and minor structure stakes (i.e., culverts and drop inlets). The location and elevation of these grade stakes may be determined from the plans or from computer printout sheets.

The techniques of placing these points are described in most surveying textbooks. The *FHWA Construction Manual* also contains procedures for construction project stakeout. Construction surveys (staking) may be performed by the contractor as a bid item or as a subsidiary obligation.

7. Bridge Site Surveys. The field work of performing a bridge site survey is similar to a normal preliminary survey. The activities of placing project control, running levels, taking cross sections, and making ties to cultural features and land corners are still required. However, for bridges and culverts over an estimated size of 2400-millimeter diameter, the engineer shall obtain the following additional information.

a. Stream cross sections. Obtain a minimum of three cross sections of the stream and flood plain. These sections shall be about 150 meters apart if practical. Take the middle section close to centerline with the other sections upstream and downstream. Take care to ensure that these sections are typical of the stream section. Show the stream bottom, with a note about the composition of the bed material, the water elevation, high watermarks and date of high water, if available.

b. Water surface profile. Determine a water surface profile, when requested, between the cross sections and any high water marks recorded.

c. Improved land. Note any improved land adjacent to the structure site that may be inundated, and determine the elevation to control flooding.

d. Fish passage. Note any existing obstructions to fish passage and any details concerning fish passage.

e. Existing bridges. Tie existing bridges in the immediate vicinity upstream and downstream of site and record type, condition, location, and ownership. Note the number and length of spans, pier orientation, elevation, date and source of high water, any overtopping of fills, and the cross section of the waterway under the bridge.

f. Effect of adjacent structures. Document any information available on the size and location of dams, flumes, spillways, etc., adjacent to the bridge site that may affect the water passage at the bridge.

g. Drift. Estimate the amount and kind of drift and debris that will occur during high water.

h. Photographs. Photograph each site looking ahead and back on line. Include views upstream and downstream from the proposed crossing.

i. Flood plain. Where the proposed road will encroach on the flood plain of streams having a design flow of about 15 cubic meters per second or greater, the engineer will take cross sections of the flood plain where the size of the stream changes. The engineer will also note the type and height of vegetation covering the flood plain. The hydraulic and environmental sections of this manual, list other more specific surveying requirements for addressing wetlands and particular hydraulic structures.

8. Sundry Surveys. Sundry Surveys is a term for describing all other miscellaneous types of survey activities. These surveys are information gathering in nature and consist of establishing a control line and then either cross sectioning the area in question or blanketing the area with a series of side shots ties. Typical sundry surveys include quarry sites, landslide areas, and parking or vista areas.

These surveys are to be monumented similarly to preliminary surveys.

9. Automated Surveys. The surveying procedures as described in the preceding sections have been the traditional methods used to gather and process surveying information. The use of computers have allowed surveying to be automated.

The overall concept of automated surveying and mapping is shown in Exhibit 5.2. This exhibit shows the flow of survey information as it is collected by either ground or aerial surveying techniques. The data passes through a variety of processing equipment and is delivered to the designer in the form of maps, paper listings, and computer files.

No matter what kind of data collector is used to record an item of survey information, a system of feature codes is required to indicate special topographic and planimetric items. A code is entered into the data collector when a recording is made of the unknown point. These feature codes are carried through the system and are used by the CADD system to plot appropriate symbols for each code. See Exhibit 5.3 for a listing of suggested numeric codes.

5.5 RECORDS AND REPORTS

As with any engineering activity, the process of recording activities and preparing reports is essential to an efficient and timely operation.

The most important information that is recorded during a survey is that of actual field measurements. This information may be recorded in a variety of formats and media. Typically, these measurements are recorded in electronic notebooks and data collectors although field notebooks are still in use .

Besides the daily note keeping required during the performance of normal surveying activities, the surveyor is required to prepare various other reports. Two such reports are the weekly progress reports and the project cost report. These reports permit the engineer to make estimates regarding production rates for a variety of situations and to also provide cost estimates for accounting purposes. Refer to Exhibits 5.4 and 5.5 for sample formats of these reports.

A. Field Notes for Traditional Surveys. Unless data collectors or electronic notebooks are used on the project, several types of notebooks shall be maintained. Begin each book with an introductory identification page. (See Exhibit 5.6). Include the date, names of crew members and their assignments, instrument ID numbers when applicable, and the weather. Depending on the size and complexity of the survey, these notebooks may be combined.

The exact format and type of record to be maintained will be as approved by the location and/or survey engineer.

A description of the various types of notes follows. See Exhibit 5.7 for sample formats.

1. Index. An index or index book shall be made for each project. It will contain indexes to the other field books used on the project. It will also contain indexes and references to the other various maps (such as plats and utility plans). The index will be sectioned off into categories and kept current.

2. Traverse Notes. Traverse notes will contain all field data relative to either control or preliminary traverses. Include any references and descriptions of control ties used to establish the preliminary traverse. Notes are to run up the page.

3. Cross Section Notes. Cross section notes must clearly identify the method used to obtain the measurements, as well as listing the abbreviations and symbols used at the beginning of each book. Notes are to run up the page with the right and left sides correctly oriented.

4. Project Notes. Record any miscellaneous field notes to describe special features and activities throughout the project, such as instructions for execution of the survey and other similar items of information.

5. Level Notes. The level notes contain the location and description of all bench marks as well as all profile and closure loops. Notes are to run down the page.

6. Drainage Notes. List all drainages that the project crosses from the beginning of the book as they occur along the line of the survey. Make an estimate of the size of the culvert or structure required, with pertinent notes regarding drift, grade, foundations, fish passage, etc. All existing culverts or structures shall be measured with notes for condition, material type, type of corrugation, etc. See Chapter 7, Section 7.3 for more details.

Show a sketch of any stream bed for 150 meters upstream and downstream from the site. Include profile elevations for streams requiring culverts over 900 millimeters in diameter and less than 2400 millimeters in diameter. Show a cross section of the stream bed. Include a high water mark if possible.

7. Classification Notes. Identify the soil type by visual classification, such as clay, silt, sand, gravel, boulders, and rock type; record the location of each type.
Locate wetlands and areas of potential slides and give a recommendation as to possible mitigation measures.

Identify deposits of gravel or rock on or near the line.

The notes should include design recommendations as to location of the final line, its grade, and possible channel changes.

8. Cultural Notes. Ties can be shown on sketches showing the angle and distance from centerline points, or the angles from the centerline point to the object can be numbered, the distance shown and the actual angle placed on the other page of the notes.

9. Section Corner/Property Tie Notes. Show traverses to corners in standard traverse form on the left side of the notes with sketches showing what was done on the right side. Describe in detail and sketch their location.

B. Field Notes for Automated Surveys. At least one field book shall be used for each project. (See Exhibits 5.8 and 5.9 for recommended formats.) Provide an index to show major headings. Any rolls, maps or other books that are not practical to include directly in the *field book* are to be cross-referenced. There are different formats for preliminary and location surveys. Control surveys shall be considered preliminary surveys.

C. Mapping Procedures. The planimetric, topographic, and cadastral maps are the means by which survey information is passed to the roadway designer. These maps can be drawn by hand, but are normally processed by the computer.

Two other types of maps are often discussed in the field of highway design. These are the detail map and the vicinity map. The detail map (manuscript) is a combination of the planimetric, topographic, and cadastral maps. The detail map is used to evaluate various highway corridors and roadway alignments. Vicinity maps are detail maps that are used to show a small section of the project in large detail. These maps are typically used at bridge and quarry sites.

1. Conventional. Conventional mapping refers to the process of transferring the survey information collected during a ground survey onto the detail map. The procedure for this type of mapping is to establish the coordinate system and stationing layout as described in Section 5.4. Once this has been done, the control traverse line is plotted using the coordinates. From this base, the cross section points and culture ties can be located. The engineer then interpolates the contour lines and draws them on the map. Special notes are added to complete the map.

Manual plotting has been nearly replaced by the Computer Aided Design and Drafting (CADD) system and digital terrain modeling (DTM) computer programs. These tools transfer the survey data into a graphics design file where mapping technicians add the final modifications to the map.

2. Aerial. Aerial mapping refers to the process of using a stereoplotter to draw a planimetric and topographic map from aerial photographs and local ground control points. The process of adjusting the stereoplotter by setting scales, calibration, orientation, and optic adjustments is explained in photogrammetry manuals.

The process of using a coordinate system is essentially the same as that of mapping by conventional means. The points obtained from the aerial photographs are digitized and plotted by a computer program that interpolates the contours.

3. Mapping Guidelines. Maps, conventional or photogrammetric, shall be prepared in accordance with the guidelines set forth in Chapter 9. In addition, the following criteria are also applicable.

- Indicate the basis for the bearings and the level datum used. Where applicable, show the datum adjustment factor on each map sheet by a note.
- Show the coordinates of all section corners, permanent monuments, etc. on the map.
- Show the grid lines or grid ticks of the mapping coordinate system on all maps. Space the gridlines or ticks at 200 mm regardless of map scale.
- Plot all planimetric and topographic features on the maps. Plot spot elevations on the maps.
- Show the ownership and/or deed references of all property abutting or adjacent to the survey on the map.
- Locate and describe all sections, plats, lots, blocks, political subdivision lines, and property corners.
- Show, identify, and give right-of-way dimensions for existing roads, railroads, streets, alleys, lanes, etc.
- Identify and give dimensions for easements for public utilities, drainages, districts.
- Give complete information regarding all parts of the old right-of-way.
- Show the location of all geotechnical boring holes.
- Show the length and size of all existing bridges, culverts and drainage structures.
- Give the names of streams and their direction of flow.
- Show the direction of flow, elevation and gradient; typical cross section; size of existing structures; and required and anticipated future flow in cubic meters per second for irrigation canals and ditches.
- Show utility facilities with the approximate elevation to the lowest wire--or if underground, the depth below the surface. Show exact position of poles, and manholes. Show the ownership and any joint usage of poles.

Drafting should be in accordance with the drafting standards in Chapter 9, Section 9.6.A.

4. Layout. All maps will be plotted by the coordinates used for traverse computations. The stationing on the map should increase northerly on North-South routes and easterly on East-West routes. Stationing must increase on the map from left to right. Rotate the coordinate grid to meet the stationing direction requirements.

5. Symbols. Standard mapping symbols and legends for use in the preparation of contract plans have been adopted and are shown in Exhibit 9.31 in Chapter 9.

6. Scales and Contour Intervals. See Table 5.2 for mapping scales and contour intervals to be used in compiling maps.

Table 5-2
Mapping Scales and Contour Intervals

Purpose of Maps	Map Scales	Contour Interval (m)
Reconnaissance Studies		
Topography-Mountainous	1:20 000	10
Rolling to Flat	1:20 000	5
Location Studies		
Topography-Mountainous	1:5000 Max.	5
Rolling to Flat	1:5000	2
Rural Design		
Topography-Mountainous	1:500, 1:1000 or 1:2000	2
Rolling to Flat	1:1000 or 1:2000	1
Urban Design	1:500	0.5
Selected Site Design	1:100 to 1:200*	0.2
Selected Site Design for Structures Less Than 40 m Long	1:100*	0.2

* Maps can be developed from ground survey data or by photographically enlarging smaller scale maps.

7. Automated Mapping. Once the data is processed by the field project engineer it is then transmitted to the Division office for further processing using the digital terrain modeling program . This program uses three-dimensional data from field surveys and by a triangulation algorithm produces a highly accurate contour map. The planimetric features, which were recorded using feature codes during the ground survey, are plotted by DTM onto the map. The mapping engineer uses a CADD work station (see Exhibit 5.2) to edit and add enhancements to the generated map. Besides producing a contour map, the DTM program also produces a data base of triangles which connects every ground point located during the survey. Both the map and the data base are given to the designer.

The designer is able to place any highway alignment into the DTM tin file data base and generate cross sections taken, not at a skewed angle to the original ground survey, but, at right angles to the desired alignment.

The stereoplotter operator digitizes the planimetric and topographic features of the project by using a stereoplotter connected to the CADD system. The graphic capabilities of the CADD system allow the operator to place the planimetric symbols and features with a single push of a button. The operator uses both the CADD station and the stereoplotter during this operation (see Exhibit 5.2). After the photographs have been digitized with discontinuity and scan lines, the resulting design file is processed through the DTM program.

The DTM program generates the same triangular data base file and three-dimensional contour map as it does for the ground survey data. The program also allows the blending of the two data types into one common map and data base.

The Geopak system is the main design tool of the FLH Divisions. This system includes a fully integrated DTM program and no additional modifications are required.

5.6 (RESERVED)

5.7 DIVISION PROCEDURES

Reserved for Federal Lands Highway Division office use in supplementing the policy and guidelines set forth in this chapter with appropriate Division procedures and direction.

LIST OF EXHIBITS

Exhibit

Control Monument Data

State: Montana

Projection: Transverse Mercator

Order of Survey: Third

Zone: Central

State Plane Coordinate System: Adjusted Idaho

Name of Station: 19-11

County: Ravalli

Year 19 70

X =

Y =

Vert. Datum:

Elevation (meters): 1412.193

Established by: FHWA

Year: 19 70

Distances and directions to reference marks and prominent objects observed at station

Object	Distance - Meters	Grid Azimuth
19 - 10		
19 - 12		
Sula Peak (Forest Service)		

The coordinates listed hereon have been adjusted to a project datum. The Datum Adjustment Factor (DAF) used is 1. 00032215 . To reduce coordinates to the sea level datum, divide by the DAF.

Party Chief: J.M. Kirkpatrick

☒ Established
☐ Recovered
(check one)

Date: 1970

Condition: Excellent

Description and Sketch of Station:

Station is located 3.5 km south along U.S. Highway 93 from the post office at Sula, Montana. Station is in a pasture approximately 36.5 m east of the highway at the end of a long tangent and in a through cut section approximately 460 m south of the Sula Ranger Station. Station is a standard FHWA brass cap set in a concrete monument and stamped "19-11, 1970". Station is marked by a standard FHWA plaque on a steel post 600 mm northeast of the cap.

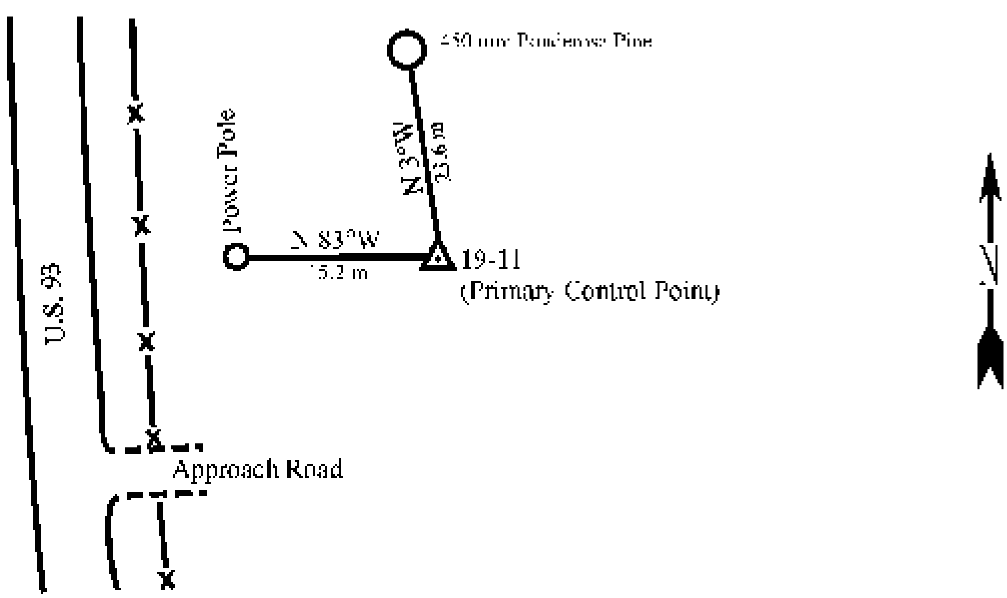
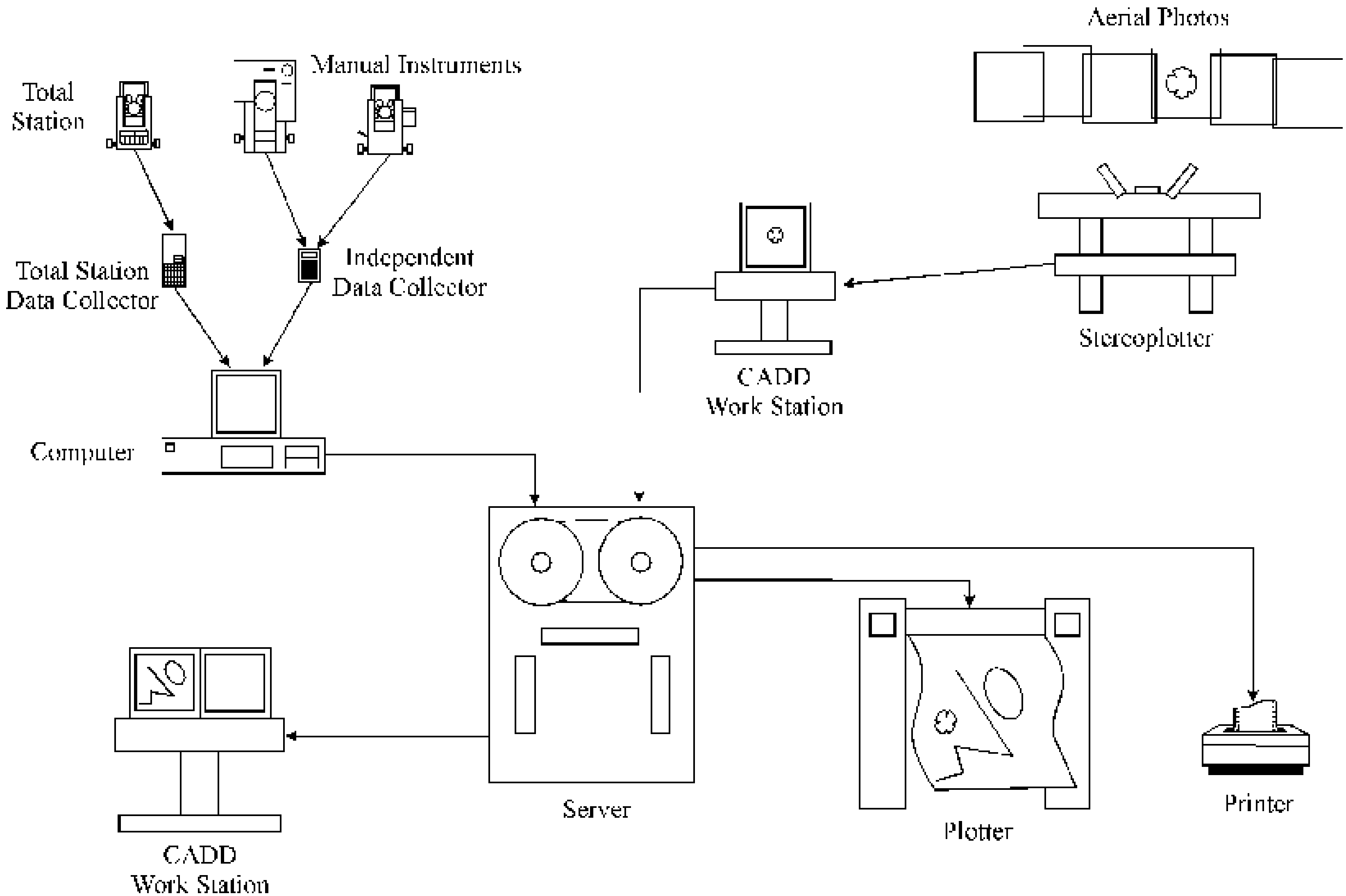


EXHIBIT 5.1
Sample of Documented Monument Reference

EXHIBIT 5.2

Flow Chart of Automated Surveying and Mapping

Automated Surveying and Mapping Data Collection Process



Side Shot Features

Code (a)	Facility
11	Power Pole
12	Telephone Pole
13	Utility Pole
14	Service Pole
15	Underground Power
16	Underground Telephone
17	Underground Water
18	Storm Sewer
19	Sanitary Sewer
20	Underground Gas
21	Street Light
31	Right Edge of Road
32	Left Edge of Road
33	Right Edge of Pavement
34	Left Edge of Pavement
35	Right Edge of Curb
36	Left Edge of Curb
37	Right Edge of Approach Road
38	Left Edge of Approach Road
39	Guardrail
40	Sign
45	Bridge
46	Round Metal Culvert - (size)
47	Metal Pipe Arch - (size)
48	Round Concrete Pipe - (size)
51	House
52	Barn
53	Shed
54	Out Building
55	Well
56	Septic Tank
57	Property Corner
58	Monument
66	Steel Gate - (size)
67	Wire Gate - (size)
68	Wood Gate - (size)
70	Centerline
71	Ditch
72	Edge of Clearing
73	Edge of Water
74	Top of Cut
75	Edge of Pavement
76	Toe of Fill
78	Reference Point (R.P.)
79	Edge of Road
80	Fence

Note: *(a) Unlisted code numbers may be used for site specifics.*
(b) Enter code after shot.

Traverse/Side Shots

Code (a)	INF1	INF2	INF3	INF4
1	Instrument Station	H.I.	Ref. Elev.	
2	Backsight Station	H.I.		
3	Foresight Station	H.I.		
4	Intermediate Station	H.I.		
5	Side Shot Station	H.I.	Feature	Size
8	Boot Amount			

Straight Topog

Code (a)	INF1	INF2	INF3	INF4
6	X-Section Station	H.I.	Offset Distance	Offset Rod
7	Reference Elevation			
8	Boot Amount			
10	Turn (b)			
70	Centerline Shot (b)			
71	Ditch (b)			
72	Edge Clearing (b)			
73	Edge Water (b)			
74	Top of Cut (b)			
75	Edge Pavement (b)			
76	Toe of Fill (b)			
77	Reference Point (R.P.) (b)			
78	Edge Rock (b)			
79	Edge Road (b)			
80	Fence (b)		Side	
100	Rod	Dist.	Side	
104	% Slope	S. Dist.	Side	
107	Degree of Slope	S. Dist.		

X-Point Topog

Code (a)	INF1	INF2	INF3	INF4
1	Inst. Station	H.I.	Ref. Elev.	
2	B.S. Station	H.I.		
6	X-Section Station	H.I.	Offset Dist.	
8	Boot Amount			
70	Centerline Shot (b)			
71	Ditch (b)			
72	Edge Clearing (b)			
73	Edge Water (b)			
74	Top of Cut (b)			
75	Edge Pavement (b)			
76	Toe of Fill (b)			
77	Reference Point (R.P.) (b)			
78	Edge Rock (b)			
79	Edge Road (b)			
80	Fence (b)			

EXHIBIT 5.3
Standard Coding for Data Collection

Survey Weekly Report for Week Ending ______________

Project: ____________________

Engineer: ____________________

____
(Type of Survey)

Routing
- ☐ **Survey** ____________
- ☐ **Design** ____________
- ☐ **Other** ____________
- ☐ **Files** ____________

Date Work Began: ____________ **Length (km):** ____________

Estimated Completion: ____________ **Beginning Station:** ____________

Percent Complete: ____________ **%** **Ending Station:** ____________

Personnel: ____________ ____________ ____________
____________ ____________ ____________
____________ ____________ ____________

Remarks: ____________________
____
____

Weather: ____________________

Safety Meeting: ____________________

Progress Chart

Description of Work		**Percent Complete*** 0	10	20	30	40	50	60	70	80	90	100
Brush	____________											
Line	____________											
Topog	____________											
Ties	____________											
Row	____________											
RP's	____________											
Levels	____________											
Misc.	____________											

***Completed previously - use lower case x**
Completed this week - use upper case X

EXHIBIT 5.4 Sample Weekly Report
(page 1 of 2)

Survey Weekly Report for Week Ending ____________

Project: FDR N90 Cougar Wa.

Engineer: Jay S. Worthington

Single Pass Survey
(Type of Survey)

Routing
- ☒ Survey
- ☐ Design
- ☐ Other
- ☒ Files

Date Work Began: 03-09-87 | **Length (km):** 24.8

Estimated Completion: 05-12-87 | **Beginning Station:** 5 + 450

Percent Complete: 55 % | **Ending Station:** 30 + 300

Personnel:

Jay S. Worthington	Glen Kutzera	Daniel Jackson AOP 4/6/87
Jack S. Bright	Barbara Rippey AOP 4/6/87	
David B. Jackson	Barry Marshall AOP 4/6/87	

Remarks: Turned X-line angles X113 to X134 EOP P-line P161 to P434 EOP Chain tied X1 to X134 EOP. Culture taken in conjunction with angles & P-line. Topog P1 to P55.

Weather: Rain all week

Safety Meeting: Safe driving, care of vehicles

Progress Chart

Description of Work	Percent Complete* (0 10 20 30 40 50 60 70 80 90 100)
Brush	
Line	xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxXXXXXXXX
Topog	XXX
Ties	xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxXXXXXXXX
Row	
RP's	
Levels	xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxXXXXXXXX
Misc.	

*Completed previously - use lower case x
Completed this week - use upper case X

EXHIBIT 5.4 Sample Weekly Report
(page 2 of 2)

Report of Survey

Project: ______________________________

State: ______________________ **Time:** ______________

Type: ______________________ **Cost:** ______________

Began: ______________ **End:** ______________ **Engineer:** ______________

Terrain: ______________________________

Cover: ______________________________

Weather: ______________________ **Length:** ______________

Working Hours per Day: ______________________ **Overtime Used:** ______________

Item	Work Hours	Work Hours per km	% of Total Time	Cost per km
Brushing				
Line				
Levels				
Topog				
Ties				
Clearing				
Misc.				
Totals				

Cost of Distribution	
Type	% of Total
Salaries	
Per Diem	
Equipment	
Miscellaneous	
Total	

Remarks:

Engineer: ______________________________
Signature

Date: ______________________________

EXHIBIT 5.5
Sample Report of Survey

U.S. Department of Transportation
Federal Highway Administration

IDENTIFICATION

IF THIS BOOK IS FOUND PLEASE DROP IN
ANY GOVERNMENT MAIL BOX OR POST OFFICE
NO POSTAGE WILL BE REQUIRED

RESERVED FOR PROJECT STAMP

BOOK NO. ______________________ **TYPE OF NOTES:** ______________________

PROJECT NAME: ____

ACCOUNT NO. ____

ROUTE NO. ______________________ **SECTION NO.** ______________

COUNTY: ______________________ **STATE:** ______________

____ **LOCATION**
FOREST, PARK, OR OTHER **CONSTRUCTION**

CONTRACTOR: ____

ENGINEER: ______________________________ **YEAR:** __________

This space reserved for headquarters use.

EXHIBIT 5.6
Identification Format for Field Note Books

EXHIBIT 5.7
Sample Page for Recording Field Data
(page 1 of 4)

PAGE

DATE ___________ LINE ____________ PARTY __________

PROJECT

(Back)

U.S. Department of Transportation
Federal Highway Administration

PAGE______

Transit

(Front)

EXHIBIT 5.7
(page 2 of 4)

DATE: __________ PARTY: ____________________

LINE: __________ ____________________

PROJECT:

Type of TOPOG
☐ Straight
☐ Percent
☐ Degree

STATION	Elevation		Cross-Section
	GRADE	GROUND	LEFT

(Back)

U.S. Department of Transportation
Federal Highway Administration

PAGE _____

Cross-Section

READINGS		REMARKS AND / OR SKETCHES
℄	RIGHT	

(Front)

EXHIBIT 5.7
(page 3 of 4)

DATE: ________ LINE: ________ PARTY ____________________

PROJECT ____________________

____

____

(Back)

U.S. Department of Transportation
Federal Highway Administration

Misc. Construction Notes

(Front)

COMPUTER BY: ________________ CHECKED BY: ________________
DATE: ____________ DATE: ____________

Field Book Format—Preliminary Survey

A. Introduction
   1. Basis of survey control
      a. Coordinates
      b. Bearing/azimuth
      c. Elevation
   2. Narrative of survey
      a. Describe the type of survey, beginning and ending dates, and the terrain in general.
      b. Describe the major design standards used (horizontal curvature, gradient, typical section).
      c. Describe the control used, the kinds of referencing used, and other features of the survey.
      d. Describe each pass; what was done and the average crew size.
      e. Describe any work not completed or partially completed and reasons for such.

B. Sketches
   1. Control diagram
   2. Control point references
   3. Angle point (P-line) references
   4. Existing structures
   5. Other culture
   6. Miscellaneous

C. Design Data
   1. Classification
      a. Soils (visual). Include cut and fill slope recommendations and shrinkage factors. Note natural angles of repose and the degree of any fracture plans.
      b. Clearing and grubbing (visual). Identify growth (light, medium, heavy). Merchantable Timber?
   2. Recommendations
      a. Design, including horizontal and vertical controls, walls, wet areas, slides, etc.
      b. Drainage, including existing sizes, recommended sizes, existing channel condition, inlet or outlet control, etc.
      c. Existing drainage structures suitable for extension or modification. Show size, type, type of material, size and type of corrugation, length of damaged portion to be removed, slope of bevel, etc.

D. Miscellaneous
   1. Photographs sufficient to cover the entire project without gaps, looking both ahead and back.
   2. Photographs showing specific problem areas of existing structural details.
   3. List of property owners contacted for permission to survey and notes regarding any problems.
   4. Names and titles of other agency personnel contacted.
   5. Copies of deeds and/or plats showing ownership and public rights-of-way.
   6. List of all other rolls, maps, and books used on the survey with a description and file number (if known).

EXHIBIT 5.8
Field Book Format for Preliminary Survey

Field Book Format—Location Survey

A. Introduction
   1. Narrative of survey
      a. Describe the type of survey, beginning and ending dates, and the terrain in general.
      b. Describe the major design standards used.
      c. Describe the control used, the kinds of referencing used, and other features of the survey.
      d. Describe each pass; what was done, and the average crew size.
      e. Describe any work not completed or partially completed and reasons for such.

B. Additional Staking
   1. Describe areas where R/W was staked
   2. Describe area where clearing was staked

C. Sketches
   1. Control point references which were changed or added
   2. Miscellaneous

D. File Data
   1. Names of all files used
      a. Traverse (control and P-line)
      b. Horizontal Alignment
      c. Earthwork Design
      d. Final Topog

E. Miscellaneous
   1. Photographs sufficient to cover the entire project without gaps, looking both ahead and back.
   2. Photographs showing specific problems or conditions.
   3. List of property owners contacted for permission to survey and notes regarding any problems.
   4. Names and titles of other agency personnel contacted.
   5. List of rolls, maps, or other books used on the survey by description and file number (if known).

EXHIBIT 5.9
Sample Field Book Format for Location Survey

CHAPTER 6 - GEOTECHNICAL

TABLE OF CONTENTS

LIST OF TABLES

Tables **Page**

CHAPTER 6 - GEOTECHNICAL

6.1 GENERAL

This chapter provides guidance for all geotechnical investigations, analyses, and reports produced by the Federal Lands Highway Divisions. Although greatly advanced in recent years, the state-of-the-art of the geotechnical engineering field is still largely dependent upon engineering judgment to provide the most efficient and economical investigations. Dealing with the variability of projects, terrains, climates, and client agency constraints requires flexibility and resourcefulness.

Although primarily intended for use by a geotechnical engineer/geologist, the information contained herein can be used by designers and others during the design process. Geotechnical responsibilities include conducting investigations, performing analyses, and providing recommendations for the following:

- Geological and geotechnical reconnaissance.
- Roadway soils.
- Cut and fill slopes.
- Foundations.
- Landslides.
- Material sources.
- Retaining walls.
- Subsurface drainage.
- Pavements.

Each of these areas are addressed individually, providing guidelines, direction, and references for more specific and detailed information.

6.2 GUIDANCE AND REFERENCES

The publications listed in this section provided much of the fundamental source information used in the development of this chapter. While this list is not all inclusive, the publications listed will provide additional information to supplement this manual.

A. General References.

Bowles. *Foundation Analysis and Design*. 4th ed. McGraw-Hill Book Company. 1988.

Peck, Hanson, and Thornburn. *Foundation Engineering*. John Wiley and Sons, Inc. 1974.

Terzaghi and Peck. *Soil Mechanics in Engineering Practice.* John Wiley and Sons, Inc. 1967.

Wintercorn. *Foundation Engineering Handbook*. 2nd ed. Van Nostrand Reinhold Company. 1991.

Canadian Foundation Engineering Manual. 3rd ed. Canadian Geotechnical Society. 1992.

Geotechnical Engineering Notebook. DOT, FHWA. Office of Engineering, Bridge Division.

Geotextile Engineering Manual. DOT, FHWA. 1984.

Soil Dynamics, Deep Stabilization, and Special Geotechnical Construction. NAVFAC Design Manual 7.3. Department of the Navy. April 1983.

Soil Mechanics. NAVFAC Design Manual 7.1. Department of the Navy. September 1986.

B. Geology, Landslides, and Field Procedures.

Acker. *Basic Procedures for Soil Sampling and Core Drilling*. Acker Drill Co., Inc. 1974.

Beck. *Physical Principles of Exploration Methods.* New York. John Wiley and Sons, Inc. 1982.

Hamblin and Howard. *Physical Geology Laboratory Manual*. Minneapolis. Burgess Publishing Co. 1975.

Hunt. *Geotechnical Engineering Investigation Manual*. New York. McGraw-Hill Book Co. 1984.

Pitts. *A Manual of Geology for Civil Engineers*. Salt Lake City. John Wiley and Sons, Inc. 1984.

Manual on Subsurface Investigations. AASHTO. 1988.

Driller's Safety Manual. U.S. Department of the Interior, Bureau of Reclamation. 1973.

Geotechnical Instrumentation (FHWA Workshop Manual). DOT, FHWA.

The Cone Penetrometer Test. FHWA-SA-91-043. DOT, FHWA. 1992.

The Flat Dilatometer Test. FHWA-SA-91-044M. DOT, FHWA. 1992.

Advanced Technology for Soil Slope Stability, FHWA-SA-94-005. DOT, FHWA. 1994

Handbook of Engineering Geophysics (Volume 1, Seismic, 1984 and Volume 2, Electrical Resistivity, 1980). Minneapolis. Bison Instruments, Inc.

The Pressuremeter Test for Highway Application. FHWA-IP-89-008. DOT, FHWA. 1989.

Landslides Investigation and Mitigation. Transportation Research Board, National Academy of Sciences. Washington, DC. 1995.

Rock Slopes: Design, Excavation, Stabilization. FHWA-TS-89-045. DOT, FHWA. 1989.

Rock Blasting and Overbreak Control. FHWA-HI-92-001. DOT, FHWA. 1991.

Duncliff. *Geotechnical Instrumentation for Monitoring Field Performance*. John Wiley & Sons, Inc. 1988.

C. Structures and Foundations.

Poulos and Davis. *Pile Foundation Analysis and Design*. 1980.

Drilled Shafts: Construction Procedures and Design Methods. DOT, FHWA. 1988.

Handbook on Design of Piles and Drilled Shafts Under Lateral Load. FHWA-IP-84-011, DOT, FHWA. 1984.

Behavior of Piles and Pile Groups Under Lateral Load. FHWA-RD-85-106. DOT, FHWA. 1986.

AASHTO LFRD Bridge Design Specifications. AASHTO. 1994.

Reeves. *Applications of Walls to Landslide Control Problems*. American Society of Civil Engineers. 1982.

Spread Footings for Highway Bridges. FHWA-RD-86-185. DOT, FHWA. 1987.

Manual on Foundation Investigation. AASHTO. 1978.

AASHTO-AGC-ARTBA Taskforce Report. *In Situ Improvement Techniques*. 1990.

Foundation and Earth Structures. Design Manual 7.2; NAVFAC DM-7.2. Department of the Navy. 1982.

Permanent Ground Anchors. FHWA-DP-68-1R. DOT, FHWA. 1984

Manual on Design and Construction of Driven Pile Foundations. FHWA DP-66-1. DOT, FHWA. Office of Engineering, Bridge Division. 1986.

Retaining Wall Design Guide. Second Edition (FHWA-FLP-94-006). U.S. Department of Agriculture, Forest Service. September 1994.

Soils and Foundation Workshop Manual. DOT, FHWA. Office of Engineering, Bridge Division. 1993.

D. Material and Pavement Design.

Techniques for Pavement Rehabilitation, A Training Course. 3rd Revision, ERES Consultants, Inc. 1987

Pavement Design Principles and Practices, A Training Course. ERES Consultants, Inc. 1987

Krebs and Walker. *Highway Materials*. McGraw-Hill Book Company. 1971.

Yoder and Witczak. *Principles of Pavement Design*. 2nd ed. John Wiley and Sons, Inc. 1975.

AASHTO Pavement Overlay Design. FHWA-HI-94-048. DOT, FHWA. 1994

Distress Identification Manual for the Long-Term Pavement Performance Projects. SHRP-P-338, SHRP. 1993

Guide for Design of Pavement Structures. AASHTO. 1993.

Pavement Rehabilitation Manual. DOT, FHWA. Office of Engineering, Pavement Division. 1990.

Soils Manual for the Design of Asphalt Pavement Structures. The Asphalt Institute. 1986

Thickness Design - Asphalt Pavements for Highways and Streets. The Asphalt Institute. 1991.

Pavement Notebook for FHWA Engineers. Office of Engineering, Pavment Division.

E. Subsurface Drainage.

Geotextile Design and Construction Guidelines. FHWA-HI-95-038. DOT, FHWA. 1995.

Drainage of Asphalt Pavement Structures. The Asphalt Institute Manual Series No. 15. September 1984 edition.

Geocomposite Drains. Report No. FHWA/RD-86/171. DOT, FHWA. October 1986.

Geotechnical Fabrics. Report No. FHWA/RD-80/021. DOT, FHWA. 1980.

Highway Subdrainage Design. Report No. FHWA-TS-80-224. DOT, FHWA. 1980.

Improving Subdrainage and Shoulders of Existing Pavements. Report No. FHWA/RD-81/078. DOT, FHWA. January 1982.

Underground Disposal of Storm Water Runoff. Report No. FHWA-TS-80-218. DOT, FHWA. February 1980.

F. Computer Programs. The following is a listing of computer programs that are available and may be used when appropriate:

Foundations

- GRL WEAP 1.994-1 - Wave Equation Analysis of Piles
- NAVPILE - Nevada Pile Analysis (Static)
- COM 624 P Version 2 - Lateral Load Analysis of Driven and Non-Driven Piles
- SPILE - Ultimate Static Capacity for Driven Piles
- CBEAR - Bearing Capacity Analysis for Shallow Foundations

Pavment Design

- DARWin - Pavement Design Analysis and Rehabilitation for Windows
- DAMA - Pavment Structural Analysis Using Multi-Layer Elastic Theory

Slope Stability

- LEASE I - Limiting Equilibrium Analysis in Soil Engineering
- STABL4 - Slope Stability Analysis
- SLOPIN - Calcomp Plot of Inclinometer Data
- INCLIN - Print Plot of Inclinometer Data
- XSTABL - Slope Stability Analysis
- DIGIPRO - Data Reduction and Graphing Software for Inclinometers
- EMBANK - One Dimensional Consolidation due to Embankment Loads

Geophysical Programs

- SEISMIC12 - Channel Refraction Seismic Test Data Analysis
- RESIST - Resistivity Data Analysis
- SEISREFA - Sesimic Refraction Analysis

6.3 INVESTIGATION PROCESS

The primary purpose of a geotechnical investigation is to provide design engineers with a knowledge of the subsurface conditions at a specific project site. The investigation should also provide the construction project engineers and contractors with information concerning the materials and conditions that may be encountered in the field.

The scope and cost of a geotechnical investigation should be adjusted to the size and complexity of the proposed project. The potential for catastrophic failure and/or failure consequences must be evaluated when establishing scope of the investigation.

In all geotechnical investigations, safety of field crew and traveling public must be of high priority. The nature of the equipment used and climatic conditions often present potential hazards that must be evaluated on an individual basis. It is the responsibility of the geotechnical engineer/ geologist, as well as field crew members to adjust the investigation program and/or provide equipment, training, and other means to provide safe working conditions. Field crews should be aware of and use traffic safety control plans based upon MUTCD requirements.

Geotechnical investigations should not be attempted until certain project-specific information has been obtained. The following list identifies typical project requirements and suggests where the necessary information on specific subjects may be obtained. Exhibit 6.1 is used to gather and document this preliminary information.

Possible Sources for Site Specific Information

Project Specifics	Information Sources
Type of proposed project. Proposed project termini. Funds available. Schedule requirements. Items requiring investigation. Local authorities to contact. Location and type of utilities present.	Planning and Coordination or Project Development Unit
Scope of investigation desired. Availability of equipment.	Geotechnical Engineer
Location of structures.	Structures/Bridge Unit
Site maps and field reference systems.	Location and/or Survey Unit
Specific site restrictions such as water quality, environmental considerations, or client agency considerations.	Environmental Unit
Right-of-entry (access) restrictions.	Applicable property owners

Special situations occasionally require in situ testing or instrumentation to obtain accurate information for both design and construction. These tests and instrumentation may be highly specialized and may require specialized assistance. The following are typical reasons for specialized instrumentation:

- Construction control, both during design and/or construction.
- Safety.
- Verifying design assumptions.
- Verifying new construction techniques.
- Verifying long-term satisfactory performance.
- Verifying contractor compliance with specifications.
- Advancing the state-of-the-art.
- Legal reasons.

A. Geotechnical Equipment. Sometimes to perform geotechnical investigations, specialized subsurface investigation equipment is required. In cases of sporadic use or when highly trained technicians must be assigned exclusively to operate equipment, the geotechnical unit may prefer to use consultants and/or contractors to provide such services in lieu of actually purchasing and maintaining such equipment. Below are typical sources for technical assistance to obtain equipment or expertise:

- Other FLH Offices.
- FHWA Research and Implementation units.
- Local government agencies.
- Other Federal Government agencies.
- Universities.
- Private consultant.
- Equipment manufacturers.

Each geotechnical unit should maintain access to the latest equipment and technology so it can perform efficient and effective investigations. This policy also provides FHWA the opportunity to implement and experiment with new technology, equipment and ideas. Equipment can be grouped into three major categories:

1. Drill equipment and sampling tools
2. Geophysical and in situ testing equipment
3. Pavement evaluation equipment.

In addition to these major areas, incidental hand tools are required for the generalized reconnaissance type of investigations usually performed by an engineer or geologist. This equipment consists of (as a minimum), a Brunton compass, survey transit, cloth tape, hand level, rock hammer, hand augers, test pit excavation equipment, and record keeping notebooks.

Minimum drill equipment should consist of a power auger drill rig capable of advancing an 200 millimeter hollow stem auger 35 meters in very stiff clays or dense sand and gravel. The drill should be capable of traversing soft ground, moderately steep slopes, and rough terrain. The drill should also have capabilities for obtaining at least 45 meters of "N" size or larger rock cores. Soil testing and sampling capabilities should consist of at least the "Standard Penetration Test AASHTO T 206" and the "Thin Walled Tube Sample AASHTO T 207". In addition to the large drilling equipment, a portable drill capable of drilling at least "B" size core a minimum of 15 meters, is desirable. Geotechnical Engineering Investigation Manual, by Hunt, provides an excellent source of detailed information on investigation equipment requirements.

The geophysical equipment should consist of a portable, single channel seismic unit and a resistivity unit. In addition, a multi-channel seismic unit with enhancement capability is desirable. Physical Principles of Exploration Methods, by Beck, and manufacturer's literature provide the best source of geophysical equipment information.

Minimum in-situ test equipment should include a cone penetrometer, a vane shear, and in-place density equipment (sand cone, nuclear gauge, etc.). Project site instrumentation such as inclinometer, piezometer, and strain gage readout devices should also be available. A detailed instrumentation equipment listing is available in the Geotechnical Instrumentation for Monitoring Field Performance, by Dunncliff.

Available pavement evaluation equipment should consist of a calibrated distance measuring device, pavement deflection equipment, roughness measurement, and pavement core drill. In addition, access and familiarity with skid testing devices, photo logging and video tape equipment is desirable.

Table 6-1 provides guidelines for the type of equipment and the frequency of use that is typical for different types of geotechnical investigations.

Table 6-1
General Investigation Equipment Requirements

Type of Investigation	Use by Equipment Type									
	Hollow Stem Auger Drill	Large Core Drill	Small Core Drill	Seismic	Resistivity	Roughness and Deflection	Water Supply Equipment	In situ Strength Devices	In situ Monitors	Back-hoe
Roadway Soils	1	4	4	2	3	3	4	3	4	1
Foundations	1	1	2	2	2	4	2	2	2	4
Existing Pavement Evaluations	4	2	1	4	4	1	1	4	4	4
Material Sources	1	1	2	2	2	4	1	4	3	1
Landslides	1	3	3	2	2	4	4	1	1	4
Cutslopes	2	2	2	2	3	4	2	3	2	2

Use Code:
1 = Frequently 3 = Seldom
2 = Occasional 4 = Usually Inappropriate

B. Planning Geotechnical Investigations. After the project has been initiated, the first phase of any geotechnical investigation should consist of a desk review of available geotechnical information and project specific requirements and information. This information is vital to planning an efficient, cost-effective field investigation. The information is used to do the following:

- Determine the nature and scope of the geotechnical field investigation.
- Select proper field equipment.
- Estimate manpower, time, and total costs.
- Select field reference system for geotechnical reports.
- Determine site conditions that may restrict or limit the investigation.

The wide range of geographical areas where projects may be located requires access to geotechnical information from a variety of sources. Table 6-2 provides an initial listing of potential sources and a brief description of information available. Each geotechnical unit should supplement the sources listed in Table 6-2 by establishing and maintaining a file of commonly used regional information.

6.3 Investigation Process. (continued)

In addition, the following should be available from the local and/or in-house resource center:

- Aerial photographs.
- Previous geotechnical reports.
- Survey notes.
- As-built plans.

After this information is obtained and studied, a preliminary boring plan should be developed. This boring plan should contain information on the following:

- Type, number, and location of proposed test holes.

- Estimated depth, type of testing, and sampling interval for each hole.

- Type and location of utilities.

- List of local contacts for right-of-access and for utilities.

- Arrangements for traffic control (flagmen, signing, etc.).

- Source of drilling water.

- Instructions for communications, sample handling.

Table 6-2
Sources of Regional Geotechnical Information

Source: U.S. Geological Survey (USGS). Consult USGS Index of Publications. Index from Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402. Maps available from U.S. Department of Interior, Geological Survey, National Center, 12201 Sunrise Valley Drive, Reston, VA 22092.

- Geological index maps
  Individual maps of each State showing coverage and sources of all published geological maps.
- Geological Quadrangle Maps of United States
  This series supplants the older geological folios including areal or bedrock geology maps with brief descriptive text. Series is being extended to cover areas not previously investigated.
- Bulletins, professional papers, circulars, annual reports, monographs
  General physical geology emphasizing all aspects of earth sciences, including mineral and petroleum resources, hydrology and seismicity. Areal and bedrock geology maps for specific locations included in many publications.
- Water supply papers
  Series includes papers on groundwater resources in specific localities and are generally accompanied by description of subsurface conditions affecting groundwater plus observations of groundwater levels.
- Topographic maps
  Topographic contour maps in all States, widespread coverage being continually expanded.

Source: Geological Society of America. Consult societies publications. Index available from Geological Society of America, P.O. Box 9140, 3300 Penrose Place, Boulder, Colorado 80302.

- Monthly bulletins, special papers, and memoirs
  Texts cover specialized geological subjects and intensive investigations of local geology. Detailed geology maps are frequently included in the individual articles.
- Geological maps
  Publications include general geological maps of North and South America, maps of glacial deposits, and Pleistocene aeolian deposits.

Source: U.S. Department of Agriculture (USDA) Soil Conservation Service. Consult List of Published Soil Surveys (published annually). Available from USDA, Soil Conservation Service, Washington, D.C.

- Soil maps and reports
  Surveys of surface soils described in agriculture terms. Physical geology summarized. Excellent for highway or airfield investigations. Coverage mainly in Midwestern, Eastern, and Southern United States,

Source: State Geological Surveys/Sate Geologist Offices. Most States provide excellent detailed local geological maps and reports covering specific areas or features in the publications of the State geologist. Some offices are excellent sources of information on foreign countries.

Tables 6-3 and 6-4 may be used as guidelines for development of the investigation plan. An on-site visit is desirable and often required as part of the development of a detailed investigation plan before field crews begin work at the project site.

Table 6-3
Use of Trenching and Test Pits

Exploration Method	General Use	Capabilities	Limitations
Hand-Excavated Test Pits and Shafts	Bulk sampling, in-situ testing, visual inspection.	Provides data in inaccessible areas, less mechanical disturbance of surrounding ground.	Expensive, time-consuming, limited to depths above groundwater level.
Backhoe Excavated Test Pits and Trenches	Bulk sampling in-situ testing, visual inspection, excavation rates, depth of bedrock and groundwater.	Fast, economical, generally less than 3 meters deep, can be up to 6 meters deep.	Equipment access, generally limited to depths above groundwater level, limited undisturbed sampling.
Drilled Shafts	Pre-excavation for piles and shafts, landslide investigations, and drainage wells.	Fast, more economical than hand excavated, minimum 750 mm diameter maximum 2 meters diameter	Equipment access, difficult to obtain undisturbed samples casing may obscure visual inspection, and costly mobilization.
Dozer Cuts	Bedrock characteristics, depth of bedrock and groundwater level, rippability, increase depth capability of backhoes, level area for other exploration equipment.	Relatively low cost, exposures for geologic mapping.	Exploration limited to depth above groundwater level.

Table 6-4
Guidelines for Geotechnical Drilling Investigations*

*Information obtained from drilling may be supplemented by geophysical investigations.

Type of Investigation/Number of Borings	Depth of Borings
Structure Foundations: Minimum one boring per substructure unit.	**Continue borings**: (1) through unsuitable foundation soils (such as peats, highly organic soils, soft fine-grained soils, loose coarse grained soils, etc.) into competent material of suitable bearing capacity and; (2) to depth where added stress due to estimated footing load is less than 10 percent of the existing effective soil overburden stress or; (3) minimum of 3 meters into bedrock if bedrock is encountered at shallower depth as determined by (2).
Retaining Walls: Minimum 1 boring per wall. Additional borings spaced 15 to 60 meters. Some borings should be in front of and in back of wall.	Continue borings to depth of 2 times wall height or minimum of 3 meters into bedrock.
Bridge Approach Embankments Over Soft Ground: When approach embankments are placed over soft ground at least one boring should be made at each embankment to determine the problems associated with stability and settlement of the embankment. Test borings at proposed abutment locations may serve both stability and structural investigations.	Same as established above for structure foundations: Additional shallow explorations (hand auger holes) taken at approach embankment locations are an economical way to determine depth of unsuitable surface soils or topsoil.
Cuts and Embankments: Space borings every 60 meters (erratic conditions) to 150 meters (uniform conditions) with at least one boring taken in each separate land form. For high cuts and fills (8 meters or greater), it is desirable to have a minimum two borings along a straight line to establish geological cross section for analysis.	**Cuts** 1) In stable materials extend borings minimum 3 meters below proposed centerline grade. 2) In weak soils, at or near proposed centerline grade, extend borings below grade to competent materials. **Embankments** Continue borings to competent material or to depth of twice the embankment height.
Landslides: Minimum 2 borings along a straight line to establish geologic cross section for analysis. Number of sections depends on extend of stability problem. For an active slide, place at least one boring above and below sliding area.	Extend borings to an elevation below active or potential failure surface and into competent stratum, or to a depth for which failure is unlikely because of geometry of cross section. Bore holes used to install inclinometers must be extended to competent material below the slide movement.
Material Sites (Borrow Sources and Quarries) Space borings or test pits on a grid pattern every 30 to 45 meters or change of material.	Extend exploration to base of deposit or to depth required to provide needed quantity.
Pavement Rehabilitation Minimum one boring or test pit per kilometer with additional exploration as needed to define changes in subgrade material, pavement section, and locally distressed areas.	Extend depth to at least 0.6 meters below expected subgrade.

C. Drilling and Sampling. The purpose of a drilling and sampling program is to obtain samples that reasonably represent subsurface conditions over the entire project site. Guidance for selection of the applicable test boring type can be found in Table 6-5.

Sampling type and frequency is dependent upon both the type of material encountered and the purpose of the investigation. The AASHTO Manual on Subsurface Investigation provides additional detailed information. When appropriate, continuous sampling provides the most complete and accurate information. When equipment, materials, or cost effectiveness prevent continuous sampling, typical sampling frequencies used are provided in Table 6-6. The preliminary boring plan is documented and transmitted to the field crews by use of Exhibit 6.2. Exhibits 6.3, 6.4, and 6.5 are used to document the materials encountered in the borings.

Table 6-5
Test Borings - Types and Application

Boring Method	Procedure Utilized	Applicability
Auger Boring (AASHTO T 203)	Hand or power operated augering with periodic removal of material. In some cases continuous auger may be used requiring only one withdrawal. Changes indicated by examination of material removed.	Probe investigations to bedrock, and shallow disturbed soil samples (less than 6 meters in depth). **Typical uses** : Disturbed soil sampling. Determine depth of overburden.
Hollow-stem Auger (AASHTO T 251)	Power operated, hollow stem serves as a casing.	General purpose for soils and other locations requiring a cased hole. **Typical uses:** Disturbed and undisturbed soil sampling and insitu testing. Foundation and landslide investigations.
Rotary Drilling (AASHTO T 225)	Power rotation of drilling bit as circulating fluid removes cutting from hole. Changes indicated by rate of progress, action of drilling tools, and examination of cuttings in drilling fluid. Casing usually not required except near surface.	A method to advance borings through a variety of materials including large boulders and broken rock. **Typical uses:** Obtaining rock cores, drilling probes, horizontal drains, and installing instruments.
Wire-line Drilling	Rotary type drilling method where the coring device is an integral part of the drill rod string which also serves as a casing. Core samples obtained by removing inner barrel assembly from the core barrel portion of the drill rod. The inner barrel is released by a retriever lowered by a wire-length through drilling rod.	Efficient method of recovering core samples of rock. **Typical uses** : Foundations, material sources, and rock cut investigation. General rock coring.

Table 6-6
Sampling Guidelines

Sand-Gravel Soils
- SPT[1] (split-spoon) samples should be taken at 1.5 meter intervals and at significant changes in soil strata.
- Continuous SPT samples are recommended in the top 4.5 meters of borings made at locations where spread footings may be placed in natural soils.
- Representative SPT jar or bag samples should be laboratory classified for verification of field visual soil identification.

Silt-Clay Soils
- SPT and "undisturbed" thin wall tube samples[2] should be taken at 1.5 meter intervals and at significant changes in strata.
- SPT and tube samples may be alternated in same boring or tube samples may be taken in separate undisturbed boring.
- Representative SPT jar or bag samples should be laboratory classified for verification of field visual soil identification.
- Tube samples should be tested for consolidation (for settlement analysis) and strength (for slope stability and foundation bearing capacity analysis).
- Field vane shear testing also recommended to obtain in-place shear strength of soft clays, silts, and nonfibrous peats.

Rock
- Continuous cores should be obtained in rock or shales using double or triple tube core barrels.
- For foundation investigations, core a minimum of 3 meters into the rock.
- Core samples should be evaluated for strength testing (unconfined compression) for foundation investigations, and valued for quality tests for quarry investigations (aggregate or riprap).
- Determine percent core recovery and RQD[3] value for each core run and record in the bore log.

Groundwater
- Record water level encountered during drilling, at completion of boring, and at 24 hours after completion of boring in the bore log.
- When water is used for drilling fluid, adequate time should be permitted after hole completion for the water level to stabilize (more than one week may be required). In impermeable soils, a plastic pipe water observation well should be installed to allow monitoring of the water level over a period of time.
- Artesian pressure and seepage zones, if encountered, should also be noted in the bore log.
- The top 300 mm or so for the annular space between water observation well pipes and the borehole wall should be backfilled with grout, bentonite, or a sand-cement mixture to prevent surface water inflow which can cause erroneous groundwater level readings.

NOTES:
1. Standard Penetration Test, AASHTO T 206
2. Thin-Walled Tube Sampling of Soils, AASHTO T 207
3. Rock Quality Designation

Soil samples and rock cores obtained represent a considerable investment of time and money. The samples should be properly labeled, transported, and stored. A detailed treatment of procedures for handling and storing samples is provided in the AASHTO Manual on Subsurface Investigations. However, any method that satisfactorily protects a sample from shock, large temperature changes, and moisture loss may be used. All containers used for storage should be identified with the following:

- Project name and number.
- Box number of total set.
- Bore hole number.
- Applicable depth information.

The identification markings should be on the exterior as well as the interior of the storage container. Rock cores should be routinely photographed, in color, as soon as possible after being taken from the bore hole and before laboratory testing. All samples not used in laboratory testing should be retained until the proposed construction is completed and/or all claims are settled.

D. Geophysical and In-Situ Tests. Geophysical methods are used to gather information on the geological surface features. Generally, geophysical methods are used as a reconnaissance investigation to cover large areas and/or to supplement information between bore holes. The methods given in Table 6-7 should be considered to determine when geophysical testing may provide an economical means of obtaining information. Many benefits may be obtained by use of geophysical tests, but specific procedures and limitations of the testing methods should always be considered. Additional information regarding geophysical investigations is contained in Physical Principles of Exploration Methods.

Seismic refraction geophysical tests are used to provide preliminary subsurface information for the items below:

- Planning detailed drilling investigations.
- Writing project feasibility studies.
- Engineering studies.
- Estimating rippability of rock excavation (see Exhibit 6.20).
- Extending data between bore holes.

Exhibit 6.12 is a form commonly used to collect field seismic information. Detailed procedures can be found in Bison's Handbook of Engineering Geophysics, Volume I. Seismic refraction can only be used to provide reliable information when subsurface strata become more dense with depth. When the subsurface strata are expected to violate this situation, electrical resistivity has provided good results on specific projects. Resistivity is somewhat more difficult to interpret but should be routinely considered. Exhibit 6.13 may be used to collect field data. Detailed analysis procedures and other resistivity information can be found in Bison's Handbook of Engineering, Geophysics, Volume II.

The most commonly used in-situ test for surface investigations is the Standard Penetration Test (SPT). See AASHTO T 206. Some common problems or procedural errors that can provide misleading results are given in Table 6-8. The use of automatic hammers for SPT is recommended if standard drop height and hammer weight can be maintained. SPT values obtained with automatic hammers should be calibrated by field comparisons with standard drop hammer methods. All SPT values should be corrected for overburden pressure. The Bazaraa method as given in the FHWA publication Soils and Foundation Workshop Manual should be used for FLH projects. Table 6-9 provides empirical soil parameters from corrected SPT values for granular soils.

Table 6-7
Guidelines for Using Geophysical Methods

Method	Basic Properties and Measurements	Applications	Frequency of Use
Electrical Resistivity	Electrical conductivity of subsurface materials as measured by apparent resistance.	Identify layers of less competent material laying below more competent layers. Interpolate surface condition between bore holes	Common
Induced Polarization	Electrochemical properties or rock particles and ion concentrations in pore fluids measured by polarization voltages.	Identify location and concentration of potentially environmentally harmful rock material (primarily iron sulfides).	Rare
Seismic Refraction	Density and elasticity of subsurface material as measured by velocities of compression waves.	Estimate depth of more competent materials underlaying less competent material. Interpolate subsurface condition between bore holes.	Common

Table 6-8
Common Procedural Errors
Using Standard Penetration Test

Problem	Circumstance/Cause
Inadequate cleaning and/or seating of sampler.	Sludge and debris trapped in sampler or in bottom of hole.
Failure to maintain adequate hydrostatic pressure and/or over washing ahead of casing.	Fill-up inside casing. Disturbance of in-situ material. Too large pump.
Use of damaged and/or inadequate equipment.	Tip of sampler damaged by heavy driving. Drive weight nonstandard or does not strike drive cap evenly.
Hammer does not free-fall and/or correct height of fall is not maintained.	More than 1.5 turns around cat head or wire line will restrict fall. Proper height is not maintained by operator.
Operator and/or inspector errors.	Incorrect blow count. Incorrect location and/or depth. Sampler overdriven.

Table 6-9
Empirical Values, Relative Density, and Mass Density of Granular Soils*

Description	Very Loose	Loose	Medium	Dense	Very Dense
Relative Density, D_r	0 0.15	0.35 0.65	0.85	1.00	
Corrected Standard Penetration No. N'	4	10	30	50	
Approximate Angle of Internal Friction Φ**	25-35° 27-32°	30-35°	35-40°	38-43°	
Approximate Range of Moist Mass Density (ρ) kg/m^3	1100-1600	1400-1800	1700-2100	1700-2200	2100-2400

*Empirical values for (Φ), Relative density (D_R), and unit mass (γ) of granular silts based on corrected N' (Correlations may be unreliable in silts containing gravel.)

** Use larger values for granular material with 5 percent or less fine sand and silt.

Another commonly used in-situ test is the Cone Penetrometer Test (CPT). This test can provide in-situ soil strength parameters and a differentiation between end bearing and side friction for pile design. The test can provide accurate and economical test results in soft to medium dense sands, silts, and clays. Major drawbacks of CPT are that samples are not recoverable and that tests in dense and/or gravel deposits are difficult and may damage equipment. FHWA-SA-91-043 manual entitled The Cone Penetrometer Test should be reviewed before field CPT is attempted. Exhibit 6.11 is a form used to record field CPT data.

Other commonly used in-situ devices are vane shear tests and pressure meter tests. Geotechnical Engineering Investigation Manual and AASHTO Manual on Subsurface Investigations provide additional details on these devices.

The following are types of specialized geotechnical instrumentation commonly in use:

- Inclinometers.
- Piezometer.
- Displacement stakes.
- Strain gauges.
- Earth pressure cells.

The Geotechnical Instrumentation for Monitoring Field Performance by Duncliff is a recommended reference for planning, designing, and specifying instrumentation projects. Exhibits 6.14 and 6.15 are data collection sheets commonly used for field shear tests and inclinometer instrumentation.

E. Laboratory Tests. After collecting soil and rock samples, laboratory tests are routinely performed to quantify material properties and verify design assumptions. The type and number of tests required are primarily a function of the variability of the site, the purpose of the investigation, and the amount of risk and potential consequences of failure. Sufficient testing should be performed so that the geotechnical project engineer or geologist is satisfied that the test results are representative of in-situ conditions.

Table 6-10 provides a guideline for estimating laboratory test requirements for the different types of analysis. Table 6-10 is representative of past experience with projects and is not intended to limit either the type of laboratory test or the frequency of testing but to provide a starting point for evaluation. See Geotechnical Engineering Investigation Manual for additional information.

Requesting and transmitting samples for laboratory testing and evaluation is handled differently in each FLH Division.

Samples shall be clearly identified as to (1) project, (2) bore hole or test pit number, and location, (3) depth of sample taken, and (4) specific test requested. All detailed test results should be included in the finalized geotechnical report. Care should be taken to ensure that only factual data is presented or that all interpretations of laboratory data are clearly identified as such.

Table 6-10
Guideline for Selection of Laboratory Tests

	Laboratory Tests Selection Frequency									
Test Analysis Type	A	B	C	D	E	F	G	H	I	J
Roadway Soil	F	F	F	L	F	F	L	M	L	L
Structural Foundation	F	M	F	L	L	R	F	M	F-M	M
Retaining Wall	F	M	F	M	L	R	F-M	F-M	F-M	M
Pavement Design	F	F	F	M	F	F	L	L	L	L
Material Source	F	F	F	R	F	F	R	M-L	L	L
Landslides	F	F	F	F	L	R	F-M	F-M	F	M

Test Description:

A: Gradation (Classification) AASHTO T88, T89, T90, T100
B: Fine Grain Analysis AASHTO T88
C: Atterberg Limits AASHTO T89, T90
D: Permeability Tests AASHTO T215
E: Remolded Density AASHTO T180 or T99
F: R-Value/CBR/M_r AASHTO T190, T193, T292, T294
G: Unconfined Compression AASHTO T 208
H: Direct Shear AASHTO T 236
I: Triaxial AASHTO T296, T297
J: Consolidation AASHTO T216

Selection Legend:

F: Frequent/Routine Use
M: Moderate Use
L: Limited Use
R: Rarely Used

6.4 GEOTECHNICAL ANALYSIS

An engineering analysis combines the information obtained from the geotechnical field investigation and the laboratory test results to determine the engineering properties and drainage characteristics of the subsurface materials. In addition, the analysis should alert designers, contractors, and construction personnel of potential problems and provide economical solutions with consideration given to alternatives. Finally, the analysis should provide an assessment of risk associated with each of the possible solutions. This section does not give detailed textbook solutions to engineering problems but will provide general guidelines, potential pitfalls of these guides, and specific references to assist the engineer in performing a detailed analysis.

The quality of the analysis depends on several factors. Knowledge of engineering principles and practical experience in application of these principles is of course very important; but a thorough analysis cannot be accomplished without a clear understanding of the proposal details. This understanding requires a flow of communication and information between Project Development, Bridge Design, Planning and Coordination, and the geotechnical engineer. To provide an acceptable analysis of geotechnical information that is practical, economical, and of sufficient detail, final alignment and grade are necessary. The project development process must provide for this information to be obtained and must incorporate sufficient time to allow proper investigation and analysis.

As a minimum, the geotechnical analysis should result in a subsurface profile with design soil strength parameters and an engineering evaluation of the subsurface conditions.

The following sections address the types of projects typical of the Federal Lands Highway Divisions. Within each section, an outline of typical geotechnical procedures with references to appropriate tables and exhibits is provided to focus on the more pertinent items. It is beyond the scope of this chapter to address all details of analysis performed by the geotechnical unit. These outlines are only provided to ensure that basic geotechnical items are consistently considered.

A. Roadway Soils. The vast majority of FLH projects require a roadway investigation. The guidelines presented may be applied to all lengths of roadway projects but the frequency of testing and sampling should be adjusted based upon site specific problems and practical engineering judgment. The following outline provides the basic procedural steps and thought process for typical projects. Sources for site specific information and detailed references are provided. Typical sample forms are provided that may be used as part of the investigation and analysis process.

TYPICAL ROADWAY INVESTIGATION AND ANALYSIS PROCESS

1. Initiate Project.

- Identify available preliminary information (see Exhibit 6.1).
- Obtain or review other pertinent preliminary project development information.

    Engineering study reports
    Location study reports
    Environmental impact documents
    Design scoping reports

2. Review Available Geotechnical Data.

- Review any geotechnical reports and information for projects in the vicinity with emphasis placed on projects on the same route.
- Review published information (see Table 6-2). Place emphasis on USDA soil survey information.
- Obtain survey information such as cross sections, drawings, and plans.

3. Plan Field Investigation.

- Determine drilling requirements (see Table 6-4).
- Review checklists for site investigations (Exhibit 6.27) and roadway cuts and embankments (Exhibit 6.32) to identify needed information to be collected.
- Determine preliminary equipment requirements (see Tables 6-1, 6-3, 6-5 and 6-7).
- Determine site restrictions and revise equipment requirements. A site visit may be required.
- Develop a preliminary boring and testing plan (see Exhibit 6.2).

4. Plan Sampling and Testing.

- Determine sampling and testing requirements (see Tables 6-1, 6-4, and 6-6).
- Record field information (Exhibits 6.3 and 6.10 through 6.15 as applicable).

5. Summarize Field Data.

- Summarize soil survey information (Exhibit 6.8) and water problem areas (Exhibit (6.9).
- Determine appropriate shrink/swell factors (Table 6-12).
- Summarize soil profile information (see Exhibits 6.6 and 6.7).

6. Perform Analysis and Write Report.

- Review roadway cut and embankment checklist (Exhibit 6.32) to ensure all appropriate information is available.
- Draft report (see outline format in Section 6.6.A).
- Refer to the general report checklist (Exhibit 6.26) and the site investigation checklist (Exhibit 6.27) to ensure appropriate report content.
- Finalize report.

On longer projects, the sampling frequency may be reduced. Therefore, more emphasis needs to be placed on carefully inspecting and assembling the field information and laboratory test results to determine sections of roadway with similar characteristics. The characteristics that are of primary importance are in-situ material properties and existing conditions. Other items (such as proposed use, surface and subsurface water, vertical and horizontal alignment (cut/fill)) can also influence the analysis. The selection of the grouping factors used to identify similarities is usually determined by problems that are likely to be encountered on a specific project. Obviously, this type of analysis requires practical experience for effective implementation. Table 6-11 provides some guidance in selecting detailed factors and conditions that may be used. Table 6-12 may be used to estimate unit weights and shrink/swell factors.

After determination of areas with similar conditions and material, engineering properties are assigned to materials for evaluation and design. These properties are determined either from direct laboratory tests or from correlated and/or assumed properties from manuals or textbooks referenced in Section 6.2. The analysis of a roadway soil investigation should concentrate on defining area limits and severity of the following problems and conditions:

- Establish design cut and fill slope ratios.
- Locate suitable materials for embankments.
- Identify shrink/swell factors for excavation.
- Identify areas requiring subexcavation.
- Locate wet areas (seepage of excessive water).
- Identify potential areas of instability.
- Determine the subgrade strength values for pavement structure design.

Table 6-11
Roadway Soils Analysis Factors

Identifying Characteristic	**Potential Problem/Condition**					
	Soil/Rock Interface	Variability of Pavement	Settlement	Frost Heave	Poor Drainage	Slope Instability
In-Situ Properties						
Soil Classification	X	X	X	X	X	X
Plasticity			X	X	X	X
Natural Moisture	X		X		X	X
Subgrade Strength		X		X		
Existing Conditions						
Standing/Seeping Water	X		X	X	X	X
Subgrade Support		X				
Pavement Thickness		X		X	X	
Slope Ratio	X					X
Pavement Distress		X	X	X	X	X

Table 6-12
Shrink/Swell Factors for Common Materials*

Material	Measured				
	In Situ	Loose		Embankment	
	Mass Density [1]	Mass Density [2]	% Swell [3]	Mass Density [2]	% Swell/Shrink [3]
Andesite	2930	1760	67	2050	43
Basalt	2935	1790	64	2160	36
Bentonite	1600	1185	35	—	—
Breccia	2400	1800	33	1890	27
Calcite-Calcium	2670	1600	67		
Caliche	1440	1245	16	1900	-25
Chalk	2410	1285	50	1810	33
Charcoal	—	610	—	—	—
Cinders	760	570	33	840	-10
Clay					
Dry	1910	1275	50	2120	-10
Damp	1985	1180	67	2205	-10
Conglomerate	2205	1660	33		
Decomposed rock					
75% R. 25% E.	2445	1865	31	2185	12
50% R. 50% E.	2225	1610	38	2375	-6
25% R. 75% E.	2005	1405	43	2205	-9
Diorite	3095	1855	67	2165	43
Diotomaceous earth	870	540	62		
Dolomite	2890	1725	67	2015	43
Earth, loam					
Dry	1795	1230	50	2090	-12
Damp	2000	1400	43	2090	-4
Wet, mud	1745	1745	0	2090	-20
Feldspar	2615	1565	67	1825	43
Gabbro	3095	1855	67	2165	43
Gneiss	2700	1615	67	1885	43
Gravel					
Dry—					
Uniformly Graded	1770	1600	10	1870	-5
Average Gradation	1945	1620	20	2120	-8
Well Graded	2180	1645	33	2450	-11
Wet—					
Uniformly Graded	1965	1870	5	1870	-5
Average Gradation	2160	1950	10	2120	-2
Well Graded	2425	2090	16	2450	-1
Granite	2695	1565	72	1880	43
Gumbo					
Dry	1915	1275	50	2120	-10
Wet	1985	1200	67	2205	-10
Gypsum	2420	1410	72		
Igneous rocks	2795	1675	67	1960	43

Table 6-12 (Continued)
Shrink/Swell Factors for Common Materials*

Material	Measured				
	In Situ	Loose		Embankment	
	Mass Density [1]	Mass Density [2]	% Swell [3]	Mass Density [2]	% Swell/Shrink [3]
Kaolinite					
Dry	1915	1275	50		
Wet	1985	1190	67		
Limestone	2600	1595	63	1910	36
Loess					
Dry	1910	1275	50	2120	-10
Wet	1985	1190	67	2205	-10
Marble	2680	1600	67	1875	43
Marl	2220	1330	67	1555	43
Masonry, rubble	2325	1395	67	1630	43
Mica	2885	1725	67		
Pavement					
Asphalt	1920	1150	50	1920	0
Brick	2400	1440	67	1685	43
Concrete	2350	1405	67	1645	43
Macadam	1685	1010	67	1685	0
Peat	700	530	33		
Pumice	640	385	67		
Quartz	2585	1550	67	1780	43
Quartzite	2680	1610	67	1875	43
Rhyolite	2400	1435	67	1700	43
Riprap rock	2670	1550	72	1870	43
Sand					
Dry	1710	1535	11	1920	-11
Wet	1835	1915	5	2050	-11
Sandstone	2415	1495	61	1795	34
Schist	2685	1610	67	1880	43
Shale	2640	1470	79	1775	49
Silt	1920	1410	36	2310	-17
Siltstone	2415	1495	61	2705	-11
Slate	2670	1540	77	1870	43
Talc	2750	1650	67	1930	43
Topsoil	1440	960	56	1945	-26
Tuff	2400	1600	50	1810	33

***Western Construction, November 1958.**

Note: [1]Kilograms per cubic meter. Subject to average ±5% variation.
[2]Kilograms per cubic meter. Mass Densities subject to adjustments in accordance with modified swell and shrinkage factors.
[3]Based on average in situ densities. A negative number represents a shrinkage. Factors subject to ±33% variation.

B. Structure Foundations. Structure foundation investigations are usually confined to the area of the substructure units. Open communication and a close working relationship with the structure design engineer is required to provide efficient, cost-effective analysis of foundations. The outline on Page 6-25 provides the basic procedural steps for a typical structural geotechnical investigation.

One of the most critical steps in analyzing structural foundations is the selection of foundation types that are applicable to specific site conditions. To systematically select or eliminate types of foundations, the following steps should be considered:

1. Identify the type of superstructure and loads to be applied to the foundation.

2. Define and summarize subsurface conditions.

3. Subjectively assess the applicability of each type of foundation for their capability of carrying the required loads and estimate the amount of settlement that is likely.

4. Eliminate obviously unsuitable foundation types and prepare detailed studies and/or tentative designs for new foundations.

5. Refer to Table 6-13 for a summary of applicable soil conditions for different foundation types. Select and recommend the foundation type that meets structure requirements, is best suited for site subsurface conditions, and is the most economical.

6. Perform an analysis to provide the structural designer with at least the following information.

   - Recommended foundation type and bottom of footing or pile tip elevations.

   - Ultimate bearing capacity of foundation unit and recommended allowable or design value with appropriate factors of safety.

   - Limitations and/or potential problems with the recommended foundation type.

   - Suitable alternative foundation types.

   - Potential construction problems and recommended construction control measures.

Recommended minimum and typical ranges for factor of safety for the geotechnical soil substructure interaction are as follows:

Shallow Foundations	Factor of Safety
Bearing Capacity	3.0
Sliding Along Base	1.5
Overturning (Rotational Failure)	2.0

Deep Foundations	Factor of Safety
Driven Piles (Static Method)	2.0-3.0
Drilled Shafts	2.0-2.5

Exhibits 6.21 and 6.22 illustrate samples of forms that are used to present allowable bearing capacities. In addition, settlement criteria should be established for specific subsurface conditions and structural requirements. The typical settlement criteria is a maximum 40 to 50 millimeter settlement that corresponds to 20 to 25 millimeter differential settlement between substructure units at allowable structural loadings.

The geotechnical unit is also responsible for ensuring that pile foundations can be installed to design requirement without damage. In situations where concrete piles, high lands or difficult installation is anticipated, dynamic pile analysis is often performed. The wave equation computer program is often used to establish installation equipment requirements and pile stress during construction. As an alternative and/or supplement to the wave equation, dynamic pile monitoring during actual installation may be used. Detailed information on these procedures, along with other detailed structural foundation analysis techniques and design procedures, are provided in FHWA Soils and Foundation Workshop Manual and Manual on Design and Construction of Driven Pile Foundations.

TYPICAL STRUCTURE FOUNDATION INVESTIGATION AND ANALYSIS PROCESS

1. Initiate Project

- Identify available preliminary information (see Exhibit 6-1).
- Obtain or review other preliminary pertinent project development information from Programming and Coordination Unit or the Project Development Unit as applicable.

2. Review Available Geotechnical Data.

- Review as-constructed plans for any existing structure at or near proposed project site.
- Review any geotechnical reports and subsurface information for structures in the vicinity of proposed site.
- Review published information (see Table 6-2). Place emphasis on localized geological and USDA soil survey information.
- Obtain bridge layout sheet from Bridge Unit.

3. Plan Field Investigation.

- Determine drilling requirements (see Tables 6-4 and 6-13).
- Review checklist for site investigation (Exhibit 6.27) to identify needed information to be collected.
- Discuss structure type and foundation requirements with bridge engineer.
- Determine preliminary equipment requirements (see Tables 6-1, 6-3, 6-5 and 6-7).
- Determine site restrictions. A site visit may be required.
- Develop a preliminary boring and testing plan (see Exhibit 6.2).

4. Plan Sampling and Testing.

- Determine sampling and testing requirements (see Tables 6-4, and 6-10).
- Make preliminary selection of applicable foundation types (see Table 6-13).
- Record field information (see Exhibits 6.3 and 6.10 through 6.15, as applicable).

5. Summarize Field Data.

- Review Table 6-9 and Exhibit 6.27.
- Summarize soil profile information (see Exhibits 6.6 and 6.7).

6. Perform Analysis and Write Report.

- Review checklist items for spread footings (Exhibit 6.28), piles (Exhibit 6.29) and drilled shafts (Exhibit 6.30) as applicable.
- Provide allowable bearing pressure (Exhibit 6.21) and pile capacity (Exhibit 6.22) as applicable.
- Refer to the General Report Checklist (Exhibit 6.26) and the Site Investigation Checklist (Exhibit 6.27) to ensure appropriate report content.
- Finalize report.

Table 6-13
Preliminary Foundation Type Selection

Foundation Type	Use	Applicable Soil Conditions
Spread Footing	Individual columns, walls, bridge piers.	Any conditions where bearing capacity is adequate for applied load. May use on single stratum; firm layer over soft layer or soft layer over firm layer. Check immediate, differential, and consolidation settlements.
Mat Foundation	Same as spread and wall footings. Very heavy column loads. Usually reduces differential settlements and total settlements.	Generally soil bearing value is less than for spread footings; over one-half area of building covered by individual footings. Check settlements.
Friction Piles	In groups to carry heavy column, wall loads. Requires pile cap.	Low strength surface and near surface soils. Soils of high bearing capacity 18 - 45 meters below ground surface, but by disturbing load along pile shaft solid strength is adequate. Corrosive soils may require use of timber or concrete pile material.
End Bearing Piles	In groups (at least 2) to carry heavy column, wall loads. Requires pile cap.	Low strength surface and near surface soils. End of pile located on soils 7.5 to 30 meters below ground surface.
Drilled Shafts (End bearing)	Larger column loads than for piles but eliminates pile cap by using caissons as column extension.	Low strength surface and near surface soils. End of shaft located on soils 7.5 to 30 meters below ground surface.
Sheetpile	Temporary retaining structures for excavations, alloy waterfront structures, cofferdams.	Any soil. Waterfront structures may require special or corrosion protection. Cofferdams require control of fill material.

C. Retaining Walls. Retaining walls are a specialized structure; therefore, comments and guidelines given in Section 6.4.B are relevant to retaining wall analysis. The outline following Section 6.4.C provides the basic procedural steps, thought process, and initial source of reference and standard forms for a typical geotechnical retaining wall investigation. Many different wall types are available. See Chapter 9, Section 9.4.D and Chapter 10, Section 10.4.K for retaining wall designs.

The numerous proprietary wall designs require review and comparisons of specific wall design parameters. When proprietary wall designs are suitable for specific site conditions, alternative bid procedures are recommended. To ensure that these alternatives are equal, a review by the geotechnical unit prior to advertisement of the construction contract is required. Designs submitted for approval must contain all calculations and assumptions made by the proprietary wall design. Include with the submittal, copies of any computer programs used. The computer programs shall be in a format compatible with Government equipment. Major points of comparison will include but are not restricted to the following items:

- Design life.
- Maximum total and differential settlements.
- Maximum stress in wall members.
- Magnitude and direction of external loads.
- Surface and subsurface drainage required.
- Backfill quantity and quality requirements.
- Previous experience with other highway applications.

An overview of the basic retaining wall fundamentals and procedures can be reviewed in the Forest Service's Retaining Wall Design Guide. Manufacturers' design charts should only be used as preliminary estimates, and final wall design should be checked by the geotechnical staff. When information is not provided or is unsubstantiated, Rankine analysis and conservative values should be used. See Chapter 10, Section 10.4.K, for safety factors and other critical design elements applicable to walls. In addition, consider the following when analyzing retaining wall foundation and backfills.

- Do not include material in the upper 1.5 meters in front of the wall when evaluating resistance to sliding along the base and overturning.

- The resultant of all forces acting on the wall should fall within the middle third of the base.

- Live loads due to temporary construction activities (materials and equipment) and traffic loading should be in the order of 11 to 17 kPa.

- Avoid backfill material such as silts and clays unless special precautions and analyses are made to account these materials.

- Evaluate expected settlements to ensure that their magnitudes are consistent with the rigidity of the type of wall selected.

- Evaluate subsurface and surface drainage requirements and include any specifications in the geotechnical analysis and recommendation.

TYPICAL RETAINING WALL INVESTIGATION AND ANALYSIS PROCESS

1. Initiate Project

- Identify available preliminary information (see Exhibit 6.1).
- Determine specific site requirements such as wall location, heights, and aesthetic restrictions.

2. Review Available Geotechnical Data.

- Review any geotechnical reports and information for project location.
- Review published information (see Table 6-2).
- Review Geotechnical Engineering Notebook retaining wall chapters.
- Obtain survey information such as cross sections and plans from the Design Unit.

3. Plan Field Investigation.

- Determine drilling requirements (see Table 6-4).
- Review checklists for site investigations (Exhibit 6.27) and retaining walls (Exhibit 6.31) to identify needed information to be collected.
- Determine preliminary equipment requirements (see Tables 6-1, 6-3 and 6-5).
- Determine site restrictions and revise equipment requirements. A site visit may be required.
- Develop a preliminary boring and testing plan (see Exhibit 6.2).

4. Plan Sampling and Testing.

- Determine sampling and testing requirements (see Tables 6-4, 6-6 and 6-10).
- Record field information (Exhibits 6.3 and 6.10 through 6.15, as applicable).

5. Summarize Field Data.

- Review Table 6-9 and Exhibit 6.27.
- Review checklists for general report (Exhibit 6.26) or site investigation (Exhibit 6.27) as appropriate.

6. Perform Analysis and Write Report.

- Review checklists for retaining walls (Exhibit 6.31) and spreadfootings (Exhibit 6.28), piles (Exhibit 6.29), or drilled shafts (Exhibits 6.30) if applicable.
- Provide allowable bearing pressure (Exhibit 6.21) and pile capacity (Exhibit 6.22) as applicable.
- Write draft report.
- Refer to the General Report Checklist (Exhibit 6.26) and the Site Investigation Checklist (Exhibit 6.27) to ensure appropriate report content.
- Finalize report.

D. Pavement Design. The pavement design procedures used by FLH Divisions use empirical data developed from the AASHO road tests and modified by experience gained from pavements built for use on Federally owned lands. The concepts are based upon procedures presented in the AASHTO Interim Guide for Design of Pavement Structures 1972, revised 1981. It is anticipated that the new concepts and procedures presented in the 1993 AASHTO Guide for Design of Pavement Structures will eventually be incorporated into the Federal Lands Highway pavement design procedures. Until such time, correlation between the existing procedures and the new procedures presented in the new AASHTO manual is encouraged to establish a data base for the purpose of confirming the reliability, standard deviation, and changes in serviceability input parameters required by the new procedures.

Pavement designers should familiarize themselves with the DARWIN computer program. This program incorporates the design procedures provided in the AASHTO Guide for Design of Pavement Structures 1993.

Generally, only flexible pavements are built by FLH Divisions and therefore this section will deal primarily with flexible pavement design procedures. When rigid pavements are required and designed, the procedures and guidelines used in the AASHTO Design of Pavement Structures 1993 are to be followed.

The outline on the following page provides the basic procedural steps, initial sources of reference materials, and standard forms for a typical pavement design investigation.

TYPICAL PAVEMENT DESIGN INVESTIGATION AND ANALYSIS PROCESS

1. Initiate Project

- Identify available preliminary information (see Exhibit 6.1).
- Obtain project related restrictions (costs, aesthetics, environmental etc.) imposed by others by reviewing preliminary project development information.

2. Review Available Geotechnical Data.

- Review any geotechnical reports and information for project location.
- Review published information (see Table 6-2) with emphasis on USDA soil surveys for project site.
- Determine thickness of the existing pavement, and identify initial design material properties.

3. Plan Field Investigation.

- Determine drilling requirements (see Table 6-4).
- Review Pavement Design Checklist (Exhibits 6.33) to identify needed information to be collected.
- Determine preliminary equipment requirements (see Tables 6-1, 6-3, and 6-5).
- Develop a preliminary boring and testing plan (see Exhibit 6.2).

4. Plan Sampling and Testing.

- Determine sampling and testing requirements (see Tables 6-4, 6-6, 6-11 and 6-15).
- Record field information (Exhibits 6.16, 6.17 and 6.18 as applicable).

5. Summarize Field Data.

- Review Tables 6-14 and 6-15.
- Summarize soils and other data as appropriate (see Exhibits 6.6, 6.7, 6.8 and 6.9).
- Prepare Exhibit 6.6 or 6.7 and Exhibit 6.8 or 6.9 as applicable.

6. Perform Analysis and Write Report.

- Review the pavement design checklist (Exhibit 6.33) to ensure all appropriate information is available.
- Document the pavement design parameters (Exhibits 6.23, 6.24, and 6.25) as applicable.
- Write draft report.
- Refer to the General Report Checklist (Exhibit 6.26) and the Site Investigation Checklist (Exhibit 6.27) to ensure appropriate report content.
- Finalize report.

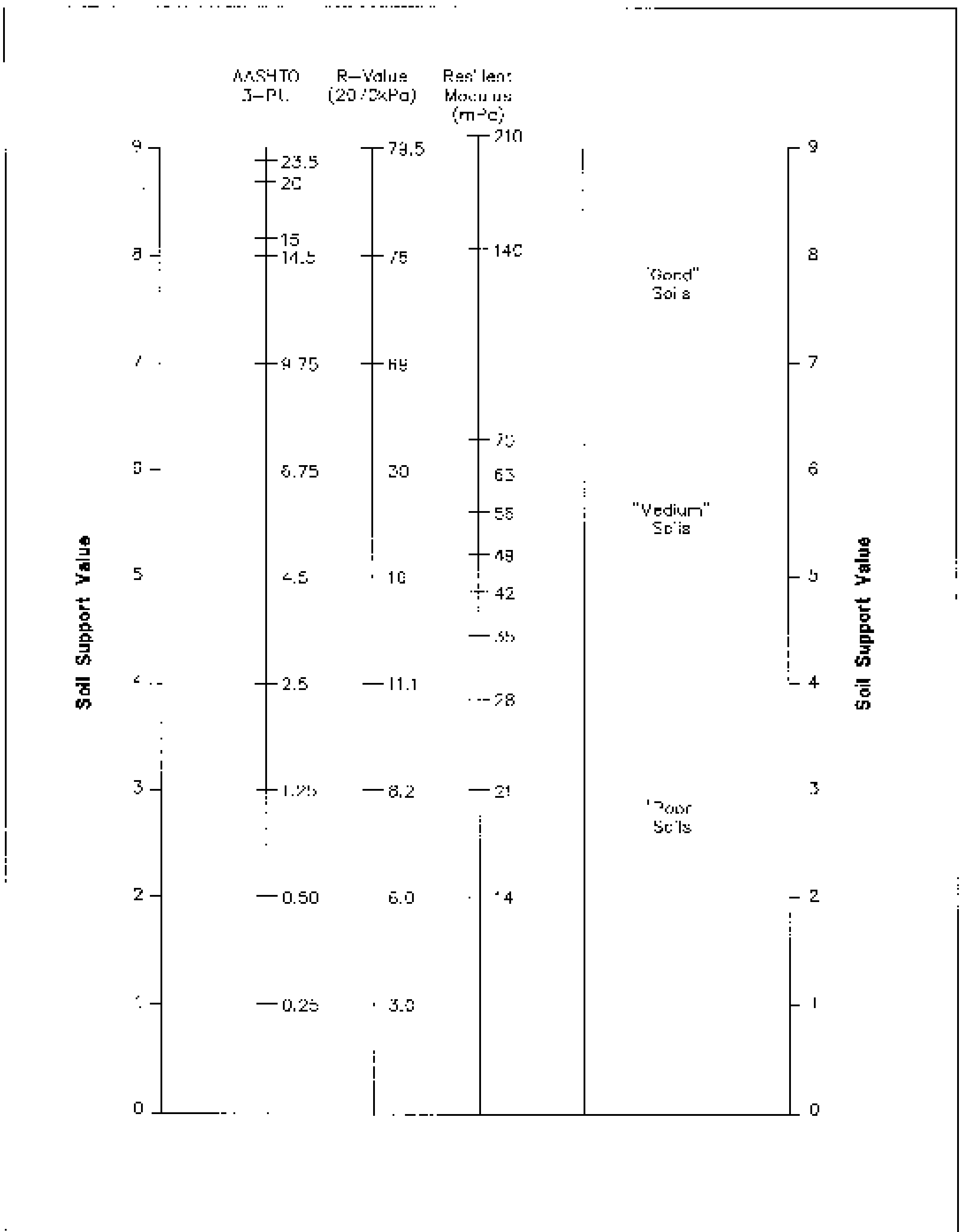


Table 6-14
Soil Support Correlations

1. New and Reconstructed Pavement Design. Design of the new flexible pavements requires (1) traffic data analysis, (2) existing soils strength determinations, (3) site specific environmental data, (4) strength and durability characteristics for the new materials to be used in construction, and (5) a system to combine these inputs to provide pavements for all types of roadways. The information provided here should be considered a guideline and is subject to revisions and deviation based upon new developments and sound engineering judgment and analysis.

a. Traffic Analysis. Detailed analysis of traffic requires loadometer data and breakdown of annual daily traffic for specific vehicle types and axle arrangements. Detailed examples of the procedures are given in Appendix C.2 of the AASHTO Interim Guide for Design of Pavement Structures. This type of information is not often available on FLH roads. Therefore, simplified traffic analysis is often used. Annual Daily Traffic (ADT) is estimated and the estimated percentage of major vehicle types is combined with Equivalent 80 kN Axle Loads (EAL) to determine an EAL/day to represent all traffic data.Typical EAL values for common vehicles are:

Type of Vehicle	Typical Values
Automobile	0.0004
Recreation Vehicle	0.20
Light Truck	0.20
Heavy Maintenance Truck	0.60
Logging Truck	2.30
Bus	0.88

In lieu of other data, typical values used in traffic analysis for FLH pavements are (1) 20 year design periods and (2) 2-percent growth factors and minimum 5 EAL/days.

b. Soil Strengths. Existing subgrade soil strengths are evaluated by using the soil support correlation values. Three acceptable methods of obtaining soil support values are listed:

- 3-point (CBR) test.
- Resilient Modulus (M_r) test.
- HVEEM Resistance (R) test.

The design soil support values can be determined from a percentile evaluation, an average, or a minimum value, depending upon the situation and allowable risk of premature or localized pavement distressed areas. However, it is recommended that the eightieth percentile and Table 6-14 be used to determine soil support values. The following can be used as a general guide for subgrade soil conditions.

Soil Type	Soil Support Value
Poor Soils	0 - 4
Medium Soils	4 - 6.5
Good Soils	6.5 - 10

c. Environmental Considerations. The site specific environmental data is evaluated by using regional factors. The basic components are precipitation, drainage, and elevation. Table 6-15 may be used to determine a site specific environmental regional factor.

These factors should be adjusted for other conditions such as seasonal traffic loads, subgrade frost heave potential, and subgrade shrink/swell potential.

d. Construction Material Strengths. The different construction material strengths are evaluated by using a structural coefficient. The ranges of structural coefficients (SC) for material used on FLH projects are shown in Exhibit 6.25.

For other material types, typical Structural Coefficient (SC) values may be found in the AASHTO Interim Guide or may be estimated from:

$$SC = 0.14 - 0.006(83 - R)$$

Where:

R = R-value determined at 2070 kPa exudation pressure (AASHTO T 190).

e. Serviceability. Generally, FLH roads should be designed for a terminal serviceability index of 2.0. However, roads with ADT's greater than 500 and/or roads considered primary routes may be designed using a terminal serviceability index of 2.5.

These elements are combined by using the design charts and procedures provided by Exhibits 6.23 and 6.24. Actual layer thickness is determined by using Exhibit 6.25 to satisfy the required structural number (SN).

For new construction, recommended minimum thicknesses of pavement structure materials are the following:

Type of Material	Thickness (mm)
Asphaltic concrete pavement	50
Aggregate base course	150

Table 6-15
Regional Factor Guidelines for Pavement

Precipitation		Elevation		Drainage	
Millimeters	**Factor (P_f)**	**Meters**	**Factor (E_f)**	**Condition**	**Factor (D_f)**
< 250	0	< 2000	0	Good	0
≥ 250 to <325	0.25	≥ 2000 to <2300	0.25	Fair	0.50
≥ 325 to< 425	0.50	≥ 2300 to <2600	0.50	Poor	1.0
≥ 425 to <600	1.0	≥ 2600 to <2900	1.0	Severe	2.0
≥ 600	1.5	>2900	1.5		

Note: Total Regional Factors (RF) = $P_f + E_f + D_f$

2. Pavement Overlay Design. Four different design methods are used to design pavement overlays. These are the minimum thickness, engineering judgment, structural deficiency, and deflection based methods. Generally, the method used on any given design problem will be dictated by the information available to the designer. If more than one design method is practical, the overlay should be checked by the other available methods.

a. Minimum Thickness. Very thin pavement overlays tend to tear and separate from the underlying pavement during construction and are almost impossible to construct. If an overlay is not intended to serve any structural purpose, but only to correct a surface defect in the pavement, no further design is necessary and the overlay can be the minimum thickness. If, however, the overlay will serve a structural purpose, another design method must be used to determine thickness requirements.

A 50 millimeter lift of asphaltic concrete pavement is normally the minimum depth of overlay for structural improvement. Overlays less than 50 millimeters but no less than 20 millimeters may be used under the following conditions:

- Additional structural capacity is not required for the section proposed for resurfacing.
- The primary function of the overlay is to improve the surface properties of the roadway (skid, noise, and riding quality adversely affect operational safety characteristics).

b. Engineering Judgment. If a designer has extensive experience with pavements that are similar to the one being overlayed, it may be possible to arrive at the required design thickness by applying engineering judgment. While in the hands of an experienced engineer this method can yield good results, it is still little more than an educated guess. Therefore, using engineering judgement as the prime design method should be limited to those projects so small that it is uneconomical to gather the data for a more sophisticated approach. On the other hand, engineering judgment should always be used to check the reasonableness of the results of the more analytical methods.

c. Structural Deficiency. The structural deficiency method consists of finding the structural number that would be required of a new pavement to support the design traffic and then subtracting the structural number of the existing pavement from it. The structural deficiency method can be summarized in these two equations:

$$SN_O = SN_N - SN_E$$

$$SN_O = a_O D_O$$

Where:

SN_O = Structural No. for the proposed overlay
SN_N = Structural No. for a new pavement
SN_E = Structural No. for the existing pavement
a_O = Layer coefficient for the overlay material
D_O = Overlay thickness in millimeters

SN_N, the structural number required for a new pavement, can be computed using the standard pavement design methods. Unfortunately, there is no such single, clear-cut way to compute SN_E. There are several semiempirical methods, but their use must be tempered with good judgment and, when possible, checked against one another. To a large extent, the accuracy of the structural deficiency method is dependent upon the accuracy of SN_E.

d. Deflection and Mechanistic Based Method. This method uses dynamic deflection measurements to estimate the condition of the existing pavement and the thickness of the required overlay. The first step in the design process is to take deflection measurements periodically along the roadways to be overlayed. Generally, a measurement is taken every 150 meters along the roadway in each traveled lane. The measurements in adjacent lanes should be staggered by 75 meters so that the maximum roadway coverage can be achieved.

These are only guidelines, however, and can be varied if there is reason to believe that the existing pavement is more or less variable than usual.

DARWin provides an overlay design methods based upon deflection analysis and back calculation. Other mechanistic based design and back calculation programs are also available. The thickness of the full depth asphalt needed to sustain the design traffic is found by processing the deflection data through the computer program. The required overlay thickness can then be computed from the following formula:

$$T_O = T_D - T_E$$

Where:

T_O = Overlay thickness
T_D = Design thickness for new pavement
T_E = Equivalent existing pavement thickness

3. Pavement Rehabilitation Design Other Than Overlay. The following are some of the major rehabilitation methods used as non-overlay techniques:

- Full-depth repair
- Partial-depth patching
- Crack sealing
- Subsealing
- Milling
- Wedge and leveling
- Subdrainage
- Surface treatments
- Recycling

Descriptions of these methods can be found in the AASHTO Guide for Design of Pavement Structures 1993, FHWA Pavement Rehabilitation Manual, and numerous Asphalt Institute publications dealing with specific techniques. Exhibits 6.16, 6.17, and 6.18 may be used to collect and document pavement distress.

E. Material Sources. The outline following Section 6.4.E. provides the basic procedural steps, initial source of reference material, and standard forms for a typical material source investigation. Commercial sources do not normally require an investigation.

The analysis of potential material sources often presents unusual and site specific problems that require coordination with environmental planning sections as well as the project designer. Detailed investigations are sometimes limited by access and/or lack of detailed site information. A concentrated effort should be made to fully investigate and analyze each material source. Excavation with backhoe and/or core (auger) borings should outline boundaries of the proposed source and should extend at least 3 meters beyond the expected floor elevation of the source. The remainder of the source should then be proven out by additional borings and/or excavations.

For typical FLH projects, 4 to 6 bore holes and 2 to 4 complete sets of aggregate quality tests are required.

The total quantity of materials available from all material sources provided for a specific project should be 10 to 20 percent in excess of the project needs.

A material source investigation should provide the following minimum information:

- Expected quality of processed materials and procedures necessary to obtain that quality.

- The boundary limits of proven materials and limits of previously used areas.

- Specific areas and elevation of nonusable materials.

- Previous uses of material from the source.

- Recommendations on uses and limitations for processed materials.

- Listing of potential development, processing, and handling problems that may occur during construction.

TYPICAL MATERIAL SOURCE INVESTIGATION AND ANALYSIS PROCESS

1. Initiate Project.

- Identify available preliminary information (see Exhibit 6.1).
- Review local permit requirements.

2. Review Available Geotechnical Data.

- Review previous material source geotechnical reports in vicinity of proposed project.
- Review published information (see Table 6-2) with emphasis on geological surveys.
- Identify locations of existing commercial sources in the vicinity.
- Obtain survey contour map and/or site specific cross sections.

3. Plan Field Investigation.

- Determine drilling requirements (see Table 6-4).
- Review checklists for site investigations (Exhibit 6.27) and material source investigation (Exhibit 6.34) to identify information to be collected.
- Determine preliminary equipment requirements (see Tables 6-1, 6-3 and 6-7).
- Determine site restrictions and revise equipment requirements. A site visit may be required.
- Develop a Preliminary Boring and Testing Plan (see Exhibit 6.2)

4. Plan Sampling and Testing.

- Determine sampling and testing requirements (see Tables 6-4, 6-6, and 6-10).
- Record field information (Exhibits 6.3 and 6.10 through 6.15 as applicable).

5. Summarize Field Data.

- Summarize soils and boring data as appropriate (Exhibit 6.7).

6. Perform Analysis and Write Report.

- Review the Material Source Investigation Checklist (Exhibit 6.34) to ensure all appropriate information is available.
- Write draft report. See outline format in Section 6.6.A.
- Refer to the General Report Checklist (Exhibit 6.26) and the Site Investigation Checklist (Exhibit 6.27) to ensure appropriate report content.
- Finalize report.

F. Landslide Analysis. Landslide analysis is perhaps one of the more difficult types of geotechnical analyses due to the variable size and complexity of landslides. TRB Landslide Investigation & Mitigation provides a basis for analysis techniques and requirements. It is essential that survey information extend beyond the landslide limits to provide detailed analysis. For most Federal Lands Highway projects, the total size of the landslide and costs of correction must be subjectively evaluated in relationship to potential costs of noncorrection before detailed investigations are authorized and initiated.

The outline following Section 6.4.F. provides the basic procedural steps, initial source of reference material, and standard forms for a typical landslide investigation.

Factor of safety for landslide analysis should vary with the type of facility, potential damages, amount and quality of soil strength data, and size of the landslide. In addition, the reliability of site specific rainfall and ground water level should be considered. Generally, a factor of safety in the 1.25 to 2.0 range is used, with an FS = 1.3 being most common. Use of low-cost methods such as alignment shifts, grade changes, horizontal drains, rock buttresses, and excavation to remove driving forces should be routinely considered.

Information required from landslide analysis should include the following:

- Physical limits and dimensions of the landslide.
- Listing of probable causes for landslide.
- Magnitude and rate of existing movements.
- Recommendations for corrective actions and evaluation of future risk.

TYPICAL LANDSLIDE INVESTIGATION AND ANALYSIS PROCESS

1. Initiate Project.

- Identify available preliminary information (see Exhibit 6.1).
- Identify project related restrictions (financial, aesthetic, environmental, etc).

2. Review Available Geotechnical Data.

- Review all previous geotechnical reports and information for specific project.
- Review published information (see Table 6-2).
- Identify landslide problem history of the general area, and determine site specific history.
- Obtain survey information such as contour maps, cross sections and plans.

3. Plan Field Investigations.

- Determine drilling requirements (see Table 6-4).
- Review checklists for landslide correction (Exhibit 6.35) to identify needed information to be collected.
- Determine preliminary equipment requirements (see Tables 6-1, 6-3, 6-5, and 6-7).
- Identify site access restrictions, and revise equipment requirements accordingly. A site visit may be necessary.
- Develop a Preliminary Boring and Testing Plan (see Exhibit 6.2).

4. Plan and Sampling Testing.

- Determine sampling and testing requirements (see Tables 6-4, 6-6 and 6-10).
- Appraise the need for in-situ testing and long-term monitoring devices.
- Record field information (Exhibits 6.3 and 6.10 through 6.15 as applicable).

5. Summarize Field Data.

- Summarize soil profile information (see Exhibit 6.6 and 6.7).

6. Perform Analysis and Write Report.

- Review the Landslide Correction Checklist (Exhibit 6.35) to ensure all appropriate information is available.
- Perform appropriate analysis.
- Write draft report (see outline in Section 6.6.A).
- Refer to the General Report Checklist (Exhibit 6.26) and the Site Investigation Checklist (Exhibit 6.27) to ensure appropriate report content.
- Finalize report.

G. Subsurface Drainage. The presence of saturated soils or shallow ground water may produce adverse effects on the construction and maintenance of roadways and embankments. The sources of this subsurface water may be free water penetrating the subsurface due to the force of gravity, capillary water that moves upward through the underlying soil strata as a result of capillary action, or water vapor moving upward through the subgrade soil strata as a result of thermal gradients. In general, these adverse effects of excessive subsurface water cause slope failures including the sloughing and sliding of cut and fill slopes, and unsatisfactory pavement performance as manifested in premature rutting, cracking, faulting, increasing roughness, and a relatively rapid decrease in the level of serviceability.

This damage may be caused in various ways, including the following:

- **Weakening.** When a roadbed is wholly or partly saturated, the application of dynamic loadings causes increased pore pressures, and these reduce the internal friction and lower resistance to shearing action.

- **Buoyancy.** The buoyant effect of the water reduces the weight of the particles and correspondingly lowers the friction between them.

- **Expansion.** The volume of some soils is greatly increased by added water, causing differential heaving and weakening of the pavement structure.

- **Frost Heave.** Freeze-thaw activity related to water in or under a pavement structure is the most common cause of volume changes leading to pavement break-up and potholes.

Prevention of subsurface water problems in highway engineering may be accomplished by either selective highway location, replacement of poor soils and the use of select, free draining, granular subbase materials, or by using subsurface drainage systems. This chapter will only discuss design guidance for subsurface drainage systems. The functions of subsurface drainage are to reduce the previously mentioned adverse effects on roadways. These functions are more specifically stated in terms of the following requirements:

- To draw-down or lower a highway water table in the area of a highway, parking lot, or other type of transportation improvement project.

- To eliminate active springs or seeps beneath the pavement by intercepting the seepage above an impervious boundary.

- To drain surface water infiltrating into the structural section by the following:

  » Through a pervious pavement.
  » Through cracks, joints, or other breaks in the continuity of the pavement and shoulder surfaces.
  » From an improperly-drained median area.
  » From side ditches.

- To collect discharge from other drainage systems.

In order to design a reliable, economic and adequate subsurface drain, it is desirable to collect the following information:

- Determine, during the preliminary soil survey, the location of all seepage areas that may cause water to enter the structural elements of the pavement.

- Determine the maximum rate of flow of water that may enter the structural section from any seepage and infiltration.

- Find the location of a source of aggregate suitable for filter material to prevent clogging of drains by water-borne soil, or determine the suitability of using a filter fabric.

- Determine source of aggregate which, if needed, may be used as drainage blanket to remove the water from beneath the pavement.

- Obtain and evaluate climatic data with respect to frost heaving.

The most common way of identifying subdrainage systems is in terms of their location and geometry. The most familiar classifications of subsurface drainage systems include underdrains, horizontal drains, drainage blankets, and wells.

1. Underdrains. These subsurface drains are categorized as longitudinal drains if they are located parallel to the roadway centerline (both in the horizontal and vertical alignment) and as transverse drains if they run beneath the roadway either at right angles to the roadway centerline or skewed in the so-called "herringbone" pattern. These drains are located not only at the edge of or under the pavement, but may also act as interceptor drains in wet cut slopes. Typically, these drains involve a trench of substantial depth, a collector pipe, free draining aggregate, and a protective filter fabric of some kind.

The function of fabrics as filters is to allow removal of ground water without the build-up of excessive seepage forces or water pressures. The fabric must also prevent piping or subsurface erosion of the soil. In these applications, water flows across the filter into a water-conducting medium, which is usually a trench filled with a free draining aggregate and a slotted or perforated pipe that quickly removes the water. Geotechnical filter fabrics are manufactured from a number of different materials, including polypropylene, polyester, nylon, polyethylene, and polyvinylidene chloride.

For details concerning specifications for various kinds of underdrain pipe, free draining aggregate and filter fabrics, refer to the references in Section 6-2.

In lieu of pipe underdrains, the use of prefabricated drainage systems (geocomposite drains) for subsurface drainage is increasing rapidly. Variables that should be considered in the design of a geocomposite drain application are drain orientation, in-situ stress, temperature, hydraulic conditions, potential for clogging, permeability, and chemical resistance.

Depending on the source of subsurface water and the function of the drain, less sophisticated underdrains may be used. These may include "french drains," consisting of a shallow trench filled with open graded aggregate, or a deep trench drain with filter fabric enveloping an open graded aggregate. Exhibits 6.36 through 6.40 show various underdrain details. These drains perform the basic requirement of carrying off all water entering the system by using a protective filter medium to prevent clogging of the drain.

2. Horizontal drains. This drainage system consists of horizontal pipes drilled into cut slopes or fill slopes to tap springs and relieve porewater pressures. The skew and inclination of horizontal pipes must be determined on a project-by-project basis, and may have to be adjusted in the field as groundwater is encountered. In ordinary installation, the ends of the perforated, small diameter drain pipes are simply left projecting from the slope and the flow is picked up in drainage ditches.

In more elaborate installations, however, drainage galleries or tunnels may be required to carry the large flows, and some type of pipe collector system may be used to dispose of the water outside of the roadway limits.

3. Drainage blankets. Drainage blankets are applied as a very permeable layer, the length (in the direction of flow) and width of which are large relative to its thickness. Drainage blankets used in conjunction with a longitudinal drain can help to improve the surface stability and thus relieve sloughing of cut slopes by preventing the development of a seepage surface. Horizontal drainage blankets can be used beneath or as an integral part of the pavement structure to remove water from infiltration or to remove ground water from both gravity and artisan sources.

Although relatively pervious granular materials are often used for base and subbase courses, these layers will not function as drainage blankets unless they are specifically designed and constructed to do so. This requires an adequate thickness of material with a very high coefficient of permeability, a positive outlet for the water collected, and in some instances the use of one or more protective filter layers.

4. Wells. Wells can be used to control the flow of ground water and relieve pore water pressures in potentially unstable highway slopes. Wells are sometimes used in conjunction with another drainage system to penetrate an impervious layer that prevents or hinders the necessary percolation of subsurface water.

6.5 APPROVALS. (Reserved)

6.6 GEOTECHNICAL REPORTS

The purpose of geotechnical reports is to transmit and document all pertinent geotechnical information in a systematic, concise format with specific design recommendations and alternatives. Pertinent information should consist of site specific physical, environmental, and geological data (field boring logs); station by station field notes; geophysical field data; material properties laboratory test results; discussion of analyses used; listing of all major assumptions and/or data used for analyses; and design and construction recommendations.

Reports are primarily intended for highway designers but are also made available to project construction personnel and prospective bidders.

A. Report Structure and Outline. All geotechnical reports should be consistent and organized to follow the same general structure to allow for familiarity by even the occasional reader. The following topic areas should be considered for final reports:

- Introduction
- Procedures and Results
- Analysis
- Discussion
- Recommendations
- Appendixes and Attachments (as required)

The introduction section of the geotechnical report should contain information as to the specific location of the project site, the purpose of the report, authorization for the work, and any limitations and restrictions that may apply.

Include a review of the project and history of the site as background information when it is relevant to the investigation and/or proposed project.

The procedures and results reported should basically contain information as to what field procedures and tests were performed and what engineering values were determined from the test results. Discuss the existing conditions and pertinent geological setting and features in the report. Use data summaries, tables, and charts whenever possible. Document any previous report and/or other specific references used to generalize conditions, estimate engineering parameters, and develop recommendations. Include all test data (both field and laboratory) in the report and reference in the appropriate appendixes.

The analysis section of a geotechnical report should contain information as to what type of analyses were performed. When appropriate, include the applicable analysis procedures, including limitations and pertinent assumptions.

The discussion section of the report should draw upon all the previously mentioned sections and present the various possible alternative solutions that were considered for each specific feature or project. Include a general discussion that communicates the major advantages and disadvantages of each alternative.

Recommendations in the report should be concise and directed to the preferred alternative. All detailed information necessary to design and construct the recommended alternative should be provided and all reference literature cited. Identify areas where special treatment may be required and make recommendations on the type of treatment or corrective action to be taken.

The appendixes of a geotechnical report should contain all detailed laboratory test results, boring logs, and field test data used to generate the report. Specific calculations would not normally be included, but all standard terminology and reference charts used to prepare the report may be included.

The following is the generalized geotechnical outline guide:

- Title page
- Table of contents
- Introduction
- Procedures and results
- Analysis
- Discussion
- Recommendations
- Attachments - Location map, drawings, etc.
- Appendix A - Field bore/core log
- Appendix B - Laboratory test results
- Appendix C - Geophysical test results
- Appendix D, etc. - Photographs, miscellaneous test results and/or information as deemed necessary

B. Checklists. As a guide to ensure that all pertinent items are considered in geotechnical reports, checklists have been prepared from FHWA's 1985 publication Checklist and Guidelines for Review of Geotechnical Reports and Preliminary Plans and Specifications. These checklists are presented in Exhibits 6.26 through 6.35. The checklists are intended to be used primarily by reviewing and approving officials. Therefore, all geotechnical project engineers and geologists preparing reports should become very familiar with the contents, concepts, and procedures presented in the checklists. Exhibits 6.26 and 6.27 contain information that is generally common to all geotechnical reports. Exhibits 6.28 through 6.35 are to be used for specific items addressed in specialized geotechnical reports.

C. Standard Forms. Geotechnical forms that are common to all Federal Lands Highway Divisions have been standardized and are presented in Exhibits 6.1 through 6.25. Completed examples of the more routinely used forms are also included within these exhibits.

6.7 DIVISION PROCEDURES

Reserved for Federal Lands Highway Division office use in supplementing the policy and guidelines set forth in this chapter with appropriate Division procedures and direction.

LIST OF EXHIBITS

Exhibit

Preliminary Information for Geotechnical Investigations

Project: ______________________ Date: ______________________

Account Number: ______________________ Estimated quantity needed: ______________________

Funding: ______________________ Information needed by: ______________________

Type of Investigation? Structure Foundation Roadway Slope Analysis Materials Source

Landslide Other ________

Report Type? Preliminary Final Informal Formal

Site Specific Information

Location: ______________________

Termini: ______________________ To: ______________________

Field Reference Available (stakes, MP, etc.):______________________

Terrain/Access? Easy Moderate Difficult Very Difficult

Utilities? Water Electric Telephone Unknown

Local Contacts:

Agency Name: ______________________ Property Owner: ______________________

Address: ______________________ Address: ______________________

Telephone: ______________________ Telephone: ______________________

Additional Information Needed By Geotechnical

Mapping? Not Available Availability Date:______________________

Structure Foundation Projects

Structure Type: ______________________ Bridge Spans (No. & Length)______________________

Max. Wall Height: ____________ Max. Loads Expected: ______________________

Availability of Preliminary Plans:______________________

Restrictions:______________________

Comments: ______________________

Roadway Projects

Type? Overlay Widening Reconst. New Alignment Other

Pavement Surface Type: ______________________

Traffic Data Availability: Where? ________ When? ________

Restrictions: ______________________

Comments:______________________

Material Source Projects

Use of Material? A.C. Pavement Base Borrow Other ______

Amount Needed: ______ ______ ______ ______
(cubic meters)

Suggested Source: ______________________

Previous Use: ______________________

Slope/Landslide Projects:

History/Maint. Problems: ______________________

Estimated Max. Movement Per Year: ______________________

Previous Correction Attempts:______________________

Initial Correction Concepts:______________________

Estimated Number of Holes:

Depth: ______________________ Backhoe or Dozer work required?______________________

Is Water Available? ______________________ How Far? ______________________

Estimated Conditions:______________________

EXHIBIT 6.1 Preliminary Information for Geotechnical Investigations

Preliminary Boring and Testing Plan

Project ____

Account Number: ____

Driller: ______________________ **Engr/Geol:** ______________________

Location (station/offset)	Power Auger			Backhoe Depth	Hand Auger Depth	Pene-trometer Cone Depth	Seismic Line Length	Resistivity Maximum Spacing	Other Tests or Remarks
	Depth	SPT	Shelby Tube						

EXHIBIT 6.2 Preliminary Boring and Testing Plan

Sample Bore Log

Project Name:	Boring No. / Date	Sheet of
Boring Location:	Type of Boring	
Drill: / Driller:	Casing Used / Size	
Field Logged By;	Boring Began:	Completed:
Revisions/Final By:	Ground Elev.	Weather:

Run or Sample Number	Depth From: To: (In Meters)	Core Length Recovered / % Recovered	RQD / Fracture Spacing	SPT Blows per 150 mm	Lab Test / Adjusted SPT (N') per 0.3 m	Water Depth: / Date/Time / Description: (Density, Color, Type, Moisture, Other)

EXHIBIT 6.3 Bore Log
(page 1 of 2)

Sample Bore Log

Project Name: WA FH101 Cascade Rd.		Boring No. 1	Date: 1/12/95	Sheet 1 of 1
Boring Location: 30m Lt. of P-103 stake		Type of Boring Auger		Drilling Mud Used From To
Drill: CME 75	Driller: P. Soon	Casing Used N/A	Size	
Field Logged By: P. Soon		Boring Began: 1/12/95	Completed: 1/12/95	
Revisions/Final By: D. Lofgren		Ground Elev.	Weather: Fair/Cold	

Water Depth:	5.8	5.8	6.4
Date/Time	4 P.M. 1/12	7 A.M. 1/13	7 A.M. 1/1[illegible]

Run or Sample Number	Depth From: To: (in meters)	Core Length Recovered / % Recovered	RQD Fracture Spacing (mm)	SPT Blows per 150mm	Lab Test Adjusted SPT (N1) per 0.3m	Description: (Density, Color, Type, Moisture, Other)
1	0 / 0.8					Augered topsoil
2	0.8 / 1.2	0.4 / —	— / —	3 / 6 / 8		Firm, dark brown silt with some clay
3	1.2 / 2.3	— / —	— / —			Same as above. More difficult near 2m
4	2.3 / 2.7	0.1 / —	—	12 / 50+		Very dense, brown, decomposed rock with some silt. Auger refusal at 2.7m Begin Core.
5	2.7 / 4.6	1.2 / 63	0 / 10–50			Broken brown siltstone. Drill vibrates when drilling. No water return
6	4.6 / 6.1	1.4 / 93	15 / 50–150			Brown siltstone, Vibration stopped at 5.6m. Water returned at 5.8m.
7	6.1 / 7.6	1.5 / 100	75 / 75–200			Continuous brown siltstone. (soft R2) Drilled easy
8	7.6 / 10.0	2.4 / 100	90 / 200+			Same as above. Hole terminated by engineer at 10 meter depth.

Exhibit 6.3 Bore Log
(Page 2 of 2)

Bore Log Terminology

Description

(1) Soil Density, Consistency or Hardness*

(2) Color

(3) Major Grain Size* - Composes more than 50% of the sample

(4) Modifying Term -
'AND' - 40% to 50% of the minor grain size
'SOME' - 10% to 40% of the minor grain size
'TRACE' - Less than 10% of the minor grain size

(5) Minor Grain Size(s)

(6) Moisture Content - Dry (D), Moist (M), Wet (W)

(7) Laboratory Classification (AASHTO or Unified)

Soil Color

BR	-Brown	**GR RD**	-Grey-red
LT BR	-Light Brown	**BR RD**	-Brown-red
DK BR	-Dark Brown	**YELL**	-Yellow
GREY	-Grey	**PURP**	-Purple
LT GR	-Light grey	**GREEN**	-Green
DK GR	-Dark grey	**WHITE**	-White
RED	-Red	**GR GN**	-Grey-green
BLK	-Black	**MOTT**	-Mottled
BLUE	-Blue	**ORAN**	-Orange
GR BR	-Grey-brown		

Example

(1) (2) (3) (4) (5) (4) (5) (6) (7)
Medium dense, reddish brown SILT, some fine sand, trace of clay (moist), A-4
↑ ↑
(10% - 40%) (1% - 10%)

*See Exhibit 6.5 - Field Classification for Soil and Rock.

EXHIBIT 6.4 Bore Log Terminology

Particle Size Limits of Soil Constituents[1]		Cohesive Soils			Granular Soils		Rock Hardness[4]		Rock Quality[3]	
	Sieve Size	Consistency	Field Identification	Resistance[3] By SPT	Relative Density	Resistance[3] By SPT	Hardness	Field Identification	Structural Quality	RQD[5]
Boulder (BLDR)	305mm +	**Very Soft (SI)**	Easily penetrated 100 to 150 mm by fist	0-1	**Very Loose**	0-4	**Very Soft (R1)**	Crumbles under firm blows with point of geological pick. Can be peeled by a pocket knife.	**Very Poor**	0-25%
Cobble (COBB)	75-305mm	**Soft (S2)**	Easily penetrated 50 to 75 mm by thumb	2-4	**Loose**	5-10	**Soft (R2)**	Can be peeled by a pocket knife with difficulty, shallow indentations made by firm blow of geological pick.	**Poor**	25-50%
Gravel (GR)	2-75mm	**Firm (S3)**	Can be penetrated 50 to 75 mm by thumb with moderate effort	5-8	**Medium Dense**	11-24	**Medium Hard (R3)**	Cannot be scraped or peeled with a pocket knife, specimen can be fractured with single firm blow of hammer end of geological pick.	**Fair**	50-75%
Sand (SA)	0.075-2mm	**Stiff (S4)**	Readily indented by thumb but penetrated only with great effort	9-15	**Dense**	25-50	**Hard (R4)**	Specimen required more than one blow with hammer end of geological pick to fracture it.	**Good**	75-90%
Silt (SI)	Smaller than 0.075mm (nonplastic)	**Very Stiff (S5)**	Readily indented by thumbnail	16-30	**Very Dense**	50 +	**Very Hard (R5)**	Specimen required many blows of hammer end of geological pick to fracture it.	**Excellent**	90-100%
Clay (CL)	Smaller than 0.075mm (plastic)	**Hard (S6)**	Indented with difficulty by thumbnail	31 +			**Extremely Hard (R6)**	Specimen can only be chipped with geological pick		

Notes:
[1]**ASTM D653**
[2]**ASTM D2113**
[3]**Standard penetration test, AASHTO T-206 No. of blows 0.3m, N corrected for overburden pressure (N[1])**
[4]**Douglass Piteau, 1977**
[5]**Rock quality designation, percent of core run 100mm or greater in length**

EXHIBIT 6.5 Field Classifications for Soil and Rock

Interpreted Design Soil Profile

Material Number	Description	Soil Parameters		
		C	ϕ	γ_T

EXHIBIT 6.6 Sample of Interpreted Design Soil Profile

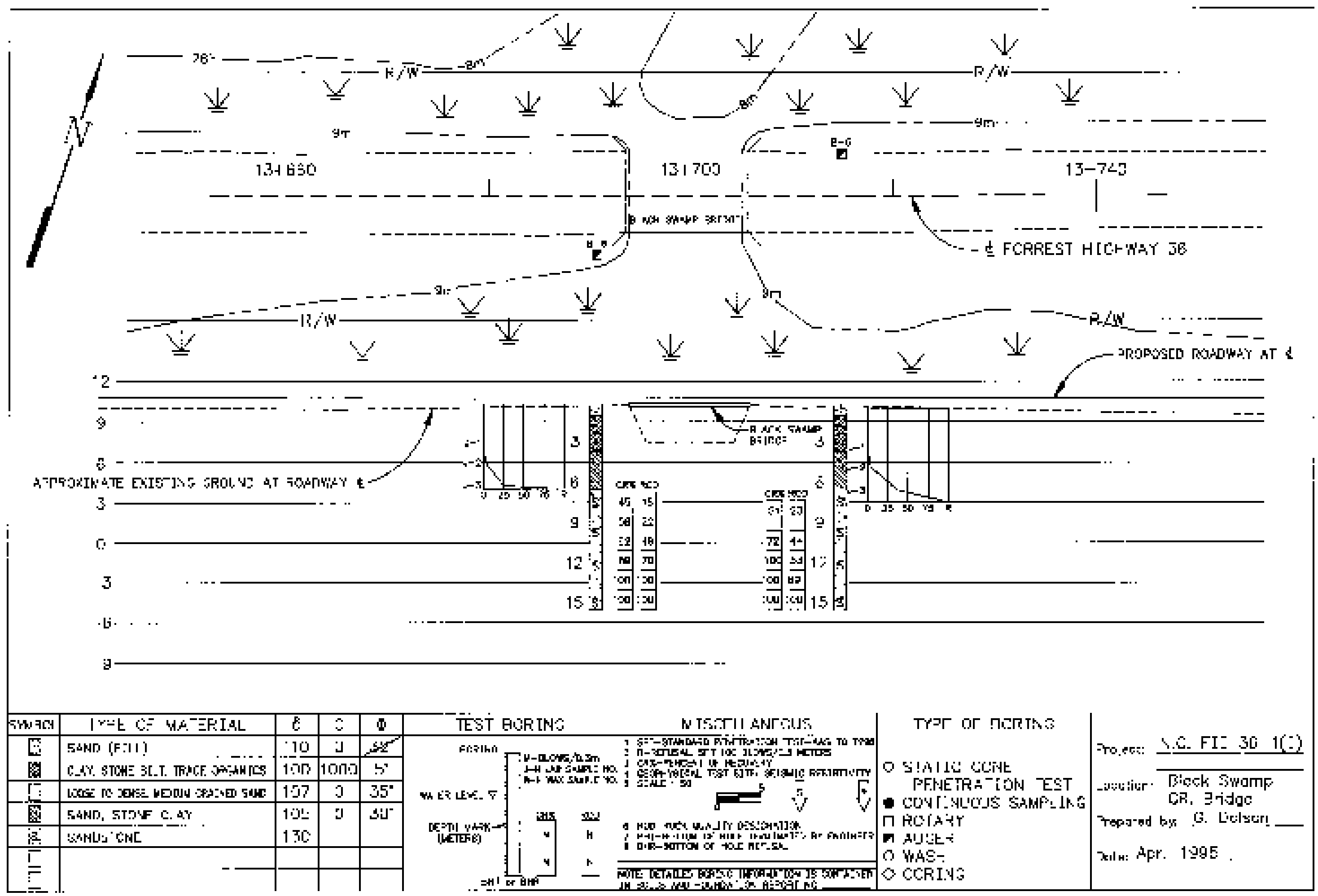


Exhibit 6.7 Sample of Soils and Foundation Plan and Profile Sheet
(Page 2 of 2)

Summary of Soil Survey

Project:_______________________ Date Performed: ________________
Beginning Reference Location: ____________________ Performed by: _________

Station to Station	Description of Soil or Rock	Recommended Slope Ratios	Shrink/Swell Factor	Water Problem Area (Yes/No)	Remarks

EXHIBIT 6.8 Sample of Summary of Soil Survey

Summary of Water Problem Areas

Project: ____________________

Beginning Reference Location: ____________________

Performed By: ____________________ **Date Performed:** ____________________

From Station to Station	Description of Problem	Recommended Solution

EXHIBIT 6.9 Summary of Water Problem Areas

Exhibit 6.10
Field Mapping - Rock Structures*
(Page 1 of 2)

Exhibit 6.10
Field Mapping - Rock Structures*
(Page 2 of 2)

EXHIBIT 6.11 (Reserved)

EXHIBIT 6.12 Seismograph Data Sheet

Resistivity Data Sheet

Project Name: ____________________ **Date:** ____________________

Location Description: ________________ **Operator:** ____________________

Notes: ____

____

____

Apparent Resistivity = (Electrode Spacing) (Dial Reading) (Scale Factor)

No.	Electrode Spacing (Meters)	Dial Reading	Scale Factor	Apparent Resistivity ($\Omega \cdot m$)	Cumulative Resistivity ($\Omega \cdot m$)

EXHIBIT 6.13 Resistivity Data Sheet
(Page 1 of 2)

EXHIBIT 6.13
(Page 2 of 2)

EXHIBIT 6.14 Bore Hole Shear Test

EXHIBIT 6.15 Inclinometer Data

EXHIBIT 6.16 Pavement Bore Log

Exhibit 6.17
Sample of Asphalt Concrete Pavement Condition Survey

EXHIBIT 6.18 Portland Cement Concrete Pavement Condition Survey*
(Page 1 of 2)

Portland Cement Concrete Pavement Condition Survey (cont)
Instructions

Distress Information

a. Amount of faulting - greater than or equal to 3mm, 1 meter from curb joint.

b. Location and severity of all cracks located from joint -
   L = hairline (less than 2 meters long - do not survey)
   M = working crack - less 13mm fault
   H = greater than 25mm and/or greater than 13 mm

Maintenance and Repair

a. Edge drain installations - location of cut areas
   |CUT→ ←CUT|

b. Joint repair due to spalls
   L = less than 75mm from joint
   M = 75mm to 150mm from joint
   H = greater than 150mm from joint

c. Asphalt patch area and location

d. Mudjacking hole locations

General Information

a. Station number locations

b. Marking beginning and ending locations of entrance and exit ramps

c. Location of mainline and overhead bridges, culverts, and inlets

d. Location of expansion joints - traverse (slab length)

e. Joint spacing - longitudinal (slab width)

f. Record road grade as uphill (+) or downhill (-)

g. Joint width (nearest 3mm) - put in remarks section of survey form

h. Slab dip (|→ down from profile)

i. Faulting measurement for each joint is to be recorded in the space provided under each joint

j. Notations such as grade, super elevation, grinding and such other information which remain constant for considerable distances need only be noted on the first and last slab on each survey sheet and at its beginning and ending occurrence. The arrow must be included to indicate that the condition is occurring on all slabs and not in the individual slab marked.

EXHIBIT 6.18 Portland Cement Concrete Pavement Condition*
(Page 2 of 2)

EXHIBIT 6.19 Rock Slope Design Criteria*

EXHIBIT 6.20 Estimating Rippability of Materials from Seismic Wave Velocities*

EXHIBIT 6.21 Allowable Bearings Pressure for Spread Footings

EXHIBIT 6.22 Allowable Pile Capacity Curve

EXHIBIT 6.23 Design Chart for Flexible Pavements - $P_t = 2.0$

EXHIBIT 6.24 Design Chart for Flexible Pavements - $P_t = 2.5$

EXHIBIT 6.25 Pavement Structure Layer Thickness Worksheet (Page 1 of 2)

EXHIBIT 6.25
(Page 2 of 2)

General Report Checklist

Project: ______________________________

Location: ______________________________

Prepared by: ____________ **Date:** ____________

Components	Check Appropriate Box		
	Yes	**No**	**Not Applicable**
1. Is a title page included?			
2. Is a vicinity map included?			
3. Is a standard report format followed? (i.e., introduction, results, discussion, recommendation, details, and appendices)			
4. Is the scope and purpose of report and authority for investigation summarized in the introduction?			
5. Is the summary of field explorations and lab testing given in the results?			
6. Is the description of general subsurface soil, rock, and groundwater conditions given in the results?			
7. Are concise descriptions given for geologic features and topography of the area in the discussion?			
8. Are recommendations concise and in sufficient detail to design the project or serve the intended purpose?			
9. Is the following information included with the geotechnical report? (typically included in report appendices): •Test hole logs? •Laboratory test data? •Field test data? •Photographs?			

Comments ______________________________

____

EXHIBIT 6.26 Sample of General Report Checklist

Site Investigation Checklist

Project: ______________________________

Location: ______________________________

Prepared by: ____________________ **Date:** ____________________

Components	Check Appropriate Box		
	Yes	No	Not Applicable
1. Is a plan profile (subsurface cross section) of the investigation site provided and clearly identified?			
2. Are the locations of all samples, boring, test pits, probes, geophysical, and field testing shown on a plan view?			
3. Are the locations of the proposed geotechnical features, existing structures, utilities, and other physical site features shown on a plan view?			
4. Are test hole numbers and dates included for each boring or exploration.			
5. Do the profile boring logs contain a word description and/or graphic depiction of soil and rock types?			
6. Is sample type and depth at which each sample was taken noted on the boring logs?			
7. Are SPT blow counts provided on the boring logs?			
8. Are groundwater levels and date measured shown on the boring logs?			
9. Are percent rock core recovery and RQD values shown on the boring logs?			
10. If cone penetrometer probes are made, are logs of cone probes shown, including plots of cone resistance and friction ration with depth?			
11. Is location of other field tests performed at the boring site (such as vane shear, pressure-meter, drive casing, etc.) shown on the boring logs?			
12. Are soil classification tests determined on selected representative samples to verify field visual soil identifications?			
13. Are laboratory test results (natural moisture content, gradation, Atterberg limits, shear strength, consolidation, etc.) included and summarized?			

EXHIBIT 6.27 Sample of Site Investigation Checklist

Spread Footings Checklist

Project: ______________________________

Location: ______________________________

Prepared by: ____________________ **Date:** ____________________

Components	**Check Appropriate Box**		
	Yes	**No**	**Not Applicable**
1. Are spread footings recommended for foundation support or provided as an alternative to deep foundations?			
2. Are recommended bottom of footing elevations and reasons for recommendations (e.g., based on frost depth, estimated scour depth, or depth to competent bearing material) given?			
3. Are the recommended allowable soil or rock bearing pressures given?			
4. Are estimated footing settlements given?			
5. Where spread footings are recommended to support abutments placed in the bridge end fills, are gradation and compaction requirements provided for select end fill and backwall drainage material?			
6. Construction considerations—have the following important construction considerations been adequately addressed?			
a. Materials on which the footing is to be placed — method by which project inspector can verify that material is as expected?			
b. Excavation requirements — safe slopes for open excavations, need for sheeting or shoring?			
c. Fluctuation of groundwater table?			
7. Are necessary contract special provisions provided?			

Comments ______________________________

____

EXHIBIT 6.28 Sample of Spread Footing Checklist

Piles Checklist

Project: ______________________________

Location: ______________________________

Prepared by: ______________ **Date:** ______________

Components	Check Appropriate Box		
	Yes	No	Not Applicable
1. Are most suitable pile types (displacement, nondisplacement, pipe pile, concrete pile, H-pile, etc.) analyzed?			
2. Are reasons given for choice and/or exclusion of certain pile types?			
3. Are estimated pile lengths and estimated tip elevations given?			
4. Are recommended allowable pile design loads given?			
5. Has pile group settlement been estimated? (only of practical significance for friction pile groups in cohesive soils or large heavy structures on friction pile groups in sand)			
6. If a specified or minimum pile tip elevation is recommended, is the reason given for the required tip elevation? (such as underlying soft layers, scour, downdrag, piles uneconomically long, etc.)			
7. Has design analysis verified that the recommend pile type can be driven tot he estimated or specified tip elevation without damage? (especially applicable where dense gravel-cobble-boulder layers or other obstructions have to be penetrated)			
8. Where the bridge abutment is to be supported on end-bearing piles and significant long-term settlement of the subsoil will occur (such as for embankments built over clays or soils with high organic content):			
a. Has abutment downdrag load been estimated and considered in design?			
b. Has bridge approach slab been considered to moderate differential settlement between bridge ends and fill?			
9. If the majority of subsoil settlement will not be removed prior to abutment construction, has estimate been made of the amount of abutment rotation that can occur due to lateral squeeze of soft subsoil?			

EXHIBIT 6.29 Sample of Piles Checklist
(page 1 of 2)

Piles Checklist

Project: ______________________________

Location: ______________________________

Prepared by: ____________________ **Date:** ____________________

Components (continued)	Check Appropriate Box: Yes	No	Not Applicable
10. Has horizontal abutment movement been considered?			
11. Has pile load test program or dynamic testing been considered?			
12. For a structure in high seismic risk area, has assessment been made of liquefaction potential of foundation soil during design earthquake? (Note only loose saturated sands and silts are "susceptible" to liquefaction)			
13. Construction considerations - have the following important construction considerations been adequately addressed?			
a. Pile driving details and what may be encountered during driving such as boulders or other obstructions (any need for pre-augering, jetting, spudding, pile tip reinforcement, driving shoes, etc.?)			
b. Excavation and the need for sheeting or shoring? (Safe slopes for open excavating)			
c. Fluctuations in groundwater table?			
d. Have effects of pile driving operation on adjacent structures been evaluated? (such as protection against damage caused by footing excavations or pile driving vibrations)			
e. Should preconstruction condition survey be made on adjacent structures? (to document for possible construction damage claims)			

Comments

____

____

____

____

____

EXHIBIT 6.29
(page 2 of 2)

Drilled Shaft Checklist

Project: ______________________________

Location: ______________________________

Prepared by: ____________________ **Date:** ____________________

Components	Check Appropriate Box		
	Yes	No	Not Applicable
1. Recommended shaft diameter(s) and length?			
2. Allowable design load given for various diameter shafts recommended?			
3. Allowable end bearing value given?			
4. Allowable side friction value given?			
5. Settlement estimated for recommended design load?			
6. Where lateral load capacity of shaft is an important design consideration, are P-Y (load versus deflection) curves or soils data provided in geotechnical report which will allow structural engineer to evaluate lateral load capacity of shaft?			
7. Is static load test (to plunging failure) recommended?			
8. Construction considerations?			
a. Have construction methods been evaluated? (i.e., can dry method or slurry method be used or will casing be required)			
b. If casing will be required, can casing be pulled as shaft is concreted? (this can result in significant cost savings on very large diameter shafts)			
c. If artesian water may be encountered in the shaft excavation, have provisions been included? (such as by requiring casing and tremie seal)			
9. Are boulders likely to be encountered? (Note - if boulders are likely to be encountered, then the use of shafts should be questioned due to serious construction installation difficulties and possible higher costs.)			
10. Are recommended contract special provisions provided?			

EXHIBIT 6.30 Sample of Drilled Shaft Checklist

Retaining Wall Checklist

Project: ______________________________

Location: ______________________________

Prepared by: ____________________ **Date:** ____________________

Components	Check Appropriate Box		
	Yes	No	Not Applicable
1. Does the geotechnical report include recommended soil strength parameters and groundwater elevation for us in computing wall design lateral earth pressures and factor of safety for overturning, sliding, and external slope stability?			
2. Does the design lateral earth pressure include the effects of soil backfill strength, slope geometry, and surcharge loads?			
3. Has the most suitable and cost-effective wall type(s) been selected for the specific site conditions?			
4. Are reasons given for the choice and/or exclusion of certain wall types (gravity, reinforced soil, tieback, cantilever, bin, gabion, etc.)?			
5. Does wall design provide for and identify minimum acceptable factors of safety against overturning, sliding, and external slope stability?			
6. If wall will be placed on compressible foundation soils, is estimated total settlement, differential settlement, and time rate of settlement given?			
7. Can selected wall system(s) tolerate the estimated differential settlement?			
8. If special drainage details are needed behind and/or beneath the wall, are recommended details provided in the geotechnical report?			
9. Is proposed to bid alternative wall designs?			
10. Construction considerations:			
a. Are excavating requirements covered (safe slopes for open excavations, need for sheeting or shoring, etc.)?			
b. Fluctuation of groundwater table?			
11. Are recommended contract special provisions provided?			

EXHIBIT 6.31 Sample of Retaining Wall Checklist

Roadway Cut and Embankment Checklist

Project: ______________________________

Location: ______________________________

Prepared by: ________________ **Date:** ________________

Components	Check Appropriate Box		
	Yes	No	Not Applicable
1. Are station to station descriptions included for:			
a. Existing surface and subsurface drainage?			
b. Evidence of springs and excessively wet areas?			
c. Slides or slumps noted along the alignment?			
2. Are station to station recommendations included for:			
a. Cut slope design?			
b. Are clay slopes designed for minimum FS = 1.50?			
c. Fill slope design?			
d. Will slope design provide minimum FS = 1.25?			
e. Usage of excavated soils?			
f. Estimated shrink-swell factors for excavated materials?			
g. Specific surface/subsurface drainage considerations?			
h. Identifying subexcavation limits of unsuitable soils?			
i. Erosion protection measures for backslopes, sideslopes, and ditches, including riprap or special slope treatments?			
j. Are special blasting specifications needed to insure stable rock slopes and minimize future rockfall?			
k. Need for special rock slope stabilization measures (e.g., rockfall catch ditch, wire mesh slope protection, shotcrete, rock bolts, etc.) identified?			
3. Are recommended contract specifications provided?			
Note: Factor of Safety (FS)			

EXHIBIT 6.32 Sample of Roadway Cut and Embankment Checklist

Pavement Design Checklist

Project: ______________________________

Location: ______________________________

Prepared by: ____________________ **Date:** ____________________

Components	Check Appropriate Box		
	Yes	No	Not Applicable
1. Has a visual distress assessment of the existing pavement been made and is summary of results provided?			
2. Has the roughness of the existing pavement surface been measured and are results summarized?			
3. Have deflection tests been made on the existing pavement and the results summarized?			
4. Has a subsection breakdown been provided to group similar existing conditions, pavement structure, and expected traffic loads within the project?			
5. Are traffic estimates provided that include total ADT, trucks, and accumulative equivalent 80KN?			
6. Are strength properties and thickness of each of the pavement layers and subsections included?			
7. Is the design method used to develop the pavement alternatives identified and are all inputs used for design clearly summarized?			
8. Are advantages and disadvantages of each alternative provided for the acceptable pavement structures?			
9. Are reasons for recommended pavement structure alternatives clearly stated?			
10. Are construction problems, weather restrictions, water and/or material problems considered?			
11. Are recommended contract specifications provided?			
12. Has a life cycle cost analysis been performed?			

EXHIBIT 6.33 Sample of Pavement Design Checklist

Material Investigation Checklist

Project: ______________________________

Location: ______________________________

Prepared by: ____________________ **Date:** ____________________

Components	Check Appropriate Box: Yes	No	Not Applicable
1. Is material site location (include description of existing or proposed access routes, bridge load limits, etc.) identified?			
2. Have representative samples of materials encountered during the investigation been tested?			
3. Are laboratory quality rest results included in the report?			
4. Aggregate sources.			
a. Do the laboratory quality test results (such as LA abrasion, sodium sulfate, degradation, absorption, reactive aggregate, etc.) indicate acceptable materials can be obtained from the deposit using normal processing methods?			
b. If acceptable material cannot be obtained from the source using normal processing methods, have special requirements been provided for processing or controlling production?			
5. Borrow sources, have possible difficulties (such as above optimum moisture content clay-silt soils, waste due to high PI, boulders, etc.) been noted?			
6. Where high moisture content clay-silt soils must be used, are recommendations provided on the need for aeration to allow the materials to dry out sufficiently to meet compaction requirements?			
7. Has previous use of proposed source been discussed?			
8. Does estimated quantity of proven material satisfy the estimated project needs?			
9. Where materials will be excavated from below the water table, has seasonal fluctuation of the water table been determined?			
10. Are special permit requirements covered?			
11. Are pit reclamation requirements covered adequately?			

EXHIBIT 6.34 Sample of Material Source Investigation Checklist (Page 1 of 2)

Materials Investigations Checklist (continued)

	Check Appropriate Box		
	Yes	**No**	**Not Applicable**
12. Has a material site sketch (plan and profile) been provided for inclusion in the plans, which contains:			
• Material site number or identification?			
• Owner identified?			
• North arrow and legal subdivision?			
• Test hole or test pit logs, location, number, and date?			
• Water table elevation and date?			
• Depths of unsuitable layers including overburden which are not acceptable.			
• Potential disposal areas?			
• Potential mining area and previously mined areas?			
• Existing stockpile locations?			
• Existing or potential access roads?			
• Bridge load limits?			
• Reclamation details?			
13. Are recommended contract provisions provided?			

Comments ____

EXHIBIT 6.34 Sample of Material Source Investigation Checklist (Page 2 of 2)

Landslide Correction Checklist

Project: ______________________________

Location: ______________________________

Prepared by: ____________________ **Date:** ____________________

Components	Check Appropriate Box: Yes	No	Not Applicable
1. Does the report include a site plan and typical cross section showing ground surface conditions both prior to and after failure?			
2. Has a site reconnaissance been conducted to define the limits of the slide improvement?			
3. Are slide limits (including location of ground surface cracks, head scarp, and toe bulge) shown on the site plan?			
4. Is past history (movement history, maintenance work and costs, and corrective measures taken) of slide are summarized?			
5. Is summary given of results of size investigation, field and lab testing, and stability analyses, including cause(s) of the slide?			
6. Is as-built cross section (used for slide stability analysis) included and does cross section show major soil and rock layers and water table location as determined from drilling and sampling?			
7. Is location of slide failure plane (determined from slope indicators and/or drilling) shown on the slide cross section?			
8. Are soil strength values, soil unit weights, and water table elevation (s) (used in the design stability analyses) shown on the slide cross section?			
9. For existing active slide, was soil strength along slide failure plane backfigured using a safety factor equal to 1.0 at time of failure?			
10. Is the following included for each proposed correction alternative:			
a. Cross section of proposed alternative?			
b. Estimated safety factor?			
c. Estimated cost?			
d. Advantages and disadvantages?			

EXHIBIT 6.35 Sample of Landslide Correction Checklist (Page 1 of 2)

Landslide Correction Checklist

Project: ____________________

Location: ____________________

Prepared by: ____________________ **Date:** ____________________

Components (continued)	Check Appropriate Box: Yes	No	Not Applicable
11. Is recommended correction alternative given?			
12. Does proposed correction alternative provide a minimum FS = 1.25?			
13. Have the most feasible and cost-effective correction alternatives been considered for the particular slide problem? (typical correction methods include buttress, shear key, rebuild slope, surface drainage, subsurface drainage - interceptor drain trenches or horizontal drains - and retaining structures).			
14. If horizontal drains are proposed as part of slide correction, has subsurface investigation located definite water bearing strata that can be tapped with horizontal drains?			
15. If a toe counterberm is proposed to stabilize an active slide, has field investigation confirmed that the toe of the existing slide does not extend beyond the toe of the proposed counterberm?			
16. Construction considerations:			
a. Where proposed correction will require excavation into the toe of an active slide (such as for buttress or shear key) has the construction backslope FS been determined?			
b. Has seasonal fluctuation of groundwater table been determined and was highest water level used in computing open excavation backslope FS?			
c. If open excavation FS is near 1.0, has excavation stage construction been proposed?			
d. Should slide repair work only be allowed during driest period or the year?			
e. Should stability of excavation backslope be monitored?			
17. Are recommended contract specifications provided?			

Comments ____________________

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EXHIBIT 6.35 Sample of Landslide Correction Checklist (Page 2 of 2)

CHAPTER 7 - HYDROLOGY/HYDRAULICS

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CHAPTER 7 - HYDROLOGY/HYDRAULICS

7.1 GENERAL

This chapter emphasizes the policies and techniques for investigating and designing highway related water resource systems. To encourage a broader perspective, the term *water resources* is often used in this section instead of *drainage* or *hydraulics* to emphasize that water represents a vital resource having multiple values to both the natural and human environment. Water resource systems and highway systems should, therefore, be designed to complement one another.

Since the technical complexity of water resource analysis covers a broad range of literature, only general guidelines for such analysis are provided. To facilitate implementation of these guidelines, sample checklists and forms are shown as exhibits at the end of the chapter. Each checklist and form is cross-referenced to the appropriate section for explanation and background information.

For an in-depth approach, the designer should consult either the technical references given in the following discussions or a hydraulics engineer. Highway designers should derive enough information from this chapter to properly integrate highway design and water-related systems. Table 7-1 lists the division staff with primary and support responsibilities for design of drainage facilities.

A. Highway Designer's Responsibilities. The designer is responsible for the overall design of the highway and should be familiar with the available guides, the investigation and design processes, the required approvals, and the reporting practices associated with hydrology and hydraulics. The designer should understand the general value of water resource systems such as reservoirs, irrigation canals, potable water supplies, and fish/wildlife habitat.

The designer should acquire available field and aerial surveys for proper hydrologic and hydraulic analysis of the water system, and should investigate the erosion and sediment characteristics of the general highway environment.

The hydrologic process requires the knowledge of the various methods used to determine the volume of water per unit time for a given design situation. The hydraulic process also requires the understanding of open channel flow, culvert design, erosion control methods, and bridge waterways. In hydrologic and hydraulic analyses, the designer must understand the trade-offs involved when weighing risks against total design costs. To develop a scope of water-related responsibilities, the designer should become familiar with the guidelines contained in this chapter.

B. Hydraulic Engineer's Responsibilities. The hydraulics engineer is responsible for providing technical assistance and guidance to the designer for complex drainage problems.

These types of problems include the design of bridge waterways, large culverts, urban drainage systems, and environmental mitigation systems. (Environmental systems include flood protection in urban areas, fish passage designs, water quality, and wetlands replacement.)

The hydraulics engineer is also a source of information concerning applicable water resource laws, FHWA water related policies, AASHTO design policies, and current developments in water resource system designs. The hydraulics engineer should be consulted early during project development for hydrologic input and roadside channel design criteria. The hydraulics engineer should review the final PS&E of all highway designs that have water related systems.

Table 7-1
Staff Design Responsibilities

Drainage System	Division Staff				
	Design	Hydraulics	Bridge	Geotechnical	Environmental
Culverts, 1200 millimeters and smaller	P	S			
Culverts, larger than 1200 millimeters	S	P			
Bridge waterway analysis	S	P	S		
Ditches	P	S			
Small stream channels	S	P			
Urban drainage	S	P			
Environmental mitigation	S	P			S
Underdrain systems	S	S		P	
Erosion protection	S/P	P/S		S	S
Water quality	S	P			S

P = Primary responsibility (performs most of the design)
S = Secondary responsibility (provides consultation and support for the design)

7.2 GUIDANCE AND REFERENCES

This section briefly discusses the laws, regulations, policies, and guidelines for integrating water resource systems with proposed highway systems. To implement these regulations and policies, guidelines (i.e., hydraulic engineering circulars) have been developed. The following information provides the designer with background and reference materials for incorporating these laws, policies, and guidelines into the highway design process.

A. Applicable Laws. Federal, State, and local governments have many laws and regulations related to water resource systems. These will generally affect the design, approval, and construction of water resource designs. The designer should be familiar with these laws and regulations. These laws are summarized in AASHTO's *Highway Drainage Guidelines - The Legal Aspects of Highway Drainage,* Volume V.

1. Federal Laws. Federal laws provide protection for water quality, fish and wildlife, flood disasters, navigable and non-navigable waters, and coastal zones. These protective laws are formulated under various legislative acts.

- Federal-aid Highway Act (1970).
- National Environmental Policy Act (1969).
- Flood Disaster Protection Act (1973).
- River and Harbor Act (1899).
- Federal Water Pollution Control Act (1972).
- Fish and Wildlife Coordination Act (1956).
- Tennessee Valley Authority Act (1933).
- Coastal Zone Management Act (1972).

The laws and regulations are numerous, powerful, and complex. The following is a brief summary of the most common and important regulations affecting highway designs and water resources.

a. National Environmental Policy Act (NEPA). This act is the primary Federal regulation for the protection of the environment. (See Chapter 3).

Although the environmental engineer performs the evaluation and preparation of the documents required by NEPA, the designer as well must consider the impacts of highway designs upon water quality and ecological systems such as wildlife, fish, and marine life.

(1) Water Quality. Water quality may be affected by the following:

- Surface runoff, such as paved surfaces replacing natural surfaces.
- Sedimentation and erosion caused by such factors as loss of vegetation due to highway construction.
- Chemical composition, such as pH, turbidity, oxygen demand levels, and minerals (i.e., pavement and soil leaching).
- Ground water quantity and quality.

(2) Ecological Systems. The ecological systems that could be affected are as follows:

- Habitat diversity related to fisheries and wetlands.
- Size and quality of habitat area.
- Interrelationships with water quality factors.

The designer can still strive to integrate highway systems into the natural water resource systems to minimize negative impacts and enhance the positive characteristics of both systems.

b. Flood Disaster Protection Act. Under this act, local communities must have land use controls to qualify for the National Flood Insurance program. This program applies primarily to urban areas that have households located within a designated flood-way area.

This flood-way area is designated by the Federal Emergency Management Administration (FEMA). Generally, the flood-way limits are defined by the 100-year flood plain. Flood insurance maps may be obtained that define the regulated flood ways for a given area. These maps may be acquired from the State or local planning agency that administers the flood insurance program.

If the highway encroaches upon the 100-year flood plain, the increase in water surface elevation must be evaluated for various flood frequencies. If the encroachment area lies within a regulated flood way, then local land-use controls may limit the increase of flood patterns caused by the encroachment (i.e., maximum 300 millimeters increase for the 100-year flood). Flood insurance regulations within the project area may affect the proposed highway hydraulic designs.

c. Navigable and Non-navigable Water Acts. The Federal Water Pollution Control Act and the River and Harbor Act may require permits to be obtained for the following:

- Dredging or filling into navigable or non-navigable waters (including wetlands and lakes).
- Erecting structures over navigable waters.
- Discharging pollutants (i.e., storm sewer systems).

For filling and dredging in lakes and streams, the designer should contact the U.S. Army Corps of Engineers (USACE). For erection of structures over navigable waters, the designer should consult both the U.S. Coast Guard and the U.S. Corps of Engineers. For point discharges of pollutants, the U.S. Environmental Protection Agency should be consulted. These agencies should be contacted for permit approval during the preliminary design stages.

d. Fish and Wildlife Coordination Act. Federal agencies are required by this act to contact the U.S. Fish and Wildlife Service, Department of Interior, when there are plans to modify the waters of any stream or body of water for any purpose. Although the U.S. Fish and Wildlife Service does not have direct permitting authority, the design engineer should be aware that a Memorandum of Understanding (MOU) exists between the U.S. Fish and Wildlife Service and the U.S. Corps of Engineers giving the U.S. Fish and Wildlife Service considerable influence in the issuance of fill and dredging permits.

Fill and dredge permits for such highway features as bridge abutments, roadway embankments, and material sources will be the most common permits obtained for highway activities in water resource systems. The classification of water resource systems is explained in the *Classification of Wetlands and Deep water Habitats of the United States* by the U.S. Fish and Wildlife Service. Also, *A Method for Wetlands Functional Assessment*, Volumes I and II by the Federal Highway Administration should be reviewed.

e. Tennessee Valley Authority (TVA) Act. The TVA is responsible for the conservation and development of the Tennessee River Valley and surrounding area. Highway designs that are located in or affect this region must be approved by the TVA. Approval is based upon impacts on the general quality of the environment, control of pollution, and attainment of State water quality certification. Also, the TVA may require an environmental assessment before issuing the permit.

f. Coastal Zone Management Act. This act encourages State and Federal agencies to develop procedures and programs for managing coastal areas. Although the National Oceanic and Atmosphere Administration is responsible for administering the provisions of this act, the States in cooperation with local governments generally develop and administer coastal zone management programs. These programs define the coastal zone boundaries, define the acceptable land and water uses, and describe the procedures for implementing the coastal zone management program.

If a proposed highway project is located within a coastal management zone, a certificate from the administering agency may be required. The certificate will state that the proposed project is consistent with the local coastal zone management program.

2. State and Local Laws. State laws related to water resources generally are based upon common laws and statutory laws. Common laws are derived from long-standing usages and customs, while statutory laws are developed by legislative governments. Under common law, water-related legalities are based upon a classification system of surface waters, stream waters, flood waters, and groundwaters. Under statutory law, water-related legalities are based upon legislative mandate generally defined by eminent domain, water rights, water resource districts, agriculture drainage, and environmental laws.

At the State level, the most common water-related legal problems involve diversion, collection, concentration, augmentation, obstruction, erosion and sedimentation, and groundwater interference. Since laws related to these problems will vary from State to State, the following is a brief generalization of each problem:

a. Diversion. This relates primarily to the detention, or changing the course, of a stream or drainage way from its natural or existing condition. Depending upon the type or resource system (human or natural) that the diversion affects, the State laws will vary in their scope of jurisdiction. Water diversions should be evaluated for their impact upon property owners upstream, downstream, and adjacent to the project. Any changes in the flow characteristics due to the diversion may require mitigation with the affected property owners. Also, water diversions should be evaluated for their impact upon fish and wildlife habitat. The State fish and wildlife agencies should be contacted for questions of jurisdiction and possible mitigations. Basically, diversions of streams or drainage ways should be designed to recreate flow conditions (i.e., depth velocity flowrates, backwater) that are as similar as possible to those that existed before the diversion while still accomplishing the highway design objectives.

b. Collection, Concentration, and Augmentation. Water may be collected and concentrated by a highway drainage system, causing flow rates at the point of discharge to be in excess of those flow rates that would naturally occur without the drainage system. Also, the concentration of flow upstream from a primary culvert may increase the backwater elevations at the culvert inlet. If this occurs, drainage easements and mitigation may be required if the backwater extends beyond the highway right-of-way.

On RRR projects, the flow rates should not be appreciably affected. However, flow rates should be compared in terms of *before* and *after* conditions for proper evaluation of the highway drainage system and protection from potential litigation problems associated with the drainage system.

c. Obstruction. As discussed under collection, concentration, and augmentation, backwater from culverts, and bridges, may require special measures. Culverts and bridges generally affect the flow characteristics within their proposed locations. These structures can cause backwater upstream, increase velocities in the structure area, and affect erosion and sedimentation characteristics downstream. The effects can be significant. Evaluate the effects for various flow conditions and contact impacted individuals and agencies such as adjacent property owners and State water resource agencies. Based upon feedback from the affected parties, the appropriate flow conditions and hydraulic characteristics can be determined.

The evaluation of obstructions may be rather complex and the designer should consult hydraulic and other technical specialists. The designer should ensure that the proper analysis is performed and documented for evidence of compliance with State-related laws.

d. Erosion and Sedimentation. Highways and their structures can have pronounced impacts upon erosion and sedimentation characteristics of a water resource system. If the flow characteristics are significantly changed, then the erosion and sedimentation characteristics will also be changed. Coordinate the design with the appropriate individuals and State agencies that may be affected by a change in these characteristics. Normally, the individuals and State agencies involved in diversions, augmentations, and obstructions will have an interest in highway-affected erosion and sedimentation.

e. Groundwater Interference. Legal problems may occur if proposed highway designs and construction alter the quantity and/or quality of groundwater systems. Legal suits may be initiated by individual owners or public agencies who have groundwater supplies altered by construction operations or encounter groundwater contamination caused by highway runoff. Legally, groundwater is considered to be a part of the real property in which it lies. Therefore, evaluate the potential for groundwater impacts by the proposed highway design. If potential problems do exist, the designer should consult technical experts like the hydraulics engineer or geotechnical engineer.

Local laws, like State laws, may vary considerably from locality to locality. However, most local governments have regulations or statutes that pertain to

- the Flood Disaster Protection Act,
- municipal water supplies, and
- storm water management.

In coastal areas, local governments also participate in the management of coastal zoning.

Because of the variation in local statutes, the designer should consult the county and/or city officials that have jurisdiction over the water resources in the area of the proposed highway project.

B. Federal-Aid Policy Guide (FAPG). The following FHPM sections relate to water resource considerations on FLH projects.

1. Permits. FAPG 650H stipulates that the USACE and U.S. Coast Guard should be contacted for required navigational clearances under bridges. This subsection also discusses the permits required for highway work in or adjacent to streams. While the information contained in this subsection is written primarily for Federal-aid projects, it provides references and historical information related to water resource permits. For additional guidance, see Chapter 3.

2. Erosion and Sediment Control. FAPG 650B specifies that highway projects must be located, designed, constructed and operated according to standards that will minimize erosion and sediment damage to the highway and adjacent properties and prevent pollution of surface and groundwater resources. This subsection provides information for developing erosion and sediment control plans. The erosion and sediment control measures discussed in this subsection include structures for erosion control, detention or sedimentation basins, and soil treatments.

3. Flood plain Encroachments. FAPG 650A specifies that highway projects shall be evaluated for their impacts and costs when they encroach upon flood plains. This evaluation includes an assessment of the capital costs, risks, natural flood plain values, and human flood plain values associated with the encroachment. To complete this evaluation, location studies, hydrologic and hydraulic analysis, and design documentation shall be performed by environmental and design personnel.

The designer must assess the benefits of the highway encroachments against the costs. Both tangible and intangible factors are to be considered. Often, an optimal design can be found that can balance both the inherent risks and costs of the project.

4. Mitigation of Environmental Impacts to Privately Owned Wetlands. FAPG 777 requires State agencies to evaluate and mitigate adverse environmental impacts to privately owned wetlands caused by new construction of Federal-aid highway projects. These laws and regulations also apply to FLH projects that affect privately owned wetlands.

Generally, fish and wildlife officials require some type of mitigation if a highway project encroaches upon a wetlands. The loss or disruption of wetlands can be mitigated by enhancing nonimpacted wetlands, creating new wetlands within the highway right-of-way, or acquiring additional right-of-way for the sole purpose of developing new wetlands. Before wetland losses are mitigated, evaluate the wetland in terms of its vegetative, hydrologic, hydraulic, wildlife, and fish habitat characteristics. Based upon this evaluation, proposed mitigation measures for any adverse wetlands impacts can be developed.

C. FHWA Technical Advisories. FHWA advisories provide technical guidance for the design of highways. In water-related areas, the designer will find few technical advisories. The designer should contact the Hydraulics Engineer for the most current technical advisories.

D. AASHTO Guidelines. The American Association of State Highway and Transportation Officials (AASHTO) published eleven volumes of Highway Drainage Guidelines. AASHTO is currently developing two additional volumes.

These guidelines provide qualitative information on the planning, hydrology, hydraulics, and legal aspects of highway drainage design.

The first seven of these guidelines are summarized as follows:

- Volume I, *Hydraulic Considerations in Highway Planning and Location*. This volume summarizes the general aspects of highway drainage design. The topics include preliminary drainage surveys, flood hazards, location problems, construction and maintenance problems, coordination with water resource systems, permits, legal considerations, reports, and documentation.

- Volume II, *Hydrology*. This volume describes those hydrologic aspects that are most important for determining the design flowrate. The topics discussed include drainage basin characteristics, stream channel characteristics, flood plain characteristics, precipitation, flood history, selection of design flood frequency, and the prediction of flood magnitudes.

- Volume III, *Erosion and Sediment Control in Highway Construction*. This volume discusses erosion and sediment aspects of natural drainage patterns, geology and soils, geometric design, drainage design, construction practices, and maintenance practices.

- Volume IV, *Hydraulic Design of Culverts*. This volume covers the basic highway functions of a culvert and its impact on the surrounding environment. The topics discussed include surveys (i.e., topographic, drainage area, channel characteristics, fish life, high water information, existing structures, field reviews), culvert location, culvert type, culvert hydraulic design, multiple-use culverts (i.e., utilities, stock and wildlife passage, land access, fish passage), irrigation, debris control, service life, safety, design documentation, construction considerations (i.e., temporary erosion control), and maintenance considerations.

- Volume V, *Legal Aspects of Highway Drainage*. This volume provides supplemental information about the legal aspects of highway drainage facilities. The topics described include Federal, State, and local laws (i.e., common and statutory), common drainage complaints, and legal remedies.

- Volume VI, *Hydraulic Analysis and Design of Open Channels.* Open channel hydraulics is a complex and dynamic subject. Simplified design methods and computer programs have evolved over the years that may be used by the designer for the hydraulic analysis of highway systems. However, many of the methods may be inappropriate for certain situations. A culvert may be analyzed with simple charts or calculator programs to determine the general flow characteristics, while a major bridge design across a flood plain will probably require considerable field data and computer analysis for proper determination of the associated flow conditions.

  This volume provides only enough information for familiarity with the subject matter. It provides general information on planning, surveys, hydrology, types of flow conditions, analysis of open channel flow, stream morphology, effects of channel alterations, channel stabilization and bank protection, roadside drainage channels, structural considerations, construction considerations, and maintenance considerations.

- Volume VII, *Hydraulic Analysis for the Location and Design of Bridges.* This volume contains considerable information for the location and hydraulic design of bridges. The primary topics discussed include planning and location, surveys, hydrologic analysis, hydraulics of the stream, stream crossing design, deck drainage, design documentation, construction considerations, and maintenance considerations. Bridges represent an important and expensive part of highway systems. They may also have considerable impact upon their water-related environment.

- Volume VIII, *Hydraulic Aspects in Restoration and Upgrading of Highways.* The other AASHTO guidelines primarily discuss drainage aspects relative to new highway construction. This guideline discusses highway drainage involving existing highways and their drainage structures. The designers should incorporate the information from this volume with the other drainage volumes for highway restoration/upgrade projects.

- Volume IX, *Storm Drain Systems.* This volume provides guidance on the compatible design of storm drain systems and existing drainage impacts to existing drainages, protecting the traveling public from large runoff events (i.e., pavement drainage), and protecting the roadway structure (i.e., embankment, subgrade, pavement) from surface runoff.

- Volume X, *Evaluating Highway Effects on Surface Water Environments*. This volume presents design practices for protecting the surface water environment from highways. The volume discusses the surface water environment in general. It also discusses the effects and their significance of highway drainage designs to the surface environment. Furthermore, it discusses threshold values that the designer and other technical personnel should realize when assessing the interrelationship of highway drainage systems with the surface water environment.

- Volume XI, *Highways Along Coastal Zones and Lake Shores.* This volume discusses the hydraulic aspects of highways in coastal-type environments. These environments include tidal basins, bays and estuaries, large lakes and reservoirs, and the lower reaches of major river systems. These guidelines address the special details of wind, wave, current, and tidal actions upon banks and shores. Such details may significantly affect the design and construction of highways in the coastal environment.

AASHTO is developing additional guidelines, Volume XII on Stormwater Management and Volume XII on Training.

E. Agency Agreements and Standards. Existing statutes, regulations, agency policies, guidelines, and standards influence the integration of highway systems into water resource systems. For this reason, agency project agreements and standards may vary the design criteria for a specific project and the designer should have copies of all such agreements and standards in the project files before proceeding with the drainage design.

F. AASHTO Model Drainage Manual (MDM), 1991. This manual presents 21 chapters on design procedures, example problems, and computer solutions for most aspects of highway hydraulic design. Although the manual is rather generic, it presents large volumes of relevant information for the design of highway drainage systems. Highway designers, hydraulic engineers, and other technical personnel should have access to this important reference manual.

G. Technical References. The publications and computer programs listed in this section provided much of the fundamental source information used in the development of this chapter. While this list is not all inclusive, the publications listed will provide the designer with additional information to supplement this manual. These publications and programs provide the technical assistance for developing and completing highway-related water resource designs.

FHWA publications are generally available from the National Technical Information Service, Springfield, Virginia, 22161.

FHWA Hydraulic Engineering Circulars

HEC No. 1, *Selected Bibliography of Hydraulic and Hydrologic Subjects*. 1983.

HEC No. 9, *Debris-Control Structures.* 1971.

HEC No. 10, *Capacity Charts for the Hydraulic Design of Highway Culverts.* 1972.

HEC No. 11, *Design of Riprap Revetment*. 1989.

HEC No. 12, *Drainage of Highway Pavements*. 1984.

HEC No. 14, *Hydraulic Design of Energy Dissipators for Culverts and Channels*. 1983.

HEC No. 15, *Design of Roadside Channels with Flexible Linings*. 1988.

HEC No. 17, *The Design of Encroachments on Flood plains Using Risk Analysis*. 1981.

HEC No. 18, *Evaluating Scour at Bridges.* Edition 2. 1993.

HEC No. 19, *Hydrology*. 1984.

HEC No. 20, *Stream Stability at Highway Structures.* 1991.

HEC No. 21, *Bridge Deck Drainage Systems*. 1993.

FHWA Hydraulic Design Series

HDS No. 1, *Hydraulics of Bridge Waterways.* Second Edition. Revised 1978.

HDS No. 2, *Hydrology*. SI Version (Planned 1994).

HDS No. 3, *Design Charts for Open-channel Flow*. 1961 (reprinted 1973).

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7.3 INVESTIGATION PROCESS

In the investigative process, the designer should obtain all available field and aerial survey data, water resources data, geomorphological data, and water quality data that is related to the highway design. This section basically describes the information required for each of these items and the methods for obtaining the required water resource data for highway design purposes. As an aid, check lists for identifying and recording necessary water resource data have been included as Exhibits. When completed, Exhibits 7.1 through 7.5 will provide the designer with a general listing of the critical investigative data necessary for proceeding with the roadway design.

A. Field and Aerial Survey. The designer should strive to obtain accurate and comprehensive field and aerial survey data. Hydrologic and hydraulic analyses are only as good as the data they are based upon. The following is a brief summary of the survey data required for these processes.

1. Existing Surveys. Survey data should be obtained to encompass as much of the proposed highway project and surrounding areas as possible. The United States Geological Survey (USGS) quadrangle maps provide a good starting point for evaluating the highway system and related water resource systems. These maps normally have a plan scale of 1:24 000 to 1:64 000. The USGS maps will show existing highway corridors, natural streams and their tributary systems, manmade structures (i.e., bridges, dams), and topographic features such as lakes, flood plains, stream patterns, and drainage basins with their respective shape, size, and elevations.

Other survey data should be obtained from as many different sources and for as many different time periods as possible. This data can be used to develop a historical perspective of the manmade and natural water resource developments within the project area.

If existing survey data is limited, then the USGS quad maps may indicate other Federal and State agencies that have performed surveys within the area. For example, man-made reservoirs may indicate design involvement by the U.S. Bureau of Reclamation. If so, then the U.S. Bureau of Reclamation may have conducted field, aerial, and hydrologic surveys of the project area. Other agencies that may have conducted surveys include USACE, FS, NPS, U.S. Fish and Wildlife, State and County Highway Departments, and various resource agencies that may have had interests in the project area. If survey data is obtained from outside agencies, then the designer should ensure that this survey data can be correlated. For example, all surveys should be converted to the same elevation datum.

Both aerial and field surveys may be used. Aerial surveys provide a general perspective of the water resource system. Specifically, they can be used to define the flood plain limits of a stream or river. Aerial surveys will only show the water surface elevation of the main stream, but not its channel bottom. Usually field survey data will be required for the channel cross section. The following is a checklist of items that should be evaluated for existing field and/or aerial surveys.

Items to be Evaluated	Type of Survey	
	Field	Aerial[1]
Drainage Areas:		
• Size		X
• Shape		X
• Elevations		X
• Vegetation		X
• Lakes/Reservoirs		X
• Urban Development		X
Natural Streams and their Tributaries:		
• Floodplains		X
• Stream Channels	X[2]	X[3]
• Vegetation	X	X
• Sedimentation	X	
Man-Made Structures:		
• Culverts	X	
• Revetments	X	X
• Bridges	X	X
• Reservoir/Dams	X	X
• Gaging Stations	X	X
• Water Supply and Waste	X	
• Water Treatment Systems	X	X

Note:
[1] Includes USGS topographic maps.
[2] Cross sections
[3] Location and pattern

2. Proposed Surveys. Review all available existing field survey records and determine the extent and type of additional data needed to complete the investigation and analysis of the water-related systems. For determining the extent of additional data, the following is a brief summary of the minimum required survey information.

a. Drainage Areas. Data is obtained for drainage areas primarily to determine the amount of water within a given water resource system. Most of the required data for this process can be obtained from USGS quad maps. The information required for this item includes drainage area size (acres or square miles), drainage area shape (e.g., narrow and deep versus shallow and wide), elevation differences between the drainage area divide and the point at which the volume of flow is to be evaluated (e.g., bridge location), type of vegetation (e.g., percent of forests), urban development (e.g., percent of drainage area), and storage capacity (e.g., lakes and reservoirs for collecting rainfall). If this information cannot be obtained from USGS quad maps, it may be necessary to conduct aerial or field surveys to determine the drainage area characteristics.

b. Natural Streams and Their Tributaries. Data is obtained for natural streams and their tributaries primarily to determine the flow characteristics that occur in them such as depth of flow, velocity of flow, sedimentation, and erosion. Generally, a combination of USGS quad maps, aerial surveys, and field surveys will be required to obtain sufficient analytical data. The information required for this item includes flood plain width, main channel cross sections, cross sections of tributary channels, flood plain vegetation characteristics (i.e., grasses, trees), channel bedding (i.e., sand, clay, gravel, and boulders), channel bed slope, channel water surface slope, flood plain and channel forms (i.e., straight or curved, pools and riffles), and high water marks. Of this information, the channel cross sections are the most costly and difficult to obtain. Also, the exact locations for obtaining channel cross section is primarily judgmental. Basically, channel cross sections should be taken at locations where there is a significant change in channel width, slope, bedding, and/or alignment. In any event, the hydraulics engineer, should be consulted and/or the USGS publication Computation of *Water-Surface Profiles in Open Channels*, and the USACE publication *Accuracy of Computed Water Surface Profiles* reviewed before submitting requests for channel cross sections to the Survey engineer.

c. Manmade Structures. These are normally culverts and bridges. For culverts, data for the existing type, size, shape, length, inlet elevation, outlet elevation, top of roadway elevation, and approaching and existing stream channel cross sections will be required for analyzing the existing hydraulic conditions. If a culvert does not exist at a proposed culvert location, then channel cross sections should be obtained at the proposed culvert inlet and outlet. For bridges, cross sections should be obtained at the proposed bridge site, upstream from the proposed site, and downstream from the proposed site. In addition to this information for culverts and bridges, the survey data required for analyzing natural streams and tributaries should also be obtained within the proposed structure location.

Other hydraulic structures should be surveyed if they have the potential to affect or be affected by the flow characteristics of proposed culverts and bridges. For example, downstream reservoirs may cause backwater through culverts and bridges. Therefore, elevations, and locations of principal reservoir components (i.e., spillways) should be obtained for determining the controlling water surface elevations at the proposed project sites. Also, upstream irrigation systems may cause significant surge flows at the proposed project site during high runoff periods. Therefore, cross sections and location data should be obtained at the controlling irrigation structures.

Gaging stations, water supply and waste water treatment systems, revetments (i.e., riprap stream banks), and storm drain systems should at least be documented in the survey records. The hydraulics engineer should be consulted if additional information is required for hydraulic structures other than culverts and bridges.

B. Water Resource System Characteristics. After the required survey information is obtained, identify those characteristics of the water resource systems that may affect or be affected by the proposed highway project.

The following is a short list of water resource systems and their characteristics that should be investigated.

1. Human Resources. The designer may encounter several water systems associated with human resources. These systems exist for the enhancement and benefit of the human environment. Since these systems may have an impact on the highway design and vice versa, the following is a brief description of systems the designer may encounter during the development of a proposed highway project.

a. Reservoir Systems. If a highway with culverts and/or bridges is located upstream or downstream from a reservoir system, then the hydraulic and hydrologic characteristics of these systems should be investigated. Basically, reservoirs are designed for flood protection, municipal water supply, irrigation water, and recreation. They generally have significant impacts upon the flood peaks, sediment transport, and water surface profiles of natural streams and their tributaries. For example, reservoirs will normally reduce the downstream flood peaks, trap upstream sediment and increase the natural upstream water surface elevations.

If a bridge is located downstream from a reservoir, the designer should contact the U.S. Bureau of Reclamation and U.S. Geological Survey for annual peak flow rates during the period of operation. The water released downstream from the reservoir will be clean due to the reservoir's capacity to trap upstream sediment.

If the bridge is located in erodible material near the reservoir (i.e., alluvial stream), then the clean water will tend to pick-up or erode the existing stream bed material in the vicinity of the bridge.

If a bridge is located just upstream from a reservoir, the natural water surface elevation will be controlled by fluctuations in the reservoir water surface. The fluctuations in the reservoir surface will also influence the sedimentation characteristics near the upstream bridge. For example, if the bridge is located in the vicinity of where the stream meets the reservoir, then the stream will tend to deposit its material at the bridge site location (i.e., alluvial fan). This will tend to increase the water surface elevation in the bridge vicinity. However, if the bridge site water surface is controlled by the reservoir only part of the time, then the streambed may tend to erode from the higher velocities of the natural stream during low water reservoir periods.

If a highway is contiguous to the perimeter of a reservoir, then bank protection may be required between the reservoir and highway. In addition to the fluctuation in reservoir elevations, consider wave action when determining bank protection material and its placement. Also, to minimize sediment entering the reservoir, erosion protection measures should be considered for highway embankments and excavation areas.

Consult the U.S. Geological Survey and U.S. Bureau of Reclamation for information on the following:

- Annual peak flows.
- Upstream and downstream sedimentation characteristics.
- Hydrologic design data of reservoir components such as principal spillway and emergency spillways.
- Reservoir elevations such as normal pool, minimum freeboard, and seasonal elevations.
- Restrictions on turbidity and fish migration in relation to highway projects.

The designer should tie this information to the horizontal and control data of the project. Together, a composite model of the hydrologic and hydraulic characteristics of the reservoir and highway can be developed for analysis.

b. Canal Systems. Canal systems may include irrigation channels, drainage channels, diversion channels, and navigational channels. Since these systems tend to have straighter alignments and less erodible banks than natural stream channels, the hydraulic analysis may be more complicated for bridges and culverts crossing these systems than for natural channels.

For example, a straight channel with nonerodible banks will tend to experience greater erosion of its bed material than a natural meandering stream with erodible slopes. Therefore, bridge foundations may experience scour. However, canals with flat slopes that receive heavy sediment loads from natural streams on steep slopes may have material deposited within their channel sections. This may result in a corresponding increase in water surface elevation at a bridge site or "filling" of a culvert crossing. Also, the effects of highway designs upon sedimentation characteristics of canals should be considered by the designer (i.e., excavation slopes, road ditches).

Canals may also significantly affect the peak flows at highway crossings. For example, most hydrologic methods for predicting peak flows at ungaged sites will not consider the effects of man-made structures such as reservoirs and canals. Therefore, the designer should be aware of the location of the highway crossing relative to structures that regulate the flow through a canal system.

A field survey should locate and document all significant features of the canal system, such as diversion gates.

The U.S. Bureau of Reclamation and local water districts should be contacted for operation and design details of the canal system.

The U.S. Geological Survey should be contacted for hydrologic information related to the canal system, while the U.S. Coast Guard should be contacted for bridge clearances over the canal if it is a navigable waterway.

c. Storm Drainage Systems. New or reconstructed highway drainage may have to connect with an existing storm drainage system. The storm drainage system normally consists of curbs, gutters, inlets (i.e., grates or curb openings), catch basins, manholes, underground pipe systems, and outfall pipes draining into natural streams. Obviously, such drainage systems are normally found in urban areas.

The designer should obtain the available hydrologic and hydraulic information used to design the existing storm drain system from the responsible agency. After this information is obtained, then the proposed highway drainage can be designed to complement the existing storm drain system. For example, if the proposed highway drainage design is downstream from the existing storm drain system, then the proposed drainage design must be adapted for increased runoff or detentions that result from the storm drain system. On the other hand, if the new highway drainage system flows into the existing storm drain system, then the existing system may require modification to handle the additional flow.

Finally, the designer should consult with planning authorities for information on future developments within the project area (i.e., subdivisions). If a new storm drain system is proposed with the highway design, then it should be capable of adapting to new developments within the area.

d. Regulated Flood Ways. As previously discussed under Section 7.2.A.1., the Federal Emergency Management Agency has designated certain flood ways in urban areas for protection under the National Flood Insurance Program. These regulated flood ways are subject to local, State, and Federal restrictions concerning increases in the 100-year water surface elevations due to encroachments.

When a highway design encroaches upon a 100-year flood plain area of residential population, the Federal, State, or local officials should be contacted for Flood Insurance maps of the project area. If these maps show the highway system encroaching within the regulated flood way, then a flood study will be required.

The flood study begins with the methods for obtaining such information as survey data and computer water surface profiles utilized by FEMA for determining the existing 100-year flood plain limits.

If possible, the highway encroachment should be modeled with the existing FEMA information to evaluate the increase in 100-year water surface elevation due to the encroachment. The primary objective is to develop a *before* and *after* comparison so appropriate officials can determine if the highway encroachment is consistent with the National Flood Insurance Act. Since this analysis will normally require considerable survey data and sophisticated computer modeling, the hydraulics engineer should be consulted for proper flood plain evaluation of the project area.

The designer should be primarily concerned with whether or not a regulated flood way exists within the project area and to what extent any highway encroachments must be minimized.

e. Water Supply and Waste Water Treatment System. Highways may influence water supply and treatment systems. For example, highway developments may increase the sediment load to water supply and waste water treatment systems for both short-term and long-term periods. If the sediment load increases are significant, then the water supply and treatment processes may be adversely impacted. For example, increased sediment load may cause premature filling of settling basins. Normally, local governments will try to regulate the amount of sediment and the timing of sediment discharges through a permitting process.

The flows from water treatment plants will generally be small compared to the flow of the streams in which they discharge. If they have any potential impact upon the highway drainage system, however, the collection of flow by both water supply and treatment systems should be considered in the highway design process.

The appropriate local agencies are to be contacted for permits and hydrologic and hydraulic information related to water supply and waste water treatment systems.

2. Fish and Wildlife Resources. Most FLH projects are located in rural and remote areas such as National Parks and National Forests. The U.S. Fish and Wildlife Service has developed a classification system for wetlands and deep water habitats. This classification system provides methods for identifying types of fish and wildlife habitats. It also provides a method for identifying some of the hydrologic and hydraulic characteristics of natural water resource systems.

To aid the development of highway designs, the following classification system similar to the U.S. Fish and Wildlife system is recommended.

a. Riverine System. This system includes practically all moving bodies of fresh water contained within a channel. Given a cross section of a stream channel and its flood plains, the riverine area includes the permanently flooded channel areas and that portion of the flood plain area which is seasonally flooded.

A riverine system may be subclassified as being intermittent, upper perennial, lower perennial, and tidal. Normally, a moving body of water will pass through all four subclassifications.

At the upper part of a drainage basin, the flow in a natural channel will occur only part of the year. This is classified intermittent.

As the channel progresses down the drainage basin, the contributing drainage area increases until the channel can sustain year-round flows, (an upper perennial channel). Both intermittent and upper perennial channels are characterized by (1) steep streambed slopes (greater than 1 percent), (2) high velocities (greater than 2.5 meters per second during flood periods), and (3) very little flood plain development. Since upper perennial streams flow year-round and have high velocities, their stream beds will normally consist of gravel, cobbles, and/or boulders. These gravel-type beds provide excellent spawning areas for fisheries. Also, upper perennial streams provide high levels of dissolved oxygen (an important feature for maintaining good fish habitat) due to the extremely turbulent flow caused by the intermix of high stream velocities and boulders and cobbles. The larger boulders may also create pools that provide feeding and resting areas for fish. An optimum upper perennial stream for fish habitat will have both pools and riffles normally associated with high velocity flows over gravel beds.

A stream classified as lower perennial is located in the lower reaches of the drainage basin. It is primarily characterized by (1) mild stream bed slopes (less than 1 percent), (2) slow velocities (less than 2.5 meters per second during flood stage), and (3) a well developed flood plain. Because lower perennial streams have slower velocities, their ability to transport large bed material is reduced. Also, the upstream sediment particles will be weathered or broken down into smaller sediment particles as they progress downstream.
Therefore, lower perennial stream beds tend to consist of fine sand to silty-clayish materials. Also, the slower velocities and fine stream bed material provide little mixing of air and water. Thus, dissolved oxygen levels will tend to be lower than those found in upper perennial streams. Given the finer stream bed material and reduced dissolved-oxygen levels, fishery spawning habitat will not be as abundant as in upper perennial areas.

Thus, fish passage provided to upper perennial streams may be the primary fishery importance of lower perennial streams.

Tidal riverine subsystems are similar to lower perennial subsystems except that their water surface elevations are influenced by ocean tides. However, the tidal riverine subsystem is still a "fresh" water body with only small amounts of ocean derived salts.

b. Palustrine System. This system consists of flood plain areas with heavy year-round vegetation and isolated bodies of water with less than 8 hectares in surface area. These isolated bodies of water are commonly recognized as marshes, swamps, and ponds.

Although these areas may not present significant hydraulic problems, they may pose serious environmental problems for new or reconstructed highway systems. Since these areas often support diverse species of plant, wildlife, and fisheries, fish and wildlife agencies should be contacted in the early planning and design stages. Basically, the two main concerns for fish and wildlife officials will be the total surface area eliminated by the highway design and the location of the eliminated surface area.

c. Lacustrine System. This system consists of natural lakes and man-made reservoirs with more than 8 hectares in surface area. The section under reservoir systems should be reviewed for hydrologic and hydraulic constraints. Environmentally, the same concerns expressed for palustrine systems will also apply to lacustrine systems.

The above classification systems provide a good starting point for the hydrologic and hydraulic evaluation of highway systems. For example, intermittent and upper perennial streams will have super critical to critical flows, steep hydrographs, very minor and localized backwater from culverts and bridges, and will experience less localized scour at hydraulic structures than those installed in lower perennial streams. On the other hand, lower perennial and tidal streams will tend to have subcritical flows, flatter hydrographs, major and more extensive backwater effects if highways and their hydraulic structures constrict flood plain areas, and will experience considerable localized scour at hydraulic structures. Classification of the particular system by physical observation will aid the designer and/or hydraulic engineer in selecting the appropriate analytical processes for evaluating water-related highway designs.

The classification system will provide information on areas of potential concern to fish and wildlife agencies. For example, upper perennial streams with high velocities and steep gradients present difficulties in the design of culverts for fish passage. However, the good sediment-transporting ability and high dissolved-oxygen levels will minimize the short-term and long-term negative impacts of highway construction within the area. However, lower perennial streams will normally be crossed by highway bridges in lieu of culverts. Thus, fish passage is not a problem. But short-term construction work in streams and long-term runoff from highway pavements and slopes may cause negative impacts that will be more difficult for lower perennial streams to adjust to if these streams have lower velocities and lower dissolved-oxygen levels. Therefore, fish and game officials may request different types of mitigation for different types of situations.

C. Geomorphologic Characteristics. Geomorphology is the geological study of the configuration and evolution of land forms. Along with precipitation and human developments, the hydrologic (drainage basin) and hydraulic (stream channel and flood plains) attributes of the project area are primarily determined by its geomorphology. Geomorphologic items include the following:

1. Drainage Basins. The drainage basin should be evaluated for size, shape, slope, storage, vegetation, and surface infiltration. These characteristics primarily affect the hydrologic runoff to a given hydraulic structure. However, these characteristics may also aid in the hydraulic analysis of such items as sediment runoff versus water surface elevation.

The size of the drainage basin is the most important property affecting runoff. Basically, the runoff will increase as the drainage basin size increases. As mentioned in earlier discussion, a USGS quadrangle map and/or aerial photographs may be used to evaluate the basin size.

The basin shape should be the next characteristic to be investigated. Long narrow drainage basins generally have lower runoff peaks than fan or pear-shaped drainage basins. The shape may be outlined by the main basin channel and its tributaries. The outlined shape allows analysis of preliminary hydraulic flow relationships between the main basin channel and its tributaries, which may also be analyzed for such items as size of tributary versus main channel size and the angle of approach by the tributary to the main channel.

The slope of the drainage basin may be defined as the change in its vertical distance to the change in its horizontal distance. The slope is normally measured at 10 percent and 85 percent of the distance along the main channel from the hydraulic structure to the drainage basin divide. Generally, the runoff will increase as the basin slope increases. Also, the main channel steepness will indicate the existing flow conditions (i.e., rapid or mild) and the sediment transport capabilities within the basin. Multiplying the basin slope by the design runoff or discharge, will provide a relative index for comparing the sediment transport power to other drainage areas where the slope, discharge, and sediment transport characteristics are known.

The storage of the drainage basin is essentially the amount of natural and manmade depressions capable of detaining or delaying runoff to the hydraulic structure location. For determining runoff, most hydrologic methods evaluate only the natural storage such as lakes, ponds, and swamps. The natural storage is normally evaluated as a percent of the total drainage basin. The presence of natural storage of up to 25 percent of the total drainage basin area may reduce the peak runoff by more than 50 percent as compared to a drainage basin with no storage. If manmade storage structures exist within a drainage area, then gaging station data should be used for determining peak runoffs.

The vegetative characteristics of the drainage basin may affect the anticipated runoff. The runoff will decrease as the vegetative percent of drainage basin area increases. When hydrologic equations consider this factor, it is normally evaluated as a percent of forested drainage area.

For example, a drainage basin with 80 percent forest cover may experience a 25 percent or more decrease in runoff as compared to a drainage basin with 25 percent forest cover. Also, the peak runoff at a hydraulic structure will tend to be more stable and longer lasting (i.e., a flat and long hydrograph curve) for a forested area as compared to a nonforested area.

Surface infiltration will affect flow characteristics such as surface flow versus ground water flow within the drainage basin. The surface infiltration within a drainage basin is a function of soil porosity (i.e., gravel versus clay), rainfall intensity, vegetal cover, and the antecedent condition of the basin soils (i.e., percent of saturation). As an example, a paved parking area will pass nearly 90 percent of its rainfall to the area downhill from it, while a porous lawn will absorb nearly 90 percent of the rainfall within its area.

Determine the drainage basin size, shape, slope, storage, and vegetative characteristics from USGS quadrangle maps and/or aerial surveys. Soil infiltration characteristics are normally field investigated. Fortunately, most hydrologic methods will indirectly compensate for soil infiltration and a field investigation may not be necessary. A field investigation of all the drainage basin characteristics is recommended for comparison of the office analysis and with the geomorphologic characteristics of the hydrologic equations.

2. Stream Channels and Flood Plains. Although drainage basins will experience some changes in their form and characteristics during the life of a project, these changes are usually not as pronounced as those that a stream channel with flood plains will experience. For example, a bridge crossing a meandering river in a wide flood plain may be abandoned if a major flood cuts a new channel within the flood plain limits. Also, riprap bank protection may reduce erosion of the riprap area, but increase downstream bank erosion. Further-more, stream channel bottoms may tend to erode downward, thus lowering the water surface elevation for a given flow and possibly causing the stream to abandon its flood plain.

The cross section of a stream channel and its flood plain is a function of the flow, the quantity and character of the sediment in movement through the section, and the character or composition of the materials making up the bed and banks of the channel. These characteristics tend to be dynamic and inter-reactive. Predicting the future shape of a channel or flood plain is beyond the scope of this publication. The following discussion centers upon the classification of stream channels and flood plain development.

Stream channels may be defined as nonalluvial and alluvial. The term alluvial generally applies to deposits of silts, sands, or gravel. Nonalluvial and alluvial may be considered synonymous with nonerodible and erodible, respectively. Since many of the basic hydraulic methods for determining stream depths and velocity are based upon rigid or nonchanging boundaries, the distinction of nonalluvial and alluvial channels is important.

Nonalluvial channels are normally found in rock valleys or in situations where manmade activities have converted the stream channel to essentially a rigid boundary. Also, stream channels near the headwaters area may experience only channel bed erosion without appreciable bank erosion, thus being a hybrid of a nonalluvial and alluvial stream. The methods for determining the hydraulic characteristics of these types of streams will normally be uncomplicated provided the analysis is confined to the rigid boundary portion of the stream and its flood plain.

Alluvial streams normally have a wavy or meandering pattern with well developed flood plains. These streams tend to erode into the outside part of their bends while depositing the eroded material just downstream on the inside of the same bend. Thus, the stream channel flow will tend to be deeper on the outside portion of the bend.

If the outside bank material is erodible, the stream will continue to erode toward the outside. Eventually, the stream pattern will take the form of a well-bent bow. The beginning and ending portions of the stream bend will come closer and closer together. If a major flood occurs and the bank material between the beginning and ending bend portions is erodible, then the flow may break through the plug between these portions and cut-off the bend. This is the typical formation of oxbow lakes. Although the main stream channel will be temporarily straight within this area, a new meander pattern will tend to form due to the stream's tendency to have helical flow.

If the material within the flood plain valley is homogeneous, the river may meander back and forth within the same flood plain area over many decades. Generally, the bank materials will consist of coarse material at the bottom and fine material at the top. This is due to the fact that coarser material is transported in the stream near the bottom and finer material near the top of the flow. If the stream overflows its bank, it may deposit enough fine material on the top of the bank to form natural levees. This will normally occur for a flood frequency comparable to 2 to 5 years.

Another important characteristic of alluvial stream channels is their tendency to have degrading (eroding) or aggrading (depositing) beds. A stream will degrade if its capability to transport material exceeds the supply of material available for transport. However, a stream will aggrade if the material available for transport exceeds the stream's capacity for transporting material. In a given location, a stream may experience both aggradation and degradation over a short period of time.

Although the availability of transportable material is difficult to estimate, the transport capability of a stream can be correlated to its water surface slope and its runoff values (peak discharge). This relationship is most useful in evaluating changes in transport power along the stream channel.

For example, a steep water surface slope is capable of transporting more material than a mild water surface slope. Thus, when the stream slope changes from steep to mild, the stream will tend to deposit material in the mild slope location that was being transported in the steep slope location. As another example, a tributary will generally have a steeper slope than the main channel which it flows into. At the point the tributary meets the main channel, the tributary will deposit its material to form an alluvial fan, assuming that the tributary experiences a backwater effect from the main channel.

An easier method for evaluating changes in sediment transport power is to consider the differences in stream velocities between two closely located stream sections.

For example, a bridge stream section will generally have less area for discharge than the stream section just upstream from the bridge. Since discharge (Q) is a function of stream velocity (V) times the flow area (A) and since the discharge must also remain constant throughout the given stream reach, then the velocities will be greater within the bridge section than those velocities just upstream of the bridge. Thus, the bridge section will have greater stream power for transporting material than the section just upstream of the bridge.

If a bridge section erodes, it is called *general* or *contractual scour*, because its flow area is smaller than the stream's natural cross section. If the bridge piers and/or abutments experience considerable adjacent erosion, it is called *local scour* because the erosion is localized to the vicinity of the obstruction. The term *degradation* applies to a stream reach that erodes over long distances while the term scour applies to more localized erosion.

Several methods should be used in evaluating the alluvial and nonalluvial aspects of streams and their flood plains. These methods include the following:

- Studying historical data (such as quad maps, aerial photos, and old bridge plans).
- Making physical observations such as viewing channel slopes of tributaries at their confluence with main streams (for possible degrading of the main channel) or by identifying a braided stream (for possible aggrading).
- Making numerical evaluations such as solving sediment transport equations (a function of slope, discharge, and sediment size).

Collectively, these methods will provide a composite perspective of the changes that may occur within the project area.

The designer should recognize that stream channels and flood plains are subject to constant change and these changes may profoundly alter the analytic processes. How reliable is the computed depth of flow if the streambed is constantly fluctuating as it degrades and aggrades? The designer should be prepared to evaluate the risks versus costs of designing for the dynamic processes of streams and their flood plains.

D. Water Quality Characteristics. Water quality characteristics include information on the value of the water resource system to humans, fish, and wildlife.

Characteristics such as pH, turbidity, conductivity, dissolved oxygen, water temperature, flow rate, and biological oxygen demand provide information for evaluating the potability of, the suitability of, fish habitat, and the compatibility of hydraulic structures with the water resource system.

Generally, water quality characteristics are only evaluated at the request of other agencies such as the U.S. Environmental Protection Agency, U.S. Fish and Wildlife, and State water resource agencies. However, water quality data should be obtained whenever possible.

The following is a summary of definitions, standards, and plans for evaluating water quality characteristics.

1. Government Water Quality Standards. The State generally is the most responsible for establishing water quality standards within the project area. There are no nationwide water quality standards. Federal laws have set goals for eliminating all point and nonpoint pollution sources. Also, local governments and environmental groups may have considerable regulations covering municipal water supplies and recreational uses of reservoirs. The type of regulations and standards will depend primarily on the type of highway project and its location.

Use the following defined parameters and values in evaluating water quality for highway systems.

a. pH. pH is a measure of the hydrogen ion activity in a water sample. It is an indirect indicator of acidity and alkalinity and can range from 0 to 14 with a value of 7.0 being neutral. If a pH is less than 7, it is considered acidic. If a pH is greater than 7 it is considered alkaline. Most fresh water aquatic life and culvert pipe materials can tolerate a pH range of 6.5 to 9.0.

b. Conductivity. Conductivity is the ability of water to carry electrical current. It is dependent upon the concentration of dissolved ionized substances thus giving an indication of the concentration of dissolved solids in the water.

A body of water that has an electrical conductance greater than 350 mhos/cm will probably be unsafe for drinking. Most freshwater aquatic life should tolerate an electrical conductance as high as 1,000 mmhos/cm.

c. Turbidity. Turbidity is an indication of the amount of suspended solids in the water. Excessive turbidity may reduce the rate of photosynthesis, cause changes in predator relationships, and cause changes in temperature. It is aesthetically displeasing. Generally an acceptable turbidity range is from 0 to 50 NTU (nephelometric turbidity units). Contract specifications may need to give maximum limits by which construction activities can increase water turbidity and temperature.

d. Dissolved Oxygen. Dissolved oxygen is the oxygen dissolved in water. It is a good indicator of the aesthetic and aquatic quality of the water. Most bodies of water having good aquatic environments are characterized by nearly saturated dissolved oxygen levels. However, a euthrophic body of water may exhibit high dissolved oxygen levels during the daytime while reaching nearly zero levels during the night. This phenomenon is due to plant photosynthesis (oxygen producing) taking place during daylight hours only, while plant respiration (oxygen consuming) continues into the night. Most unpolluted streams will show a dissolved oxygen fluctuation of only 1 to 3 mg/L per 24 hours.

While the dissolved oxygen saturation level of water may vary from 6 to 14 mg/L, de-pending upon local temperature and altitude, a range of 5 to 10 mg/L is considered satisfactory for supporting most freshwater aquatic life and producing aesthetically pleasing qualities.

2. Water Quality Data. If water quality standards exist for the project area, then water quality data has probably been collected within the region. This data can be used to develop a base for future water quality monitoring plans.

The National Water Data Exchange (NAWDEX) is a national confederation of water-oriented organizations working together to improve access to water data. It consists of member organizations from all sectors of the water-data community.

NAWDEX provides direct, on-line access to its data bases by its members and other organizations. The program is also authorized to provide limited access to the data bases of the U.S. Geological Survey's National Water Data Storage and Retrieval System (WATSTORE) and the U.S. Environmental Protection Agency's Storage and Retrieval (STORET) System.

The NAWDEX and WATSTORE data bases are maintained on the U.S. Geological Survey's computer system located at its National Center in Reston, VA. The STORET data base is maintained on the U.S. Environmental Protection Agency's computer located in the Research Triangle Park in Raleigh-Durham, NC. Users are provided with complete instruction and user manuals for accessing these data bases.

a. NAWDEX. Two data bases are maintained. The Water Data Sources Directory contains information about organizations that are sources of water or water-related data and services, types of data available, and locations from which data or services may be obtained.

The Master Water Data Index contains information about individual sites at which surface-water or ground water data are collected, locations of the sites, types of data collected, periods of record, frequency of measurements, and identification of the source organizations.

b. WATSTORE. Several files and data bases are maintained that store most hydrologic data collected by the Geological Survey.

The Station Header File contains identification, location, and physical descriptions of sites for which data are stored.

The Daily Values File contains river stages, stream flow values, water temperatures, conductance values, sediment concentrations and discharges, and other parameters that are measured on a daily schedule.

The Peak Flow File contains peak stream flow and stage values for surface-water sites.

The Unit Values File contains stream discharge values, temperatures, and other parameters measured more than once each day.

The Water-Quality File contains the results of chemical, physical, biological, and radiochemical analyses for both surface and ground waters. Access to this file is pending. This data is available through STORET.

The Ground Water Site Inventory File contains inventory information such as site location and identification data, well construction data, geohydrologic characteristics, and other data pertinent to wells, springs, and other sources of ground water.

The Water-Use File contains limited summary data on water use throughout the Nation.

c. STORET. This data base contains water quality data for both surface and ground waters. Data are stored for several Federal agencies and over 40 State agencies. These data include chemical, physical, biological, and radiochemical analyses of water samples and many other types of data.

Contact the hydraulics engineer for more information on how to obtain data from the NAWDEX data bases.

3. Monitoring Plans. The FHWA publications *Highway Water Quality Monitoring Manual and Highway Runoff Water Quality Training Course Workbook* are reference sources suitable for use in developing water quality monitoring plans.

If warranted, water quality monitoring should be conducted 12 months before construction, during construction, and 12 months after construction. Water quality testing should be performed upstream and downstream of the project area. Tests should be performed at least once per month during low flows and twice per month during high flows.

During heavy construction periods, some tests such as turbidity should be performed on a daily basis.

Monitoring should include pH, turbidity, conductivity, and dissolved oxygen. In addition to these tests, the time, date, water temperature, air temperature, and flow rate should be obtained by the monitor.

The collected data should be permanently filed with the USEPA STORET system for future reference by FHWA and other interested agencies.

7.4 DESIGN PROCESSES

Hydrologic analyses and hydraulic designs are necessary whenever water enters or crosses the highway right-of-way. It is essential to estimate the flow and provide a means to safely convey that water. The drainage structure required may be a small roadside ditch or a large bridge.

Once a flood frequency has been selected and flow rates established, the hydraulic analysis or design can be completed. This consists of establishing criteria, developing and evaluating alternatives, and selecting the alternative which best satisfies the established design criteria. Possible damages to the highway, the channel, and surrounding properties must be considered in the analysis.

Provide drainage structures with adequate carrying capacities to minimize damages. In analyzing a structure, examine the channel both upstream and downstream. Culverts should be located and oriented with the stream alignment. A drainage structure that is too small may result in backwater problems with flooding of upstream property or damage to the highway. If the channel is erodible, evaluate scour in the vicinity of the structure to determine if a lining is necessary.

This section provides guidelines and design criteria for culverts, open channels and stream crossings.

A. Criterion for Analyses and Designs. The design of a drainage system begins with the selection of the appropriate standards and the choosing of a design flood frequency. Once the design flood frequency is chosen, freeboard and other special configurations or restrictions can be established. The following standards are provided to assist in the selection process for determining the appropriate design criterion.

1. Floods. Adequate drainage designs provide facilities with capabilities of withstanding certain flood intensities without sustaining major damage. The minimum design frequencies in Table 7-2 are recommended for rural roads. See Section 7.4.B for the procedures to determine a project's design flood frequency.

A minimum design flood frequency of at least 50 years shall be used for all bridges. See Chapter 10, Section 10.3.B.

A minimum design flood frequency of 10 years should be used for all urban drainage systems (including ditches). Urban drainage systems should not cause flooding of more than one-half of a single travel lane width for the selected frequency. It may be impractical to design for less frequent flooding of these drainage systems (because of right of way considerations, costs, etc.).

Design temporary detour structures using a flood frequency of at least 10 years. However, detour structures to be used for 6 months or less may be designed on a lesser flood frequency if site specific circumstances permit. Major detour structures may require design flood frequencies substantially greater than 10 years.

Table 7-2
Flood Frequencies for Rural Roads

Projected ADT	Minimum Design Flood Frequencies (years)				
	Curbs and Ditches	Road Culverts and Embankment Protection	Small Streams Creeks ($Q_{10} < 1.5\ m^3/s$)	Large Streams Rivers ($Q_{10} > 1.5\ m^3/s$)	Bridges[1]
≤400	5	25	10	50	50
>400	10	50	25	50	50

Note: [1]See FAPG 650A. Check for 100 year flood.

2. Freeboard. Freeboard is the vertical distance between a water surface at design flow and the low point of a bridge beam or the top of a road surface. Overtopping of bridges should not be permitted unless the bridge is specifically designed to withstand the overtopping. Based on the design flood frequencies established from the guidelines set forth herein, the following freeboard criteria shown in Table 7-3 should be used.

3. Other Design Components. While freeboard may be one of the primary considerations in developing the design of a drainage structure, there are many other integral parts to be considered and evaluated in the total design of a facility.

a. Flow Rates. Culverts are generally capable of handling flow rates of less than 30 m^3/s. Bridges should be considered for stream crossings with a design flood exceeding 30 m^3/s.

Table 7-3
Freeboard Criteria[1]

Drainage Feature	Freeboard[2] (meters)
Culvert[3], Ditches, Slope protection[4], etc.	None[5]
Bridges (including long span culverts)	0.4[5,6,7]
Low water crossings	None

Notes:
[1]Floodplain ordinances or other legislative mandates may limit allowable backwater or encroachment on the floodplain. Social considerations including the importance of the facility as an emergency evacuation route or as a National defense access road should be considered.

[2]Ecological considerations and geological or geomorphic conditions may affect freeboard selections.

[3]Headwater at culvert inlets should not exceed 2.4 meters. When this occurs, the designer should consult the Hydraulics Engineer.

[4]Channel stability considerations may limit velocity or the amount of constriction.

[5]If the design flood has an inaccuracy of more than 10%, allow at least 300 millimeters of freeboard between the top of subgrade and the top of the design flood. Increase the freeboard for bridges to 600 millimeters. Freeboard for bridges is measured from the lowest point of the lowest member of the superstructure to the top of the design flood.

[6]When wooded debris is a factor to be considered, bridges should have a freeboard of 1 to 1.5 meters. When ice flows become a factor, freeboard should be from 1.5 to 3 meters.

[7]Special clearances may be required for bridges over a navigable body of water.

b. Headwater. The headwater to diameter ratio for culverts 1200 millimeters in diameter and smaller should not exceed 2.0. For larger culverts, the ratio should not be greater than 1.5.

c. Size. See Section 7.4.D for size selection criteria.

d. Gradients. Culverts should not be installed on grades steeper than 10 percent without being anchored. The minimum gradient for all minor channels and ditches shall not be less than 0.5 percent.

e. End Treatments. Concrete headwalls should be installed on the inlets of culverts 2400 millimeters in diameter and larger. On culverts 1200 millimeters in diameter or larger but less than 2400 millimeters, special end treatments such as special end sections and sloped or beveled ends should be considered. End sections should be used on culverts smaller than 1200 millimeters in diameter when the invert is within 1.5 meters or less of the shoulder elevation. This criterion may be waived when fill slopes are 1:2 and steeper or where the end of the culvert is in back of guardrail. See Section 7.4.D.11.

f. Fish Passage. Culvert barrel velocities should not exceed 1.2 meters per second for a 2-year flood.

g. Scour. When velocities at a pipe outlet exceed 2 m/s, erosion protection measures shall be considered. See Section 7.4.C.3.

h. Culvert Materials. Culvert materials and their approved applications are set forth in Section 7.4.D.

B. Hydrology. A hydrologic analysis must be performed before the hydraulic design of a drainage structure can be initiated. This process, utilizing flood discharge and frequency data, enables the designer to make a rational decision in selecting the proper drainage facilities for a functional highway.

Begin by determining the peak discharge for the site or develop a design hydrograph. The peak discharge is the maximum flow for a given storm event. A hydrograph is a graph of water flow versus time from which the maximum or peak flow of a flood and its time distribution can be determined.

Annual peak flows should be used to develop flood discharge and frequency relationships for use in economic analysis and design of drainage structures. The flood discharge and frequency relationship is best shown with a logarithmic plot of a flood magnitude versus return period.

Hydrographs may be used to estimate the length of time a road will be flooded or to evaluate the temporary upstream storage of flood waters when determining the water surface elevation for a culvert.

1. Flood Design Frequency. One of the first steps in making a hydrologic analysis is the selection of a design flood frequency. See Section 7.4.A.1 and Table 7-2. When determining flood frequency, give consideration to all significant impacts and risks involved. This determination is the responsibility of the designer. The selection of the design flood frequency shall be documented.

Design factors to be considered and the degree of documentation required depends on the individual structure and site characteristics. The hydraulic design must be such that risks to traffic, potential property damage and failure from floods are consistent with good engineering practice and economics. Recognizing that floods can not be precisely predicted and that it is seldom feasible to design for the very rare flood, all designs should be reviewed for the extent of probable damage, should the design flood be exceeded.

Design headwater/backwater and flood frequency criteria should be evaluated relative to the following:

- Damage to adjacent property.
- Damage to the structure and roadway.
- Traffic interruptions.
- Hazard to human life.
- Damage to stream and flood plain environment.

The potential damage to adjacent property or inconvenience to owners should be of major concern in the design of all hydraulic structures.

2. Estimating Peak Flow. For any given site, there are several methods available for estimating peak flows and their return periods. No single method is applicable to all watersheds. Engineering judgement and a good understanding of hydrology are essential in selecting the method to be used in a particular design or for a given watershed. The method chosen should be a function of drainage area (size and type), availability of data, the validity of the method for the site, land use, and the degree of accuracy desired. Several methods should be used and the results compared. Hopefully, the results obtained from one method will supplement the results of another method.

There are many methods available for estimating peak flows at sites without gages. These methods include the rational formula, U.S. Geological Survey (USGS) regression equations, Federal Highway Administration (FHWA) regression equations, Soil Conservation Service (SCS) methods, USGS Index Flood method, and other local methods. Most of these methods and techniques are discussed in detail in Hydraulic Engineering Circular No. 19.

a. Rational Formula. The rational formula is one of the most commonly used equations for estimating peak flows from urban, rural, or combined areas for *watersheds smaller than 124 hectares*. This formula presents a relationship between rainfall intensity and peak runoff.

$$Q = CiA/360$$

where:

- Q = Peak flow in cubic meters per second.
- C = A dimensionless runoff coefficient assumed to be a function of the cover of the watershed.
- I = Rainfall intensity in millimeters per hour, for the selected frequency and for a duration equal to the time of concentration.
- A = The drainage area in hectares.

Some values of the runoff coefficient, C, are reported by a joint committee of the American Society of Civil Engineers and the Water Pollution Control Federation. These values are considered to be applicable for storms of 5- to 10-year frequencies. Storms with greater recurrence intervals require the use of higher coefficients because infiltration and other abstractions have a proportionally smaller effect on peak runoff.

The rainfall intensity (i) can be obtained from an Intensity-Duration-Frequency (I-D-F) curve for the local area. In the eastern United States this curve can be developed from information in NOAA Technical Memorandum NWS HYDRO-35, *5 to 60- Minute Precipitation Frequency for Eastern and Central United States*. HYDRO-35 contains precipitation and frequency information for durations of 60 minutes and less. For durations of greater than 60 minutes, rainfall intensity-frequency data are obtained from

Weather Bureau Atlas Technical Paper 40, *Rainfall Frequency Atlas of the United States*. In the western 11 States, isopluvials for 2-year and 100-year frequencies and 6- hour and 24-hour durations are provided in the 11 volumes of NOAA Atlas 2.

The time of concentration (t_c) for overland flow can be determined by various methods. Nomographs are presented in HDS No. 4 and various Natural Resources Conservation Service publications. Mathematical methods are also available as presented in HEC No. 19 and HEC No. 12. The design engineer needs to be aware of the assumptions implicit in these methods.

When using the rational formula, make the following assumptions:

- The peak flow occurs when the entire drainage area is contributing flow.
- The rainfall intensity is uniform over a duration of time equal to or greater than the time of concentration.
- The time of concentration is the time required for the runoff to flow from the most remote point in the watershed to the point of interest.
- The frequency of the peak flow is equal to the frequency of the rainfall intensity.

b. Natural Resources Conservation Service (NRCS) Methods.
The SCS has published a method of calculating peak flows for *watersheds with areas smaller than 800 hectares*. The method uses charts and tables for a generalized 24 hour storm. The graphs relate discharge to precipitation and drainage area for various soil curve numbers and for flat, moderate, and steep slopes. This method was developed for rolling agricultural and rolling undeveloped land.

A detailed explanation of this method can be found in Section 4 of the NRCS *National Engineering Handbook* and in HEC No. 19.

The NRCS has also published a tabular method of estimating peak discharges and a crude hydrograph for use on *watersheds up to 50* square kilometers in area. This method is used to estimate the effect of:

- changes and development in the watershed, and
- detention storage for small watersheds.

Experience is necessary in determining the various parameters required in the NRCS methods.

c. Regional Regression Equations. Regression equations are one of the most commonly accepted methods for estimating peak flows at sites without gages or sites with insufficient data. Multiple regression analysis techniques are used to determine the relation of basin characteristics and climatic conditions to flood peaks of selected recurrence intervals. Information from gaged basins with similar drainage patterns and climatological characteristics are used to develop regression equations. Studies throughout the country have established peak flow equations based on multiple linear regression techniques. The equations are of the form

$$Q_T = a\ A^b\ B^c \ldots M^n$$

Where:

Q_T	=	flood magnitude having a recurrence interval T.
a	=	Regression constant.
A, B, C,...M	=	basin and climatic parameters.
b, c, d,...n	=	regression exponents.

The primary basin characteristic is the drainage area. Almost all regression equations include drainage areas above the point of interest as an independent variable. Other parameters typically required are precipitation, channel slope, basin elevation, etc.

The advantages of using a multiple regression analysis are as follows:

- Provides a mathematical relation between a dependent variable (Q) and independent variables (A, B, C, etc.).

- Provides an evaluation of the independent variables that best define the dependent variable.

- Provides a measure of the accuracy of the equation (standard error of estimate) and tests the significance of the coefficients of each independent variable.

- Evaluates relative significance of each independent variable by indicating those variables that have a coefficient that is significantly different from zero at a particular percent confidence level.

The U.S. Geological Survey, in cooperation with the States, has developed regression equations for most of the United States. The equations are contained in individual State reports. These regression equations permit peak flows to be estimated for recurrence intervals ranging from 2 to 100 years for natural streams. Regression equations are developed using independent variables (basin characteristics) within given ranges for each State and hydrologic region. The equations should be applied within the range of independent variables utilized in the development of the equations since the relationships of the equations outside these ranges is not known.

Whenever possible, peak flows obtained from regression equations should be compared to flow frequencies at nearby gaging stations to evaluate validity. Regression equations may give better estimates of peak flows of various frequencies than formal statistical analyses, especially since the regression equations more nearly predict the potential of the watershed to experience a peak flow of a given magnitude whereas a frequency analysis is biased by what has been recorded at the site.

The FHWA method for estimating peak flows from small rural watersheds relates the peak flow to easily determined hydrophysiographic parameters. A multiple regression approach was used to develop equations for each of 24 hydrophysiographic zones identified for the United States and Puerto Rico. The rainfall isoerodent factor, watershed area, and difference in elevation are the independent variables required for predicting the 10-year discharge with the FHWA 3-parameter method. Five- and seven-parameter methods, as well as an all-zone technique, are also available. Adjustment to the 10-year equations must be made for basins with surface storage greater than 4 percent. Discharges for other return periods are determined as a function of the storage-adjusted 10-year event.

The FHWA method is intended for use on watersheds smaller than 130 square kilometers but may be used on areas up to 250 square kilometers. The FHWA method is outlined in the report, *Runoff Estimates for Small Rural Watersheds and Development of a Sound Design Method*. This method was developed from a smaller data base than USGS regression equations, but does provide the designer with an alternate method for estimating peak flows. This method should not be used if the area of interest is covered by USGS regression equations.

A multiple regression analysis method (channel geometry method) exists that uses channel characteristics in the estimating procedure. This method is primarily used in some of the western States with bankfull width as the primary factor. Considerable difficulty can be experienced when determining channel characteristics for use with this method.

Generally, the more comprehensive the area over which the regression equations are developed, the less reliable the results. Each of the regression equations has been developed for a specific range of variables.

The designer needs to fully understand the limitations and applications for each of the regression analysis techniques to most effectively estimate a peak flow.

d. Flood Frequency Analysis Using Recorded Data. When a sufficient period of record is available, a more desirable method for determining the peak flow may be a flood- frequency analysis of flows that have occurred at or near the site. Analyzing flood-frequency relationships from actual streamflow data uses records of past events and statistical relationships to predict future flow occurrences. The best circumstance for estimating peak flows is to have a stream gage near the site for a large number of years. The more years of record, the more accurate the estimate will be. It is recommended that the period of record should be at least one-half the frequency of the design flow. Unfortunately, flow records are generally insufficient or do not exist for the site of interest. This is usually true for locations where most Direct Federal drainage structures are required. This method assumes that there have been no significant changes in the characteristics of the drainage area or climatological patterns that will alter the ability of the basin to produce runoff.

Several of the more popular techniques include Log-Pearson Type III, Normal and Log-Normal, and Gumbel Extreme Value Distributions. Refer to HEC No. 19 for analysis methods of gaged data.

Regional equations may improve peak flow estimate at gaged sites by weighting the statistical analysis estimate with the regression estimate.

Peak flow estimates obtained by one method should be compared to estimates obtained by another applicable method. Significant differences may indicate the need to review data from other comparable watersheds or the need to obtain historical data.

e. Verification of Flow by Historical Observations. Data can sometimes be obtained that can be used to estimate the discharge of historical floods through stage-discharge relationships or open-channel flow techniques. Useful information might include:

- highwater marks, and

- eyewitness reports of overtopping depths of highways and bridges.

Flows determined by historical observations should be used only as a check on other methods. Because of the small number of observations or inherent inaccuracies, flood-frequency curves should not be developed solely from this method.

3. Hydrographs. To estimate time of peak flows for a drainage basin, time of water overtopping a road, or the effect of upstream storage on peak discharge, a plot of flow versus time (hydrograph) is necessary. The method used to develop the hydrograph depends on the data available for the drainage area, the validity of the method for the site, and the experience of the designer with the method.

One of the following methods, whichever is most appropriate, should be used for the site under consideration.

a. Unit hydrographs. A unit hydrograph is defined as the direct runoff resulting from a rainfall event, which has a specific distribution in time and space and lasts for a unit duration of time. Unit hydrographics are most accurate when based on continuous readings from stream and rainfall gages. The ordinates of the unit hydrograph are such that the volume of direct runoff represented by the area under the hydrograph is equal to one inch of runoff from the drainage area. Using a unit hydrograph, a hydrograph for other rainfall events can be developed based on differing amounts of precipitation.

b. Synthetic unit hydrographs. When gage data is not available for stream crossings, one of the following methods for synthetic unit hydrographs shall be used.

(1) Snyder and NRCS synthetic unit hydrographs. These are two of the most common synthetic unit hydrograph methods. Use the HEC-1 computer program to develop unit hydrographs, using either of these methods.

(2) USGS synthetic unit hydrographs. The USGS is developing reports for each State that will give hydrographs for a range of return periods. This method uses USGS procedures for estimating peak flows to find the hydrograph peak. The shape of the hydrograph depends on basin characteristics.

Stream gage data is the basis for most flow prediction methods. Gages can give continuous flow measurements or they may give only the peak flow that occurred between readings. Continuous reading gages give the entire hydrograph of a flood.

Where the site being studied is on the same stream and near a gaging station, peak discharges can be adjusted to the site by drainage area ratios using drainage area to some power. Gaging station records of similar streams in the region should be used as a guide in making this adjustment.

C. Open Channels. Open channels may be natural or manmade channels in which water flows with a free surface, and are the primary facilities for conveying surface runoff.

Channels in roadway design include the following types:

- Roadside ditches in cut sections.
- Gutters in curbed sections.
- Toe-of-slope ditches.
- Interceptor ditches placed back of the top of cut slopes.
- Inlet and outlet channels for culverts.
- Channel changes of existing streams.
- Rivers and streams parallel to the roadway.
- Stream channels under bridges.

The analysis and understanding of open channel hydraulics is used to evaluate or design channels for roadway hydraulic structures.

In the analysis which establishes the best hydraulic design criteria, factors such as capital investment and probable future costs including maintenance and flood damage to properties, traffic service requirements, and the stream must be evaluated. The hydraulic design of open channels consists of establishing the criteria, developing and evaluating alternatives, and selecting the alternative which best satisfies the established criteria. The detail in which risks are considered should be commensurate with the flood hazard at the site, economics, and current engineering practices.

The adequacy of channels under bridges, and those channels immediately upstream and downstream from bridges, as well as their stabilization, are the responsibility and concern of the hydraulics engineer and the bridge design staff. However, the designer (concerned with the location and alignment of bridges) is responsible for providing a vicinity map to the bridge design staff for each bridge site.

1. Hydraulics of Open Channels. This section contains a general discussion of the fundamentals of open channel hydraulics and the application of the methods and procedures for analysis and design of channels.

The following are the major objectives of open channel hydraulic analysis:

- Documentation of existing conditions.
- Analysis and documentation of the effects that alternate design will have on existing conditions.
- The design of a proposed facility.

The water surface profiles, velocity and flow distribution are of primary concern in achieving these objectives.

a. Types of Flow. Open channel flow is usually classified as uniform or nonuniform; steady or unsteady; and subcritical, critical, or supercritical. Of these, nonuniform, unsteady, subcritical flow is the most common type of flow in open channels. Due to the complexity and difficulty involved in the analysis of nonuniform unsteady flow, most hydraulic computations are made with certain simplified assumptions that allow the application of steady, uniform, or gradually varied flow principals and methods of analysis.

Steady flow methods assume that the discharge at a point does not change with time. Uniform flow methods assume that there is no change in velocity, magnitude, or direction with distance along a stream line. Therefore, steady uniform flow assures constant velocity and flow rate from section to section along the channel.

Steady uniform flow is an idealized concept of open channel flow that seldom occurs in natural channels and is difficult to obtain even in model channels. *For most practical highway applications the flow can be assumed to be steady and changes in width, depth, or direction are sufficiently small that flow can be considered uniform.* The changes in channel characteristics occur over a long distance such that flow gradually varies. For these reasons use of the uniform flow theory is usually within acceptable degrees of accuracy.

By plotting specific energy head against depth of flow for a constant discharge, a specific energy diagram is obtained. When specific energy is minimal, the corresponding depth is critical depth. Flow depths less than critical are termed supercritical flow, and depths greater than the critical depth are termed subcritical flow.

The distinction between subcritical and supercritical flow is important in the analysis of open channel flow. Supercritical flow is often characterized as rapid or shooting with flow depths less than critical depth, whereas subcritical flow is tranquil and slow with depths greater than critical. The location of control sections, and the method of analysis will depend upon which type of flow prevails within the channel reach being studied. The Froude number uniquely describes these flow regimes, with the Froude number of critical flow being equal to one. Values greater than one indicate supercritical flow, and values less than one indicate subcritical flow.

In open channel flow, critical depth is the flow depth in which the specific energy is a minimum. The specific energy is expressed as:

$$H_E = d + \frac{V^2}{2g}$$

Where:

HE = specific energy (meters)

d = depth of flow (meters)

V = velocity of flow (m/s)

g = acceleration constant (m/s^2)

b. Equations. The following equations are most commonly used to analyze open channel flow.

Manning's Equation:

$$V = \frac{1}{n} R^{2/3} S^{1/2}$$

Energy Equation:

$$d_1 + Z_1 + \frac{(V_1)^2}{2g} = d_2 + Z_2 = \frac{(V_2)^2}{2g} + H_L$$

Continuity Equation:

$$Q = AV$$

Conveyance Equation:

$$k = \frac{Q}{S^{1/2}} = \frac{1}{n} AR^{2/3}$$

where:

Q = Discharge. (m^3/s)
A = Cross section of flow area. (m^2)

$$R = \frac{A}{WP} \ (hydraulic \ radius)$$

WP = Wetted perimeter of flow area. (m)
V = Mean velocity. (m/s)
S = Slope of energy grade line. (m/m)
n = Manning's roughness coefficient.
d = Depth of flow at a point. (m)
Z = Elevation or height above some datum in meters.
H_L = Energy head loss. (m)
K = Conveyance

There is no exact method for selection of "n" values in Manning's equation as this coefficient expresses the resistance of flow which consists of many variables. The factors affecting Manning's "n" values include the following:

- Surface roughness.
- Vegetation.
- Channel irregularity.
- Channel alignment.
- Scour and sedimentation.
- Obstructions.
- Size and shape of channel.
- Flow depth and discharge.
- Seasonal changes in vegetation.
- Sedimentation bedload and forms.

Some typical Manning's "n" values can be found in Hydraulic Design Series No. 3, *Design Charts for Open Channel Flow*.

In addition, the FHWA manual titled *Guide for Selecting Manning's Roughness Coefficients for Natural Channels and Flood Plains and Roughness Characteristics of Natural Channels*, WSP 1849 list procedures for the determination of Manning's roughness coefficient for channels and flood plains. Photographs of flood plain segments where "n" values have been verified are presented as a comparison standard to aid in assigning "n" values to flood plains.

Manning's equation is used for open channel analysis where uniform flow exists or can be reasonably assumed to exist. Nonuniform or varied flow requires the use of methods other than, or in addition to, Manning's equation. The energy equation is used to analyze flow where changes in the flow resistance, size, shape, or slope of channel occur (gradually varied flow). The energy balance concept of the energy equation is especially useful for computing water surface profiles.

The conveyance equation is a convenient method for analyzing the flow velocity and distribution where the cross section consists of multiple subdivisions each with a different "n" value or geometric character. The continuity equation and Manning's equation are used to compute channel discharges directly for a given or assumed depth of flow.

c. Flow Depths. There are various flow depths that are used in a hydraulic analysis.
Some of the more common are the following:

(1) Normal depth. Depth at which uniform flow will occur for a given discharge and channel.

(2) Critical depth. Depth for which specific energy is a minimum for a given discharge.

(3) Mean depth. Depth determined by dividing the area of flow in a given channel by the width of flow at the surface. This is sometimes referred to as the hydraulic depth.

(4) Equivalent depth. Depth computed by converting the area of flow to a rectangular flow area with the width of the rectangle twice the depth (equivalent depth) of the rectangle.

2. Analysis of Open Channel Flow. Channel design is a process of establishing criteria, analyzing existing conditions, and using trial and error solutions to develop a design that meets the established criteria.

The following are factors to consider when analyzing open channel flow:

- Stage and depth.
- Channel roughness, geometry and alignment.
- Waterway area.
- Conveyance.
- Energy gradeline and water surface slopes.
- Discharge.
- Velocity.
- Flow distribution.
- Drift and debris.

The stage-discharge relationship is one of the more important factors considered in analysis and design. The total discharge of the stream may be computed for various depths. The data plotted in graphic form (sometimes termed a rating curve) gives the designer a visual display of the relationship.

For channel design, an accurate stage-discharge relationship is necessary to evaluate the interrelationships of flow characteristics (such as width and depth of flow) with certain design characteristics (such as freeboard, conveyance capacity, and type and degree of channel stabilization). The stage-discharge relationship can be used to evaluate a range of conditions.

The stage-discharge relationship may be estimated by several techniques. A single section analysis may be used with limited data for preliminary analysis or for situations where the basic assumptions in a single section analysis are reasonably applicable. A more accurate but more complex method of estimating stage-discharge relations involves the use of water surface profile computations. The method to be used will depend upon the accuracy required, the risk involved, the cost of the study, and the validity of the basic assumptions of a single section analysis.

a. Single Section Analysis. The single section analysis method of establishing a stage-discharge relationship is based on certain simplifying assumptions that must reasonably apply to the actual channel conditions if the relationship is to be used for other than preliminary studies. The analysis can be used for design studies or in a control section, to identify a starting elevation for a water surface profile, or for preliminary studies. This type of stage-discharge analysis is approximate and may be subject to large error if the assumptions implicit in single-section analysis are not reasonably applicable.

The single section method assumes uniform discharge, cross section, slope, and "n" values. These values must be reasonably representative of the average channel characteristics within a uniform cross section. Computations involve designating subsections of the cross section according to geometric and roughness characteristics and computing the conveyance of each subsection for various depths of flow. The total conveyance of the section at any given stage is equal to the sum of all subsection conveyances.

The conveyance equation is used to compute conveyance in subsections. The total discharge is equal to the sum of all subsection conveyances across the channel section multiplied by the slope factor ($S^{0.5}$). The slope used should be the water surface slope. However, the channel slope is assumed to be parallel to the water surface, for uniform flow and if a one section analysis is valid, S must also be equal to S_o.

When estimating a stage-discharge relation by the single section method, it is desirable to have at least one reference point of known stage-discharge data. With this information, the known point can be compared with the computed rating curve and if necessary, adjustments made to roughness or slope values to obtain satisfactory correlation. The computed stage is very sensitive to the estimated slope, and small adjustments within the range of accuracy of estimation of the water surface slope are not contrary to the assumption that $S = S_o$.

b. Water Surface Profiles. The use of a water surface profile is a more accurate method of establishing the stage-discharge relationship for open channels. This method should be used in critical areas and for final studies where uniform steady flow cannot be assumed to be reasonably representative of actual flow conditions.

Water surface profile computations take into account the many variables and controls that influence the stage-discharge relationship. The computation procedures permit taking into account changes in cross section, roughness, or slope along the stream. Rapidly varied flow conditions such as hydraulic jumps, drawdowns and abrupt transitions must be computed individually and integrated into the profile analysis.

The energy equation should be used to compute water surface profiles. The energy regime (subcritical or supercritical) of the channel, as well as the type of channel, (natural and irregular or uniform prismatic), will determine which of the following procedures is to be used. When flow is subcritical, the hydraulic control is downstream and the analysis must begin a sufficient distance downstream of the channel reach in question and proceed upstream. In supercritical flow, the control section is located upstream and the profile computations must begin at the control and proceed downstream. The control is critical depth where flow passes from subcritical to supercritical. Additional discussion of control sections is contained in the next section. For natural or irregular channels, use is made of an energy balancing technique, usually the standard Step Method or some variation. Cross sections and channel roughness descriptions are required at each location along the stream where changes in section, slope, and roughness occur.

When the water surface profile computation involves a channel of uniform cross section and roughness but with reaches of different slopes, a direct step method is normally employed. Chow's *Open Channel Hydraulics* and the U.S. Geological Survey's *Computation of Water-Surface Profiles in Open Channels* include discussions of theory and computational procedures for these methods. These methods require iterative computations but various computer programs are available that carry out these computations.

WSPRO/HY-7 is the water surface profile program developed for the analysis of bridge waterways and the program recommended. An alternative program is the U.S. Army Corps of Engineers HEC-2 program.

c. Control Sections. Sections of stream channel where the geometric and physical characteristics control the depth of flow (a stable stage-discharge relationship) are known as control sections. In stable channels with subcritical flow, this relationship is controlled by a section or reach downstream of the site known as section control or channel control, respectively.

Section controls may be either natural or manmade and may consist of a dam, a ledge or rock outcrop, a boulder-covered riffle, a roadway or railroad embankment, a constriction at a bridge crossing, or other topographic feature. Section controls are frequently effective only for low flows, becoming completely submerged and thus ineffective at medium and high stages. Control sections of this type are most easily identified by field observation.

Channel control consists of all the channel's physical features which, for a given discharge, will determine the stage at a site. These features include waterway area and geometry of channel cross sections; roughness characteristics of the channel bed, banks and flood plain; and channel and flood plain alignment. If channel control is known or suspected to govern the stage-discharge relationship through a channel reach, the water surface profile calculation should begin downstream of that reach with two or more alternate starting water surface elevations and separate profiles computed upstream. If sufficient distance and sections are employed in the Standard Step Method between the starting point and the channel section for which the stage-discharge relationship is desired, the separate profiles will tend to converge on the same water surface elevation.

The stage-discharge relationship for channels where flow is supercritical is controlled by features located upstream of the site. This feature could be a change from a mild or flat slope to a steep slope, a constricted section, a weir, an overflow dam, or other feature. Water surface profile computations must begin at the control section and proceed downstream through the site to the next control section in order to determine if supercritical flow at the site will be submerged by subcritical flow downstream. Water surface profile computations will be grossly in error if the computations are carried upstream through a channel reach subject to upstream control.

3. Channel Stabilization. Design channels to proper size and type to convey the runoff. They must be stable so that excessive erosion and/or scour does not occur along the channel bottom or channel banks. This may require protecting the channel with some form of lining.

For roadside drainage channels and the smaller streams, rock riprap, concrete, and vegetation may be used as means for channel lining. Procedures for the design of roadside drainage channels are contained in Hydraulic Engineering Circular No. 15, *Design of Stable Channels with Flexible Linings*.

For the larger streams and rivers, rock riprap or some other means of stabilization may be necessary. The design procedure of rock riprap for the larger streams and rivers is included in Hydraulic Engineering Circular No. 11.

The small channels normally associated with the typical section of the roadway may be minor drainage channels and include the following:

- Roadway ditches in cut sections.
- Gutters in curbed sections.
- Toe-of-fill and top-of-cut ditches.
- Furrow ditches.
- Small channels formed by berms.
- Spillways and waterways.
- Inlet and outlet ditches for small culverts.

The cross sections of these channels are generally based on minimum standard dimensions to permit easy construction and maintenance with highway equipment. These channels normally have adequate capacity as long as they are properly maintained; have sufficient grade; and erosion, siltation, slides, or plugged culverts are not a problem. Consider the spacing of culverts or inlets to prevent excessive buildup of water in the ditch or gutter when designing roadway cut ditches and curbed gutters. Minor drainage channels may have vee, trapezoidal, rectangular, or triangular shapes.

In areas where it will provide adequate protection, vegetation is generally the most economical lining. Fiberglass roving, jute or other organic netting, or a type of synthetic fabric may be needed to establish a vegetative lining in some ditches.

In areas where vegetation will not provide adequate protection, the channel may be lined with rock or stone of suitable size, or with asphalt or concrete. Smooth linings generate higher velocities than rough linings such as stone and vegetation, and provisions must often be made at the outlet of a smooth lined channel to dissipate the energy of high velocity flow in order to avoid undue scour. This is generally the case at the bottom of spillways and waterways down cut and fill slopes. If high velocity flow (supercritical velocity) is developed in a channel because of smooth lining or steep grades, a special channel design may be required.

If a minor drainage channel is to carry more than the normal runoff from the highway cross section or if its grade will be very flat, the channel shall be designed by the hydraulics engineer. The designer should recognize the conditions that may require this additional work and bring them to the attention of the Hydraulics engineer.

The minimum grade for minor channels should desirably be 0.5 percent. Absolute minimum grades are 0.3 percent for both curbed pavement sections and "v" ditches. In urban areas, curbed sections may have a minimum grade of 0.15 percent. Flat-bottom ditches, 2.5 - 3.0 meters wide, may have a minimum grade of 0.5 percent.

At the tops of crest-vertical curves and the bottoms of sag-vertical curves, there will be substantial lengths of ditch or gutter grade that are flatter than the absolute values above. This is generally not a serious problem on crests, but additional culverts may be needed in sags. In the bottom of sag curbed sections, place an inlet at the bottom and another inlet at a slightly higher elevation to provide protection should the bottom inlet become plugged.

It is not necessary that the ditch grade follow that of the roadbed. Also, it is not necessary for the roadside ditch to be standardized for any length of highway. Wider, deeper, or flat-bottom ditches may be used as required to meet the different amounts of runoff, slopes of channels, type of lining, and distances between points of discharge into culvert inlets. Ditches that follow the roadway can be included in the computer earthwork design by use of the *Special Ditch Grade and Slope Selection* forms.

Riprap usually consists of a layer of loose rock placed on embankments along streams, at inlets and outlets of culverts, and on open drainage channel sides and bottoms. The purpose of such riprap is to prevent scour and washouts that would damage a drainage facility, the highway, or adjacent property. Loose rock riprap may also be used as an erosion control method on slopes highly subject to erosion.

Riprap may be in forms other than loose rock, including keyed rock, hand-placed rock, mesh-enclosed rock, grouted rock, concrete in bags, concrete slabs poured in place, or precast concrete blocks.

Keyed riprap is loose rock riprap that is slapped with a piece of heavy steel plating after placement, in order to key the rocks together and provide a smoother surface. Keying also increases stability and allows the use of less rock or a smaller size rock.

a. Riprap Design. The design of riprap includes a determination of the depth of water and the velocity of flow that will impinge upon the rock for the design flood, and the determination of the class and thickness of the riprap layer that will withstand the water forces.

These determinations are the responsibility of the hydraulics engineer. (See Section 7.1.B)

There are five classes of riprap that are generally used along streams for low, intermediate, and high velocity forces. These classes and their gradations are specified in the current FP, which makes the following recommendations for their use:

- Class 1 to protect areas from minor erosion.
- Class 2 as a ditch lining in areas exposed to significant scour.
- Class 3 for scour protection at the outlets of culvert pipes smaller than 1200 millimeters in diameter.
- Class 4 for scour protection at the outlets of culvert pipe larger than 1200 millimeters in diameter and for protection of roadway embankments susceptible to scour.
- Class 5 and 6 for protection at bridge abutments, piers, or at other critical areas susceptible to erosion.

The plans shall show one or more typical sections with dimensions for the types of riprap specified and indicate the estimated quantities at each riprap site.

Two methods of constructing riprap blankets are using a foundation trench or using a thickened toe. The foundation trench is preferred where it is feasible. The foundation trench should be dug to hard rock, keyed into soft rock, or dug below the depth of scour. If the scour depth is questionable, the thickened toe may be used. The thickened toe will adjust itself should scour occur and thus provide deeper support. A foundation trench will not normally be required in solid rock. However, if the riprap will be founded on a steep rock slope above the stream bottom, a trench or a bench should be provided at the base of the riprap, or some other means used to retain the riprap.

The ends of riprap sections (particularly the upstream end) are often not given due consideration in design or during construction. Indicate on the plans or specify in the specifications that the ends of riprap sections are to be keyed into the natural ground. If this is applicable, allow a sufficient keyed depth to prevent undermining and migration of the rocks at the ends.

Ordinarily, riprap shall be placed outside the normal fill slope. However, in restricted areas, riprap may be incorporated in the normal fill slope.

Gabion mattress (See HEC No. 15) stability is similar to that of riprap but because the stones are bound by a mesh, they tend to act as a single unit. Movement of stones within a gabion is negligible. This permits use of smaller stone sizes compared to those required for loose riprap. Of course the stability of gabions depends on the integrity of the mesh. In streams with high sediment concentrations or with rocks moving along the bed of the channel, the containment mesh may be abraded and eventually fail. Under these conditions the gabion will no longer behave as a single unit but rather the stones will behave individually. Applications of gabion mattresses and baskets under these conditions should be avoided.

b. Filter Material. Many riprap failures have been the result of fine soil from the embankment being washed away through the openings in the riprap. The riprap then loses some of its stability and is easily moved by the force of the water during flood conditions. For channels protected with rock riprap or gabions, the need for a filter blanket must be analyzed.

The filter blanket may be either a granular filter blanket or a filter fabric. Filter fabric is a woven pervious synthetic cloth placed on the slope under the riprap blanket which prevents fine soil from washing out of the embankment. Specify filter fabric for all slopes along a stream where riprap is placed, except on solid rock or where the hydraulic engineer indicates that it is not necessary. Both HEC No. 11 and HEC No. 15 provide design guidance for filter blankets.

4. Channel Changes. Alterations or relocations of existing stream channels should be avoided wherever possible without incurring excessive costs to the project. Consider alternate solutions to prevent unnecessary disruption of natural channels. If a channel change is necessary, the concurrence of all agencies having legal responsibility for the waterway shall be obtained before the change is incorporated in the final plans.

Properly designed channel changes can reduce the hazard of flood damage to a highway crossing by reducing skew and curvature, and by sometimes providing a larger main channel. Unfortunately, there are nearly always unwanted side effects that damage fish habitat and generally reduce the quality of the streamside environment. Velocity of flow is almost always increased over that of the natural channel because of a reduction of channel roughness and an increase in the channel slope. Erosion and downstream siltation problems may result from a channel change that may last over a long period of time. The removal of stream bank vegetation, the raw cut slopes, and the channel lining are detrimental to the fish carrying capacity of the stream. These modifications are also visually unattractive.

When a channel change is necessary, design the channel with stable streambed and banks capable of carrying the design flood. Make special efforts to improve fish habitat and visual appearance.

a. Design. Where practical, the channel change should duplicate the existing stream characteristics including stream width, depth, slope, sinuosity, bank cover, side slopes, and flow and velocity distribution. Complete a hydraulic analysis to determine the adequacy of the channel change and whether a lining is needed.

b. Linings. In order to retain stable channels, channel changes are generally lined with riprap. The banks, and very often the bottom also, may require a lining. Riprap linings shall be designed using procedures in HEC No. 11.

c. Enhancement for Fish Habitat and Aesthetics. The following additional steps should be considered to improve on a channel change:

- Require that the clearing limits not extend outside the slope stakes.

- Design channel sections that approximate the natural channel. Such a channel will be deepest on the outside of bends. Avoid the conventional neat lines of slope and gradient. Attempt to make the new channel fit into the surroundings. An on-site review or aerial photos may be helpful here.

- Excavate all cut slopes above the waterline with rough surfaces and revegetate to stabilize the soil and provide shade.

- Do not permit riprap to extend above a natural channel bank even if overflow is anticipated. Such riprap serves little, if any, purpose and is not pleasing in appearance.

- If space is available, riprap should be topped with a layer of graded rock and then topsoil and planted with native vegetation to provide shade and help restore a natural appearance.

- Boulders may be installed in the channel bottom to improve fish habitat. This is required by some State fish and game agencies. As a rule of thumb, "fish boulders" should be large enough to withstand the force of the current, placed low enough so that the mean annual flood will inundate them and wash away accumulated debris, and be small enough so that a single boulder or cluster of boulders will occupy no more than 25 percent of the channel bottom width. Fish boulders should be located in a random manner.

If the section of existing channel that is being relocated has suitable boulders in it, it is preferable that these be used in the channel change rather than using fractured rock. This principle applies also to cobbles and gravel in the existing streambed which, if suitable, may be used to line the bottom of the channel change.

- Alternating rock jetties (groins) may be constructed to control velocity and improve fish habitat. Jetty rock should be of a larger size than those used for riprap on the banks of the channel change.

- Gabion "ribs" extending across the channel may be used as control structures or weirs and also to improve fish habitat.

d. Plans. Drawings should be prepared for all alterations, relocations, and encroachments of waterways, except for very minor encroachments. The plans should show the plan and profile for the new channel, provide an adequate number of cross sections so the channel can be constructed as designed, and include details of additional measures to restore fish habitat and a natural appearance such as boulders, weirs, groins, and plantings.

D. Culverts. The function of a culvert is to convey surface water across or from the highway right-of-way. In addition to the hydraulic function, the culvert must carry construction and highway traffic and earth loads. Therefore, culvert design involves both hydraulic and structural design considerations. Hydraulic aspects of culvert design are set forth in this section.

Culverts are available in a variety of sizes, shapes, and materials. These factors, along with several others, affect their capacity and overall performance. Sizes may vary from 300 millimeter circular pipes to extremely large arch sections that are sometimes used in place of bridges.

The most commonly used culvert shape is circular, but arches, boxes, and elliptical shapes are sometimes used. Pipe arch and elliptical shapes are generally used in lieu of circular pipe where there is limited cover. Arch culverts have application in locations where less obstruction to a waterway is a desirable feature, and where foundations are adequate for structural support. Box culverts can be designed to pass large flows and to fit nearly any site condition. A box or rectangular culvert lends itself more readily than other shapes to low allowable headwater situations since the height may be decreased and the span increased to satisfy the location requirements.

The material selected for a culvert is dependent upon several factors, such as durability, structural strength, roughness, bedding condition, abrasion and corrosion resistance, and water tightness. The more common culvert materials used are concrete, steel (smooth and corrugated), and corrugated aluminum.

Another factor that significantly affects the performance of a culvert is the culvert inlet configuration. The culvert inlet may consist of a culvert barrel projecting from the roadway fill or mitred to the embankment slope. Other inlets have headwalls, wingwalls, and apron slabs or standard end sections of concrete or metal.

1. Design. The hydraulic design of a culvert consists of an analysis of the performance of the culvert conveying flow from one side of the roadway to the other. The designer must select a design flood frequency, estimate the design discharge for that frequency, and set an allowable headwater elevation based on the selected design flood and headwater considerations. The culvert size and type can be selected after the design discharge, controlling design headwater, tailwater, and allowable outlet velocity have been determined.

The design of a culvert includes the determination of the following:

- Line, grade, and length of invert.
- Size, type, end treatment, headwater, and outlet velocity.
- Amount and type of cover.
- Type of acceptable materials and thicknesses acceptable.
- Type of coating (if required).
- Need for fish passage measures.
- Need for protective measures against abrasion and corrosion.
- Need for special designed inlets or outlets.

In addition, at critical installations, the design may have to consider special foundation work and backfill procedures.

a. Discharge. The discharge used in culvert design is usually estimated on the basis of a preselected recurrence interval and the culvert is designed to operate in a manner that is in acceptable limits or risk at that flow rate.

The rate of flow of water to be conveyed by the facility must be determined. This rate of flow (commonly known as the discharge and measured in cubic meters per second) is designated by the letter "Q" in hydraulic formulas. The design discharge is an estimated rate of flow that will occur in a flood of a preselected frequency or recurrence interval. The recurrence interval for a flood that has a 1 in 100 (1 percent) chance of happening in any 1 year is 100 years. Similarly, for a flood that has a 1 in 50 (2 percent) chance or a 1 in 25 (4 percent) chance of happening in any 1 year, the recurrence intervals are 50 or 25 years respectively. Such floods are commonly called 100, 50, or 25 year floods. A 50-year flood is substantially greater in magnitude than a 25 year flood, and a 100 year flood is substantially greater in magnitude than a 50 year flood.

b. Headwater. Culverts generally constrict the natural stream flow which causes a rise in the upstream water surface. The elevation of this water surface is termed *headwater elevation* or the total flow depth in the stream measured from the culvert inlet invert is termed *headwater depth.*

In selecting the design headwater elevation, the designer should consider the following:

- Upstream property damage.
- Damage to the culvert and the roadway.
- Traffic interruption.
- Hazard to human life.
- Headwater/Culvert Depth (HW/D) ratio.
- Low point in the roadway grade line.
- Roadway elevation above the structure.
- Elevation at which water will flow to the next cross drainage.

The headwater elevation for the design discharge should be consistent with the freeboard and overtopping criteria in Section 7.4.A. The designer should verify that the watershed divides are higher than the design headwater elevations. In flat terrain, drainage divides are often undefined or nonexistent and culverts should be located and designed for least disruption of the existing flow distribution.

c. Tailwater. Tailwater is the flow depth in the downstream channel measured from the invert at the culvert outlet. It can be an important factor in culvert hydraulic design because a submerged outlet may cause the culvert to flow full rather than partially full.

A field inspection of the downstream channel should be made to determine whether there are obstructions that will influence the tailwater depth. Tailwater depth may be controlled by the stage in a contributing stream, headwater from structures downstream of the culvert, reservoir water surface elevations, or other downstream features.

d. Outlet Velocity. The outlet velocity of a highway culvert is the velocity measured at the downstream end of the culvert, and it is usually higher than the maximum natural stream velocity. This higher velocity can cause stream bed scour and bank erosion for a limited distance downstream from the culvert outlet. Permissible velocities at the outlet will depend upon stream bed type.

If the outlet velocity of a culvert is too high, it may be reduced by changing the barrel roughness. If this does not give a satisfactory reduction, it may be necessary to use some type of outlet protection or energy dissipation device.

Variation in shape and size of a culvert seldom have a significant effect on the outlet velocity. Slope and roughness of the culvert barrel are the principle factors affecting the outlet velocity.

2. Flow Characteristics. There are two major types of flow characteristics that are described as culverts with inlet control and culverts with outlet control.

For each type of control a different combination of factors is used to determine the hydraulic capacity of a culvert. The determination of actual flow conditions can be difficult; therefore, the designer must check for both types of control and design for the most adverse condition.

a. Inlet control. A culvert operates with inlet control when the flow capacity is controlled at the entrance by

- depth of headwater,
- cross sectional area,
- inlet edge configuration, or
- barrel shape.

Sketches to illustrate inlet control flow for unsubmerged and submerged entrances are shown in Figure 7-1.

When a culvert operates in inlet control, headwater depth and the inlet edge configuration determine the culvert capacity with the culvert barrel usually flowing only partially full.

For a culvert operating with inlet control, the roughness, slope, and length of the culvert barrel and outlet conditions (including tailwater) are not factors in determining culvert hydraulic performance.

b. Outlet Control. In outlet control, culvert hydraulic performance is determined by

- depth of headwater,
- cross sectional area,
- inlet edge configuration,
- culvert shape,
- barrel slope,
- barrel length,
- barrel roughness, or
- depth of tailwater.

Culverts operating in outlet control may flow full or partly full depending on various combinations of the above factors. In outlet control, factors that may affect performance appreciably for a given culvert size and headwater are barrel length and roughness, and tailwater depth. Typical types of outlet control flow are shown in Figure 7-2.

3. Performance Curves. Performance curves are point plots of discharge versus culvert headwater or elevation. See Figure 7-3. The curves aid in the selection of culvert type, size, shape, material, and inlet geometry that fulfills site requirements.

The curves plotted in Figure 7-3 apply only to the applicable specified criteria. If any data is revised or modified, the performance curves will change. The performance curves shown are for a 1200-millimeter round corrugated metal pipe with a beveled inlet. The pipe is on a 3 percent grade and 49 meters in length. The curves cross at approximately 3.3 m^3/s.

This is the point where inlet control changes to outlet control. Under outlet control, more energy (headwater) is required to get the flow through the barrel than to get the flow past the inlet.

Performance curves should be developed for both inlet and outlet control conditions for all culverts 1200 millimeters in diameter and larger. Performance curves should also be developed for smaller cross drain culverts that are placed in locations considered to be critical or sensitive.

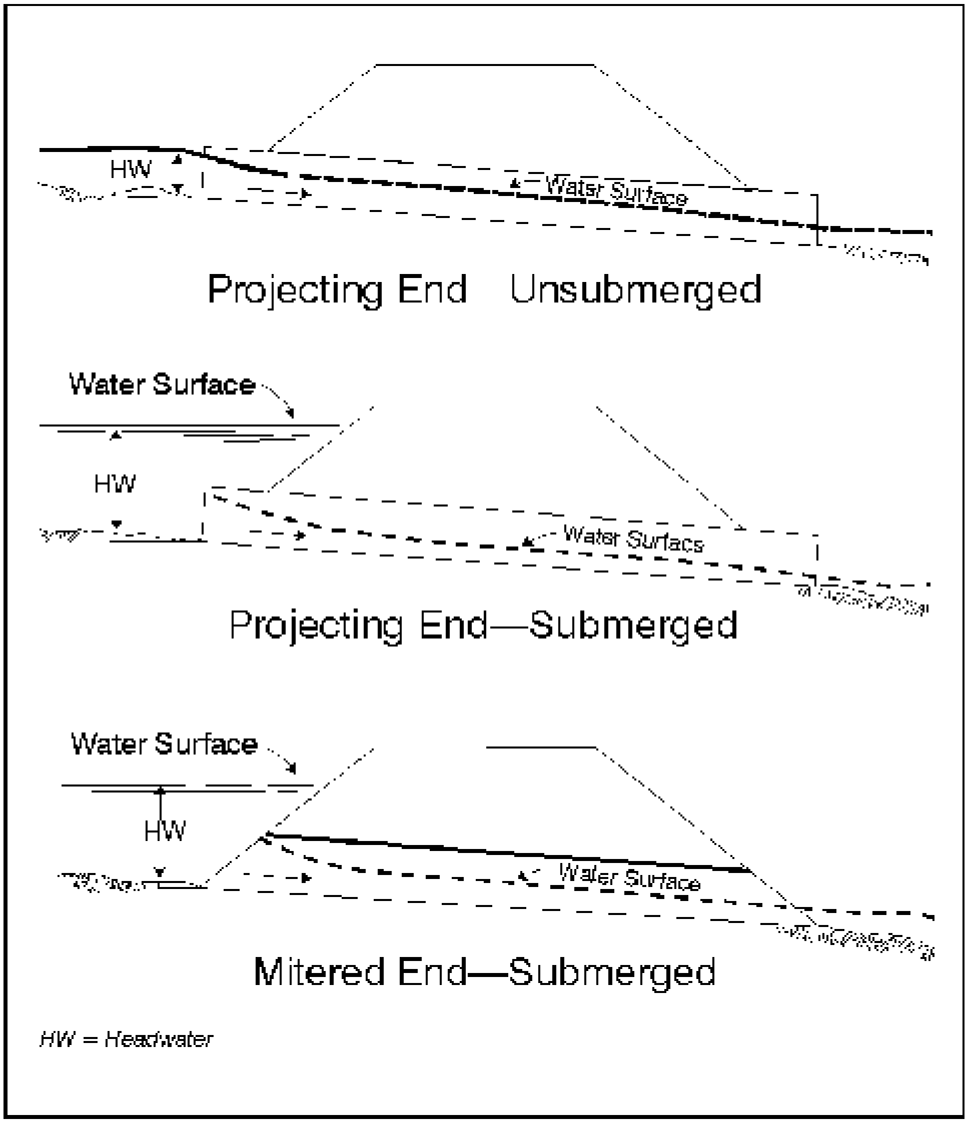


Figure 7-1
Typical Culvert Inlet Control Sections

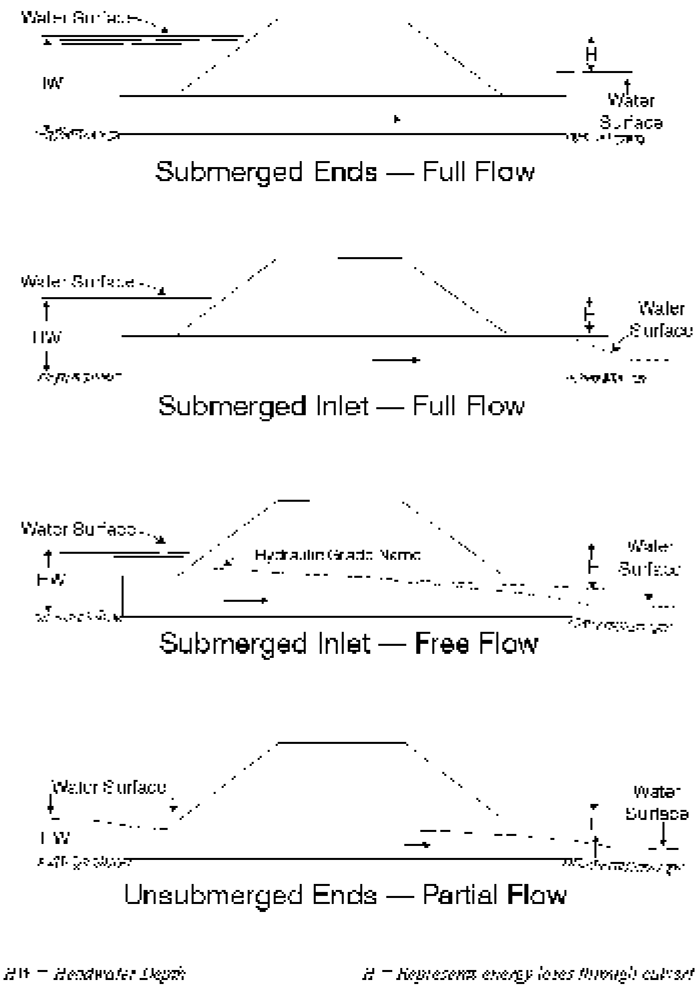


Figure 37 **Figure 7-2**
Typical Culvert Outlet Control Sections

4. Size Selection. (See Section 7.4.A.3) Hydraulic Design Series No. 5, *Hydraulic Design of Highway Culverts*, is the text to be used for the design and selection of drainage culverts. This circular explains inlet and outlet control and the procedure for designing culverts.

Culvert design basically involves the trial and error method:

(1) Select a culvert shape, type, and size with a particular inlet end treatment.

(2) Determine a headwater depth (the depth of water backed up at the inlet end of the culvert) from the charts in the circular for both inlet and outlet control for the design discharge, the grade and length of culvert, and the depth of water at the outlet (tailwater).

(3) Compare the largest depth of headwater (as determined from either inlet or outlet control) to the design criteria. If the design criteria is not met, continue trying other culvert configurations until one or more configurations are found to satisfy the design parameters.

(4) Estimate the culvert outlet velocity and determine if there is a need for any special features such as energy dissipators, riprap protection, fish passage, etc. See Exhibit 7.6 for a standard culvert design worksheet format.

Critical areas shall be checked by the designer by plotting the headwater surface elevation on the detail map. If the headwater surface extends beyond the right-of-way, the designer should evaluate alternative culvert design instead of obtaining more right-of-way or a permanent easement.

For roadside ditch drainage across road approaches, the minimum culvert size is 300 millimeters in diameter. For deeper ditches, an 450-millimeter culvert is preferable.

The minimum size culvert for crossing a highway should be a 600-millimeter diameter or equivalent. In unusual circumstances, an 450-millimeter culvert may be used in place of a 600-millimeter culvert when the length of culvert to be installed is relatively short and ditch erosion upstream of the culvert or culvert plugging is not critical.

When a culvert is connected to a catch basin or drop inlet, or is part of a storm sewer system, the minimum size is 300 millimeters in diameter.

Although the hydraulic engineer is responsible for the design of larger culverts (larger than 1200 millimeters), the designer must furnish data on the location, grade, and length of culverts; the grade of the road; and any site conditions that may be helpful to the hydraulics engineer. Once the culverts are designed, the designer must ensure that all necessary data is shown on the plans. Should it be necessary to change the location, grade, or length of a culvert, the designer should check with the hydraulic engineer to determine if the original designed culvert is still adequate.

5. Materials. The durability and service life of a drainage pipe installation is directly related to the environmental conditions encountered at the site and the type of materials and coatings from which the culvert was fabricated. Two principal causes of early failure in drainage pipe materials are corrosion and abrasion. The environmental damage caused by corrosion and abrasion can be delayed by the type of materials, coatings, and invert protection.

It is Federal Lands Highway (FLH) policy to specify alternative drainage pipe materials on all projects where feasible and to comply with the provisions of the Federal-Aid Policy Guide Section 635.411(d). All permanent drainage pipe installations shall be designed for a minimum of 50 years maintenance-free service life. A shorter service life may be used for temporary installations, and a longer service life may be considered in unusual situations.

All suitable pipe materials, including reinforced concrete, steel, aluminum, and plastic pipe shall be considered as alternatives on FLH projects. The portion of this pipe selection criteria covering metal pipe complies with the guidance contained in Federal Highway Administration (FHWA) Technical Advisory T 5040.12 dated October 22, 1979, and incorporates information contained in FHWA-FLP-91-006, Durability of Special Coatings for Corrugated Steel Pipe.

a. Definitions of Corrosion and Abrasion:

Corrosion: Alkalinity/Acidity (pH) and Resistivity: Determinations of pH and resistivity are required at each pipe location in order to specify pipe materials capable of providing a maintenance free service life. The samples shall be taken in accordance with the procedures described in AASHTO T 288 and T 289. Samples should be taken from both the soil and water side environments to insure that the most severe environmental conditions are selected for determining the service life of the drainage pipe. Soil samples should be representative of backfill material anticipated at the drainage site. Avoid taking water samples during flood flows or for 2 days following flood flows to insure more typical readings. In locations where streams are dry much of the year, water samples may not be possible or necessary. In areas of known uniform pH and resistivity readings, a random sampling plan may be developed to obtain the needed information.

In corrosive soil conditions where water side corrosion is not a factor, consider specifying less corrosive backfill material to modify the soil side environment. The mitigating effect of the specified backfill should be taken into account in making alternative pipe materials selections in situations where soil side conditions control.

Abrasion: An estimate of the potential for abrasion is required at each pipe location in order to determine the need for invert protection. Four levels of abrasion are referred to in this guidance and the following guidelines are established for each level:

■Level 1, **nonabrasive** conditions exist in areas of no bed load and very low velocities. This is the condition assumed for the soil side of drainage pipes.

■Level 2, **low abrasive** conditions exist in areas of minor bed loads of sand and velocities of 1.5 meters per second or less.

■Level 3, **moderate abrasive** conditions exist in areas of moderate bed loads of sand and gravel and velocities between 1.5 m/s and 4.5 m/s.

■Level 4, **severe abrasive** conditions exist in areas of heavy bed loads of sand, gravel, and rock and velocities exceeding 4.5 m/s.

These definitions of abrasion levels are intended as guidance to help the designer consider the impacts of bedload wear on the invert of pipe materials. Sampling of the streambed materials is not required, but visual examination and documentation of the size of the materials in the stream bed and the average slope of the channel will give the designer guidance on the expected level of abrasion. Where existing culverts are in place in the same drainage, the conditions of inverts should also be used as guidance. The expected stream velocity should be based upon a typical flow and not a 10 or 50-year design flood.

b. Alternatives to be Considered:

(1) **Reinforced Concrete**

A reinforced concrete pipe (AASHTO M 170M) shall typically be specified as an alternative whenever environmental conditions permit. The appropriate pipe Class shall be determined from approved FLH fill height standard drawings. It is FLH policy to use Class II as the minimum for all reinforced concrete pipes. Within the following limits of corrosion and abrasion, reinforced concrete pipe can be assumed to have a service life of a minimum of 50 years. Typically a minimum service life of 75 years can be assumed for reinforced concrete pipe.

Corrosion and abrasion effects on concrete pipes:

■**Corrosion:** Reinforced concrete pipe should not be specified for **extremely corrosive** conditions where the pH is less than 3 and the resistivity is less than 300 ohm centimeters (Ω·cm). Where the pH is less than 4, or the pipe is exposed to wetting and drying in a salt or brackish water environment, protective coatings, such as epoxy resin mortars or poly vinyl chloride sheets should be used. When the sulfate concentration is greater than 0.2 percent in the soil or 2000 parts per million in the water, Type V cement should be specified. When the sulfate concentration is greater than 1.5 percent in the soil or 15,000 parts per million in the water, Type V cement should be used with a sulfate resistant pozzolan, or a higher cement ratio may be used such as in an AASHTO Class V pipe design.

■**Abrasion:** On installations in **severe abrasive** environments, consider using 7 or 8 sack concrete or increasing the cover over the reinforcing steel.

(2) **Steel**

Steel pipe will typically be specified as an alternative when the environmental conditions permit. The appropriate minimum structural metal thickness shall be determined from approved FLH fill height tables. The minimum wall thickness for all steel pipes used on FLH projects is 1.63 mm, as shown in the FLH fill-height tables.

It is FLH policy that steel pipe provides a useful, maintenance-free service life for a period of time beyond the point of first perforation. This assumes an acceptable risk for most FLH projects, but at locations with erodible soils, large traffic volumes, or high fills where replacement or repair would be unusually difficult or expensive, consider increasing the steel plate by one standard thickness. In unusual situations where very high fills and severe abrasion combine, or where other environmental concerns would make replacement of a pipe culvert very costly or impractical, consider using a pipe one size larger in diameter to permit re-lining in the future by insertion of another pipe.

Steel pipe is divided into 2 categories; steel pipe with metallic coatings, and steel pipe with non-metallic coatings.

Steel Pipe with Metallic Coatings. Under **non-abrasive** and **low-abrasive** conditions, the service life of steel pipe with metallic coatings may be determined based upon corrosion (pH and resistivity) from Figure 7-4. Figure 7-4 shows the relationship between service life and corrosion for plain galvanized steel pipe. It has been adapted from the California Department of Transportation "Method for Estimating the Service Life of Steel Culverts", California Test 643. *The curves have been modified to show the expected average service life of pipe with a steel thickness of 1.63* mm assuming a useful, maintenance-free service life 25 percent longer than the number of years to first perforation. Under **moderate** and **severe abrasive** conditions, abrasion protection must also be considered.

The following types of steel pipe with metallic coatings shall be considered as alternatives on Federal Lands Highway projects:

- **Galvanized steel (AASHTO M 218).**
- **Aluminum/zinc alloy coated steel (galvalume) (AASHTO M 289).**
- **Aluminum coated steel sheets (Type 2) (AASHTO M 274).**

Steel Pipe with Non-Metallic Protective Coatings. Protective coatings may be used to protect against corrosion or abrasion. Coatings to protect against corrosion may only be used in **non-abrasive** and **low abrasive** environments, except that bituminous coated pipe should not be used in **low abrasive** environments. Under **moderate abrasive** conditions, bituminous paved pipe and concrete lined pipe may be used for invert protection *where corrosion protection is not required*.

The additional service life noted below in *italics* for each type of protective coating (for corrosion protection) are from Part V of FHWA-FLP-91-006. The added service is applicable *only* to **non-abrasive** and **moderate abrasive** conditions. All of the following types of steel pipe with non-metallic coatings shall be considered as alternatives on Federal Lands Highway projects:

- **Bituminous coated (AASHTO M 190).** Bituminous coatings can be expected to add *10 years* of service to the water side and *25 years* life to the soil side service life of pipe as determined from Figure 7-4.

■**Bituminous coated and paved (AASHTO M 190).** Bituminous paved invert with bituminous coatings can be expected to add *25 years* life to water side locations.

■**Concrete lined (ASTM A 849).** Concrete lining can be expected to add *25 years* of service life. Due to the natural cracking of the concrete, the concrete lining should be applied over an asphalt coating if corrosion protection is needed.

■**Polymer coated (AASHTO M 245M). Ethylene Acrylic Acid Film** coatings should provide an additional *30 years* service life with a 0.25 mm thickness.

Only limited data is available for the service life of **Aramid fiber bonded coated (ASTM A 885) and Epoxy coated** pipes and no additional service life is currently credited with this policy.

Corrosion and abrasion effects on steel pipes:

Within the corrosion and abrasion limits noted below, the average service life of steel pipe can be predicted. Detailed examples are included in Exhibit 7.10 which includes Figure 7.4 and Figure 7.5 for determining service life.

■**Corrosion:**Under **nonabrasive** and **low abrasive** conditions, the metal thickness of galvanized, galvalume, and aluminum coated steel (Type 2) alternatives should be determined from Figure 7-4 based on the resistivity and pH of the site. The minimum metal thickness of steel pipe, as determined from FLH standard fill height tables, may have to be increased, or the additional life of a protective coating may have to be added, in order to provide a 50 year service life. The results included in FHWA-FLP-91-006 indicate that within the environmental range of 5-9 pH and resistivity equal to or greater than 1500 Ω·cm, aluminum coated steel (Type 2) can be expected to give a service life of twice that of plain galvanized pipe. The National Corrugated Steel Pipe Association has recommended that steel pipe not be used below a pH of 4 when the resistivity is below 1500 Ω·cm.

Figure 7-4 can be used to determine various combinations of increased thicknesses, aluminum coated steel (Type 2), and protective coatings to achieve a 50 year service life, but in no case may the metal thickness specified by the structural requirements be reduced.

■**Abrasion:** Under **nonabrasive** and **low abrasive** conditions, the metal thickness of the galvanized, galvalume, and aluminum coated steel alternatives, as determined from Figure 7-4, should be used.

On installations in **moderate abrasive** environments where protective coatings are not required for corrosion protection, the thickness of the metal should be increased by one standard metal pipe thickness from that determined from Figure 7-4, *or* invert protection should be provided. Invert protection may consist of bituminous coating with invert paving with bituminous concrete, Portland cement concrete lining, installation of metal plates or rails, or velocity reduction structures.

On installations in **severe abrasive** environments where protective coatings are not required for corrosion protection, the thickness of the metal should be increased by one standard metal pipe thickness from that determined from Figure 7-4 *and* invert protection should be provided. Invert protection may consist of installation of metal plates or rails, or velocity reduction structures.

Protective coatings are not suitable for corrosion protection in **moderate-abrasive** and **severe abrasion** locations. *Metal pipes should not be specified in* ***moderate*** *and* ***severe abrasive*** *environments where coatings are required to protect against water side corrosion.*

(3) **Aluminum Alloy**

Aluminum alloy pipe (AASHTO M 196M) will typically be specified as an alternative when environmental conditions permit. The appropriate minimum structural metal thickness shall be determined from approved FLH fill height tables. It is FLH policy to use a minimum metal thickness for all aluminum alloy pipes of 1.52 mm as shown in the FLH standard fill height tables. Within the following limits of corrosion and abrasion, aluminum alloy pipe can be assumed to have a service life of 50 years. Additional service life may be achieved where required by abrasion with the addition of protective coatings or additional metal thickness as discussed below:

Corrosion and abrasion effects on aluminum alloy pipes:

■**Corrosion:** An aluminum alloy should be allowed if the pH is between 4 and 9 and the resistivity is greater than 500 Ω·cm. An aluminum alloy alternative can also be considered for use in salt and brackish environments when embedded in granular, free draining material.

■**Abrasion:** On installations in **non-abrasive** and **low abrasive** environments, abrasion protection is not required.
On installations in **moderate abrasive** environments, the thickness should be increased by one standard metal thickness or invert protection should be used. Invert protection may consist of bituminous coating and invert paving with bituminous concrete or Portland cement concrete, installation of metal plates or rails, or velocity reduction structures.

On installations in **severe abrasive** environments, the thickness of the metal should be increased by one standard metal pipe thickness from that determined for low abrasive conditions *and* invert protection should be provided. Invert protection may consist of installation of metal plates or rails, or velocity reduction structures.

(4) **Plastic**

Polyethylene and polyvinyl chloride plastic pipe may be specified as alternatives for pipe diameters and minimum resin cell classifications shown in the American Associations of State Highway and Transportation Officials (AASHTO) Standard Specifications for Highway Bridges, Division I Design, Section 18, Soil Thermoplastic Pipe Interaction Systems. The thickness of the plastic alternatives shall meet the structural requirements of the AASHTO Section 18. The assumed service life of plastic pipe designed in accordance with AASHTO Section 18 is 50 years. The maximum allowable fill heights for pipe materials listed below shall be determined from approved FLH standard fill-height tables which include the following plastic pipe materials:

■**Smooth wall polyethylene (ASTM F 714).**

■**Corrugated polyethylene (AASHTO M 294).**

■**Ribbed polyethylene (ASTM F 894).**

■**Smooth wall polyvinyl chloride (AASHTO M 278 and ASTM F 679).**

■**Ribbed polyvinyl chloride (AASHTO M304 and ASTM F 794).**

Corrosion and abrasion effects on plastic pipes:

■**Corrosion:** Plastic alternatives may be specified without regard to the resistivity and pH of the site.

■**Abrasion:** Under **nonabrasive** and **low abrasive** conditions, polyethylene and polyvinyl chloride alternatives should be allowed. Plastic alternatives should not be used under **moderate** and **severe abrasive** conditions without invert protection.

Industry representatives have pointed out that a conflict exists between the resin cell classification requirements of AASHTO Highway Bridge Specifications Section 18 and AASHTO M 294 for corrugated polyethylene pipe. Until AASHTO resolves this conflict, corrugated polyethylene pipe may also be permitted if it meets the materials requirements of AASHTO M 294. The allowable fill heights for this material are based upon permitted usage in states and is included in the FLH standard fill-height table.

The locations selected for use of plastic pipes should address owner agency concerns of possible damage due to fire, ultraviolet sunlight, and rodents. Until more experience is gained by FLH, plastic pipe will be permitted under mainline routes only after careful analyses by the designer and concurrence of the land owning agencies.

6. Culvert Location. Culvert location is an integral part of the total design. Its main purpose is to convey drainage water across the roadway section expeditiously and effectively. The designer should identify all live stream crossings, springs, low areas, gullies, and impoundment areas created by the new roadway embankment for possible culvert locations. See Sections 7.4.D.1, 7.4.D.12 and in Chapter 9, see Section 9.4.E.

a. Alignment. Locate culverts on existing stream alignments. Align the culvert to give the stream a direct entrance and a direct exit. Abrupt changes in direction at either end may retard the flow and make a larger structure necessary. If necessary, a direct inlet and outlet may be obtained by means of a channel change, skewing the culvert, or a combination of these. The choice of alignment should be based on economy, environmental concerns, hydraulic performance, and/or maintenance considerations.

Reasonable precautions should be taken to prevent the stream from changing its course near the ends of the culvert including the use of riprap, sod, paving, or metal end sections. For certain site conditions, a curved alignment may be appropriate to limit structure excavation.

b. Gradient. The grade chosen for a particular culvert will depend on the site conditions. For highway purposes, culverts may be considered to be in one of two categories:

(1) Minimum sized culverts used for cross drains to carry away intermittent roadside ditch water or water from very small drainage areas. These culverts seldom are required to carry their maximum discharge.

The grade for ditch cross drains should not be flatter than 0.5 percent nor steeper than 10 percent. See Section 7.4.A.3.

(2) Culverts sized to carry live streams and large runoffs. These culverts are individually designed to carry the design discharge for the drainage area they serve without excessively backing up water.

When placing culverts in live streams design the culvert invert to coincide with the average streambed flow line. Deviations are acceptable under the following conditions:

- When headroom is limited. The culvert inlet may be lowered below the streambed in streams where sedimentation will not be a problem, in which case the inlet basin may have to be stabilized with riprap or by other means. Alternatives to lowering the inlet include the use of a pipe arch, an oversize round pipe with the entire inlet buried below the streambed, multiple culverts, a drop inlet, or raising the road grade.

- Under high fills. The culvert should be designed with sufficient camber to allow for settlement as indicated on the plans.

- When ponding is permissible. Sometimes it may not be necessary to place the culvert at the streambed grade. If ponding is permissible or a random fill is placed on the inlet end of the pipe, the inlet can be raised. If the outlet can be placed on nonerodible soil or the pipe can be made to spill on riprap or rock, the outlet can be raised and the length of culvert reduced. If fish passage is a requirement, these methods can not be used.

- In steep sloping areas. The culvert need not always be placed on the same steep grade. It may be skewed and put on any desired grade with a spillway or cutoff wall constructed at the outlet, or a down drain may be used down the fill slope.

- When fish passage is required. The culvert will usually have to be placed on a very flat grade (less than 0.5 percent), or an oversize culvert placed with either the invert below streambed grade or fish baffles installed in the invert.

7. Inlet Protection. Inlets on culverts, especially on culverts to be installed in live streams, should be evaluated relative to debris control and buoyancy.

a. Debris Control. Accumulation of debris at a culvert inlet can result in the culvert not performing as designed. The consequences may be damages from inundation of the road and upstream property.

The designer has three options for coping with the debris problem:

(1) Retain the debris upstream of the culvert.

(2) Attempt to pass the debris through the culvert.

(3) Install a bridge.

If the debris is to be retained by an upstream structure or at the culvert inlet, frequent maintenance may be required. If the debris is to be passed through the structure or retained at the inlet, a relief opening should be considered either in the form of a vertical riser or a relief culvert placed higher in the embankment. It is often more economical to construct debris control structures after problems develop, since debris problems do not occur at all suspected locations.

Precede the design of the debris control structure with a thorough study of the debris problem.

The following are among the factors to be considered in a debris study:

- Type of debris.
- Quantity of debris.
- Expected changes in type and quantity of debris due to future land use.
- Stream flow velocity in the vicinity of culvert entrance.
- Maintenance access requirements.
- Availability of storage.
- Maintenance plan for debris removal.
- Assessment of damage due to debris clogging, if protection is not provided.

Hydraulic Engineering Circular No. 9, *Debris Control Structures*, should be used when designing debris control structures.

b. Buoyancy. The forces acting on a culvert inlet during flows are variable and indeterminate. When a culvert is functioning with inlet control, an air pocket begins just inside the inlet that creates a buoyant effect when the inlet is submerged. The buoyancy forces increase with an increase in headwater depth. These forces, along with vortexes and eddy currents, can cause scour, undermine culvert inlets, and erode embankment slopes thereby making the inlet vulnerable to failure especially with deep headwater.

In general, installing a culvert in a natural stream channel constricts the normal flow. The constriction is accentuated when the capacity of the culvert is impaired by debris or damage.

The large unequal pressures resulting from inlet constriction are in effect buoyant forces that can cause entrance failures, particularly on corrugated metal pipe with mitred, skewed, or projecting ends. The failure potential will increase with steepness of the culvert slope, depth of the potential headwater, flatness of the fill slope over the upstream end of the culvert, and the height of the fill.

Anchorage at the culvert entrance helps to protect against these failures by increasing the deadload on the end of the culvert, protecting against bending damage, and by protecting the fill slope from the scouring action of the flow. Provide a standard concrete headwall or endwall to counteract the hydrostatic uplift and to prevent failure due to buoyancy.

8. Sedimentation. Deposits usually occur within the culvert barrels at flow rates smaller than the design flow. The deposits may be removed during larger floods dependent upon the relative transport capacity of flow in the stream and in the culvert, compaction and composition of the deposits, flow duration, ponding depth above the culvert, and other factors.

Culvert location in both plan and profile is of particular importance to the maintenance of sediment-free culvert barrels. Deposits occur in culverts because the sediment transport capacity of flow within the culvert is often less than in the stream.

Deposits in culverts may also occur due to the following conditions:

- At moderate flow rates the culvert cross section is larger than that of the stream, so the flow depth and sediment transport capacity is reduced.

- Point bars form on the inside of stream bends. Culvert inlets placed at bends in the stream will be subjected to deposition in the same manner. This effect is most pronounced in multiple-barrel culverts with the barrel on the inside of the curve often becoming almost totally plugged with sediment deposits.

- Abrupt changes to a flatter grade in the culvert or in the channel adjacent to the culvert will induce sedimentation. Gravel and cobble deposits are common downstream from the break in grade because of the reduced transport capacity in the flatter section.

9. Fish Passage. At some culvert locations, the ability of the structure to accommodate migrating fish is an important design consideration. For such sites, State fish and wildlife agencies should be consulted early in the roadway planning process. Some situations may require the construction of a bridge to span the natural stream. However, culvert modifications can often be constructed to meet the design criteria established by the fish and wildlife agencies.

Early in the planning process, fish migration data should be collected including pertinent field data. If the stream crossing is located on a known, suspected, or potential fish migration route, the following data is desirable:

- Species of migrating fish.

- Size and swimming speed of fish.

- Locations of spawning beds, rearing habitat, and food producing areas upstream and downstream of the site.

- Description of fish habitat at the proposed crossing.

- Dates of start, peak, and end of migration.

- Average flow depths during periods of migration.

An understanding of design inadequacies that will inhibit natural migration patterns is desirable. Excessive velocities and shallow depths inside or adjacent to the culvert should be avoided. High outlet elevations, often resulting from the formation of a scour hole, may prevent fish from entering the culvert. High outlet velocities also dislodge sediment which fills in small pools further downstream, smothering eggs and food-producing areas in the process. High upstream invert elevations produce a large unnatural pool above the culvert that will trap sediment. Depressing the upstream invert elevation is also harmful.

Simulating the natural stream bottom conditions in a culvert is the most desirable design option to accommodate fish passage. Open bottom culverts, such as arches, have obvious advantages if adequate foundation support exists for the culvert. Oversized culverts with buried inverts have the advantage of a natural bottom while overcoming the problem of poor foundation material. However, on steep slopes, provisions may be necessary to hold bottom material in place. Another option is to construct baffles in the bottom of culverts to help simulate natural conditions.

When the simulation of natural stream bottom conditions is unrealistic or unnecessary, criteria for maintaining minimum depths and maximum velocities is most important. The high roughness coefficient of corrugated metal may be all that is required at some locations to maintain desirable depths and velocities. When maintaining a minimum depth in a culvert is a problem, downstream weirs can be constructed. However, provisions must be made for fish to bypass the weirs.

A popular method of providing for fish passage is to provide dual culverts, one culvert designed for hydraulic capacity and one culvert designed for fish passage. The latter culvert would have a flatter slope, higher roughness, and could contain fish baffles. In this case, the hydraulically efficient barrel would convey most of the flow. To design parallel, dissimilar culverts, it is necessary to construct separate performance curves (elevation versus discharge) for each culvert. The two performance curves are added together at equal elevations to obtain the combined performance curve.

The hydraulic design of culverts with fish baffles is accomplished by modifying the friction resistance of the barrel in outlet control to account for the high resistance imposed by the baffles. For inlet control, only the reduced area of the entrance due to the baffles and any edge modifications need to be considered in the procedure. See HDS No. 5 for the design procedures.

Outlet and barrel velocities are also critical for fish passage. Velocities in culvert barrels should be 1.2 meters per second or less for the flow conditions expected during fish migration periods. If these velocities cannot be obtained because of the required slope of the culvert, one of the following alternative methods may be used to provide fish passage:

- Use an oversize culvert with the invert placed below the streambed (0.3 - 1.0 meters) and backfilled with cobbles and gravel to the average streambed grade.
- Use an oversize culvert with baffles in the bottom to provide fish resting pools.
- Construct weirs downstream of the culvert to raise the water level in the culvert barrel and to slow down the velocity.

10. Outlet Protection. Scour at culvert outlets is a common occurrence. The natural channel flow is usually confined to a lesser width and greater depth as it passes through a culvert barrel. An increased velocity results with potentially erosive capabilities as it exits the barrel. Turbulence and erosive eddies form as the flow expands to conform to the natural channel. However, the velocity and depth of flow at the culvert outlet and the velocity distribution upon reentering the natural channel are not the only factors that need consideration.

The characteristics of the channel bed and bank material, velocity and depth of flow in the channel at the culvert outlet, and the amount of sediment and other debris in the flow are all contributing factors to scour potential. Due to the variation in expected flows and the difficulty in evaluating some of these factors, scour prediction is subjective.

Scour in the vicinity of a culvert outlet can be classified into two separate types called local scour and general stream degradation:

a. Local Scour. Local scour is typified by a scour hole produced at the culvert outlet. This is the result of high exit velocities, and the effects extend only a limited distance downstream.

Coarse material scoured from the circular or elongated hole is deposited immediately downstream, often forming a low bar. Finer material is transported further downstream. The dimensions of the scour hole change due to sedimentation during low flows and the varying erosive effects of storm events. The scour hole is generally deepest during passage of the peak flow. Methods for predicting scour hole dimensions are found in HEC No. 14.

b. General Stream Degradation. General stream degradation is a phenomenon that is independent of culvert performance. Natural causes produce a lowering of the stream bed over time. The identification of a degrading stream is an essential part of the original site investigation.

Both types of scour can occur simultaneously at a culvert outlet.

Since prediction of scour at culvert outlets is difficult, and protection is expensive, one approach involves providing a minimum amount of protection followed by periodic site inspection. As part of the field investigation, scour and outlet protection at similar culverts in the vicinity will provide guidance. The initial level of protection should be sufficient to withstand extensive damage from one storm event. Once the initial minimum outlet protection is constructed, an assessment of its performance after a number of storm events should be evaluated and reviewed. If the outlet protection is insufficient, additional protection should be provided. If the outlet protection is sufficient, inspection is required only after larger storm events.

Protection against scour at culvert outlets varies from limited riprap placement to complex and expensive energy dissipation devices. At some locations, use of a rougher culvert material may alleviate the need for a special outlet protection device. Preformed scour holes (approximating the configuration of naturally formed holes) dissipate energy while providing a protective lining to the stream bed.

Riprapped channel expansions and concrete aprons protect the channel and redistribute or spread the flow. Barrel outlet expansions operate in a similar manner. Headwalls and cutoff walls protect the integrity of the fill. When outlet velocities are high enough to create excessive downstream problems, consideration should be given to more complex energy dissipation devices. These include hydraulic jump basins, impact basins, drop structures, and stilling wells. Design information for the general types of energy dissipators is provided in HEC No. 14.

11. Culvert Lengths and End Treatments. The lengths of culverts are generally determined by the use of plotted cross sections. If a pipe is on a skew, the pipe section may have to be detailed using map contours.

An end section should be used on a small diameter culvert when the culvert invert grade at the inlet (or outlet) is within approximately 1.5 meters of the shoulder elevation, except on fill slopes with a 1:2 ratio and steeper, or where the end of culvert is in back of guardrail.

End sections improve the appearance of a highway; prevent run-off-the-road vehicles from striking the end of a culvert (thus eliminating a very severe hazard); prevent scour, undermining, and seepage at culvert ends; and increase the hydraulic efficiency of the culvert over that of a thin-edge projecting inlet.

When an end section is not used nor the culvert end shielded by a barrier, the end should extend beyond the clear zone for run-off-the-road vehicle recovery.

When fill slopes are 1:2 or steeper, the culvert should extend 0.3 to 0.6 meters beyond the toe of fill to prevent the end from being buried by a sloughing embankment and so that the culvert may be easily located by maintenance crews.

When fill slopes are flatter than 1:2, the culvert may end slightly inside the toe of fill and the fill slope may be steepened around the culvert end to reduce the length of exposed pipe.

12. Plans. The highway designer is responsible for showing all details on the plans for culvert installations to include the following:

- Size.
- Location.
- Alignment.
- Maximum depth of cover.
- Estimated structure excavation.
- Acceptable materials (including any specical coatings).
- End treatment.
- Allowable alternates (if any).

In addition, the information placed on the plans for culvert pipe 1200 millimeters and larger shall include a typical cross section showing length, grade, design headwater and design discharge, and any special foundation work or end treatment.

Headwalls, energy dissipator, or riprap must be shown and standard drawings or special drawings included in the plans for their construction or placement.

a. Plan and Profile. Culvert location and alignment are shown on the plans with an arrow crossing the highway alignment, the point of the arrow being the direction of flow. The length of the arrow should be the approximate length of culvert and begin and end at the proposed culvert inlet and outlet.
(See Exhibit 9.21 in Chapter 9.)

The designer should lay out culverts on plotted cross sections in order to determine culvert lengths, grades, maximum cover, and structure excavation. It is preferable that a separate culvert roll be plotted for each project and made available to the project engineer, particularly on projects where culverts may operate under outlet control or where culverts are placed under high fills. The grade and length of culvert may significantly affect the headwater depth if these are changed during construction from what was designed; and the depth of cover, if changed during construction, may require a different wall thickness than that specified in design. The designer should provide the project engineer with data relative to all such critical culverts.

b. Drainage Summary. The designer shall complete a drainage summary sheet for the plans. Show maximum pipe cover, structure excavation, type of pipe (wall thickness, size, length, etc.), and acceptable alternate pipe materials. Other items associated with culverts are also listed on this sheet. See Exhibit 9.26 in Chapter 9 for an example of a drainage summary.

Generally, corrugated steel pipe or pipe arch, with the minimum standard size corrugations and thickness suitable for the pipe cover, are specified as a pay item on the plans, and allowable alternatives to these are listed on the drainage summary. The alternatives may include steel with larger corrugations, structural plate metal, aluminum in different sizes of corrugations, and concrete. When structural plate is required, then structural plate steel pipe or pipe arch is designated as the pay item, and aluminum or concrete alternates are allowed if these are appropriate.

The designer should use the following procedure for listing culvert quantities and alternates:

(1) Lay out culverts on plotted cross section (or pipe sections), compute structure excavation, and determine maximum cover to subgrade. These two values are listed on the drainage summary, along with the station, for each culvert. It should be noted that there are minimum depths of cover shown on the standard drawings, and these must be reflected in the culvert layouts.

(2) From the standard drawings, determine the pipe wall thickness for metal pipe (or pipe arch), for the maximum depth of cover as determined above, and for the minimum size corrugations listed. The design length of culvert is then listed on the drainage summary under the item for the respective size of culvert and wall thickness. When a project has culverts of the same size, some of which require different wall thicknesses, then more than one pay item for that size of pipe should be specified.

(3) Select alternate culverts from the standard drawings and list them on the drainage summary. For metal pipe alternates, the wall thickness is indicated under the metal kind (steel or aluminum), and the size of corrugations is shown on the standard drainage summary form. For concrete alternates, the size and reinforcing class are indicated. (For concrete culverts 450 millimeters and less in diameter, which do not cross the highway, the "non-reinforced" column is checked if the pipe cover is within the limits shown on the standard drawing.)

The designer should ensure that the proposed culvert installation will meet the selected design criteria regardless of which alternative is selected. For example, the designer should realize that concrete pipe is smoother than the corrugated metal pipe, and will pass the design discharge at a greater velocity than the corrugated metal pipe. Thus, the culvert outlet pipe may require more riprap or additional fish passage features than that required for a corrugated metal pipe. Also, if concrete pipe is allowed as an alternative, the equivalent culvert size must be shown on the drainage summary for all culverts over 600 millimeters in diameter. A smaller size concrete pipe may be able to carry the same discharge as the designed corrugated metal pipe, due to its smoother barrel.

E. Roadway Drainage. Effective drainage of the roadway is essential to maintenance of the service level of the roadway and to traffic safety. Water on the roadway slows traffic and contributes to traffic safety.

The purpose of a drainage system is to remove the storm water from the surface of the road. Design of the surface drainage system is particularly important at locations where ponding can occur. If too much spread is allowed, the basic purpose of the drainage system is defeated. The designer should adopt a width of spread and storm frequency that meets the need of the project.

On curbed and uncurbed roadways it is important to maintain a minimum longitudinal slope in order to avoid undue spread of flow on the roadway.

1. Design. The flow of water in the gutter should be restricted to a depth, and corresponding width, that will not severely obstruct or cause a hazard to traffic. This flow is a function of the quantity of water, gutter gradient, roughness of pavement where the flow is contained, and cross section shape of the flow area.

Inlets shall be placed at sufficient intervals to limit the spread to 2.5 - 3 meters from the curb or one-half of the travel way in each direction, whichever is less.

Storm sewers should generally be designed to convey the 10-year runoff without surcharge. However, the system should be checked for the 50-year runoff in situations where it would be necessary to prevent flooding of major highways, underpasses, or other depressed roadways where ponded water can only be removed through the storm sewer system. Matching pipe crown lines at junctions is preferable to matching inverts.

Storm sewers should be designed with slopes sufficient to develop a self-cleaning velocity of three feet per second when flowing full.

The computed hydraulic grade line (water surface profile), predicated on the selected design flow, shall not exceed the top of any inlets, manholes, junctions, etc., to an extent that would cause unacceptable inundation of the travel way and/or adjoining property. If the computations indicate that such would be the case, the storm sewer design shall be revised as necessary so subsequent hydraulic grade line computations will indicate that escaping flow has been reduced to acceptable levels. In high risk locations, such as underpasses or other depressed roadways, the hydraulic grade should be checked using a 50-year storm.

2. Flow in Gutters. A roadway gutter is defined as the section of roadway next to the curb which conveys water during a storm runoff event. The gutter, in this sense, would include a portion or all or a travel lane. Gutter cross sections have a triangular shape with the curb forming the near-vertical leg of the triangle. The gutter may have a uniform cross slope or a composite cross slope.

Modification of Manning's equation is necessary for use in computing flow in triangular channels because the hydraulic radius in the equation does not adequately describe the gutter cross section. To compute gutter flow, Manning's equation is integrated for an increment of width across the section.

The resulting equation in terms of cross slope and spread on the roadway is:

$$Q = \frac{K}{n} S_x^{5/3} S^{1/2} T^{8/3}$$

Where:

- Q = flow rate (m^3/s)
- K = 0.38
- n = Mannings coefficient of roughness
- T = width of flow (spread) (m)
- S_x = cross slope (m/m)
- s = longitudinal (gutter) slope (m/m)

The above equation is applicable only to sections having a uniform cross slope. It neglects the resistance of the curb face, but this resistance is negligible from a practical point of view if the cross slope is 10 percent or less.

Spread on the pavement and flow depth at the curb are used as criteria for spacing roadway inlets. Charts in Hydraulic Engineering Circular No. 12, *Drainage of Highway Pavements* provide solutions for the equation. The charts can be used to determine either discharge (Q) where depth (d) and spread (T) are known or depth and spread where the discharge is known. Charts are also available to determine spread or flow in composite sections where the cross slope of the gutter adjacent to the curb is different from the cross slope of the roadway pavement.

3. Inlet Spacing. Inlets should be spaced so as to limit the spread on the roadway to a prescribed amount during the design storm. The allowable spread is part of the design criteria. The spacing of the inlets will be affected by the capacity of the individual inlets.

Where an inlet is located on a continuous grade, flow that is bypassing that inlet must be included in the total gutter flow contributing to the next inlet downstream unless it is carried off on a side road or otherwise intercepted.

Where an inlet is located at the bottom of a sag vertical curve (referred to as a sump or low point) all of the flow must go into the inlet unless it would be acceptable for some of the flow to overtop the curb or crown of the pavement.

To properly drain sag vertical curves, it is often desirable to place three inlets in each curve: one inlet at the low point and one flanking inlet on each side of the low point. The flanking inlets should be placed so that they will limit the spread in the low (flatter) gradient approaches to the sag point and will act in relief of the sag inlet if it should become clogged. The use of flanking inlets will also serve to reduce the deposition of sediment on the roadway.

The determination of the maximum spread on the roadway approaching the sag point should be based on the flattest grade in the section just upstream of the sag inlet. For most highways, the vertical curve has sufficient length to result in a gutter section whose effective gradient is 0.1 percent. There are cases where special treatment of the gutter gradient is provided and, in these instances, the flattest slope that will occur should be used instead of the customary 0.1 percent.

Large quantities of runoff from areas off the project that would normally enter the project from side roads should, wherever possible, be picked up on the side road before the runoff reaches the project.

Roadway inlets are, at best, inefficient devices for intercepting water. Where curbs are used, runoff from cut slopes and areas off the right-of-way should, wherever possible, be intercepted by ditches at the top of slopes or in a swale along the shoulder. This reduces the amount of water that has to be picked up by the inlets and prevents mud and debris from being carried onto the pavement.

4. Inlet Types and Design. Either grate inlets, curb opening inlets, a combination of curb opening and grate inlets, or slotted drain pipe inlets may be used for intercepting runoff.

Curb opening inlets are preferred on grades 3 percent or less because of their self-cleaning ability. Grate inlets clog easily. Sometimes the use of grates will be found necessary either with or without curb opening inlets. When grates are used, hydraulically efficient and safe grates should be used in areas where pedestrian and bicycle traffic is a factor. Grate bars parallel to the direction of flow of water are more effective than bars perpendicular to the flow. If clogging is a factor, the grates should be considered only partially effective.

a. Grate Inlets. Grate inlets on a continuous grade will intercept all or nearly all of the gutter flow passing over the grate--or the frontal flow, if the grate is sufficiently long and the gutter flow velocity is low. Only a portion of the frontal flow will be intercepted if the velocity is high or the grate is short and splash-over occurs. A part of the flow along the side of the grate will be intercepted, dependent on the cross slope of the pavement, the length of the grate, and flow velocity.

A grate inlet in a sag location operates as a weir at shallow depths and as an orifice at greater depths. Grates of larger dimension and grates with more open area (i.e., with less space occupied by lateral and longitudinal bars) will operate as weirs to greater depths than smaller grates or grates with less open area.

Design curves for grate inlets are provided in HEC No. 12. *Drainage of Highway Pavements*.

b. Curb Inlets. The interception capacity of curb-opening inlets is largely dependent on flow depth at the curb and curb opening length. Effective flow depth at the curb and consequently, curb-opening inlet interception capacity and efficiency, is increased by the use of a gutter depression at the curb opening or a depressed gutter to increase the proportion of the total flow adjacent to the curb. (Top slab supports placed flush with the curb line can substantially reduce the interception capacity of curb openings. If intermediate top slab supports are used, they should be recessed several inches from the curb line and rounded in shape.)

Curb-opening inlets in continuous grade situations are effective in the drainage of highway pavements where flow depth at the curb is sufficient for the inlet to perform efficiently. Curb openings are relatively free of clogging tendencies and offer little interference to traffic operation. (This type of inlet is preferred over grate inlets in locations where grates would be in traffic lanes or would be hazardous for pedestrians or bicyclists.)

For determining the length, efficiency, and equivalent cross slope for curb opening inlet systems, see HEC No. 12.

A curb-opening inlet in a sag operates as a weir to depths equal to the curb opening height and as an orifice at depths greater than 1.4 times the opening height. At depths between 1.0 and 1.4 times the opening height, flow is in a transition stage.

The weir location for a curb-opening inlet having a local depression is at the edge of the gutter. The effective weir length is the width of the locally depressed gutter section and the length of the curb opening.

c. Combination Inlets. Performance data on combined curb opening and grate inlets is limited. The capacity of a combination inlet on a continuous grade is not appreciably greater than with the grate inlet alone. Combination inlets are typically used in a sag location. The curb-opening provides a relief opening if the grate should become clogged.

d. Slotted Drain Inlets. Slotted inlets function in essentially the same manner as curb opening inlets (i.e., as weirs with flow entering from the side). Interception capacity is dependent on flow depth and inlet length. Efficiency is dependent on flow depth, inlet length, and total gutter flow.

On continuous grade, flow interception by slotted drain inlets is subjected to lateral acceleration due to the cross slope of the pavement. Research results indicate that for slotted inlets with slot widths greater than or equal to 45 millimeters, the length of slotted inlet required for total interception can be computed by the same method as for curb opening inlets.

Slotted drain inlets located in sags perform as weirs to depths of about 60 millimeters, depending on slot width and length. At depths greater than about 120 millimeters, they perform as orifices. Between these depths, flow is in a transition stage.

e. Median and Roadside Ditch Inlets. Medians and roadside ditches may be drained by grate inlets similar to those used for pavement drainage. Grate inlets should be flush with the ditch bottom and cross drainage structures should be continuous across the median unless the median width makes this impractical. Ditches tend to erode at grate inlets. Paving around the inlets helps prevent erosion and may increase the interception capacity of the inlet marginally by acceleration of the flow.

Small dikes placed downstream of median or ditch inlets ensure complete interception of the flow. The dikes usually need not be high and should have safe slopes. The height of the dike required for complete interception on continuous grades or the depth of ponding in sag vertical curves can be computed. The effective perimeter of a grate in an open channel with a dike should be taken as 2(L+W) since one side of the grate is not adjacent to a curb.

f. Bridge Deck Inlets. Bridge decks are most effectively drained where the gradient is sufficient to convey accumulated water off the deck for interception. Such practice, of course, would be dependent on keeping accumulated spread within acceptable limits. It is frequently possible to eliminate or at least minimize deck drainage by intercepting accumulated flow upgrade of the bridge.

The principles of inlet interception on bridge decks are the same as for roadway inlets. However, specific requirements for a bridge deck drainage system usually differ from those of an approach roadway drainage system in the following respects:

- Total or near total interception is usually desirable upgrade of expansion joints.
- Deck drainage is highly susceptible to clogging.
- Inlet spacing is often restricted by bent spacing.
- Inlet sizes are often restricted by structural considerations.

The design of bridge deck drainage systems should be a combined and cooperative effort by the hydraulic and structural designers.

It should be noted that small size inlets operate as orifices at lesser depths than inlets of larger dimensions. Experiments with 100 millimeter diameter deck drains have indicated that this size range would operate as an orifice at depths of less than 30 millimeters on continuous grades. Interception capacities of small deck drains are extremely low.

Use of a safety factor should be considered in computing the interception capacity of bridge deck drains since they tend to clog. The most practical way of applying a safety factor is with inlet spacing since structural constraints would usually limit the size of inlets.

5. Catch Basins. Concrete catch basins with grated tops are used to collect water from a gutter line or ditch and drain it into a culvert or storm sewer. In curbed sections of highway where a substantial concrete curb or curb and gutter is constructed (usually in urban areas), catch basins are installed to drain the pavement. In these cases the catch basins may be part of a storm drain (or storm sewer) system, or they may be connected to individual outlet pipes. The catch basins should be spaced so that water from the design storm does not spread excessively onto the traffic lanes.

Catch basins may also be installed on highway cross pipes in narrow medians between parallel highways. The locations of catch basins and the size of their grates should be determined by the hydraulic engineer along with minimum pipe sizes and minimum grades for storm drain systems.

A catch basin may be required at the lower ends of bridges where the runoff from the bridge will be sufficient to erode the fill at the corners of the bridge. It is the designer's responsibility to provide for bridge end catch basins on the plans.

6. Storm Sewer Design. The system which carries the storm water runoff, consisting of one or more pipes connecting two or more drop inlets, is referred to as the storm sewer system. The purpose of the storm sewer system is to collect storm water runoff from the roadway and convey it to an outfall.

A properly designed storm sewer system will effectively transport water for the recurrence interval for which it was intended. The system should be self-cleaning without creating unacceptable high water velocities. Storm sewers may be designed as either open channels (where there is a free water surface) or for pressure flow conditions. When the storm sewer system is to be designed as pressure flow it should be assured that the hydraulic grade line does not exceed an elevation that may create unacceptable flooding conditions. Storm drains systems may be designed either way provided the designer is consistent in the design methods used. There will be little differences in the systems if good design practices are followed.

The basic concepts of storm drain design are as follows:

- Do not use pipe sizes less than 450-millimeter diameter except in special cases.

- To determine minimum pipe size relative to flow, use critical depth of flow (circular) with a d_c to D ratio equal to 0.8.

Where:

d_c = critical depth (m).
D = diameter (m).

- If the pipe gradient is fixed (i.e., set by physical controls), determine pipe size for full flow provided the size of the pipe selected is not less than the minimum size permitted for critical depth of flow.

- At changes in size of pipe or box, always place soffits or top inside surfaces of the two pipes at the same level rather than placing flow lines at the same level. This technique will help prevent backwater profiles from rising and upstream velocities from decreasing. Naturally this rule cannot be followed in every instance, but it should be adhered to where practical.

- Do not discharge the contents of a larger pipe or box into a smaller one even though the capacity of the smaller pipe or box may be greater due to a steep slope. Special consideration should be given to available outlets of an existing system.

- Calculate the hydraulic gradient of each storm sewer run to determine water surface elevations at critical points, such as junction structures and drop inlets.

All pipes or boxes should be designed such that velocities of flow will not be less than 600 millimeters per second at design flow or lower. For very flat flow lines, the general practice is to design components so that flow velocities will increase progressively throughout the length of the pipe system. Upper reaches of a storm system should have flatter slopes than in the lower reaches. Progressively increasing slopes keep solids moving toward the outlet and deters settling of particles due to steadily increasing flow streams.

A complete and proper hydraulic analysis should be performed to ensure that the system is efficient and cost effective. A simplistic approach to the design can result in flooding or failure of the system.

The design of storm drains is discussed in the FHWA design manual, *Design of Urban Highway Drainage*. Another good reference is *Modern Sewer Design*, by the American Iron and Steel Institute.

Inlet computations (Exhibit 7.7) and storm sewer computations (Exhibit 7.8) should be performed and recorded on the appropriate worksheets. These completed worksheets should be included in the project design file. Hydraulic grade line computations (Exhibit 7.9) will be performed by the hydraulics engineer and the completed forms are to be furnished to the designer.

F. Bridge Waterways. The hydraulic requirements of stream crossings must be recognized and considered in the analysis and design of bridges. Features which are important to the hydraulic performance of a bridge include the following:

- The approach fill alignment, skew and profile.

- Bridge location, skew and length.

- Span lengths for bent and pier location and design.

- Foundation design.

- Superstructure configuration and elevations.

The hydraulics of bridge waterways will include consideration of the total crossing including approach embankments and structures on the flood plains. The hydraulic analysis involves determining the backwater associated with each alternative profile and water opening, the effects on flow distribution and velocities, and the scour potential.

1. Design. Piers and abutments should be designed to minimize flow disruption and potential scour. Piers located in any channel should be limited to a practical minimum, and piers should not be located in the channel of small streams. Piers properly oriented with the flow do not contribute significantly to bridge backwater. The type of abutment used has little effect on the total backwater except where the flow section is severely contracted by a short bridge. Orientation of abutments is usually the same as for piers in adjacent bents.

The hydraulic analysis of stream crossings should consider the following factors:

a. Backwater. No installation should create a backwater that would significantly increase flood damage to properties upstream of the crossing. The amount of backwater permissible will vary with the site, depending upon the flood conditions existing at the specific site and the damages to upstream properties. The designer may use the 2 percent (50-year) flood with backwater limited to 300 millimeters as an aid in selecting the waterway opening and crossing profile.

b. Velocity. The waterway should be designed so the velocity of water through the structure will not damage either the highway facility or increase damages to downstream property. The acceptable average velocity should be based on the characteristics of the individual site. These characteristics include the following:

- Natural stream velocity.
- Bed materials.
- Soil types.
- Foundation materials.
- Risk considerations from backwater and scour.

c. Flow. Retain existing flow distribution to the extent practicable. This will help minimize damage to property by either excessive backwater or high local velocities and will avoid concentrating flow in areas which were not subjected to concentrated flow prior to construction.

d. Freeboard. Provide adequate freeboard at structure and design pier to pass anticipated debris. A solid pier will not collect as much debris as a pile bent or a multiple column bent. Rounding or streamlining the leading edges of piers helps to decrease the accumulation of debris and reduces local scour at the pier.

Flood magnitudes ranging from the mean annual, 2.33-year, through the 100-year flood or the flood of record, whichever is larger, shall be analyzed and the results compared to the minimum flood frequency criteria. See Table 7-2.

2. Hydrologic Analysis. In order to proceed with the hydraulic design of a structure for a waterway crossing, the designer must first estimate flood frequencies. Data needs for the hydrologic analysis are largely dependent upon the methods used to estimate flood flows. Information on flood flows, drainage basin characteristics, highwater during past floods, flood history at existing structures, channel geometry, and precipitation are commonly needed hydrologic data.

3. Bridge Versus Culvert. The waterway crossing may be of such size that the waterway opening can be provided for by either culverts or a bridge. Estimates of costs and damages associated with each will indicate which structure alternative should be selected.

a. Bridges have the following advantages:

- Less susceptibility to clogging with drift and debris.
- Waterway increases with rising water surface until water begins to submerge superstructure.
- Scour increases waterway opening.
- Widening does not usually affect hydraulic capacity.

b. Culverts have the following advantages:

- Require less structural maintenance than bridges.
- Capacity increases with stage.
- Capacity can sometimes be increased by installing improved inlets.
- Usually easier and quicker to build than bridges.
- Scour is localized, more predictable and easier to control.
- Storage can be used to reduce peak discharge.
- Grade raises and widening projects sometimes can be accommodated by extending culvert ends.

4. Hydraulic Analysis. The hydraulic design of a stream crossing is a trial and error process in which alternative waterway opening designs are tried for each profile alternative. There is a variety of information required and steps to be taken in the hydraulic analysis.

Cross sections of the stream channel and flood plains are required to establish the stage discharge relationships and conveyance. Sufficient cross sections should be obtained to provide an accurate representation of the channel and flood plains. If a stream control section (such as a constriction, confluence, or dense vegetal cover) exists downstream of the crossing site, cross sections should be computed beginning at the control section.

Extend cross sections laterally to include the total flood plain for the design and larger floods. The cross section should be normal to expected flood flow directions and not necessarily normal to the stream channel. The number of sections required is dependent upon flow conditions at the site. Guidance should be sought from the hydraulic engineer who will be responsible for the analysis.

Data on land use and ground cover should be obtained for assessing roughness characteristics in conveyance computations.

Photographs (ground or aerial) of the channel and flood plains and descriptions are necessary for use in the analysis. A site inspection by the designer may be necessary to ensure a good estimate of roughness coefficients. General characteristics helpful in making design decisions should be noted; these include soil types in the stream bed, banks, and over-bank areas and stream bed material gradation if possible. Evidence of drift and debris (size and volume), bank caving, headcuts, and other conditions which could affect abutment and pier location, orientation, and type, should be recorded. Photographs of the channel and stream bed, preferably in color, can be a valuable aid to the designer and can serve as excellent documentation of existing conditions.

Water surface elevations of the stream at the crossing must be computed, and a stage discharge curve must be developed showing how the normal water surface elevation of the stream varies with the discharge. Stage discharge relationships shall be established for a range of flood magnitudes, usually the mean annual flood through the 1 percent (100-year flood) or flood of record, whichever is larger.

Stage discharge relationships are commonly estimated by either water surface profile computations (preferred) or by single section analysis.

Single section analysis assumes the following:

- Steady uniform flow in the stream.

- Cross sections, slopes, and "n" values that are reasonably representative of the stream characteristics for the reach under study.

A more reliable method of establishing stage discharge relationships is by water surface profile computations that account for variations in cross section, roughness, and channel slope.

Stage discharge computations are discussed in Section 7.4.B. This stage discharge relationship is usually presented in a stage discharge curve. From this curve the designer can determine the elevation of the water surface for various flood discharges.

The flow distribution must be analyzed. Flow distribution refers to the proportion of the total flow in the stream that is conveyed by each of the various subsections of the cross section. The analysis of flow distribution will reveal sections where the flow rates are relatively high and sections which are relatively ineffective in conveying flow. This information is necessary to properly locate bridges or other openings on the flood plains, determine bridge lengths, locate overflow sections and approach roadways, and evaluate the need for and location of spur dikes and other protective and preventive features to be incorporated in the design.

Flow distribution usually will change with changes in stage and discharge and should be determined for the various flow rates of interest in the design of the crossing. Flow distribution is determined by converting the conveyance of each subsection to discharge. The results should be carefully examined and when possible compared with observed flows to determine whether the computed flow distribution is reasonable.

Proposed structure alternatives shall be analyzed. In cooperation with the bridge engineer, the hydraulics engineer helps select span lengths, pier type and size, abutment type, and roadway profile. The location and orientation of piers and abutments must be selected. If a proposed design does not satisfy the criteria as outlined or the existing conditions are adversely affected, another alternative shall be analyzed.

Backwater calculations shall be made for a range of discharges and for each profile and structure alternative. Backwater estimates are an aid in selecting the waterway opening and crossing profile.

There are several methods currently used to calculate backwater at bridge constrictions. Most of these methods have been computerized since the equations used are complex and often require trial and error solutions. HDS No. 1, *Hydraulics of Bridge Waterways* contains a hand procedure for calculating bridge backwater.

G. Encroachments on Flood Plains. Encroachments into streams are to be avoided wherever possible and encroachments onto flood plains shall be minimized to the fullest extent practical. See FAPG 650A relative to policies and procedures for the location and hydraulic design of highway encroachments onto flood plains. Exhibit 7.4 is a sample worksheet to assist in evaluating proposed flood plain encroachments.

Procedures for the design of encroachments on flood plains are provided in HEC No. 17, *The Design of Encroachments on Flood Plains Using Risk Analysis.* The application of risk analysis to the design of drainage structures allows the designer to select the design that will result in the least total expected cost to the public.

Additional information on procedures and guidelines applicable to flood plain encroachments may be found in a paper titled *Guidelines for the Evaluation of Highway Encroachments on Flood Plains*, published in 1982 by the Office of Engineering, FHWA, Washington, DC. Also see Chapter 3 relative to consulting and coordinating the protection of flood plains with USACE and FEMA.

H. Erosion Control. Erosion and sediment control are important considerations in the development of a highway facility. It is the policy of FLHO that highways be designed and constructed to standards that will minimize erosion and sediment damage to the highway and adjacent properties.

Both temporary and permanent erosion control measures shall be considered during the design of a highway and all necessary features incorporated into the contract plans and specifications.

Temporary control measures are those features temporarily installed for use during construction activities and upon completion of the project are generally removed and disposed. The design for temporary control measures such as silt fences, brush barriers, diversion channels, sediment traps, check dams, slope drains, berms, etc. are contained in the manual *Best Management Practices for Erosion and Sediment Control*, published in 1995 by FHWA, Federal Lands Highway Office.

Standard plans detailing the more common temporary control devices are available and should be included in every set of project plans containing construction activities that could possibly affect soil degradation or water quality.

Permanent control measures are those features installed as part of the highway to minimize scour, sedimentation, erosion, etc. during the life of the facility.

Curbs, gutters and downdrains are used for controlling drainage from a highway, especially in embankment areas under certain conditions. The use of curbs (mountable type) should be limited to drainage control along roadway embankments with highly erodible soils, along cut sections where a ditch is not to be constructed, and along narrow medians. The curb should be offset 300 to 600 millimeters outside the normal shoulder line. Curbs used in conjunction with guardrail should not project inside the face of the rail. The use of curb with guardrail should be avoided. Refer to Chapter 8, Section 8.4 for precautions in using curbs.

Road inlets are often needed to collect runoff from pavements to prevent erosion of embankment slopes or to intercept water at bridges. Inlets used for these purposes differ from other uses because:

- economies that are achieved by system design are often not possible since a series of inlets is not used;
- total or near total interception is sometimes necessary to limit bypass flow from running onto bridge deck;
- a closed storm drainage system is often not available for disposal of the intercepted flow and special methods of disposal must be provided at each inlet.

Downdrains or chutes are generally used to convey the discharge water from the inlets to the embankment toe. Buried pipe downdrains are preferable because the flow is confined, erosion along the embankment slope is minimized, interference with maintenance functions is reduced, and they are aesthetically pleasing.

Erosion at the outlets of downdrains must be controlled or minimized. At locations of minimal erosion, the designer should consider placing graded gravel or a rock at the outfall to control scour. Areas where significant scour is anticipated will require a special design with specific details included in the contract.

See HEC No. 12 for details and information relative to permanent inlets, downdrains, grates, curbs, gutters, and other similar roadway drainage designs useful in controlling erosion. Section 7.2 lists additional sources of information applicable to the design of debris control structures, riprap or slope protection installations, energy dissipator systems, ditch and/or channel linings, and similar structures.

7.5 APPROVALS

Section 7.2 discusses various laws and requirements that may involve review and approval of hydraulics and related features. Approvals may be in the form of special permits or actual PS&E approvals by cooperating or client agencies. Permit requirements, clearance procedures, and approvals are also outlined in Chapter 3.

It is important to establish contact and coordination with any involved agencies early in the project development process. This will help to identify requirements, design criteria, and permits or other approvals that will be needed. Hydrologic and hydraulic analyses and designs must be developed in a manner that will facilitate necessary approvals and project clearances. Special approval actions will vary with each project and may occur at various stages of design.

The hydraulics engineer should review all drainage designs included in the plans. This review should be performed during the early development of the project prior to finalizing the design to provide time for the designer to evaluate the hydraulic engineer's recommendations and if necessary make the appropriate modifications. The review should include a check of both the hydrologic and hydraulic computations for channels, culverts, inlets, bridge waterways, and all other drainage features in the proposed work.

Proposed bridge sites and corresponding waterways should be reviewed by the hydraulics engineer during the location phase to permit a hydrologic and hydraulic analyses evaluation before the layout is finalized. This input could benefit the designer during the development of the plans and specifications of the project's hydraulic features, such as channel alterations, slope stabilization, and temporary and permanent erosion controls.

Major revisions or modifications to a designed drainage facility or feature should be reviewed by the Hydraulics engineer.

7.6 REPORTING AND DOCUMENTATION

The reports and design computations prepared for a project are just as important as the field survey and final plans. Every effort should be made to insure that data is clear, accurate, complete, and contains all information necessary for layout and design. Copies of all reports and support documents shall be placed in the project design file.

The hydrologic analysis performed on each project may be compiled in a hydrologic report or otherwise incorporated into the design file. Document all the pertinent information on which the hydrologic decision was based.
Documents normally will contain the following:

- Relevant maps.
- Drainage area data.
- Field survey information.
- Photographs.
- Hydrologic computations.
- Flood frequency analysis.
- Stage discharge data.
- Flood history (including information from local residents who witnessed or had knowledge of unusual events).

The documentation usually consists of two parts. A data section containing the hydrologic background information and an analysis section containing the design computations. The comprehensiveness of the documentation will depend on the nature of the stream crossed or flood plain encroached upon, cost of proposed structure, and the class of highway.

The preparation of the reports on large and complex drainage designs (flood plain encroachments, etc.) is the responsibility of the hydraulics engineer. Computations and documentation of routine drainage facilities (such as pipe cross drains and ditches) are the responsibility of the designer.

A. Open Channels. Documentation on the design for the protection of stream banks and open channels shall contain the following minimum data:

- Project identification.
- Location of proposed work.
- Design discharge and frequency.
- Channel cross section and gradient.
- Type of lining (size and gradation of riprap, filter blanket, etc.) including design computations.
- Other pertinent data.

B. Culverts. Documentation on the design of culverts should contain the following minimum data:

- Project identification.
- Location of proposed installations.
- Drainage area map and site topography.
- Stream profile and cross sections.
- Information on existing structures.
- Historical highwater data.
- Site investigation data (foundations, pH factors, water and soil resistivity, etc.).
- Hydrologic design computations.
- Hydraulic design calculations and culvert performance curves.
- Economic analysis.
- Other pertinent data.

Exhibit 7.6 is an example of a culvert design worksheet for use in recording the data.

C. Roadway Drainage. The design of a roadway drainage facility should be supported by documentation containing the minimum following information:

- Project identification.
- Location of proposed installation.
- Roadway gradient and applicable cross section.
- Design discharge and frequency.
- Manning's roughness coefficient (n).
- Type and size of inlets.
- Inlet efficiency computations.
- Data on intercepted and by-pass flows.
- Other pertinent data.

Exhibits 7.7, 7.8, and 7.9 are examples of roadway drainage worksheets for recording data and computations on inlets, storm sewer systems, and hydraulic grade lines, respectively.

D. Bridge Waterways. The bridge waterway analysis shall be documented and shall include the following:

- Project identification.
- Location of proposed bridge site.
- Drainage area map and site topography.
- Information on existing structures.
- $Q_{overtopping}$ and/or Q_{100}.
- Design flood frequency.
- Design discharge (include hydrologic method used).
- Design highwater and elevation versus discharge curve based upon natural stream cross section and natural or existing conditions (indicate how highwater was determined).
- Historical data (recorded highwater with dates, etc.).
- Cross sections including a cross section of the entire flood plain. Include Manning's *n* values for the various subareas, natural channel velocity, and backwaters created by the proposed structure.
- Velocity through the structure area below design highwater on a plane normal to stream flow at flood stage within the limits of the bridge.

Include a summary of any investigations accomplished for environmental review of flood plain impacts with the documentation. Computations supporting the design of riprap, spur dike placement, and for scour prevention at piers should also be included in the documentation.

7.7 DIVISION PROCEDURES

Reserved for Federal Lands Highway Division office use in supplementing the policy and guidelines set forth in this chapter with appropriate Division procedures and direction.

LIST OF EXHIBITS

Hydraulic Survey Data

Date of Survey: ______________________

By: ______________________

Project Identification: ______________________

Route No.: ______________________ Site Location: ______________________

State: ______________________ National Forest/Park: ______________________

County: ______________________

Nearest Community: ______________________

Plane coordinates or Lat. and Long. from a Highway Map: ______________________

____

1. **Existing Structures** *(any structure at the site, or upstream or downstream from the proposed site having a comparable drainage area)*

- Date of original construction: ______________________
- Was present bridge in place at time of extreme high water? ______________________
- Has bridge ever been washed out? __________ Date: ______________________

Describe what portion of bridge or approaches have been washed out: ______________________

____

- Elevation of maximum high water:

Upstream side of existing structure ______________________

Downstream side of existing structure ______________________

__________ m upstream of existing structure ______________________

__________ m downstream of existing structure ______________________

__________ m at other locations on the flood plain (describe) ______________________

____

____

Date of maximum high water: __________ Source of information: ______________________

- Other relevant information: ______________________

____

Hydraulic Survey Data
(page 2 of 3)

2. Stream Flow Data at Proposed Site

- Elevation of maximum high water of this stream at proposed location if different from data for existing site:

  ______ m on upstream side of proposed ______

  ______ m on downstream side of proposed ______

  ______ m at other locations on the flood plain (describe) ______

  ______

  Date: ______ Source of information ______

  ______

- Elevations of highest backwater caused by another stream ______

  Date ______ Stream Name ______

  Source of information ______

- Elev. of normal water ______ (Average) Elev. of extreme low water ______

  Date: ______

  Source of information ______

- Velocity of current at high water: ______ m/s
- Velocity of current at normal water: ______ m/s
- Other relevant information: ______

  ______

3. Site Conditions

- Amount and character of drift during a freshet or flood:

  ______

- Do banks or bed show scour? ______

  Description and location of scour: ______

  ______

- Describe streambed material (mud, silt, clay, sand, gravel, cobbles, boulders, soft solid rock, stratified rock, hard rock, silt sedimentation, deposition of large stones, etc.) is material loose or well compacted?

  ______

  ______

- Comment on stream ecology and wildlife habitat: ______

  ______

Hydraulic Survey Data
(page 3 of 3)

4. Influence and Control of Site

- Location and condition of dams upstream or downstream that will affect high water discharge at this site: ______________________

- Location and description of any water-gaging stations in the immediate vicinity: ______________________

Elevation ____________ on gage corresponds to elevation ____________ on survey datum.

- Extent to which sink-holes affect runoff, etc.: ______________________

- Brief description of usage of stream for navigational purposes by small boats, etc. ______________________

- Other relevant information: ______________________

5. General Remarks *(List any unusual conditions or features not covered or considered significant.)*

____

Hydraulic Design Check List*

*See HEC No. 19

Project Identification: ____________________

Route No. __________ **National Forest/Park:** ____________________

State: ____________________

County: ____________________ **Prepared by:** ____________________

Date: ____________________

Reference Data

Maps:	
USGS Quad. Scale Date	
USGS 1:250 000	
Other	
Local Zoning Maps	
Flood Hazard Delineation (Quad.)	
Flood Plain Delineation (HUD)	

Aerial Photos Scale Date	

Studies by External Agencies:	
USACE Flood Plain Inform. Report	
SCS Watershed Studies	
Local Watershed Studies	
USGS Gages & Studies	
TVA Flood Studies	
Interim Flood Plain Studies	
Water Resource Agency Data	
Regional Planning Data	
Forest Service	
Utility Company Plans	
State ( )	

Studies by Internal Sources:	
Bridge Inspection Reports	
Hydraulics Sect. Records	
Drainage Records	
Flood Records (High Water, Newspaper)	

Hydrology

Technical Resources:	
Highway Engineering Circular	
Research Reports	
Textbooks	
FHWA Directives	

Discharge Calculations:	
Drainage Areas	
Rational Formula	
USGS Regression Equation	
FHWA Regression Equation	
Regional Flood Analysis	
SCS Method	
Area-Discharge Curves	
Log-Person Type III Gage Rating	

High Water Elevations:	
Field Surveys	
External Sources	
Personal Reconnaissance	

Flood History:	
External Sources	
Personal Reconnaissance	
Maintenance Records	

Hydraulic Design

Calibration of High Water Data:	
Discharge and Frequency of H.W. el.	
Influences Responsible for H.W. el.	
Anal. Hydraulic Perform. of Existing Facility for Min. Flow thru 100 Yr.	
Anal. Hydraulic Perform. of Prop. Facility for Min. Flow thru 100 Yr.	

Design Appurtenances:	
Dissipators	
Rip Rap	
Erosion & Sediment Control	
Fish & Wildlife Protection	

Technical Aids:	
Design Manual	
Technical Library	

Computer Programs:	
FHWA Culvert Analysis (HY-8)	
FHWA Bridge Waterways (HY-7)	
HEC-2 Water Surface Profile	
QUICK HEC-12 Drop Inlet Design	
Log-Pearson Type III Analysis	

EXHIBIT 7.2
Hydraulic Design Check List

Hydraulic Site Evaluation

Project Identification: ______________________________

Route No. ____________ **National Forest/Park:** ______________________________

State: ______________________

County: ______________________ **Prepared by:** ______________________

Date: ______________________

Note: Attach site photographs with appropriate identification using separate blank pages.

Design Site Data

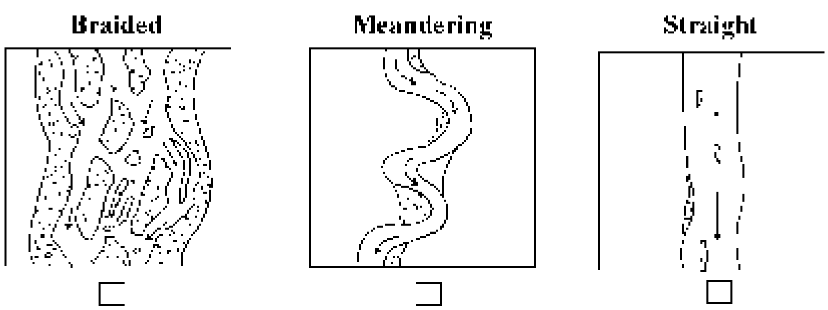
1. Existing Structure(s)—Provide Sketch of Culvert/Structure with Dimensions and Brief Description.

Comments: Include structure or culvert type and condition. Note particularly any scour adjacent to abutments or at culvert outlet and the presence of debris or sediment. Also note the location of any utilities in the area of the crossing.

2. High Water Marks - Describe the nature and location of any apparent high water marks and relate to a date of occurrence, if possible.

Stream Channel and Related Aspects

1. Stream Morphology



Is Stream Channel -	**Stable**	☐	Check Appropriate Type
	Aggrading	☐	
	Degrading	☐	

Comments:

____

____

____

____

2. Channel and Overbank Roughness Coefficients *(Check appropriate box).*

a. Basic Channel Description

☐ Channel in Earth
☐ Channel Cut into Rock
☐ Channel Fine Gravel
☐ Channel Coarse Gravel

b. Surface Irregularity of Channel.

☐ Smooth - Best obtainable section for materials involved.
☐ Minor - Slightly eroded or scoured side slopes.
☐ Moderate - Moderately sloughed or eroded side slopes.
☐ Severe - Badly sloughed banks of natural channels or badly eroded sides of man-made channels-jagged and irregular sides or bottom sections of channels in rock.

c. Variations in Shape and Size of Cross-Sections.

☐ Changes in size or shape occurring gradually.
☐ Large and small sections alternating occasionally or shape changes causing occasional shifting of main flow from side to side.
☐ Large and small sections alternating frequently or shape changes causing frequent shifting of main flow from side to side.

d. Channel Obstructions - (Judge the relative effect of obstructions - consider the degree to which the obstructions reduce the average cross-sectional area, character of obstructions, and location and spacing of obstructions). Smooth or rounded objects create less turbulence than sharp, angular objects.

The effect of obstructions is:

☐ Negligible
☐ Minor
☐ Appreciable
☐ Severe

e. Degree of Vegetation - *(Note - Amount and character of foliage).*

The effect of vegetative growth upon flow condition is:

☐ Low- Dense growths of flexible turf grasses where average depth of flow is 2 to 3 times the height of vegetation. Supple seedling tree switches where the average depth of flow is 3 to 4 times the height of vegetation.

☐ Medium - Turf grasses where the average depth of flow is 1 to 2 times the height of vegetation. Stemmy grasses, weeds, or tree seedlings (moderate cover), average depth of flow 2 to 3 times the height of vegetation. Bushy growths (moderately dense), along channel side slopes with no significant vegetation along channel bottom.

☐ High - Turf grasses where average height is about equal to the average depth of flow. Trees 8 to 10 years old with some weeds or brush. Bushy growths about 1 year old with some weeds. No significant vegetation along channel bottom.

☐ Very high - Turf grasses where average depth of flow is less than 1/2 the height of vegetation. Bushy growths about 1 year old intergrown with weeds. Dense growth of cattails along channel bottom. Tree intergrown with weeds and brush (Thick growth).

Additional Comments:

3. Requirements for Erosion Protection or Flow Control. Comment on the need (if any) for training walls, cutoff walls or special slope or channel protection.

Peripheral Site Data

1. Hydraulic Control - Note location and description.

2. Upstream and Downstream Structures - Provide sketches and brief descriptions of existing bridges/culverts. Include dimensions.

3. Maximum Allowable Headwater - Describe the nature of the apparent controlling feature and note its location.

4. Fish Passage Requirements - Comment on the apparent need for fish passage or impediments to same; such as, dams or restrictive crossings in the area.

5. Watershed Area - Check watershed boundaries for accuracy - Note current land uses within watershed.

6. Flow Control Structures Within Watershed - Note the location and type of all significant flow control structures (dams, etc.) within the watershed. Provide sketches with dimensions as required.

Risk Assessment for Encroachments

Project Identification: ____________________

Route No. __________ **National Forest/Park:** ____________________

State: __________ **County:** ____________________

General Location: ____________________

____

General Requirements

1. **Location of Crossing:** ____________________
2. **Name of Stream:** ____________________
3. **Current ADT:** __________ **Projected ADT:** __________
4. **Hydraulic Data:**

   Q_2 = __________ Stage Elevation = __________

   Q_5 = __________ Stage Elevation = __________

   Q_{10} = __________ Stage Elevation = __________

   Q_{25} = __________ Stage Elevation = __________

   Q_{50} = __________ Stage Elevation = __________

   Q_{100} = __________ Stage Elevation = __________

   $Q_{overtopping}$ = __________

   Design Flood Frequency ____________________

   Selecting Factor ____________________

5. **Site Data:**

   a) Low member elevation: ____________________

   b) Minimum roadway overflow elevation: ____________________

   c) Elevations of high risk property:

   Residences: __________

   Other Buildings: __________

   d) Elevations of prime farm land: __________

EXHIBIT 7.4 Risk Assessment for Encroachments

(page 1 of 3)

Bridge Site Analysis

1. **Backwater Damage**

(Major flood damage in this context refers to buildings, housing developments, etc.)

a. Is there flood damage potential to the residence(s) or other buildings during a 100 year flood?

Yes ☐ No ☐ (Go to 2)

b. Would this flood damage occur even if the roadway crossing was not there?

Yes ☐ No ☐ (Go to d)

c. Could the stream crossing be designed in such a manner so as to minimize this potential flood damage?

Yes ☐ No ☐ (Go to 2)

d. Analyze using Least Total Expected Cost (LTEC) design procedures. (See HEC No. 17).

2. Traffic Related Losses

a. Is a practical detour available? (i.e., emergency vehicle access, evacuation route, school bus; mail delivery, etc.)

Yes ☐ No ☐ (Go to d)

b. Does the ADT exceed 50 vehicles per day?

Yes ☐ No ☐ (Go to 3)

c. Would the duration of road closure in days multiplied by the length of detour minus the length of normal route in kilometers exceed 30?

Yes ☐ No ☐ (Go to 3)

d. Analyze using Least Total Expected Cost (LTEC) design procedures. (See HEC No. 17.)

3. Roadway and/or Structural Repair Costs

a. Is there danger of structural or roadway failure due to scour, ice, debris, or other means?

Yes ☐ No ☐ (Go to 4)

b. Will the cost of protecting the site from damage exceed the cost of providing additional waterway capacity?

Yes ☐ No ☐ (Go to 4)

c. Analyze using Least Total Expected Cost (LTEC) design procedures. (See HEC No. 17.)

4. Capital Costs

a. Will the capital cost of the structure exceed $1,000,000?

Yes ☐ No ☐ (Go to 5)

b. Analyze using Least Total Expected Cost (LTEC) design procedures. (See HEC No. 17.)

EXHIBIT 7.4

5. If an LTEC design is not required and there are no other factors requiring further study, proceed with the design, selecting the lowest acceptable grade line and the smallest waterway opening consistent with the constraints imposed on the project.

Risk Management

☐ The risk assessment has demonstrated that potential flood damage costs, traffic related coats, roadway and/or structure repair costs are minor and therefore disregarded for this project.

☐ The risk assessment has indicated the need for further analysis in one or more of the categories examined (specify).

____

____

Risk Assessment by: ____________________

Date: ____________________________

Flood Damage Report for Bridges

Location of Bridge: ______________________________

Bridge Identification: ______________________________

Highway Route No. ______________ **State:** ______________________

County: ______________________

Report Prepared By: ______________________ **Date:** ______________________

1. Extent of Damage/Repair Required

(A) Approach Roadways

- Were approaches overtopped? Yes ☐; No ☐ *(Go to B)*
- Approximately length of overtopped pavement section ________ m
- Estimated maximum depth of water over road ________ m
- Rough estimate of damage. $ ________
  Square meters of pavement to be replaced ________
  Cubic meters of roadway fill needed ________
- Comments: ______________________________

(B) Superstructure

- Was bridge deck damaged? Yes ☐ No ☐ *(Go to C)*

Damage was:
Minor ☐ Major ☐ Replacement required ________

- Was low bridge member inundated? Yes ☐ No ☐
- Was bridge deck inundated? Yes ☐ No ☐ (maximum depth ________)
- Effect of debris (clogging of waterway opening, etc.) on superstructure damage.

____

- Was bridge deck tied down? Yes ☐ No ☐
- Comments: ______________________________

EXHIBIT 7.5
Flood Damage Report-Bridge Sites

(C) Substructure

Was substructure damaged? Yes □ No □ *(Go to 2)*

	Repairs Minor	Repairs Major	Replacement Required
Abutment Damage	□	□	□
Pier Damage	□	□	□
Riprap Damage	□	*□	*□

*Estimated cubic meters of riprap needed ____________________

Comments on extent of scour at site: ____________________

____

____

Effects of debris on substructure damage: ____________________

____

____

2. **In your opinion, what were major factor(s) contributing to bridge damage/failure.** ____________________

____

3. **Length of time water flowed over road** . ________________ **hours. How long was (or is) road expected to be closed to traffic?** ____________________

4. **Is this a good site for a more detailed study by others? Yes** □ **No** □

- Is hydrologic and hydraulic data available? Yes □ No □ Don't know □
- Is this a "typical" bridge crossing or is the hydraulics complicated by other features (upstream/downstream bridges, flood plain development, etc.). Typical □ Not Typical □

- Comments: ____________________

____

____

____

EXHIBIT 7.5

(page 2 of 2)

PROJECT : ____________	STATION: ____________	**Culvert Design Work Sheet**
____________	SHEET ______ OF ______	DESIGNER/DATE: ______ / ______
		REVIEWER/DATE: ______ / ______

SEE ADD'L SHTS.

HYDROLOGICAL DATA

☐ METHOD: ____________

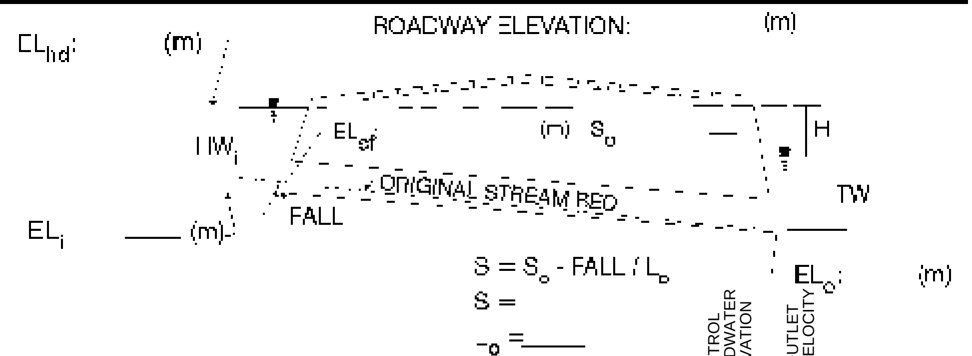
☐ DRAINAGE AREA: ______ ☐ STREAM SLOPE: ______

☐ CHANNEL SHAPE: ____________

☐ ROUTING: ______ ☐ OTHER: ______

DESIGN FLOWS/TAILWATER

R.I. (YEARS)	FLOWS (m^3/S)	TW (m)



CULVERT DESCRIPTION: MATERIAL-SHAPE-SIZE-ENTRANCE	TOTAL FLOW Q (m^3/S)	FLOW PER BARREL Q/N (1)	HEADWATER CALCULATIONS: INLET CONTROL HW_i/D (2)	HW_i	FALL (3)	EL_{hi} (4)	OUTLET CONTROL TW (5)	d_c	$\frac{d_c+D}{2}$	h_o (6)	k_e	H (7)	EL_{ho} (8)	CONTROL HEADWATER ELEVATION	OUTLET VELOCITY	COMMENTS

TECHNICAL FOOTNOTES:

(1) USE Q/NB FOR BOX CULVERTS

(2) $HW_i/D = HW/D$ OR HW_f/D FROM DESIGN CHARTS

(3) FALL = $HW_i - (EL_{hd} - EL_{sf})$; FALL IS ZERO FOR CULVERTS ON GRADE

(4) $EL_{hi} = HW_i + EL_i$ (INVERT OF INLET CONTROL SECTION)

(5) TW BASED ON DOWN STREAM CONTROL OR FLOW DEPTH IN CHANNEL.

(6) h_o = TW OR $(d_c + D)/2$ (WHICHEVER IS GREATER)

(7) $H = [1 + k_e + (19.6n^2L)/R^{1.33}]\ V^2/2g$

(8) $EL_{ho} = EL_o + H + h_o$

EXHIBIT 7.6 Sample of Culvert Design Work Sheet

(Page 1 of 2)

SUBSCRIPT DEFINITIONS:	**COMMENTS/DISCUSSION:**	**CULVERT BARREL SELECTED:**
a. APPROXIMATE f. CULVERT FACE hd. DESIGN HEADWATER hi. HEADWATER IN INLET CONTROL ho. HEADWATER IN OUTLET CONTROL i. INLET CONTROL SECTION o. OUTLET sf. STREAMBED AT CULVERT FACE tw. TAILWATER		SIZE: ________ SHAPE: ________ MATERIAL: ________ n ________ ENTRANCE: ________

PROJECT: ID FH 27-1(I) Sunrise River Road	STATION: 7 + 246 SHEET 1 OF 1	**Culvert Design Work Sheet** DESIGNER/DATE: FLH / 1-1-95 REVIEWER/DATE: /

SEE ADD'L SHTS.

HYDROLOGICAL DATA

☐ METHOD: RATIONAL

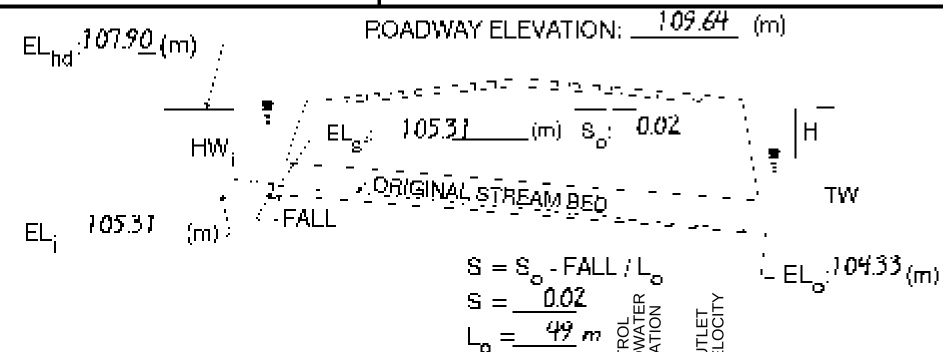
☐ DRAINAGE AREA: 21 HA ☐ STREAM SLOPE: 0.02

☐ CHANNEL SHAPE: TRAPEZOIDAL B=1.6m Z=0.6m

☐ ROUTING: ☐ OTHER:

DESIGN FLOWS/TAILWATER

R.I. (YEARS)	FLOWS (m^3/S)	TW (m)
50	3.40	0.49



CULVERT DESCRIPTION: MATERIAL-SHAPE-SIZE-ENTRANCE		TOTAL FLOW Q (m^3/S)	FLOW PER BARREL Q/N (1)	HEADWATER CALCULATIONS: INLET CONTROL HW_i/D (2)	HW_i	FALL (3)	EL_{hi} (4)	OUTLET CONTROL TW (5)	d_c	$\frac{d_c+D}{2}$	h_o (6)	k_e	H (7)	EL_{ho} (8)	CONTROL HEADWATER ELEVATION	OUTLET VELOCITY	COMMENTS
CMP 1050 mm	HEADWALL w/1:1 BEVELS	3.40	3.40	2.25	2.41	O	107.72	0.49	1.04	1.07	1.07	0.2	3.83	108.76	108.78	3.84	OUTLET CNTRL EL^{HO} > 107.90
CMP 1200 mm	HEADWALL w/1:1 BEVELS	3.40	3.40	1.5	1.83	0	107.14	0.49	0.98	1.10	1.10	0.2	1.74	107.17	107.17	3.38	OUTLET CONTROL
RCP 1050 mm	GROVED END IN HEADWALL	3.40	3.40	2.1	2.25	0	107.56	0.49	1.04	1.07	1.07	0.2	1.46	106.86	107.56	5.18	INLET CONTROL

TECHNICAL FOOTNOTES:

(1) USE Q/NB FOR BOX CULVERTS

(2) HW_i/D = HW/D OR HW_f/D FROM DESIGN CHARTS

(3) FALL = HW_i - (EL_{hd} - EL_{sf}); FALL IS ZERO FOR CULVERTS ON GRADE

(4) $EL_{hi} = HW_i + EL_i$ (INVERT OF INLET CONTROL SECTION)

(5) TW BASED ON DOWN STREAM CONTROL OR FLOW DEPTH IN CHANNEL.

(6) h_o = TW OR (d_c +D)/2 (WHICHEVER IS GREATER)

(7) $H = [I + k_e + (19.6n^2L)/R^{1.33}]\ V^2/2g$

(8) $EL_{ho} = EL_o + H + h_o$

EXHIBIT 7.6

(Page 2 of 2)

SUBSCRIPT DEFINITIONS:	COMMENTS/DISCUSSION:	CULVERT BARREL SELECTED:
a. APPROXIMATE f. CULVERT FACE hd. DESIGN HEADWATER hi. HEADWATER IN INLET CONTROL ho. HEADWATER IN OUTLET CONTROL i. INLET CONTROL SECTION o. OUTLET sf. STREAMBED AT CULVERT FACE tw. TAILWATER	BOTH A 1200 mm CMP WITH 1:1 BEVELS AND 1050 mm RCP WITH GROOVED END MEET DESIGN CRITERIA.	SIZE: 1200 mm SHAPE: CIRCULAR MATERIAL: CMP n 0.024 ENTRANCE: HEADWALL w/1:1 BVL

Instructions - Inlet Design

Summarize the computations involved in runoff and determination of inlet capacities.

Column	Description	Column	Description
1.	Identify drainage area by assigning a number, letter, etc.	16.	Efficiency of inlet (E). See HEC No. 12. Record as a decimal value to nearest hundredth.
2.	Identify inlets by a numbering system.	17.	Record flow intercepted by inlet (Q_i). Multiply value in column 16 by the value in column 9.
3.	Record location of inlet (centerline station, lt,rt,etc.)	18.	By pass flow (Q_b). Determined by subtracting the value in column 17 for the value in column 9.
4.	Compute and record CA for runoff at inlet. Multiply runoff coefficient (C) by the drainage area (A) in hectares.		
5.	Record CA for by-pass flow. Divide the value in column 18 for the previous inlet by the value in column 8 for the same previous inlet. For first inlet in a run, record zero.		
6.	Add values in columns 4 and 5 and record.		
7.	Time of concentration (t_c) for drainage area.		
8.	Rainfall intensity (i) based on t_c determined in column 7.		
9.	Total flow at inlet (Q_t). Multiply values from columns 6 and 8 and divide by 360.		
10.	Pavement cross slope (S_x) or equivalent (S_e).		
11.	Roadway grade (S_o).		
12.	Calculate depth of flow (d) at the curb for discharge. Use values from columns 9, 10, and 11.		
13.	Calculate width of spread on the pavement (T) for discharge. Use values from columns 9, 10, and 11.		
14.	Identify inlet type (grate type, curb opening, etc.)		
15.	Length of inlet (L).		

EXHIBIT 7.7 Inlet Design Worksheet

(page 2 of 2)

Instructions - Storm Sewer Design

Summarize the computations involved in sizing runs of sewer pipe.

Column	Description	Column	Description
1.	Identify inlet. Use identification number assigned to the inlet. (Column 2, on the Inlet design worksheet)	12.	Record diameter of storm sewer pipe.
2.	Record location of inlet (centerline station, lt,rt, etc.)	13.	Record slope (gradient) of pipe.
3.	Record inlet CA value. Determine CA value by dividing the value in column 17 by the value in column 8 on the inlet design worksheet.	14.	Calculate capacity of pipe using Manning's formula and record. (Note: This capacity must be approximately equal to or greater than the value for Q in column 11. If value is less, the hydraulic grade line shall be checked to determine if the HGL is lower than the gutter flow line for the run.)
4.	Determine and record CA values of flows for any contributing upstream structures.	15.	Calculate velocity of flow in the pipe using Manning's formula and record.
5.	Assign identification number to inflowing structure recorded in column 4.	16.	Record length of each run. Measure length from center to center of inlets or junctions.
6.	Add values in columns 3 and 4 and record.	17.	Record time of concentration in the pipe being evaluated. Compute the t_c by dividing the length of run (column 16) by the velocity of flow (column 15) and converting the quotient to minutes by dividing by 60.
7.	Time of concentration (t_c) for overland flow.	18.	Record inlet invert elevation.
8.	Time required for flow in the pipe.	19.	Compute and record total fall (difference in elevation between inlet and outlet inverts). Multiply value in column 16 by the value recorded in column 13.
9.	Time of concentration used for the design. For the first run, time of concentration is the inlet time for the first inlet. For all succeeding runs, time of concentration may be either the time as computed along the sewer line or the inlet time of the inlet at the beginning of the run under consideration, depending upon which of these two periods is longer.	20.	Record outlet invert elevation. Calculate by subtracting the value in column 19 from the value in column 18.
10.	Record rainfall intensity for t_c value in column 9.		
11.	Compute total discharge (Q) and record. Multiply value from column 6 by the value in column 10 and divide by 360.		

EXHIBIT 7.8 Storm Sewer Design Worksheet

(page 2 of 2)

Instructions - Hydraulic Grade Line Worksheet

The Hydraulic Grade Line (HGL) should be computed for all storm sewer systems. The purpose is to determine the elevation under design conditions to which water will rise in various inlets, manholes, junctions, etc. Computations are to be summarized on the worksheet. The HGL elevation should always be lower than the gutter flow line elevation.

Column	Description
1.	Record the station for the junction immediately upstream of the outflow pipe. HGL computations begin at the outfall and are worked upstream taking each junction into consideration.
2.	Enter the outlet water surface elevation if the outlet will be submerged during the design storm or enter 0.8 of the pipe diameter added to the invert elevation of the outflow pipe, whichever is greater.
3.	Record the outflow pipe diameter (D_o).
4.	Record the design discharge of outflow pipe (Q_o).
5.	Record the length of outflow pipe (L_o).
6.	Compute and record the friction slope in m/m of the outflow pipe using the formula: $S_{fo} = \left(\frac{Qn}{AR^{2/3}}\right)^2$ Where: Q = Discharge (m^3/s); A = Cross-sectional area of pipe (m^2); R = Hydraulic Radius (m); n = Manning's roughness coefficient
7.	Compute friction loss by multiplying the value in column 5 by the value in column 6 and record. (H_f)
8.	Record flow velocity of outflow pipe. (V_o)
9.	Record design discharges (Q_1, Q_2, Q_3 . . .) for each pipe flowing into the junction. (Q_i)
10.	Record velocity (V_1, V_2, V_3 . . .) for each pipe flowing into the junction. (V_i)
11.	Compute and record the terminal junction losses (H_{tm}) for the upper reach of each storm sewer run.*
12.	Compute and record the pipe entrance losses (H_e) for the upper reach of each storm sewer run.*
13.	Compute and record junction losses (H_j) for each junction.*
14.	Compute and record bend losses (changes in direction of flow) for each inflowing pipe.*
15.	Summarize and record total head losses (H_t). Determined by adding the values in columns 7, 11, 12, 13, and 14.
16.	Record elevation of hydraulic grade line. Determined by adding the values in columns 2 and 15.
17.	Record elevation of gutter flow line.

* See Design of Urban Drainage. FHWA. 1979.

EXHIBIT 7.9 Hydraulic Grade Line Worksheet

Inlet Design

Project: ______________________________ **Designer:** ______________________________

______________________________ **Date:** ______________________________

Comments: ______________________________

	Inlets								Gutters				Inlets				
Drainage Area No. (1)	Number (2)	Location (3)	Runoff at Inlet (4)	Bypass Flow (5)	Total (6)	t_c (7)	i (8)	Q_t (9)	S_x or S_e (10)	S_o (11)	d (12)	T (13)	Type (14)	L (15)	E (16)	Q_i (17)	Q_b (18)
			CA Values			Min.	mm/Hr.	m^3/s	m/m	m/m	meters			m		m^3/s	

EXHIBIT 7.7 Inlet Design Worksheet
(page 1 of 2)

Storm Sewer Design

Project: ______________________________ **Designer:** ______________________________

______________________________ **Date:** ______________________________

Comments: ______________________________

						t_c					Pipe Design						Pipe Inverts		
Inlet No.	Location	Inlet (3)	Contributing Flows (4)	Structure No. (5)	Total (6)	Overland Flow (7)	Flow In Pipe (8)	Flow Design Value (9)	Intensity (i) (10)	Total Discharbe Through Pipe (Q) (11)	Diameter (12)	Slope (13)	Capacity (14)	Velocity (15)	Lenght (16)	t_c In Pipe (17)	Inlet Elevation (18)	Total Fall (19)	Outlet Elevation (20)
(1)	(2)	CA Values				Minutes			mm/Hr.	m^3/s	mm	m/m	m^2/s	m/s	m	Min.	Meters		

EXHIBIT 7.8 Storm Sewer Design Worksheet
(page 1 of 2)

Hydraulic Grade Line

Project: ______________________ **Designer:** ______________________

______________________ **Date:** ______________________

Comments: ______________________

Inlet Station	Outlet Water Surface Elevation	D_o	Q_o	L_o	S_{fo}	H_f	V_o	Q_i	V_i	Head Losses				H_t	HGL Elevation	Flow Line Elevation
										H_{tm}	H_e	H_j	H_b			
	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)
(1)	Meters	mm	m^3/s	m	m/m	m	m/s	m^3/s	m/s	m	m	m	m	m	m	m

EXHIBIT 7.9 Hydraulic Grade Line Worksheet
(page 1 of 2)

Estimating Steel Pipe Service Life

The following procedure may be used for determining the expected service life of steel pipe. Examples using this procedure are shown below and in Part VI of FHWA-FLP-91-006. The "Scaling Tendency" portion of the procedure in FHWA-FLP-91-006 is not included in these guidelines.

At each pipe location estimate the abrasion level, and determine soil and water pH and resistivity. Using the fill height and pipe diameter needed, determine the minimum metal thickness due to structural needs from the fill-height tables (“structural” metal thickness). Use this information in the Service Life Estimation Chart (page 3 of 3) to determine the service life for the most critical (soil or water side) pH and resistivity. Note that the graphical information in the chart is for a plain galvanized steel with a metal thickness of 1.63 mm. The service life for 1.63 mm steel plate is referred to below and in the Figures as the "base" service life.

If the Service Life Estimation Chart is used, record the "base" service life (years), and adjust the service life for the required minimum fill height thickness by multiplying the base service life by the appropriate “structural” metal thickness factor from the table. This is referred to here and in the chart as the "structural" service life.

If the "structural" service life is greater than 50 years, check the pipe to determine if abrasion protection is needed. At **non-abrasive** or **low abrasive** sites, no additional protection is needed. At sites that are **moderately abrasive**, increase the "structural" steel thickness by one standard thickness (unless it is already the maximum thickness) or add paved invert protection. At **severely abrasive** sites, increase "structural" steel thickness by one standard thickness and add paved invert protection. If the steel plate thickness is already the maximum thickness, do not use steel pipe in severely abrasive environments. Otherwise, specify metallic coated steel pipe for use at this site.

If the "structural" service life determined above is less than 50 years, adjust the service life depending upon the abrasion level.

If the site has a **non-abrasive** or **low abrasive** environment, determine the added life for the larger steel thicknesses (multiply the "base" service by the factors in the table), and/or add the life for protective coatings as needed to reach the 50-year service life. Aluminum coated steel (Type 2), in the pH range (between 5 and 9), and the resistivity (greater than 1500 Ω-cm), has a service life which is the base service life multiplied by a factor of 2.0. Specify all combinations which provide a 50-year service life that are determined to be economically competitive. *If no metal thickness and protective coating combinations will achieve a life of 50 years, do not use steel pipe at this site*.

If the site has a **moderate** or **severely abrasive** environment, check the service life for the larger metal thicknesses until a service life of 50 years is achieved. *If no metal thickness will achieve a life of 50 years, do not use steel pipe at this site*. If additional metal thickness will achieve a 50 years service life, and the site is **moderately abrasive**, increase the metal thickness by one standard thickness (if the required metal thickness is less than 4.27 mm) or add invert protection. If the site is **severely abrasive**, and the required metal thickness is less than 4.27 mm, increase the metal thickness by one standard thickness and add invert protection. Specify all steel pipe thickness/protective coating combinations achieving a 50 year service life which are determined to be economically competitive.

A spreadsheet has also been developed as an alternate to the Service Life Estimation Chart. The spreadsheet uses the mathematical relationships and adds the service lives for various protective coatings. In addition to showing the possible service life combinations, the user is prompted to increase pipe thickness and/or add invert protection to provide needed abrasion protection. The spreadsheet computes the service life for each plate thickness based upon pH and resistivity and adds the service life for protective coatings. In making the service life determinations, do *not* reduce the metal thickness below the "structural" metal thickness needed for the fill height.

Examples of Steel Pipe Service Life Prediction:

Example PROJECT: NTP 1A STATION: 12+908

DATA:

Diameter:	900 mm	Fill Height:	15.0 m
Abrasion:	Level 2, Low-Abrasive		

	Water Side	Soil Side
pH:	5.5	5.5
Resistivity	18,000 Ω·cm	18,000 Ω·cm

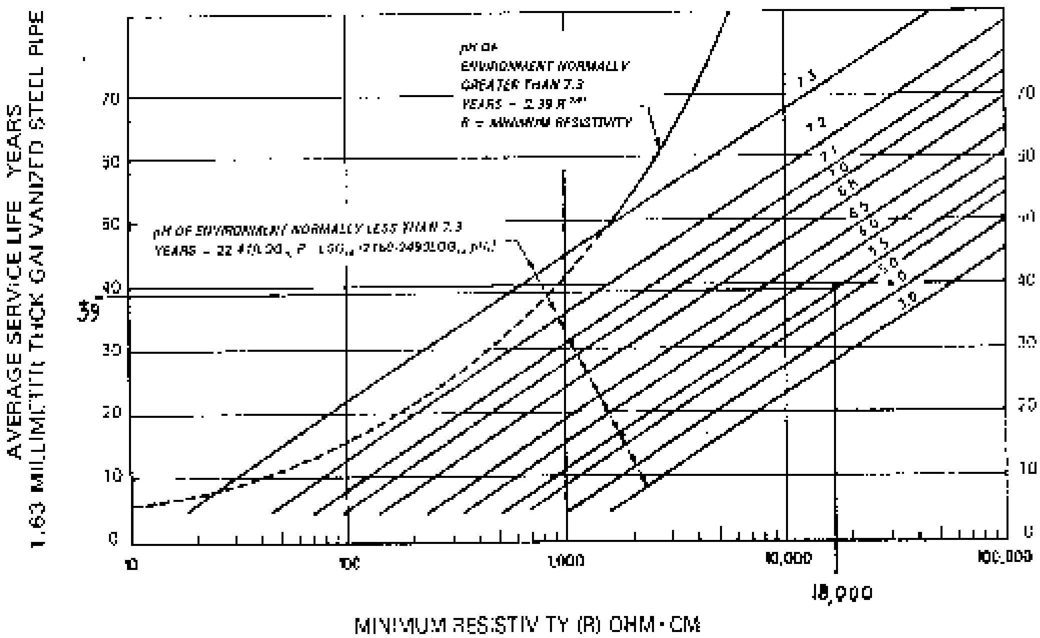
From FLH Standard Drawing M 602-1, the fill height of 15 m permits a minimum steel plate thickness for structural strength of 1.63 mm (using 68 mm x 13 mm corrugations). From the equation or graph in Exhibit 7.10 (3 of 3), the "base" service life with this pH and Resistivity is **39** years for 1.63 mm thick metal pipe. Multiply the "base" service life by the thickness factors in Exhibit 7.10 (3 of 3) to determine the "structural" unprotected (plain galvanized) metal thickness providing a minimum 50-year service life.

Abrasion levels 1 and 2 do not require adjustments for abrasion. In addition to plain galvanized pipe, the added life for protective coatings yields the following alternatives for a minimum 50-year service life:

1. 2.77 mm metal thickness for plain galvanized coated pipes **-** (**39** x 1.7 = 67 years)
2. 1.63 mm metal thickness for aluminum coated (Type 2) **-** (**39** x 1.0 x 2 = 78 years)
3. 2.01 mm metal thickness for all plain galvanized coated pipes with bituminous coating **-** (**39** x 1.2 + 10 = 57 years)
4. 1.63 mm metal thickness for all plain galvanized coated pipe with bituminous paved invert - (**39** + 25 = 64 years)
5. 1.63 mm metal thickness for all plain galvanzied coated pipes with concrete lining - (**39** + 25 = 64 years)
6. 1.63 mm metal thickness for all plain galvanized pipes with polymer coating - (**39** + 30 = 69 years)

All of the alternatives shown above are acceptable. The estimated service life is shown in parentheses. Note that the spread sheet shows similar values. The pipes which have an acceptable service life have been shaded on the spread sheet examples for ease of comparison.

FEDERAL LANDS HIGHWAY
MODIFIED CALIFORNIA METHOD CHART
FOR ESTIMATING SERVICE LIFE OF
PLAIN GALVANIZED STEEL CULVERTS



Service Life Estimation Chart
For Average Service Life of Plain Galvanized Culverts

THICKNESS FACTORS

THICKNESS, mm	1.32	1.62	2.00	2.77	3.50	4.27
FACTOR *	0.8	1.0	1.2	1.7	2.2	2.8

* MULTIPLY THE AVERAGE SERVICE LIFE BY THE THICKNESS FACTOR

Notes:

1. The curves in this Chart are based on the data in FHWA-FLP-91-006 which uses the factors in California Test 643, "Method for Estimating the Service Life of Steel Culverts". These factors increased the estimated service life by 25% after first perforation.

2. The Chart has also been modified to reflect a minimum metal thickness of 1.63 mm.

* 3. Under conditions with pH between 5 and 9, and above R≥1500, the average service life determined for plain galvanized culverts should be multiplied by 2.0 for Aluminum coated steel, (Type 2).

CHAPTER 8 - SAFETY

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CHAPTER 8 - SAFETY

8.1 GENERAL

The purpose of this chapter is to provide guidance for evaluating and developing highway safety alternatives to be incorporated into roadway and structural designs. This includes providing for the safe accommodation of traffic through construction work zones. The safety standards of any highway facility are primarily a reflection of the attitude of the administration responsible for the facility and the priority placed on the use of available funds. While the overall objective is maximum highway safety, environmental and economical restraints may prohibit achieving this goal. The designer must, therefore, ensure that the design provides the maximum safety enhancements for each dollar spent.

National concern over increasing highway death tolls resulted in congressional enactment of the 1966 Highway Safety Act (P.L.89- 564). This act created a partnership among Federal, State, and local governments to improve and expand the Nation's highway safety activities. The initial effort consisted of a series of Highway Safety Program Standards (initially 13, now 18) and Federal financial assistance.

The act requires compliance with the Highway Safety Program Standards on all public roads, not just those under the jurisdiction of State or local highway agencies. The 1986 Highway Act has subsequently amended these standards to guidelines. The Federal regulations require each department or agency to apply the applicable standards to the activities of the department or agency. Of the 18 Highway Safety Guidelines, there are several administered by the FHWA that are of concern to the Federal agencies with roads under their control. These includes the following:

- Standard No. 9, *Identification and Surveillance of Accident Locations*

- Standard No. 12, *Highway Design, Construction, and Maintenance*

- Standard No. 13, *Traffic Engineering Services*

- Standard No. 14, *Pedestrian Safety* (jointly administered by NHTSA and FHWA).

Agreements have been negotiated with most of the Federal agencies with significant public road mileage, and they have active programs to meet the applicable standards. In addition, the FLH Divisions provide technical guidance to many of these agencies in the design and construction of their road and works to assure that objectives of the Highway Safety Standards are accomplished.

A. Safety Design Policy. New construction and reconstruction involves the application of appropriate standards in the design and construction of the facility. (See Chapter 9.) The application of those standards virtually ensures uniform geometrics and safety. Even with their use, however, operational or roadside safety problems may still exist that will not be identified unless a safety analysis is performed.

It is FLHO policy that RRR projects will be treated in a manner similar to new construction or reconstruction. Because of the limited scope of RRR projects, adoption of full standards may not be possible. When this occurs, the designer should identify the substandard features and analyze their potential effect on highway safety. The analysis and proposed mitigation are to be documented as discussed in Section 9.1.B of Chapter 9.

B. Roadway Safety. An accident is seldom the result of a single cause. Usually several influences affect the situation at any given time. These influences can be separated into three elements: the human, the vehicle, and the environment. The environmental element includes the roadway and its surroundings. The designer can only control roadway elements and must make judicious selection of the roadway geometrics, drainage, surface type, and other related items to lessen the potential for accidents and/or reduce the severity should they occur. The ideal design applies appropriate standards over a section of roadway.

The designer should avoid discontinuities such as the following in the highway environment:

- Abrupt changes in design speeds.
- Short transitions in roadway cross section.
- Short radius curve in a series of longer radius curves or at the end of a long tangent.
- Changes from full to partial access control.
- Roadway width constrictions such as narrow bridges or other structures.
- Intersections with inadequate sight distances.
- Other inconsistencies in the roadway design.

Standardizing highway design features and traffic control devices reduces driver confusion and makes the task of driving easier. Through the use of these standard features, the driver learns what conditions to expect on a certain type of highway. The goal, if possible, is to design a highway so that a driver needs to make only one decision at a time. Multiple decisions confuse and distract a driver.

C. Roadside Safety. Roadside safety design has become increasingly important as new technology has made possible improvements in the alignment, grade, and roadway. When a vehicle leaves the roadway, any object in or near its path may become a contributing factor to the severity of the accident. The basic concept of a forgiving roadside is that of providing a clear recovery area where an errant vehicle can be redirected back to the roadway, stop safely, or slow enough to mitigate the effects of the accident.

Consult the *Green Book* and the *Roadside Design Guide* for guidance on appropriate clear recovery areas. The designer must evaluate these requirements in conjunction with environmental and economic constraints to determine the acceptable clear zone for the traffic, speed and terrain of the project.

Potentially hazardous features located within the identified clear zone should be treated as follows:

- Identify and remove the hazard.
- Relocate the hazard to a point where it is less likely to be struck, preferably outside the clear zone.
- When a potential hazard remains in the clear zone, make the hazard crash worthy.
- If the feature is potentially more hazardous than a barrier system that could shield it, consider installing the barrier system.

8.2 GUIDANCE AND REFERENCES.

The publications listed in this section provided much of the fundamental source information used in the development of this chapter. While this list is not all inclusive, the publications listed will provide a designer with additional information to supplement this manual.

Transportation and Traffic Engineering Handbook. Institute of Transportation Engineers. 2nd ed. 1982.

A Guide to Standardized Highway Barrier Hardware. Task Force 13 Report, ARTBA. 1995.

Local Highway Safety Studies Users Guide. DOT, FHWA. Office of Highway Safety. July 1986.

Functional Requirements of Highway Safety Features. DOT, FHWA. 1981 edition with 1983 revisions.

Manual on Uniform Traffic Control Devices for Streets and Highways (MUTCD). DOT, FHWA. 1988 edition with approved revisions.

Synthesis of Safety Research Related to Traffic Control and Roadway Elements. DOT, FHWA. Volumes I and II. 1982.

Traffic Control Devices Handbook. DOT, FHWA. 1983.

Roadway Delineation Practices Handbook. DOT, FHWA. 1994

Selection and Design Criteria of Crash Cushions. DOT, FHWA. September 1975.

Identification of Hazardous Locations. Report No. FHWA RD-77-87. DOT, FHWA. 1977.

Highway Safety Engineering Studies - Procedure Guide. Report No. FHWA-TS-81-220. DOT, FHWA. 1981.

Traffic Control for Street and Highway Construction and Maintenance Operations Notebook. DOT, FHWA. 1985.

Alternate Approaches to Accident Costs Concepts. DOT, FHWA. 1984.

A Users Guide to Positive Guidance. DOT, FHWA. September 1990.

Sign Manual. Department of the Interior, National Park Service. January 1988.

Railroad-Highway Grade Crossing Handbook Users Guide. FHWA-TS-86-216. DOT, FWHA. 2nd ed. September 1986.

Designing Safer Roads. TRB Special Report 214. Transportation Research Board. 1987.

Analysis of Highway Accidents, Pedestrian Behavior, and Bicycle Program Implementation. Transportation Research Board. 1982.

Highway Capacity Manual. Special Report No. 209. Transportation Research Board. 1985. Revised May 1992.

8.2 Guidance and References. (continued)

Operational Effects of Geometric and Improvement Evaluations. Transportation Research Board. 1981.

Recommended Procedures for the Safety Performance Evaluation of Highway Features. NCHRP Report No. 350. National Cooperative Highway Research Program. 1993.

Selection of Safe Roadside Cross Sections. NCHRP Report No. 158. National Cooperative Highway Research Program. 1975.

Highway Design and Operational Practices Related to Safety. AASHTO. 1974.

Glennon, J.C. *Roadside Safety Improvement Programs on Freeways -- A Cost Effectiveness Approach*. NCHRP Report 148. 1974.

8.3 INVESTIGATION PROCESS

The investigation process begins with the initial consideration and priority given to candidate projects for safety improvements. FLHP projects involve the preservation or improvement of the facility and the enhancement of roadway safety.

The majority of FLH projects involve existing roadways. On existing highways, historical information relating to the highway's operation or safety should be analyzed. The State Transportation Departments generally have operational and safety records for the Federal System. Respective agencies frequently have data for routes on their systems. Unfortunately, on off-system county roads, the available data may be scarce. This is often due to the low volume rural nature of the facility and many accidents on such facilities go unreported. Information retrieval systems may also be less developed for these roads. Good sources of information in such instances are law enforcement officials, local maintenance personnel, property owners, local businesses, mail carriers, school bus companies, etc. A drive through of the project, with a keen eye towards operational or safety problems or potential problems, will often detect areas requiring special attention during design.

A. Accident Data. Many State highway agencies maintain computerized accident files. They can provide statistics regarding statewide rates for fatal, injury, and property damage accidents as well as rates on specific routes. By comparing statistical trends in a given area of the State, the designer may detect clues to the basic causes or problems that should be addressed during design. For example, if a proposed FLHP project were located in a portion of a State that has higher than normal run-off-the-road accident rate, further analysis of the types of accidents (such as skidding) might be warranted.

The designer should review available accident reports to determine if any engineering features may have contributed to the problem. Law enforcement agencies can usually provide available accident reports. In the case of the National Park Service (NPS), each park maintains its own accident reports. In the past, the NPS used the same accident report forms for all accidents, and no attempt was made, until recently, to separate and file vehicle accident forms together. Recognition of this problem, however, has resulted in a service-wide effort to standardize the data input as well as to computerize it for easy retrieval. This effort, initiated in 1985, is known as the *Service-wide Traffic Accident Reporting System* (STARS). STARS will provide substantial information to the designer.

B. Traffic Safety Studies. Traffic safety studies, when available, provide excellent references for evaluating safety and operational characteristics. The NPS has had traffic safety studies performed in many of their larger parks. The States or other agencies may also have such information available on their systems. While the content and form of traffic safety studies vary widely, they usually include an introduction that describes the goals and purpose of the study and defines the study area and project specifics.

Physical and operational characteristics typically include

- functional classification,
- usage,
- traffic volumes,
- vehicle classification,
- inventories of roadway features,
- vehicle speeds,
- traffic conflict studies, and
- pedestrian/bicycle or rail conflicts.

Accident analysis tpically provide location, type, rates, severities, and associated environmental factors. The report should be supplemented with appropriate photographs, maps, or detailed plan layouts. Generally, because of funding limitations, these analyses should address alternate safety improvements and include some method of assigning priorities to the recommended improvements.

Ranking is generally done by calculating a "hazard index" at specific sites. Detailed procedures for weighing the various causal factors and arriving at the "hazard index" are included in FHWA-RD-77-83, *Identification of Hazardous Locations*, and FHWA-TS-81-220, *Highway Safety Engineering Studies, Procedural Guide*. The hazard index and the relative cost factors are analyzed to rank improvement projects and provide the basis to make appropriate recommendations.

8.4 SAFETY ANALYSIS AND DESIGN

RRR construction projects shall meet standards that (1) preserve and extend the service life of highways, and (2) enhance highway safety. The extent of appropriate safety enhancements can be determined by performing a safety analysis. A safety analysis consists of analyzing potentially hazardous features and locations: both the project's accident history and the list of potentially hazardous locations and features should be used during the project development process. As a minimum, the designer should review this information on each project when a design exception is requested. The project files should contain documentation of the safety analysis performed and any improvements or mitigations taken to enhance safety.

A. Accident Analysis. The amount of data available for analysis will vary from project to project. Also, the level of detail and accuracy of the data may also vary. Therefore, the designer must determine on a case by case basis whether the data furnished for safety analysis purposes is satisfactory.

While not a normal function of the designer, accident lawsuits may indicate the need to evaluate accident reconstruction. This involves drawing inferences concerning the interactions of speed, position on the road, driver reaction, comprehension and obedience to traffic control devices, and evasive tactics. Accident reconstruction uses basic engineering knowledge of vehicle motion analysis, force analysis, and mechanical energy. Example problems and equations can be found in the *Transportation and Traffic Engineering Handbook*.

1. Accident History. The accident history for the project should be developed and analyzed to determine possible accident causes and to select appropriate safety enhancements. When practical, accidents should be summarized by location, type, severity, contributing circumstances, environmental conditions, and time period. This will help identify high accident locations and may indicate some spot safety deficiencies.

Depending on how accident information is filed, it may be necessary to record the information first and then group all accidents occurring at specific locations. This serves to identify high accident locations. Analysis of the types of accidents can suggest appropriate corrective action. The use of computer spread sheet programs will enhance the ability to evaluate this data.

Special consideration should be given to analyzing accident data on RRR projects. Limited accident data are common on rural two-lane highways with low to moderate traffic volumes. The limited amount of such data often makes traditional methods of analysis difficult.

Data generated from a small sampling can be misleading because they can be significantly influenced by small variances. Analysis of many RRR projects may require the following special efforts:

- A study of individual accident reports including those just beyond the project termini.
- A review to relate accident data with field conditions.
- Interviews with maintenance and/or police personnel. These interviews may reveal areas where operation problems or minor accidents occur but are not documented.

Accident analysis study procedures involve determining the significance of the accident history and developing summaries of the accident characteristics. The project's accident rates and summaries are used to detect abnormal accident trends or patterns and to distinguish between *correctable* and *non-correctable* accidents. Analysis of these summaries are used to identify possible safety deficiencies of the existing facility.

When summarizing accident data for analysis purposes, adhere to the following criteria:

- Select a time period for the collection of the accident data (such as 3 years). The time period chosen should contain reasonably current information on traffic volumes, pavement condition, and other site-related data. Past changes in the character of the facility (i.e., physical changes, roadside development, etc.) are accounted for when evaluating the accident activity.

- Examine accident data with respect to the direction the vehicles were traveling.

- Examine accident data with respect to location. Accidents occurring within an intersection area should be separated from those occurring outside the area of influence of the intersection. In addition, similar accident types occurring in differing situations should be recorded separately. For example, left-turn accidents into a driveway should not be included with left-turn accidents at an intersection. Collision diagrams may be useful in the analysis.

- Examine the number of accidents and the accident rates within the project termini. A comparison of this data with statewide norms for similar facilities should provide a reasonable indication of the relative safety of the existing roadway.

- Summarize the accident data and compare it to typical statistics on similar facilities. Patterns are categorized by a specific accident type. Following the identification of accident type patterns, the results are used to suggest possible causes of the accident patterns. Look at the severity patterns to determine if particular roadway or roadside features have contributed to the overall severity of the accidents that have occurred.

- Summarize the contributing circumstances portion of the accident report. This identifies possible accident causes noted by the investigating police officer. Contributing circumstances are categorized by (1) human (driver) factors, (2) vehicle related factors, and (3) environmental factors. The contributing circumstances information is used to verify, add, or delete possible causes developed by the accident summary by type procedure.

  The contributing circumstance data can be used to separate correctable and non-correctable accidents. In separating the accidents by these classifications, careful consideration should be made to ensure that the accidents are indeed non-correctable. Table 8-1 lists the contributing circumstances found on most accident reports and indicates if they are generally correctable or non-correctable through highway improvements.

- Summarize accidents by environmental conditions. This procedure identifies possible causes of safety deficiencies related to the existing condition of the roadway environment at the time of the accident. Typical classifications used in the analysis include lighting condition (i.e. daylight, dusk, dawn, dark) and roadway surface condition (i.e. dry, wet, snowy, icy, unknown).

These summaries are compared to average or expected values for similar locations or areas to determine whether the occurrence of a specific environmental characteristic is greater or less than the expected value at the location. For example, a higher than expected number of wet-surface accidents may be an indication of slippery pavement.

2. Probable Causes and Safety Enhancement. Probable accident causes need to be defined once the accident patterns are identified. On-site or photolog reviews of field conditions of accident sites are used to reduce the list of possible causes identified on the accident history to the most probable causes. The probable causes identified can then be used as a basis for selecting appropriate safety enhancements to alleviate the safety deficiency. Exhibit 8.1 is a listing of probable accident causes and possible safety enhancements. This list is not all inclusive; however, it does provide a general list of possible accident causes as a function of accident patterns and appropriate safety enhancements.

B. Potentially Hazardous Locations and Features. Hazardous locations or features on existing roadways may or may not be high accident locations. Many locations with narrow bridges, slippery pavement, rigid roadside obstacles, or other potentially hazardous conditions, have accident potential but may not yet have an accident history. Therefore, it is important to identify potentially hazardous locations or features in the development of projects. When accident history is not available, a project listing of potentially hazardous features and locations may be used to determine the need for safety enhancements. Exhibit 8.2 shows an example of a roadside hazard review.

Table 8-1
Contributing Circumstances

Driver-Related	
• Unsafe speed (C/N)	• Sick (N)
• Failed to yield right-of way (C/N)	• Fell asleep (C/N)
• Following too close (C/N)	• Lost consciousness (N)
• Improper passing (C)	• Driver inattention (C/N)
• Disregard traffic controls	• Distraction (C/N)
• Turning improperly (C/N)	• Physical disability (N)
• Alcohol involvement (C/N)	• Drug involvement (C/N)
Vehicle-Related	
• Brakes defective (C/N)	• Tow hitch defective (N)
• Headlights defective (C/N)	• Overload or improper loaded (N)
• Other lighting defects (C/N)	• Oversize load on vehicle (N)
• Steering failure (N)	• Tire failure/inadequate (C/N)
Environment-Related	
• Animal on roadway (C/N)	• Holes/deep ruts/bumps (C)
• Glare (C/N)	• Road under construction/maintenance (N)
• View obstructed/limited (C/N)	• Improperly parked vehicle(s) (C/N)
• Debris in roadway (N)	• Fixed object(s) (C)
• Improper/nonworking traffic controls (C/N)	• Slippery surface (C)
• Shoulders defective (C)	• Water ponding (C)
• Roadside hazards	
KEY: (C) = Correctable (N) = Non-correctable by safety enhancement (C/N) = Either correctable or non-correctable depending on related circumstances	

C. Alternative Evaluations. After the accumulation of available data, a roadside safety evaluation shall be performed. The results of the accident analysis and the list of potential roadside hazards provide the input for this evaluation. From these two sources, the designer should develop a composite list that locates and describes the identified safety problems.

Alternatives for correcting the safety problems should be developed and each evaluated for effectiveness, cost, and environmental impact. Alternatives may range from site specific improvements to total reconstruction. The evaluations, alternatives, and action selected should be documented in the project files.

D. Clear Zone. A clear zone (L_c) is defined as the roadside border areas (starting at the edge of the traveled way) that is available for safe use by errant vehicles. The width of the clear zone is influenced by the type of traffic, speed, horizontal alignment, and side slopes. Slopes steeper than 1:3 are not considered traversable by vehicles and the need for traffic barriers as discussed in Section 8.4.E should be evaluated. The AASHTO *Roadside Design Guide* also discusses clear zone widths.

Determine clear zone widths for all roadway tangent sections (except tangent sections on rural collectors and local roads and streets) by using Figure 8-1.

On rural collectors and local roads and streets with a design speed of less than 60 km/h or an ADT less than 250, the clear zone width will be determined and documented on a project-by-project basis. Where feasible and environmentally acceptable, the clear zone width should be a minimum of 3 meters. Consult the AASHTO *Roadside Design Guide* and *Green Book* for additional guidance.

The clear zone on a curved alignment is determined by increasing the value obtained for a tangent section of highway. The tangent section clear zone is increased by a curve correction factor based on the degree of curvature, the design speed, and the roadside width. Clear zone widths for horizontal curves can be determined using Table 8-2.

Table 8-2
Horizontal Curve Adjustments

Radius m	Design Speed (km/h)					
	60	70	80	90	100	110
900	1.1	1.1	1.1	1.2	1.2	1.2
700	1.1	1.1	1.2	1.2	1.2	1.3
600	1.1	1.2	1.2	1.2	1.3	1.4
500	1.1	1.2	1.2	1.3	1.3	1.4
450	1.2	1.2	1.3	1.3	1.4	1.5
400	1.2	1.2	1.3	1.3	1.4	
350	1.2	1.2	1.3	1.4	1.5	
300	1.2	1.3	1.4	1.5	1.5	
250	1.3	1.3	1.4	1.5		
200	1.3	1.4	1.5			
150	1.4	1.5				
100	1.5					

$CZ_C = (L_C)\ (K_{CZ})$
Where: C_{ZC} = Clear zone on outside of curvature (meter)
L_C = Clear zone distance from Figure 8-1

K_{CZ} = Curve correction factor
Note: Curve correction factor is applied to outside of curves only. Curves flatter than 900 m do not require adjustment.

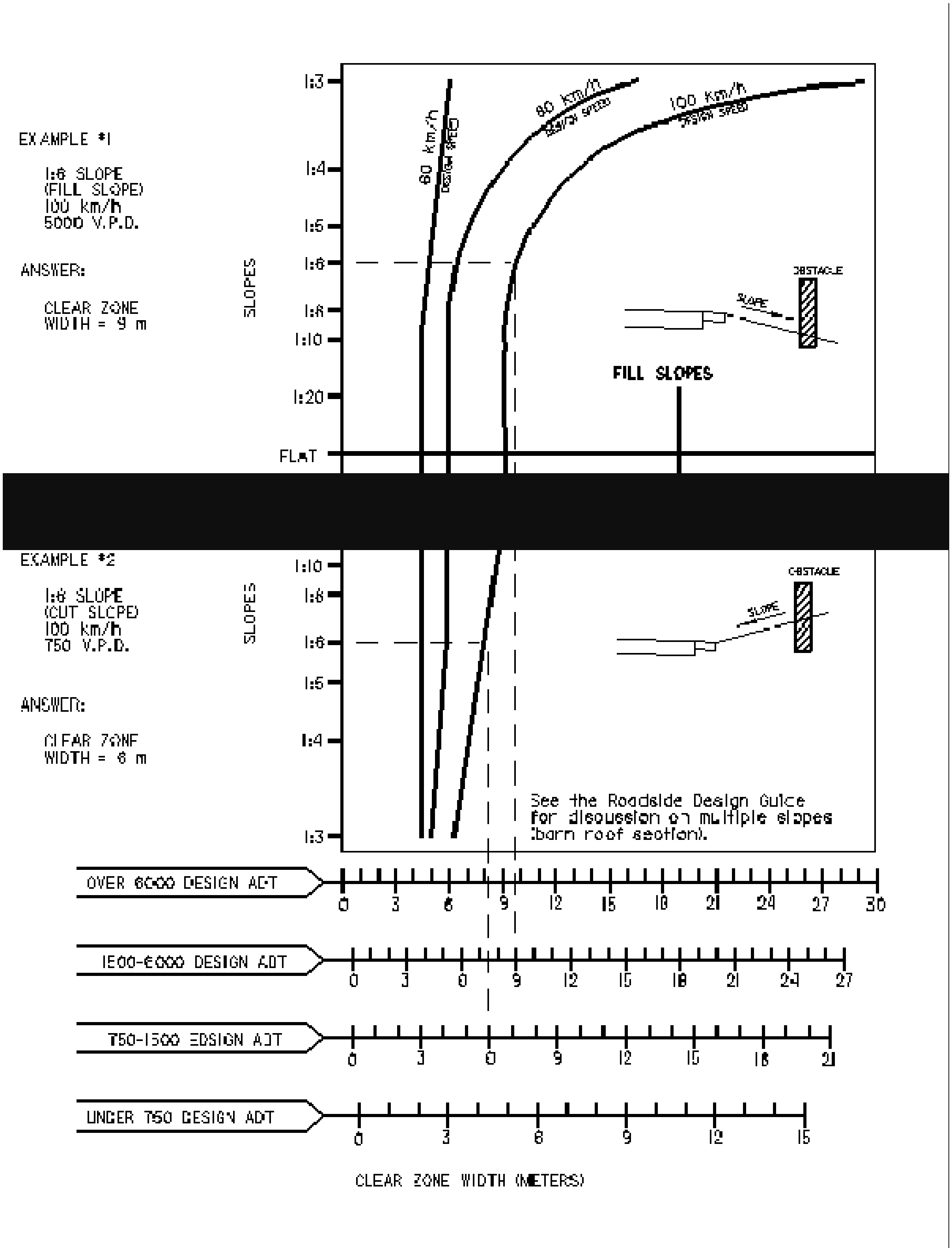


FIGURE 8-1
Clear Zone Distance Curves

E. Traffic Barriers. When clear zone requirements cannot be met, the designer should give special attention to the roadside hazards. Obstacles located within the clear zone should be *removed, relocated, or made breakaway*. If this is not feasible, then guardrail or some other type of roadside barrier should be considered, provided that the roadside barrier offers the least hazard potential.

1. Determining Needs. Roadside obstacles may be classified as non-traversable hazards or fixed objects.

The following are examples of non-traversable hazards that may warrant roadside barriers:

- Steep embankments (slopes steeper than 1:3).
- Rock cuts.
- Large boulders.
- Ditches.
- Culvert openings.
- Permanent bodies of water over 0.6 meters in depth.
- Large trees (over 100 mm diameter).
- Shoulder edge drop-offs steeper than 1:1 and depth greater than 0.6 meters.

A ditch section is safe or hazardous depending upon the type of sideslopes and widths. The *Roadside Design Guide* contains examples for a variety of ditch configurations. Frequently limited right-of-way, environmental factors and terrain will preclude the designer from being able to develop these preferred ditch sections. Preferred ditch sections should receive greater consideration on high speed, high volume facilities. Medians on divided roadways also deserve special attention.

The following are examples of fixed objects that may warrant roadside barriers:

- Bridge piers, abutments, parapets, or railings.
- Retaining walls.
- Fixed sign bridge supports.
- Trees over 100 mm in diameter.
- Headwalls of box culverts or pipe culverts.
- Culvert end sections with diameters larger than 900 mm.

The unprotected end of a bridge rail or parapet is considered a hazard. In most designs, an approach roadside barrier with a smooth transition to the bridge barrier is warranted. Exceptions to this policy may include structures designed for use on low volume, low speed highways. The *Roadside Design Guide* contains discussions for transition barriers.

Special attention needs to be given to the proper attachment of the transition railing with the bridge railing or parapet. The railing connection should develop the full tensile strength of the rail element and be designed to prevent possible pocketing or snagging of a vehicle on the end of the bridge parapet. The bridge plans should generally include special drawings of these connection details. Transition guardrail should satisfy the minimum *length of need* to develop its full tensile strength capacity. The terminal end should extend outside the lateral clear zone or be provided with a crash worthy terminal, protected by a crash cushion, or buried in a cut slope.

On many projects, existing bridges have inadequate bridge or transition railings. When replacing structurally obsolete bridges, consider railing replacement to current standards part of the work. When bridge railings are structurally adequate but functionally obsolete, engineering analysis should be performed to determine the recommended action on a case-by-case basis.

Accidents involving roadside hazards represent a problem inherent to any existing highway facility. Even on new or reconstructed projects, the complete elimination of all roadside hazards may not be feasible or practical. See Section 8.1.C for a priority list when evaluating roadside hazards.

Appendix A of the *Roadside Design Guide* provides a cost effective selection procedure for comparing alternative solutions to problem locations and instructions for operating the *ROADSIDE* computer program. The annual cost of each alternative is computed over a given period of time, taking into consideration initial costs, maintenance costs, accident costs, and salvage value. Accident costs incurred by the motorist, including vehicle damage and personal injury, are considered together with accident costs incurred by the highway department or agency. The alternative with the least total cost is normally selected, except when environmental or aesthetic considerations dictate otherwise.

When determining the need for traffic barriers, consider cost when evaluating the following four alternatives:

1. Remove or reduce hazard so that shielding is unnecessary.

2. Install a barrier.

3. Leave hazard unshielded but sign or delineate.

4. Do nothing.

The third option is normally cost effective on low volume and/or low speed facilities, or where the probability of accidents is low.

With regard to installing a barrier, the procedure allows the designer to evaluate any number of barriers that can be used to shield the hazard. Through this method the following can be evaluated: the effects of average daily traffic, offset of barrier or hazard, size of barrier or hazard, and the relative severity of the barrier or the hazard.

The ability to easily vary input data allows the designer to explore various areas of sensitivity of the analysis at a given location. The effects of current traffic and future traffic can be explored to evaluate cost effectiveness over the design life of a project. Although most of the data collected through research pertains to high speed situations, the designer can analyze how sensitive the cost effectiveness is with respect to the severity index. However, a correlation can be made provided the designer recognizes that lower design/running speeds would lessen severity. Use of this tool has been successful in persuading reluctant agencies to recognize the cost effectiveness of selected safety feature applications.

These programs access research information by Kennedy-Hutcheson for high-volume roads and Glennon for low-volume roads with roadway widths less than 8.5 meters. The program shows both *annual cost* comparison and *present worth*. Generally the *annual cost* is used to facilitate comparison of different alternatives with varying design life.

For low-volume, low-speed roads, strict adherence to the guardrail warrants shown in the *Roadside Design Guide* is frequently not practical or cost effective. The NPS and the FHWA have jointly developed *Park Road Standards*, published by NPS in 1984. Although developed specifically for NPS roads, the basic principles in these standards are applicable to other types of low- volume, low-speed roads.

The *Park Road Standards* states:

> *Guardrail or guardwall should be installed at points of unusual danger such as sharp curves and steep embankments, particularly at those points that are unusual compared with the overall characteristics of the road.*

Similar wording is used in the AASHTO *Green Book* in the section that deals with recreational roads.

Although the *Guides* are still used as a basis for determining need for barriers on recreational roads, they are not always applicable to these roads. Besides low speeds and low volumes, NPS roads frequently have other characteristics that affect barrier needs.

These include the following:

- Roads closed in winter and during periods of hazardous climatic conditions.
- Roads closed at dark.
- Roads with access limited to passenger- carrying vehicles.

Another consideration affecting the use of barriers is for areas having unusual environmental sensitivity including endangered plants and animals as well as major historic and scenic resources.

The *unusual danger* noted in the NPS standard, when compared with the rest of the roadway, has been reduced to the following criteria for roads that have continuous sharp curves and steep slopes throughout much of their lengths:

- Consider barriers in areas with high embankments and slopes steeper than 1:2 and where rock embankments and retaining walls prevent the growth of vegetation.
- Consider barriers in areas with steep slopes or other roadside hazards where unusual conditions exist that may surprise or distract the motorist. For example, sharp curves at the end of long tangents (especially on downgrades) or approaches to scenic vistas at sharp curves.
- Consider barriers at locations with accident histories, where the accident severity could have been reduced with a barrier.

Always remember that a barrier is itself a significant hazard and is more likely to be hit than the hazard that it is to protect. Therefore, the relative severity, costs, and frequency of accidents must be considered.

Although the warrants cover a wide range of roadside conditions, special cases or conditions will arise for which there is no clear choice. Such cases must be evaluated on an individual basis, and, in the final analysis, must usually be solved by engineering judgment.

2. Type Selection. Once it has been determined that a barrier is needed, type selection will be made. While the most predominant type of roadside barrier used on Federal Lands projects is metal W-beam guardrail, the designer needs to be cognizant of various selection criteria for roadside barriers. Table 8-3 lists the various criteria that should be considered.

The designer is again referred to the *Roadside Design Guide* for design criteria of the various systems. As indicated in the *Roadside Design Guide*, barrier systems are classified as either operational, experimental, or Research and Developmental (R&D). The standard drawings for W-beam guardrail mounted on wood or metal posts are examples of approved operational guardrail systems.

Crash tests performed for FLHO to evaluate a masonry-faced concrete parapet and a steel-backed timber rail system indicated acceptable crash test results. Use of these systems are classified as operational. For design and construction notes for these systems see Exhibit 8.3.

Research efforts are in progress to identify and crash test other systems for possible use on FLHP projects.

The owner agency generally selects the type of roadside barrier. It is the designer's responsibility to ensure that the selected barrier has been tested and approved for use and designed to function where installed.

Table 8-3
Selection Criteria for Roadside Barriers

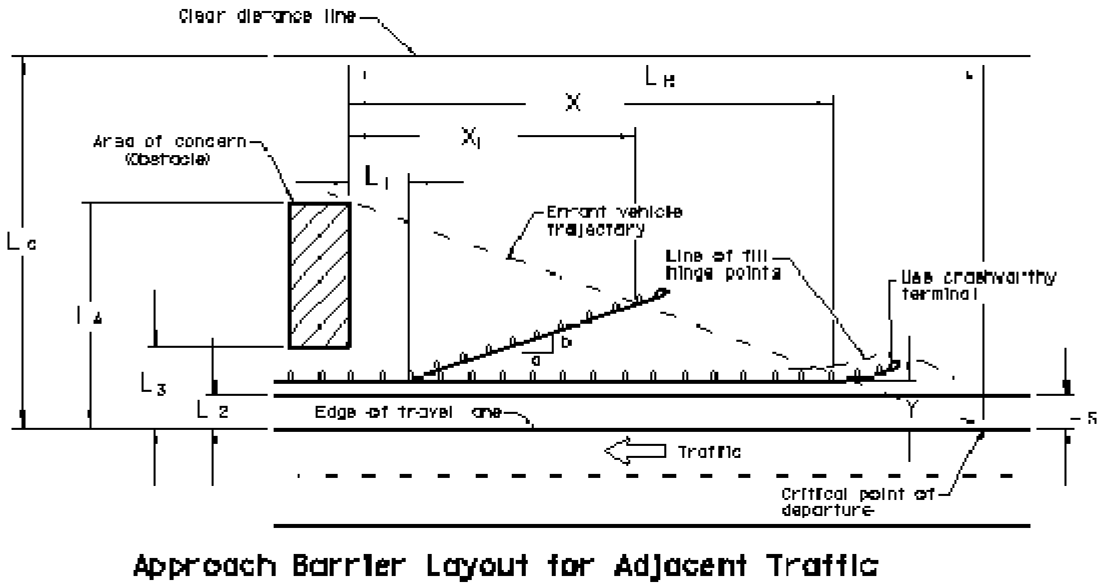
Characteristic	Considerations
Deflection	Space available behind barrier must be adequate to permit dynamic deflection of barriers.
Strength and Safety	System should contain and redirect vehicle at design conditions. System should be as safe as possible considering costs and other considerations.
Maintenance	Collision maintenance. Routine maintenance. Environmental conditions. Inventory of spare parts.
Compatibility	Can system be transitioned to other barriers? Can system be terminated properly?
Costs	Initial costs. Maintenance costs. Accident cost to motorist.
Field experience	Documented evidence of barrier's performance in the field.
Aesthetics	Barrier should have a pleasing appearance.
Promising new designs	It may be desirable to install new systems on an experimental basis.

3. Design Procedures. Once the need for barrier has been determined, the designer must determine the length and location for the barrier. The following discussion outlines the significant elements for locating and designing roadside barriers. However, the designer must refer to the *Roadside Design Guide* for specific details and limiting criteria for layout and use of the barrier selected.

a. Length of Barrier. The length of need is equal to the length of the area of concern parallel to the roadway, plus the length of the approach barrier on the upstream side (and downstream side if needed), plus a safety end treatment.

Where slopes outside of the graded shoulder are flat enough, the barrier approach should be flared or the guardrail installation located outside of the graded shoulder to minimize the length of need. More commonly, where slopes are steeper, the barrier will run along the shoulder. Figures 8-2 and 8-3 depict both cases. The minimum barrier lengths in advance of hazardous area shown are adequate for most installations. Where greater lengths of need are desired, the formulas shown in Figure 8-3 may be used or a sketch of the location may be drawn to scale and the length of need measured.

Where MELT terminals are used, the breakaway portion (two breakaway posts and approximately 38 m of rail) should extend beyond the length of need. Use of the BCT should be avoided.



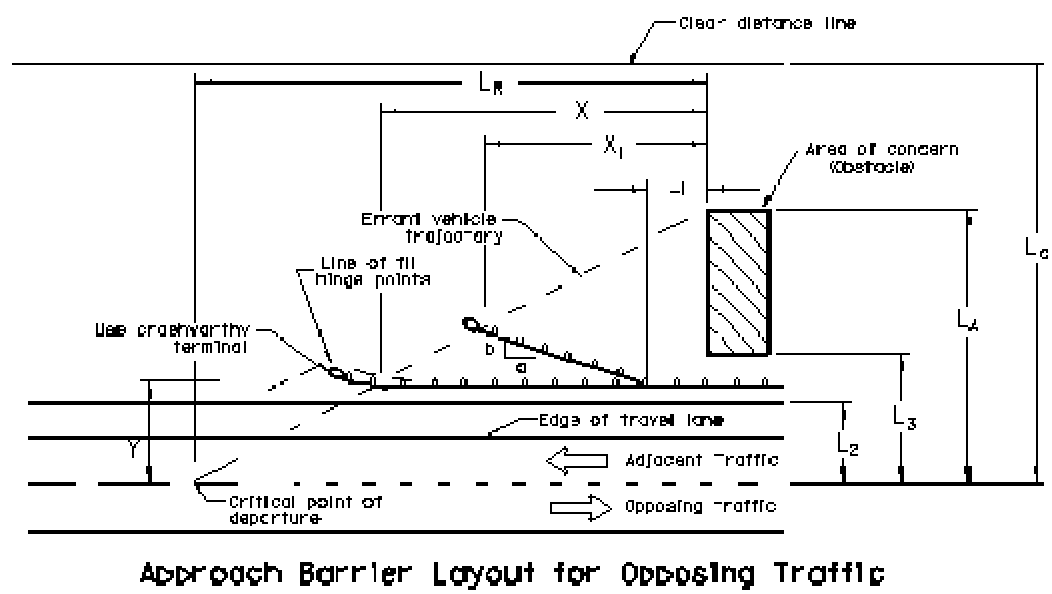


Figure 8-2
Guardrail Length Requirements

Operating Speed (km/h)	Shy Line Offset L_S (m)	Runout Length L_R (m)				Flare Rate a:b		
		Over 6000 ADT	2000-6000 ADT	800-2000 ADT	Under 800 ADT	Inside Shy	Rigid	Yielding
110	2.8	145	135	120	110	30:1	20:1	15:1
100	2.4	130	120	105	100	26:1	18:1	14:1
90	2.2	110	105	95	85	24:1	16:1	12:1
80	2.0	100	80	80	75	21:1	14:1	11:1
70	1.7	80	75	65	60	18:1	12:1	10:1
60	1.4	70	60	55	50	16:1	10:1	8:1
50	1.1	50	50	45	40	13:1	8:1	7:1

Flared Approach:

$$X_1 = \frac{L_A + \left(\frac{a}{b}\right) L_1 - L_2}{\left(\frac{a}{b}\right) - \left(\frac{L_A}{L_R}\right)}$$

Standard Approach:

$$X = L_R\left(\frac{L_A - Y}{L_A}\right)$$

Where:

The distance X or X_1 is the minimum length of need.

L_A = Distance (m) from the edge of the traffic lane to the back of the hazard or clear zone line whichever is less

Y = Distance (m) from the edge of traffic lane to the end of the barrier need

L_C = Clear zone (m)

Figure 8-3
Guardrail Length Requirements

b. Barrier Located Adjacent to the Graded Shoulder. Designers should be aware that barrier installations require widening of the shoulder to provide adequate soil support. In addition, special attention is required at barrier terminals to ensure that widened areas are graded correctly so that the terminal will function properly.

c. Barrier Located Back of the Graded Shoulder. When barriers are located in back of the graded shoulder or when barriers are flared back of the shoulder edge, slopes in front of the barrier shall be 1:10 or flatter. Also, the algebraic difference between the shoulder slope and the slope in front of the guardrail should not be greater than 8 percent. The two exceptions to this requirement are as follows:

- Barrier may be located on slopes 1:6 or flatter, provided the shoulder is adequately rounded and the barrier is placed more than 3.7 m from the edge of the graded shoulder.

- Where shop curved sections of barrier are used with buried terminals, a portion of the shop curved section (not more than 1 m in length) may extend back of the graded shoulder onto normal slopes.

Where MELT terminals are flared back of the graded shoulder, the area around the terminal will be graded 1:10 or flatter. The plans should show both the desired slopes and the required locations.

d. Barrier/Curb Combinations.

- All Barrier/Curb Combinations: Concrete curb and gutter, header curb, or other rigid type curb used in combination with barrier should be avoided whenever possible. Curb should not be used in front of barrier unless the combination has been successfully crash-tested.

- Guardrail/Curb Combinations: Where there are no other feasible alternatives to guardrail/curb combinations, the face of curb should be located behind or flush with the face of guardrail. However, crash tests have shown some guardrail/curb combinations with curb located flush with the face of the guardrail can cause vaulting due to deflection of the rail. Therefore, curb higher than 100 mm should not be used with guardrail unless: 1) the guardrail/curb combination has been successfully crash-tested; or 2) the rail is adequately reinforced (stiffened) to reduce its deflection. On lower speed roads, use of a reinforced rail may not be cost-effective. Such locations are best analyzed on a case-by-case basis, taking actual or anticipated operating speeds into account and considering the consequences of vehicular penetration.

Chapter 3 of the *Roadside Design Guide* contains additional information on curb and barrier/curb combinations.

F. Crash Cushions. Crash cushions shield errant vehicles from impacting fixed rigid hazards (e.g., intersection of bridge parapets at a gore area) by smoothly decelerating the vehicle to a stop condition when hit head on. Also, it is desirable for the crash cushion to redirect a vehicle when hit from the side by functioning in a manner similar to a longitudinal barrier.

1. Determination of Need. As with longitudinal barriers, the first consideration with regard to a rigid object or hazardous conditions is to evaluate the feasibility of removing the obstruction, relocating it, or making it breakaway. When these options are not feasible, the next step is to determine whether or not some type of barrier is warranted by analyzing the cost effectiveness as described in Section 8.4.C. The cost-effective procedure can be used to evaluate both longitudinal barriers as well as crash cushions. Before the development of crash cushions, many fixed object hazards could not be effectively shielded at all; therefore where appropriate, crash cushions may prove to be very helpful.

2. Types of Crash Cushions. The *Roadside Design Guide* lists operational types of crash cushions. The best reference source available to the designer is FHWA's *Selection and Design Criteria of Crash Cushions*. As with barriers, crash test criteria can be found in NCHRP Report 350.

3. Design Procedures. The State of the Art regarding crash cushions is rapidly changing as new products are developed and tested. The most recent manufacturers' literature should be referred to when incorporating crash cushions into a design.

FHWA periodically issues clarifying instructions regarding the use or design of various systems as modifications are made or as additional crash test data becomes available. A November 18, 1985 memorandum entitled, G-R-E-A-T Hex-Foam Crash Cushion, issued by the Associate Administrator for Engineering and Program Development modified acceptance criteria for new installations based on crash tests.

While the use of crash cushions on FLH projects is expected to be quite limited, the designer should realize that rapid development in this area is taking place. Where use of a crash cushion is warranted, the designer should ensure that the most recent design criteria is used.

G. Signing and Delineation. Communication with the motorist is one of the most complex problems of the design engineer. One of the best communication tools available is the *MUTCD*, which depicts the national standards developed for all signing, signalization, channelization, and pavement markings for all highways in the United States. The FHWA *Standard Highway Sign Book* and the NPS *Sign Manual* both provide design criteria, methods, and charts for design.

All traffic control devices shall be in accordance with the *MUTCD*. Compliance with the requirements of the *MUTCD* for all traffic control devices is mandatory and includes the following:

- Use
- Placement
- Uniformity
- Maintenance
- Color
- Size
- Shape
- Legend
- Reflectivity
- Removal when not applicable

The main message of the *MUTCD* is the importance of uniformity. Substantial adherence to this manual is required on all public roads. However, some owner agencies have supplements to it or have developed similar manuals, such as the NPS *Sign Manual*, that must also be considered when designing and constructing roads under NPS jurisdiction. The *Traffic Control Devices Handbook* provides a compendium of traffic control system technology.

Highway users are dependent on traffic-control devices (signs, markings, and signals) for information, warning, and guidance. Uniform high-quality devices are important for the safe, efficient use and public acceptance of any highway regardless of the roadways excellence in width, alignment, and structural design.

Any traffic control device should do all the following:

- Fulfill an important need
- Command attention
- Convey a clear, simple meaning
- Command respect of road users
- Give adequate time for response

It should be noted that devices controlling or regulating traffic must be sanctioned by law.

Four basic principles are used to ensure that these requirements are met:

- Design
- Placement
- Maintenance
- Uniformity

Consideration shall be given to these principles during the design stage to ensure that the required number of devices can be minimized and properly placed.

1. Signing. The above cited references provide the designer with the information required to properly select the appropriate signing. Sign supports should be designed in accordance with the AASHTO *Standard Specifications for Structural Supports for Highway Signs, Luminaries, and Traffic Signals*. Owner agency practice, in accordance with the above standards, may dictate the types of materials to be used. Sign supports and luminaries located within the clear zone should be either crash worthy or made breakaway.

Designers should be aware that the NPS-52 *Traffic Control Guideline* requires each park to have an established sign plan. These plans should be reviewed together with accident statistics and any available safety studies to ensure continued appropriateness whenever additional construction work takes place. Similar plans may exist on specific routes with other owner agencies and should likewise be requested and reviewed.

The authority for regulatory signing rests with the maintaining/regulating agency. Likewise, the client agency may have specific concerns regarding warning or informational signs. The designer's responsibility is to identify all signs required and review them with the appropriate agencies during project development.

2. Pavement Markings. Pavement markings have definite and important functions to perform in a proper scheme of traffic control. In some cases, they are used to supplement the regulations or warnings of other devices such as traffic signs or signals. In other instances, they are used alone and produce results that cannot be obtained by the use of any other device. In such cases they serve as a very effective means of conveying certain regulations and warnings that could not otherwise be made clearly understandable.

Pavement markings have definite limitations. They can be obliterated by snow, may not be clearly visible when wet, and may not be very durable when subjected to heavy traffic. ln spite of these limitations, they have the advantage, under favorable conditions, of conveying warnings or information to the driver without diverting the driver's attention from the roadway.

a. General Application. Each standard marking shall be used only to convey the meaning prescribed for it in the *MUTCD*. Before any new paved highway, surfaced detour or temporary route is opened to traffic, all necessary markings shall be in place.

Remove or obliterate markings no longer applicable and which may create confusion in the mind of the motorist as soon as practicable. Painting out markings is not an acceptable method of obliteration. Markings which must be visible at night shall be reflectorized unless specific external illumination is provided.

All two-way paved roads, 5.5 meters or more in width, shall have centerline stripes. All multi-laned highways shall have lane line markings. Edge lines shall be provided on all rural multi-lane divided highways. Edge lines should be provided on all highways as follows:

- When the traffic exceeds 2000 ADT.
- In areas of frequent inclement weather and/or reduced visibility.
- In mountainous terrain where increased delineation is desirable.

All markings shall be placed in accordance with the *MUTCD*.

b. Pavement Marking Materials. The standard material to be used for pavement markings is an applied paint with reflective beads. All other pavement marking materials are considered to be upgraded materials. To upgrade, consideration shall be given to material performance, material cost, traffic volume and type, climatic conditions, and availability of materials and installation equipment (both for initial installation and maintenance). Only when an upgraded material is established to be more cost effective than the standard material, can the upgraded material be used. The following guidelines may be used for upgrading the striping material in lieu of an economic evaluation:

(1) Epoxy thermoplastic (ETP), epoxy, and polyester materials may be specified for centerlines, lane lines, and edge lines under any of following conditions:

- The ADT is in excess of 1000 vehicles per lane.
- Because of environmental, traffic, or climatic conditions, it is necessary to restripe with paint two or more times a year.
- The location is not proposed or scheduled for sealing or resurfacing within the next 3 years.

(2) Additionally, thermoplastic and preformed plastic type materials may be allowed for centerlines, lane lines, and edge lines when both of the following conditions are met:

- The ADT is in excess of 5000 vehicles per lane.

- The location is not proposed or scheduled for sealing or resurfacing within the next 5 years.

Epoxy thermoplastic, epoxy, or polyester materials may be specified under lower traffic conditions where there is a need to emphasis transitions, channelization, or special markings such as stop lines and crosswalks. These materials should not be specified under the lower traffic condition if it is less than 3 years before the pavement is scheduled for sealing or resurfacing.

(3) The appropriate type of raised pavement markings and/or snow plowable recessed low profile markers should be considered for the following:

- Intersection channelization.
- Directional left turn lanes.
- High hazard/accident locations.
- Areas of frequent inclement weather.
- Combined installations with preformed plastic markings where no overhead lighting exists.

Pavement striping tape may be specified as a temporary measure when conditions do not permit painting or while the highway is under construction.

H. Traffic Control. The safe and efficient movement of traffic through the highway project necessitates that designers review the proposed design from a traffic operations standpoint. The designer needs to be alert for situations that involve alterations in the driver's behavior or changes in driver attention. During the design phase, make an attempt to perceive the final roadway as it will appear to the motorist to anticipate the necessary traffic control devices needed to provide the user with sufficient advance information so the highway can be driven safely. Through the proper application of design standards, the number of motorist decision points will be minimized. There will, however, always be a need for appropriate permanent traffic control devices to inform, regulate, and/or warn the motorist. A review of the safety analysis will generally identify areas of existing operational problems.

Field reviews during construction are encouraged to substantiate if the original perceived operational characteristics of the project were germane and to provide timely adjustments during construction should they be warranted. After construction is completed and the project opened to traffic, an evaluation should be made of the traffic control devices to determine their adequacy and if they are functioning as planned.

1. Traffic Control Through Construction. Construction activity presents many traffic control problems that must be addressed by the designer. Regardless of whether the project is open or closed to public traffic, some form of construction traffic control will be required. A plan directed to the safe and expeditious movement of traffic through construction and to the safety of the work force performing those operations is defined as a Traffic Control Plan (TCP).

It is FLHO policy that a TCP be designed and incorporated into all projects.

2. Traffic Control Plan (TCP) Development. The purpose of the TCP is to anticipate and describe those traffic control measures that will be necessary during project construction and to outline coordination needs with owner agencies and the public.

Traffic control plans will vary in scope and complexity depending upon the type and volume of traffic and the nature of the construction project. At an early stage in the project development, the development of the TCP should begin and a determination made of the nature and volume of current and predicted traffic. All interested agencies should be involved throughout the development of the TCP. For projects with low-traffic volumes or that otherwise have few traffic hazards or conflicts, the TCP may be quite simple.

For projects that have one or more of the following characteristics, the TCP will normally be more complex:

- High volume or high speed traffic.
- Rush hour or seasonal traffic patterns.
- Heavy use by pedestrians.
- Changing work conditions or other conditions that would be confusing to the traveling public.
- Hazards due to nighttime operations.
- Complex detours or traffic patterns.
- Closely spaced intersections, interchanges, or other decision points.

In developing the TCP, consider the following items as appropriate. (These items may be used as a checklist in either developing or reviewing the adequacy of traffic control plans.)

- Estimated traffic volumes, vehicle types, and direction of travel.
- Traffic speeds.
- Required number of travel lanes.
- Traffic control layouts including signing, markings, channelization devices, traffic signals, traffic delineators, barriers, and detour schemes.
- Restrictions on work periods such as rush hours, holidays, special events, nights, weekends, etc.
- Characteristics of adjacent highway segments.
- Requirements for partial completion and opening sections to traffic.
- Maneuvering space available for traffic.
- Requirements for installing, maintaining, moving, or removing traffic control devices.
- Turns or cross movements required by traffic.
- Restrictions on contractor hauling or moving materials.

- Provisions for accommodating adjacent businesses or residential areas.
- Provisions for accommodating emergency vehicles such as ambulance, fire, and police.
- Any special requirements for the contractor's traffic safety coordinator.
- Requirements for after hours surveillance or on-call personnel.
- Special requirements for nighttime operations.
- Restrictions on parking vehicles, storing materials, and the contractor's equipment.
- Special provisions for pedestrian movements.
- Provisions for accommodating regularly scheduled services such as postal vehicles and school buses.

All TCP features, which are obligations on the part of the contractor, shall be included in the plans and specifications.

The *MUTCD* shall be used as a standard for signs, striping, and other traffic control devices. Because of the general nature of the *MUTCD*, it will usually be necessary to use supplemental information.

When necessary, appropriate standard typical traffic schemes shall be included in the plans.

The contract PS&E shall include the minimum requirements for controlling traffic through the construction work zones. However, the contractor may furnish alternate or additional means for accommodating traffic, subject to approval of the engineer.

Include traffic control provisions in the PS&E distribution made to other offices and agencies for review before advertising in order that these other parties may have an opportunity to review the provisions for adequacy and coordination.

Payment for TCP activities will usually be made by individual bid items for services, traffic control devices, signing, etc. For projects with only light traffic where traffic control procedures are minimal, payment may be incidental to other items of work or paid for on a lump sum basis.

There may be certain traffic control information that is of value to the project engineer but should not be included in the contract. In this case, such information should be documented and copies provided to the appropriate Construction units. This information may include the following:

- The need for public relations, such as notifications to the local news media.
- Any special agreements reached with other agencies relating to traffic control or traffic management.
- Accident reporting requirements.
- Any special guidance on traffic management for the project engineer.

The TCP as contained in the contract must be adopted by the contractor unless an alternate TCP is developed by the contractor and approved by the engineer prior to beginning construction operations.

3. Temporary Pavement Markings. The TCP should reflect FLH policy that pavement markings conforming to full MUTCD standards (Sections 3A and 3B) shall be installed as quickly as practical in the construction process. Special standards described below are available to accommodate the periods of time before installation of permanent markings is practical. These standards are consistent with the 1988 Edition of the MUTCD, Revision 3, dated September 3, 1993.

a. Definitions.

■ **Temporary Pavement Markings -** Either interim or standard markings installed prior to the installation of permanent markings.

■ **Interim Markings -** Interim markings are special, reduced dimension, temporary centerline, and lane line markings which are permitted by MUTCD Subsection 6F-6b. on new pavement lifts unless additional pavement lifts or standard markings are installed within specific time frames. Interim markings must conform to the color and retroreflection requirements of MUTCD Sections 3A and 3B.

■ **Standard Markings -** Standard markings are centerline, lane line, and no-passing zone markings which comply fully with the dimensional, color and retroreflection requirements of MUTCD Sections 3A and 3B. Standard markings may be either temporary or permanent, although permanent markings typically have additional contractual requirements.

■ **Vehicle Positioning Guides -** Temporary raised pavement markers, installed on centerline and lane lines immediately after paving but prior to the installation of temporary or permanent pavement markings. See MUTCD Section 3B-14.

■ **Severe Curvature -** Roads with a design speed of 55 km/h or less, or curves with design speeds of at least 15 km/h less than the design speed for the remainder of the road.

b. Unmarked Pavement. The MUTCD permits a limited period of unmarked pavement upon opening to traffic and prior to the required installation of temporary or permanent markings. During this period, it is important that adequate delineation and signing be provided as follows:

■ Vehicle positioning guides shall be installed on centerline and lane lines at a maximum spacing of N (N= cycle length, usually 12 meters) in combination with appropriate signs, channelizing devices and other delineation. Spacing should be reduced to 0.5 N in severe curvature situations.

■ A warning sign, "**Unmarked Pavement**" shall be placed at the beginning of each unmarked section, and after each major intersection or entrance ramp.

■ If sections of severe curvature or restricted visibility dominate the construction area, such that passing zones are inappropriate throughout the project, standard advance warning signing at the beginning of the project shall include "**No Passing Next ____ Miles**". In addition an R 4-1 "**Do Not Pass**" sign shall be installed at the beginning of the project and approximately every kilometer thereafter.

■ If each no-passing zone is to be signed separately, an R 4-1 "**Do Not Pass**" sign shall be used at the beginning of each zone, and repeated at maximum one-kilometer intervals if necessary. At the end of each zone an R 4-2 "**Pass With Care**" sign shall be used. On other than low volume roads, and when special hazards are present, the R 4-1 sign at the beginning of each zone should be supplemented by a W 14-3 "**No Passing Zone**" sign.

c. Marked Pavement. Temporary markings shall be required if the time limitations as described below for Unmarked Pavement, are exceeded and it remains impractical to install permanent markings. Temporary markings should be **standard markings**, unless the specific time limitations of interim markings can be met. The following are special standards for **interim markings**:

■ **Centerlines and Lane Lines -** MUTCD Section 6F-6b(1). and the Standard Specifications require interim broken-line pavement markings to be 1-meter stripes on 12-meter cycles (11-meter gaps), or 0.5-meter stripes on 6-meter cycles in severe curves. When 30 percent or more of the road is designated as meeting the criterion for severe curvature, the entire road may be striped on a 6-meter cycle. Temporary raised pavement markers may be substituted for broken line segments as permitted by the Standard Specifications.

■ **No Passing Zone Lines -** MUTCD does not recognize an special standard for interim no-passing zone lines. Whenever interim centerline markings are used, standard no passing zone lines shall be used, and shall meet the dimensional requirements of MUTCD Section 3A and 3B. Temporary, raised pavement markers spaced at 1.5 meters may be substituted for a solid line except during extended delays (six weeks or more) and winter shutdowns.

■ **Edge Lines -** Temporary edge lines are not required, except that if there is a winter shutdown or extended delay (of 6 weeks or more) in the completion of paving and installation of permanent markings, temporary edge lines meeting the requirements of Sections 3A and 3B shall be installed on those roads where edge lines were present prior to construction, and permanent edge lines are specified in the contract.

d. Time Limitations - Low Volume Roads [ADT ≤ 1000] . When average daily traffic does not exceed 1000 vehicles per day, and when the installation of permanent markings is not practical or possible immediately prior to opening the road to traffic, the use of the following standards are applicable.

■ For a scheduled duration of not more than two weeks after opening of a new lift of pavement, the minimum requirements of **8.4.3.b. Unmarked Pavement**, above shall apply.

■ As an option to unmarked pavement during the same two week time frame, temporary centerline markings meeting the standards of **interim markings** as defined in **8.4.3.c. Marked Pavement** above are permitted.

■ For scheduled duration of more than two weeks after opening of a new lift of pavement, the minimum requirements of **standard markings** as defined in **8.4.3.a.** shall apply; as well as the requirements for edge lines in **8.4.3.c. Marked Pavement**.

e. Time Limitations - Other Than Low Volume Roads [ADT > 1000]. When average daily traffic exceeds 1000 vehicles per day, and when the installation of permanent pavement markings is not practically possible immediately prior to opening the road to traffic, the use of the following standards are applicable.

■ For a scheduled duration of not more than three days after opening of a new lift of pavement, the minimum requirements of **8.4.3.b. Unmarked Pavement**, above shall apply.

■ For a scheduled duration of not more than two weeks after opening of a new lift of pavement, the minimum requirements of **interim markings** as defined above in **8.4.3.c. Marked Pavement** shall apply.

■ For scheduled duration of more than two weeks after opening of a new lift of pavement, the minimum requirements of **standard markings** as defined in **8.4.3.a.,** as well as the requirements for edge lines in **8.4.3.c. Marked Pavement** shall apply.

f. Contract Items. Contract requirements and contract items should be structured so as assure safety while not subsidizing or encouraging delays, inefficiencies and excessive use of temporary markings and related traffic control.

■ Vehicle Positioning Guides are not considered centerline markings, but may be paid for as Temporary Raised Pavement Markers, or considered a subsidiary obligation. Additional signing and/or channelization devices necessary during periods of unmarked pavement should be anticipated and included in TCP's.

■ Generally the use of a contract item for temporary pavement markings is discouraged, especially on low-volume roads, unless it is determined that the installation of permanent markings within the available time limitations is not practical or possible. If permanent marking are not installed within the available window, temporary markings should be required at the expense of the contractor.

■ Since the Standard Specifications prohibit painted temporary markings on the final lift of pavement, it may be appropriate to include a contract item for temporary markings for lifts other than the final lift, but not for the fianl lift. This will minimize the cost of the temporary markings item, and encourage the contractor to schedule permanent markings on the final lift in a timely manner.

g. No Existing Markings. When the existing road, prior to construction, has no centerline/passing zone markings, then temporary markings are not required prior to completion of the work, except if the construction is nearly complete (including one or more lifts of pavement materials), and has upgraded the geometrics and increased prevailing speeds, temporay markings shall be required in accordance with **c.** above.

h. One-Lane Paving. During construction when only one lane of a two-lane road is being paved, with the second lane paved the following day (as is permitted by the FP depending on lift thicknesses), the paving shall be offset so as not to obscure the existing markings, or temporary markings shall be installed on the one lane mat prior to opening it to traffic. In addition a symbolic or worded uneven lanes sign should be used in this situation.

i. Special Pavement Markings. The need for temporary school zone, railroad, cross walk, stop line, and other special pavement markings shall be evaluated on a case by case basis during the design process. Markings deemed warranted shall be included in the contract. This evaluation shall consider pedestrian traffic, limited sight distance and other potential hazards in addition to traffic volume and duration of construction.

j. Detours. Paved temporary roads and detours which are to carry other than low volume traffic, or are to be used in excess of two weeks shall receive standard markings in accordance with MUTCD Sections 3A and 3B. When two-way traffic is detoured onto what would ordinarily be a one-way road, or what may appear to be a one-way road, signing shall be supplemented with W 6-3 "**Two-way Traffic**" signs at maximum one-kilometer intervals.

k. State Standards. It is not the intention of FLH to apply temporay markings standards to its projects which are less than those applied on equivalent State highway projects. Designers should be congnizant of prevailing State standards and make upward (but not downward) adjustments to FLH requirements whenever appropriate.

l. Contract Provisions. It is important to structure contracts such that major overruns and unnecessary Government liability for short-term markings will not occur if the contractor elects to perform the paving and marking differently than the designer assumed. The following are general guidelines which must be reevaluated on a case-by-case basis.

- There should be sufficient quantities of short term markings to accommodate each lift of paving materials anticipated during construction.

- The contractor should be given the option of furnishing painted markings, reflective tape or temporary raised pavement markers. The bid item should include removal when required. Generally, painted short-term markings are cheapest and are appropriate immediately behind the paving operation on intermediate lifts. The temporary raised pavement markers are more practical on final lifts since they are easily removable prior to installing permanent markings, and are usually cheaper than reflective tape on roads with extensive no-passing zones. Where aesthetics has a high premium it may be appropriate to prohibit temporary painted markings on the final lift.

- The Government should not be obligated to pay for two systems on the same lift. If the time limit short-term (interim) markings expires due to poor scheduling, and the contractor has to install short-term (standard) markings, then the upgrade should be at the contractor's expense.

- For large projects, it is intended that the time limitations on short-term (interim) markings will force the contractor to complete manageable sections of the project through permanent striping, rather than have the entire project partially complete for an unacceptably long period of time.

I. Traffic Signals. As most FLHP work is in rural areas, there is seldom a need for signalized intersections or advanced traffic control systems such as ramp monitoring on controlled access facilities. However, temporary signals are an effective tool for managing traffic where one-lane operations are required for bridge rehabilitation or similar work. Gather all available information or traffic volumes, turning movements, and accident data (e.g., frequency, location, type, speeds).

The design of traffic signal devices and warrants for their use are covered in Part IV of the *MUTCD*. Consult additional reference sources when designing signalized intersections and other traffic control systems not covered by the *MUTCD*. The *Traffic Control Devices Handbook* provides the fundamental procedures for proper analysis and design of traffic control systems. Also of interest is the *Transportation and Traffic Engineering Handbook* as well as the Transportation Research Board's Special Report 209, *Highway Capacity Manual*.

Traffic control signals are devices that control vehicular and pedestrian traffic by assigning the right-of-way to various movements for certain pre-timed or traffic-actuated intervals of time. They are one of the key elements in the function of many urban streets and of some rural intersections. Thus the planned signal system for a facility should be integrated with the design to achieve optimum safety, operation, capacity, and efficiency. Careful consideration should be given in plan development to intersection and access locations, horizontal and vertical curvature, pedestrian requirements, and geometric schematics to ensure the best possible signal progression, speeds, and phasing. In addition to initial installation, possible future need should also be evaluated.

Owner agencies or State highway agencies are usually a good source for design assistance, particularly in the area of equipment compatibility and electrical design.

8.5 (RESERVED)

8.6 (RESERVED)

8.7 DIVISION PROCEDURES

Reserved for Federal Lands Highway Division office use in supplementing the policy and guidelines set forth in this chapter with appropriate Division procedures and direction.

LIST OF EXHIBITS

Exhibit

GENERAL ACCIDENT PATTERNS		
Accident Pattern	Probable Cause	Safety Enhancement
Run-off roadway	Slippery pavement	Improve skid resistance Provide adequate drainage Groove existing pavement
	Roadway design inadequate for traffic conditions	Widen lane/shoulders Relocate islands Provide proper superelevation Install/improve traffic barriers Improve alignment/grade Flatten slopes/ditches Provide escape ramp
	Poor delineation	Improve/install pavement markings Install roadside delineators Install advance warning signs
	Poor visibility	Improve roadway lighting Increase sign size
	Inadequate shoulder	Upgrade roadway shoulders
	Improper channelization	Improve channelization
Bridges	Alignment	Realign bridge/roadway Install advance warning signs Improve delineation/markings
	Narrow roadway	Widen structure Improve delineation/markings Install signing/signals
	Visibility	Remove obstruction Install advance warning signs Improve delineation and markings
	Vertical clearance	Rebuild structure/adjust roadway grade Install advance warning signs Improve delineation and markings Provide height restriction/warning device
	Slippery surface (Wet/icy)	Resurface deck Improve skid resistance Provide adequate drainage Provide special signing
	Rough surface	Resurface deck Rehabilitate joints Regrade approaches
	Inadequate barrier system	Upgrade bridge rail Upgrade approach rail/terminals Upgrade bridge - approach rail connections Remove hazardous curb Improve delineation and markings

EXHIBIT 8.1
General Accident Patterns

GENERAL ACCIDENT PATTERNS		
Accident Pattern	**Probable Cause**	**Safety Enhancement**
Overturn	Roadside features	Flatten slopes and ditches Relocate drainage facilities Extend culverts Provide traversable culvert end treatments Install/improve traffic barriers
	Inadequate shoulder	Widen lane/shoulder Upgrade shoulder surface Remove curbing/obstructions
	Pavement feature	Eliminate edge drop-off Improve superelevation/crown
Parked vehicles	Inadequate road design	Widen lanes/shoulders
Fixed object	Obstructions in or too close to roadway	Remove/relocate obstacles Make drainage headwalls flush with side slope Install breakaway features to light poles, signposts, etc... Protect objects with guardrail Delineation/reflectorize safety hardware
	Inadequate lighting	Improve roadway lighting
	Inadequate pavement markings, signs, delineators, and guardrail	Install reflectorized pavement lines/raised markers Install reflectorized paint and/or reflectors on the obstruction Add special signing Upgrade barrier system
	inadequate road design	Improve alignment/grade Provide proper superelevation Install warning signs/delineators Provide wider lanes
	Slippery surface	Improve skid resistance Provide adequate drainage Groove existing pavement
Sideswipe or head-on	Inadequate road design	Provide wider lanes Improve alignment/grade Provide passing lanes Provide roadside delineators Sign and mark unsafe passing areas
	Inadequate shoulders	Improve shoulders
	Excessive vehicle speed	Install median devices
	Inadequate pavement markings	Install/improve centerline, lane lines, and edge lines Install reflectorized markers
	Inadequate channelization	Install acceleration and deceleration lanes Improve/install channelization Provide turning bays
Sideswipe or head-on (Continued)	Inadequate signing	Provide advance direction and warning signs Add illuminated name signs

EXHIBIT 8.1
General Accident Patterns

GENERAL ACCIDENT PATTERNS		
Accident Pattern	Probable Cause	Safety Enhancement
Access-related	Left-turning vehicles	Install median devices Install two-way left-turn lanes
	Improperly located driveway	Move driveway to side street Install curbing to define driveway location Consolidate adjacent driveways
	Right-turning vehicles	Provide right-turn lanes Increase width of driveways Widen through lanes Increase curb radii
	Large volume of through traffic	Move driveway to side street Construct a local service road
	Large volume of driveway traffic	Signalize driveway Provide acceleration and deceleration lanes Channelize driveway
	Restricted sight	Remove obstructions
	Inadequate lighting	Improve street lighting
Intersection (signalized/ unsignalized) left turn, head-on, right angle, rear end	Large volume of left/right turns	Widen road Channelize intersection Install STOP signs Provide signal Increase curb radii
	Restricted sight distance	Remove sight obstruction Provide adequate channelization Provide left/right turn lanes Install warning signs Install STOP signs Install signal Install advance markings to supplement signs Install STOP bars
	Slippery surface	Improve skid resistance Provide adequate drainage Groove pavement
	Large numbers of turning vehicles	Provide left- or right-turn lanes Increase curb radii Install signal
	Inadequate lighting	Improve roadway lighting
	Lack of adequate gaps	Provide signal Provide STOP signs

EXHIBIT 8.1
General Accident Patterns

GENERAL ACCIDENT PATTERNS

Accident Pattern	Probable Cause	Safety Enhancement
Intersection (signalized/ unsignalized) left turn, head-on, right angle, rear end (Continued)	Crossing pedestrians	Install/improve signing or marking of pedestrian crosswalks Install signal
	Large total intersection volume	Install signal Add traffic lane
	Excessive speed on approaches	Install rumble strips
	Inadequate advance warning signs	Improve warning devices Install advance warning signs
	Inadequate traffic control devices	Upgrade traffic control devices
	Poor visibility of signals	Install/improve advance warning signs Install overhead signals Install 300 mm signal lenses Install visors/back plates Relocate signals Remove sight obstructions Add illumination/reflectorized name signs
	Unwarranted signals	Remove signals
	Inadequate signal timing	Upgrade signal system timing/phasing
Nighttime	Poor visibility or lighting	Install/improve street lighting Install/improve delineation/markings Install/improve warning signs
	Poor sign quality	Upgrade signing Provide illuminated/reflectorized signs
	Inadequate channelization or delineation	Install pavement markings Improve channelization/delineation
Wet pavement	Slippery pavement	Improve skid resistance Groove existing pavement
	Inadequate drainage	Provide adequate drainage
	Inadequate pavement markings	Install raised/reflectorized pavement markings
Pedestrian/bicycle	Limited sight distance	Remove sight obstructions Install/improve pedestrian crossing signs and markings
	Inadequate protection	Add pedestrian refuge islands
	Inadequate signals/signs	Install/upgrade signals/signs
	Mid-block crossings	Install warning signs/markings

EXHIBIT 8.1
General Accident Patterns

GENERAL ACCIDENT PATTERNS		
Accident Pattern	Probable Cause	Safety Enhancement
Pedestrian/bicycle (Continued)	Inadequate pavement markings	Supplement markings with signing Upgrade pavement markings
	Lack of crossing opportunity	Install traffic/pedestrian signals Install pedestrian crosswalk and signs
	Inadequate lighting	Improve lighting
	Excessive vehicle speed	Install proper warning signs
	Pedestrians/bicycles on roadway	Install sidewalks Install bike lanes/path Eliminate roadside obstructions Install curb ramps
	Long distance to nearest crosswalk	Install pedestrian crosswalk Install pedestrian actuated signals
Railroad crossings	Restricted sight distance	Remove sight obstructions Reduce grade Install active warning devices Install advance warning signs
	Poor visibility	Improve roadway lighting Increase size of signs Install advance markings to supplement signs
	Inadequate pavement markings	Install STOP bars Install/improve pavement markings
	Rough crossing surface	Improve crossing surface
	Sharp crossing angle	Rebuild crossing with proper angle

EXHIBIT 8.1
General Accident Patterns

ROADSIDE HAZARD REVIEW

State: **Montana** Prepared by: **Paul Schneider**
County: **Flathead** Date: **May 19, 1996**

National Forest/Park: **Glacier National Park**

Highway Route: **U.S. Route 2** Limits: **193+116 to 202+128** Length: **9.0 km**
General Location: **Beginning 1 km south of Camas and extending north to top of graveyard hill at Essex.**

Item	Hazard Location		Description of Hazard	Action	Cost	Remarks
	Station	Lt/Rt (m)				
1	193+438	6.0 Rt	100 x 100 wood sign post	Yes	$ 90	Relocate to backslope
2	194+082	4.9 Rt	100 x 100 wood sign post	Yes	$ 90	Relocate to backslope
3	194+243	5.5 Lt	Concrete culvert headwall	Yes	$ 500	Replace existing culvert
4	194+323	4.9 Rt	Concrete culvert headwall	Yes	$ 600	Replace existing culvert
5	194+564	3.7 Lt	Mailbox in no-passing zone	Widen	$1000	Provide mailbox turnout
6	194+886	4.3 Rt	Two 100 x 150 wood sign posts (not drilled)	Yes	$ 50	Drill posts
7	195+530	4.9 Lt	Abrupt culvert ends	Yes	$ 250	Lengthen culvert - metal end sections
8	196+013	4.6 Lt	Mailbox - good sight distance	No	-	Tight right-of-way
9	196+013	5.5 Lt	Abrupt approach road culvert	Yes	$ 600	Extend approach culvert and flatten slope to 1:10
10	196+174 to 196+656	6.7 Rt	Steep fill slope	None	-	Not cost effective guardrail
11	197+300	6.0 Lt	Concrete culvert headwall	Yes	$ 500	Replace and extend
12	198+105	5.5 Rt	Abrupt approach road culvert	Yes	$ 600	Extend culvert and flatten slope to 1:10
13	200+680	4.3 Rt	Concrete culvert headwall	Yes	$ 500	Replace existing culvert
14	201+645	3.7 Lt	Mailboxes (4)	Widen	$2500	Provide mailbox turnout

EXHIBIT 8.2
Sample of a Roadside Hazard Review

Design and Construction Notes for Aesthetic Barriers

Steel-backed Timber Guardrail

1. The steel-backed timber guardrail has been crash tested and meets the requirements of NCHRP Report 350. The blocked-out option, type A, is approved for design speeds of 100 km/h and less. The option without the block-out, type B, is approved for use for design speeds of 80 km/h and less. Unless there are objections, the preferred installation is the type A.

2. Numerous designs for the steel-backed timber guardrail and its terminals have been reviewed and tested during the development of this system. Federal Lands Highway Standard Drawings for berms, turn-down terminals, and back-slope anchored terminals reflect the best compromise of safety, aesthetics, and ease of construction. Due to the possible effect on the crash worthiness of the guardrail, any modifications to Federal Lands Highway Standards for the steel-backed timber guardrail must be approved by the Federal Lands Highway Office.

3. The grading in front and directly behind the guardrail and terminals must be at a slope of 1:10 or flatter for the guardrail to be effective.

4. The maximum dynamic deflection of the steel-backed timber guardrail is approximately 450 mm for design speeds of 80 km/h and less. The dynamic deflection is approximately 750 mm for design speeds between 80 and 100 km/h. The back of the rail must be set at least these distances from a fixed object, such as a tree or bridge pier.

5. Field modifications to the structural steel, such as enlargement of the bolt slots, are not permitted, due to the effect on the crash worthiness of the system.

6. There should be at least 600 mm between the back of the guardrail posts and the top of a 1:2 slope or steeper. If this is unobtainable, the length of the guardrail posts should be increased to 2.4 m. The increase strength of the 2.4 m posts without the 600 mm soil backup is marginal and should only be used for short segments.

7. No steel-backed timber guardrail terminals have been crash tested. The Federal Lands Highway Office has standard drawings designed specifically for the steel-backed timber guardrail for a berm, a back-slope anchored terminal, and a flared anchored terminal (turn-down), and may be used:

   a. Where there is adequate room, the preferred terminal is the flared anchored terminal (FAT) with an earth berm. The terminal section should be located outside the clear zone, but if this is impractical it should be flared as far from the roadway as possible. The earth berm should be oriented approximately parallel to the roadway. It is intended that each berm will be stacked to fit its particular location. For safety, aesthetics, and maintenance considerations, it is desirable to flatten the slopes of the berm as much as possible. A 1:3 sideslope on the berm facing the roadway is considered minimally acceptable. It is also desirable to increase the height of the berm, but the 1:20 approach slope must be maintained.

EXHIBIT 8.3
Design and Construction Notes for Aesthetic Barriers

Steel-backed Timber Guardrail (Continued)

b. Where there is a back-slope to tie to, the preferred terminal is the back-slope anchored terminal (BAT). Crash tests with similar designs with W-beam guardrail have established a weakness in this design where the guardrail crosses a ditch. Due to this weakness, ditches under this terminal should be as flat as possible. It is recommended that the sideslopes of the ditches be no steeper than 1:10.

c. Where it is not possible to construct an earth berm or tie to a backslope, the guardrail may be terminated using the FAT without a berm. Crash tests on similar turn-down designs have demonstrated the potential for this type terminal to launch a vehicle or produce a rollover. However, this terminal is superior to leaving the exposed guardrail end that could snag or even penetrate a vehicle. The widened shoulder area and guardrail flare aids is providing stability for a vehicle riding up on the terminal.

Stone Masonry Guardwall

1. The stone masonry guardwall has been crash tested and meets the requirements of NCHRP Report 350. This rough-faced barrier system is approved for design speed of 100 km/h or less. A smooth-faced wall with smaller projections and shallower raked joints and beds is also approved.

2. The crash tested rough stone masonry guardwall used specifications that defined the maximum projections up to 38 mm beyond the neat line, 50 mm deep raked joints, and beds 50-75 mm thick. Based on aesthetics and available stone, specifications for the guardwall may be revised to specify any smoother stone face, such as class A or B masonry. Stone faces with critical dimensions greater than those listed above are not considered crash worthy.

3. Numerous designs for the stone masonry guardwall and its terminals have been reviewed and tested during the development of this system. One of the critical dimensions is the 500 mm between the ground line and the top of the corewall. Federal Lands Highway Standard Drawings for berms, turn-down terminals, and back-slope anchored terminals reflect the best compromise of safety, aesthetics, and ease of construction. Prior designs are not to be used. Due to the possible effect on the crash worthiness of the guardwall, any modifications to Federal Lands Highway Standards for the stone masonry guardwall must be approved by the Federal Lands Highway Office.

4. The grading in front of the guardwall and terminals must be at a slope of 1:10 or flatter for the guardwall to be effective.

5. The maximum dynamic deflection of the stone masonry guardwall is 0 m for design speeds of 100 km/h or less.

6. During construction, care should be taken to avoid large rock projections oriented toward oncoming traffic. Such projections have a tendency to snag a vehicle resulting in greater vehicle and occupant injury. The recommended orientation for the projections is away from oncoming traffic, so that the vehicle can ride over the projections.

Design and Construction Notes for Aesthetic Barriers

Stone Masonry Guardwall (Continued)

7. No stone masonry guardwall terminals have been crash tested. The Federal Lands Highway Office has standard drawings designed specifically for the stone masonry guardwall for a berm Buried terminal (BT), a back-slope anchored terminal (BAT), and a stand alone terminal (SAT) (turn-down), and may be used:

   a. Where there is adequate room, the preferred terminal is the buried terminal (BT) with an earth berm. The terminal section should be located outside the clear zone, but if this is impractical it should be flared as far from the roadway as possible. The earth berm should be oriented approximately parallel to the roadway. It is intended that each berm will be stacked to fit its particular location. For safety, aesthetics, and maintenance considerations, it is desirable to flatten the slopes of the berm as much as possible. A 1:3 sideslope on the berm facing the roadway is considered minimally acceptable. It is also desirable to increase the height of the berm, but the 1:20 approach slope must be maintained.

   b. Where there is a back-slope to tie to, the preferred terminal is the back-slope anchored terminal (BAT). Special consideration will be needed to maintain drainage, because this terminal will not accommodate a drainage ditch.

   c. Where it is not possible to construct an earth berm or tie to a backslope, the guardrail may be terminated using the SAT. Crash tests on similar turn-down designs have demonstrated the potential for this type terminal to launch a vehicle or produce a rollover. However, this terminal is superior to leaving the exposed guardrail end that could snag or even penetrate a vehicle. The widened shoulder area and guardrail flare aids is providing stability for a vehicle riding up on the terminal.

Precast Concrete Guardwall

1. The precast concrete guardwall has been crash tested and meets the requirements of NCHRP Report 350. This artificial stone system is approved for design speed of 100 km/h or less.

2. Based on the crash tests for the stone masonry guardwall the precast concrete guardwall may use specifications that define the maximum projections up to 38 mm beyond the neat line, 50 mm deep raked joints, and beds 50-75 mm thick. Based on aesthetics, specifications for the guardwall may be revised to specify any smoother artificial stone face. Artificial stone faces with critical dimensions greater than those listed above are not considered crash worthy.

3. Numerous designs for the precast concrete guardwall and terminal sections have been reviewed and tested during the development of this system. Federal Lands Highway Standard Drawings for berms, turn-down terminals, and back-slope anchored terminals reflect the best compromise of safety, aesthetics, and ease of construction. Due to the possible effect on the crash worthiness of the guardwall, any modifications to Federal Lands Highway Standards for the stone masonry guardwall must be approved by the Federal Lands Highway Office.

EXHIBIT 8.3
Design and Construction Notes for Aesthetic Barriers

Design and Construction Notes for Aesthetic Barriers

Precast Concrete Guardwall (Continued)

4. The grading in front of the guardwall and terminals must be at a slope of 1:10 or flatter for the guardwall to be effective.

5. The maximum dynamic deflection of the stone masonry guardwall is 0 m for design speeds of 100 km/h or less.

6. During construction, care should be taken to avoid large rock projections oriented toward oncoming traffic. Such projections have a tendency to snag a vehicle resulting in greater vehicle and occupant injury. The recommended orientation for the projections is away from oncoming traffic, so that the vehicle can ride over the projections.

7. The precast concrete guardwall was crash tested 3.66 m behind a 88.9 mm mountable curb. Since the 3.66 m is considered to be the critical offset distance, the guardwall is approved for use with any 90 mm mountable curb at any offset.

8. The precast concrete guardwall can be used as a median barrier as long as both sides of the guardwall have a vertical face.

9. No precast concrete guardwall terminals have been crash tested. The Federal Lands Highway Office has standard drawings designed specifically for the precast concrete guardwall and my use drawings designed for the stone masonry guardwall for a berm Buried terminal (BT), a back-slope anchored terminal (BAT), and a stand alone terminal (SAT) (turn-down), and may be used:

   a. The precast concrete guardwall terminal sections were designed specifically for use with an earth berm in a median. The steep 1:4.5 tapers on these terminal sections necessitate the use of a 600 mm earth berm. The sideslopes on the earth berm should be 1:4 or flatter and the approach slope should be 1:20 or flatter. The approach slope for opposing traffic may be steepened to a maximum of 1:6 if there is inadequate room for the 1:20 slope. However, in no case should the 1:20 approach slope be steepened.

   b. For roadside applications where there is adequate room, the preferred terminal is the buried terminal (BT) with an earth berm. Due to the steep 1:4.5 top tapers, the earth berm must have a 600 mm earth berm specified instead of the standard 450 mm berm. The terminal section should be located outside the clear zone, but if this is impractical it should be flared as far from the roadway as possible. The earth berm should be oriented approximately parallel to the roadway. It is intended that each berm will be stacked to fit its particular location. For safety, aesthetics, and maintenance considerations, it is desirable to flatten the slopes of the berm as much as possible. A 1:3 sideslope on the berm facing the roadway is considered minimally acceptable. It is also desirable to increase the height of the berm, but the 1:20 approach slope must be maintained.

   c. Where there is a back-slope to tie to, the preferred terminal is the back-slope anchored terminal (BAT). Special consideration will be needed to maintain drainage, because this terminal will not accommodate a drainage ditch.

Design and Construction Notes for Aesthetic Barriers

Precast Concrete Guardwall (Continued)

d. Where it is not possible to construct an earth berm or tie to a backslope, the guardwall may be terminated using the SAT (turned-down) without an earth berm. Crash tests on similar turn-down designs have demonstrated the potential for this type terminal to launch a vehicle or produce a rollover. However, this terminal is superior to leaving the exposed guardrail end that could snag or even penetrate a vehicle. The widened shoulder area and guardrail flare aids is providing stability for a vehicle riding up on the terminal. Precast concrete terminals may only be used without an earth berm if they are located outside the clear zone.

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CHAPTER 9 - HIGHWAY DESIGN

9.1 GENERAL

This chapter provides policies, procedures, and methods for developing and documenting the design of highways. It also includes the preparation of plans, specifications and estimates (PS&E) for new highway construction, reconstruction and RRR (Resurfacing, Restoration and Rehabilitation) improvements.

A. Role of the Designer. The designer shall gather all the engineering and environmental input required to provide a complete and acceptable PS&E assembly. The PS&E package depicts the commitments made during the planning, programming, and project development stages.

The designer is responsible for applying guidance from Chapter 8, Safety and Chapter 9, Highway Design. In addition, the following named chapters provide information on collecting background data for the development of the PS&E.

- Chapter 2 - Planning and Programming. Information on the planning and programming functions, interagency agreements, and general data on the scope and funding levels for individual projects are covered in this chapter.

- Chapter 3 - Environment. This chapter provides information about environmental requirements and public involvement. Environmental documents will include commitments made for mitigation and public acceptance of the project. The designer will review all environmental documents for commitments made during the conceptual studies phase that affect development and construction of the project or operation of the highway following construction. Any proposed deviation from the mitigating measures and commitments must be coordinated with the Division environmental unit and affected resource agencies.

- Chapter 4 - Conceptual Studies. These studies result in a recommended roadway location and basic design criteria for a facility. Such studies are generally developed in conjunction with the environmental process. Conceptual studies generally include significant input from the owner agency and from other interested parties.

- Chapter 5 - Survey and Mapping. The survey unit provides information on the field survey, property, utility locations, and related data. The data collected provides topographic maps, site maps, right-of-way and utility plats, and base information for developing the design.

- Chapter 6 - Geotechnical. The geotechnical unit provides subsurface data and recommendations for earthwork slopes, materials, and pavement structure design. When applicable the report includes foundation design for bridges, retaining walls, and other structures, along with landslides and subsurface water information.

- Chapter 7 - Hydrology/Hydraulics. The hydraulics unit provides runoff data for roadside drainage design. This unit also provides data to the structural unit (for major structures) and designs major hydraulic structures and special water resource features.

- Chapter 10 - Structural Design. The structural unit designs bridges, major retaining structures, and special structural elements. The unit will provide complete structural plans, proposed specifications, and an estimate of cost for incorporation into the PS&E package.

B. Design Standards. Guidelines for geometric design have changed significantly over the years. Today's emphasis is on balancing the factors of safety, economy, environmental concerns, energy conservation, and social effects with the traditional concerns for volume and speed.

The FHWA has adopted policies and standards for Federal-aid highway design that recognize all these precepts. They are listed in 23 CFR 625 and supplemented in the FAPG. These standards basically adopt AASHTO policy and are applicable to Federal Lands Highway design.

Other Federal agencies, States and many local highway agencies have adopted standards implementing AASHTO policy with supplemental and clarifying criteria.

Table 9-1 lists the principle FLH programs and corresponding design standards. The appropriate standards are normally identified in the planning, programming, or conceptual studies document for the project. Occasionally the designer will need to determine which standards are approved for use on a specific project. The appropriate unit chief should be consulted.

9.1.B. Design Standards. (continued)

The design criteria shown in Table 9-1 represent both desirable and minimum standards. Each design should be evaluated on the basis of desirable design criteria for the safest overall design.

Cost, social and environmental factors often require standards that are less than desirable. This is particularly true for RRR projects. When these factors dictate design elements resulting in less than minimum standards, the designer must evaluate the consequences and document the decision in accordance with Section 9.1.B.2., Design Exceptions.

Table 9-1
Design Standards*

Type of Roadway	Applicable Standards
Forest Highway and Public Lands Highways	23 CFR 625 and FHWA approved State or local standards.
National Park Roads and Parkways	NPS standards (1984) and 23 CFR 625.
Indian Reservation Roads	25 CFR 170, BIA design manual and 23 CFR 625.
FAA Roads	23 CFR 625.
BLM Access Roads	FAPG G6090.13 and BLM Manual, Section 9113 - Roads.
Defense Access Roads	23 CFR 625 or FHWA approved State or local standards.
FS Roads and Trails	FS Handbook (FSH 7709.11).
ERFO	Standards determined by classification of highway to be repaired or reconstructed. (See ERFO Manual)

* When there is a conflict between agency standards and 23 CFR 625, the design criteria should be mutually resolved with the client agency.

1. Policy. It is FLHO policy to use approved standards for the design of projects funded from the highway trust fund. For projects funded through owner-agency appropriations, the owner-agency's standards apply, provided they are consistent with good engineering practice.

a. Design Criteria. The 1994 AASHTO publication, *A Policy on Geometric Design of Highways and Streets*, (also known as the Green Book) is the principle source for highway design criteria. Supplements to the Green Book include other AASHTO and technical publications adopted as acceptable criteria and other Federal, State and local specifications for use on their roads. These acceptable supplements are referenced throughout this manual.

b. Design Speed. A principle element in establishing design criteria is the selection of the design speed for the facility. The design speed should be consistent with the speed the driver expects. It should be logical for the topography, adjacent land use, and type of highway. The design speed must equal or exceed the posted or regulatory speed limit of the completed facility. The Green Book, pages 62 to 68, explains the philosophy of design speed. In most instances, the owner agency has the authority to establish the posted speed for the facility. When necessary, regulatory limits should be recommended to the owner-agency to provide guidance in setting posted speeds. However, when system-wide statutory speed limits prevail (such as the national 55 mph limit) they mandate posted speed.

c. RRR Projects. The design policy for RRR projects is the same as for new construction; however, designing these projects to approved standards may not be possible. Alternative actions should be analyzed when environmental concerns, social impacts, extraordinary costs or limited funds prevent construction to full standards. Analysis should include consideration of adjacent highway sections and the relationship to future improvements, as well as existing conditions. When the analysis concludes that approved standards are not practical, the designer shall document each exception to the standards as outlined in Section 9.1.B.2.

2. Design Exceptions. When approved standards are not obtained, the designer must document all exceptions. There are 13 principle *design elements* that are considered controlling criteria and which require documentation each time they are unobtainable:

(1) Design speed.
(2) Lane width.
(3) Shoulder width.
(4) Bridge width.
(5) Structural capacity.
(6) Horizontal curvature.
(7) Vertical curvature.
(8) Gradient.
(9) Stopping sight distance.
(10) Cross slopes.
(11) Superelevation.
(12) Horizontal clearance to structures (tunnels & bridge underpasses)
(13) Vertical clearance.

In addition to these controlling criteria, the designer should document other elements of operational efficiency or safety not meeting standards. Exhibit 9.1 presents a sample format for documenting design exceptions on a project.

This documentation supporting the design exception decision shall become a part of the PS&E package presented to the owner agency.

Documentation of design exceptions should include an explanation of the conditions prohibiting full standards and a description of the mitigating measures proposed to maximize operation and safety of the facility.

3. Mitigating Design Exceptions. Tort liability is a major concern of the Government. The designer must ensure that the design process is in compliance with all applicable standards.

The exception to standards outlined in FLHM 3-C-2 permits the designer to vary the controlling criteria when alternatives merit precedence over standards.

The project plans should include curve signs, turn signs, and advisory speed plates for mitigation purposes when posted limits cannot be reduced. The MUTCD specifies installation of advisory speed plates following a determination of the safe speed by accepted traffic engineering procedures.

An accepted field method of determining safe speed for horizontal curvature uses a slope meter, more commonly referred to as the *ball bank indicator*. When advisory speed plates are warranted, the project engineer should be provided with a listing of curve signs, turn signs, and advisory speed plates needed for the project as determined by theoretical design speed criteria. Signing normally appears on the plans but occasionally supplemental studies dictate the need to forward additional data to the field.

The project engineer verifies the safe speed of the curves in question using the ball bank indicator or other accepted traffic engineering procedures. The engineer can contact a local State, county, or municipal traffic engineer to arrange for a speed determination if a ball bank indicator is not available on a project vehicle. See pages 143-145 and Figure III-4 in the Green Book for a discussion on the relationship of ball bank readings and safe speeds. Also see Figure 9-4, Safe Speeds.

Table 9-2 establishes signing requirements for curves and turns.

Some agencies have criteria other than what is shown in Table 9-2. The designer should check the agencies' standards for conflicts between the two and use the more conservative signing criteria.

Determining the appropriate standards to be used for roadway lane and shoulder widths is sometimes difficult. In some cases, the project may be the only improvement on a route for many years. In other cases, the maintaining authority may have a policy that only resurfacing projects will be applicable to a route to use available funding for higher priority transportation facilities. In these instances, the compatibility with adjacent sections of the highway may be the governing criteria. When compatibility with adjoining roads is the controlling factor, a design exception is appropriate.

Extraordinary cost or adverse environmental impacts could also result in design exceptions. When the highway operating agency's approved transportation plan specifies less than the standard widths for a route, this width requires documentation as a design exception.

The remaining controlling criteria are usually limited to site specific locations. The designer must mitigate these design exceptions through the normal design process.

Some RRR projects cannot be surveyed cost effectively in enough detail to identify many of the exceptions to the controlling criteria, such as super-elevation, grades, etc. These projects place considerable emphasis on the engineering judgment of the designer. Any on-site study or field review for RRR projects should document any identifiable exceptions to standards.

Table 9-2
Minimum Signing[1] for Curves and Turns

Safe Speed [2](km/h)

Posted Speed MPH	km/h	30 or less	40	50	55	60	70	80	90	100
60	100	TA	TA	TA	CA	CA	CA	C	C	
55	90	TA	TA	TA	CA	CA	C	C		
50	80	TA	TA	TA	CA	C	C			
45	70	TA	TA	TA	C	C				
40	60	TA	TA	T	C					
35	55	TA	T	T						
30	50	T	T							
25	40	T								
20 or less	30									

A = Advisory Speed Plate

C = Curve Warning Sign, Reverse Curve Sign (or Winding Road Sign)

T = Turn Sign, Reverse Turn Sign (or Winding Road Sign)

Notes: [1]See MUTCD (Section 2C-4 and 2C-5).
[2]Determine the safe speed by use of the ball bank indictor.

C. Computer Aided Design and Drafting (CADD). Information on Computer Aided Design and Drafting is included in the Federal Lands Highway *CADD Manual*.

9.2 GUIDANCE AND REFERENCES

The publications listed in this section provided much of the fundamental source information used in the development of this chapter. While this list is not all inclusive, the publications listed will provide the designer with additional information to supplement this manual.

A Policy on Geometric Design of Highways and Streets. AASHTO. 1994.

Highway Capacity Manual. TRB Special Report No. 209. Transportation Research Board. 1985.

Manual on Uniform Traffic Control Devices (MUTCD). DOT, FHWA. 1988.

Traffic Control Devices Handbook. DOT, FHWA. 1983.

Park Road Standards. U.S. Department of the Interior, National Park Service. 1984.

Standard Specifications for Construction of Roads and Bridges on Federal Highway Projects (FP-96). DOT, FHWA. 1995.

Standard Specifications for Structural Supports for Highway Signs, Luminaries and Traffic Signals. AASHTO. 1986.

Guide for Development of Bicycle Facilities. AASHTO. 1991.

A Policy on Design of Urban Highways and Arterial Streets. AASHTO. 1973. (Out of Print).

Railroad-Highway Grade Crossing Handbook. Report No. FHWA-TS-86-215, 1986.

Intersection Channelization Design Guide. NCHRP 279.

An Informational Guide for Roadway Lighting. AASHTO. 1984.

A Guide of Accommodating Utilities Within Highway Right-of-Way. AASHTO. 1994.

A Guide for Erecting Mailboxes on Highways. AASHTO. 1994.

Roadway Lighting Handbook. DOT, FHWA. 1978 (and addendum 1983).

Americans with Disabilities Act (ADA) Accessibility Guidelines. Architectural and Transportation Barriers Compliance Board. 1994

Roadside Design Guide. AASHTO. 1989

A Guide to Standardized Highway Barrier Hardware. AASHTO-AGC-ARTBA. 1995

Recommended Procedures for the Safety Performance Evaluation of Highway Features. NCHRP Report 350. TRB. 1993

Design Risk Analysis (Volume I and II). FHWA-FLP-91-001. FHWA. 1991

Standard Practice for Use of the International System of Units (SI). The Modernized Metric System. E380-93. ASTM. 1993

Trail Design Manual "Trails for the Twenty-First Century": Planning, Design, and Management Manual for Multi-use Trails. Rails to Trails Conservancy, 1993

Designing Safer Roads. TRB Special Report No. 214. Transportation Research Board. 1987.

Horizontal Alignment Design Consistency for Rural Two-Lane Highways. FHWA-RD-94-034. FHWA. 1995

9.3 INFORMATION GATHERING

The designer is directed to Chapter 4, Conceptual Studies, for information on scoping, background data, preliminary design standards, and mitigating measures before beginning detailed design activities.

A. Design Study. A design study documents considerations and conclusions reached during the development of a project. Although it may not always result in a formal document, the study provides a history of the project from start to completion of the PS&E.

When the designer has completed the PS&E, the following applicable data should be available in the files:

- Project Description:
  - Description of existing conditions.
  - Comparison of proposed work with "no build" alternative.
  - Extent of selection and examination of alternatives.
  - Identification of deficiencies with costs to correct.
  - Design parameters used.
- Evaluation of any substantial change in commitments made in the environmental document.
- Statement regarding hearings advertised, held, or required.
- Cost estimates including applicable right-of-way acquisition, utility relocation, permits, project costs, construction engineering, incentive/disincentive clauses, and project agreements.
- Access control requirements.
- Reasons for deviations from adopted policy and standards.
- Traffic Data:
  - Present and design year average daily traffic (ADT) and seasonal average daily traffic (SADT), when applicable, with percentage of (S)ADT used for design hour volume (DHV), for directional split (D), and for trucks (T).
  - DHV for two-lane, two-way highways, crossroads, and frontage roads.
  - Turning movements.
- Special Traffic Data:
  - Noise impact studies.
  - Signal warrants.
  - Air quality studies.
  - Illumination warrants.
  - Left turning movements.
  - Traffic control plans.
  - Other studies as required.
- Accident history.
- Geotechnical and Materials Engineers' reports.
- Involvements on railroad right-of-way such as crossings, encroachments, etc.
- Utility involvements.

- Permit requirements or agreements.
- Roadway sections, including all new or widened bridges.
- Pavement structure section.
- Drainage consisting of hydraulic concepts, floodplain studies, culvert selection, etc.
- Erosion control.
- Illumination.
- Fencing.
- Signing.
- Signalization.
- Roadside development such as landscaping, aesthetic treatments, etc.
- Traffic control in terms of delineation, traffic barriers, pavement marking, impact attenuators, etc.
- Traffic control plans through construction.
- Related data affecting the ultimate construction and operation of the facility such as right-of-way considerations.

B. Surveying and Mapping. Chapter 5 covers the surveying and mapping information the designer can expect to receive. Ideally the design, survey, geotechnical and conceptual study engineers and the owner agency review the proposed work on the ground and determine the information and limits of the survey required to complete the project.

When field reviews are not possible, it is still beneficial for the designer and survey and mapping/location engineer to discuss the field information required. In many cases the designer's experience with new construction, reconstruction, and RRR projects can increase the effectiveness of the survey crew.

At some point in the project development process the designer usually provides the appropriate survey unit with the information to stake the project in the field. This could include notes to establish centerline, set slope stakes, clearing limits, reference points, right-of-way, and other control points necessary to complete the work. The designer shall keep the design files purged so the information provided for the stakeouts is current, correct, and reflects the design criteria established for the project. All notes prepared for field use will require checking to prevent the possibility of providing incorrect data.

C. Accident Data. On all projects the accident history should be analyzed and potentially hazardous features and locations identified to determine appropriate safety enhancement. A study of accidents by location, type, severity, contributing circumstances, environmental conditions, and time periods may suggest possible safety deficiencies. The designer should refer to Chapter 8 for details on data collection, accident investigation, and analysis. Refer to Chapter 4 for details on obtaining other necessary accident data.

D. Existing Plans. An excellent source of information for reconstruction and RRR projects is *as-constructed* plans. Each Federal Lands Highway Division office has access to a set of *as-constructed* plans for its completed projects. They contain information on alignments, drainage, bridges, right-of-way, pavement structure, and other engineering features.

Local government and other Federal agencies can also provide *as-constructed* plans and a variety of information relating to a specific section of highway. The NPS maintains microfilm files of as-constructed plans.

The designer should contact the utility company first to determine the project's effect on utilities. The utilities usually are on the right-of-way by permit from the highway operating agency.

While information from as-constructed plans and from other agencies has significant value, the data should not be blindly accepted as fact. Field verification is necessary.

E. Agency Contacts. The designer will usually find that the primary agency contacts were established during the environmental and conceptual studies phases of the project by environmental and location personnel.

The designer needs to continue to coordinate with these agency contacts to achieve a smooth transition between the design and construction phases.

The SEE study team membership comprises the principle agency contacts for projects that require an EIS or FONSI. On projects with a CE, the designer may initiate contact with other agencies regarding permit requirements and clearances.

The FHWA Federal-aid Division office may participate in the development of the project. The extent of the involvement varies from office to office, but using the expertise available in the FHWA Federal-aid Division Offices provides an independent review of the design.

On National Park Service projects, the coordinator in the Denver Service Center, or if appropriate, the National Park Service Support Office is the principal contact for input and review of the design alternatives. The NPS is responsible for coordination with other agencies and outside disciplines when applicable.

When using other agency funds, the project agreement should address the principle contacts and responsibilities for coordination.

The interagency interdisciplinary approach to design is fundamental to obtaining an end product that will serve the public and be consistent with Federal, State, and local goals, objectives and standards.

Early contact and coordination with cooperating agencies ensures an end product with a minimum of conflict and controversy.

9.4 PS&E DEVELOPMENT

This section prescribes procedures and policies for the preparation of PS&E's.

Plans are graphic representations (such as typical cross sections, drawings or details) of the proposed work.

Specifications is a general term applied to all directions, provisions, and requirements concerning the quality and performance of the work for a project.

The *estimate* consists of the engineer's cost analysis to perform the work. It serves as the basis of the probable construction amount, to evaluate bidders' proposals, and for programming funds for construction, related engineering, utility work, etc.

The *PS&E* package is a term used to describe the contract documents (plans, specifications, and estimate of cost) for performing the work to construct a highway facility. The following discussions will address those decisions generally made by the highway designer within the constraints imposed by earlier environmental and engineering studies.

A. Geometric Design. Geometric design defines the physical dimensions of the visible features of a highway such as the alignment, sight distance, width, slopes, grades, roadside treatment, and related issues. Geometric design standards relate to the functional classification of highways, traffic density and character, design speed, capacity, safety, terrain, and land use.

Design highways to a standard as consistent as practical. Evaluating the route between major terminal points will aid in keeping the overall design features of a route uniform on a project-by-project basis.

Limited funding may restrict the total reconstruction of a highway segment. When this is the case, the designer should consider *stage construction* where the grading is completed first and the paving at a later time. This assures that the basic geometrics (alignment, grades, and cross section) are of an established acceptable standard without need of further modification.

1. Aesthetic Consideration in Highway Design. The visual aspect of the highway is one of the fundamental elements of any geometric design. Visual impacts encompass the view both from and of the roadway. Curvilinear alignment fits the road to the terrain and provides a pleasing experience for the user.

Exhibit 9-2 illustrates several desirable and undesirable examples of highway design. It should be apparent from the exhibit that providing for visual comfort contributes to a more relaxing experience for the driver and provides the potential for better and safer traffic operations.

The designer should be familiar with the design controls found in the Green Book on pages 294 to 304. These criteria are basic to good geometric design, and adhering to them will enhance the visual qualities of the roadway.

From an aesthetic standpoint, bridges should blend in with curvilinear alignment. Bridges should be located entirely on tangents, curves, or transitions, but not on a combination of these. This may require minor adjustments in horizontal alignment such as spiral lengths.

Design superelevation to avoid or minimize unsightly kinks, humps, or dips in bridge railing or curbs. Bridges placed on sag vertical curves can have problems with appearance and aesthetic value.

The ultimate test for an aesthetically pleasing facility is whether it truly enhances the area through which it passes. A good designer attempts to achieve this goal on all designs.

2. Horizontal and Vertical Alignment Relationship. Horizontal and vertical alignments are mutually related and what applies to one is generally applicable to the other. The designer should visualize the completed facility in a three-dimensional mode to ensure that the alignments complement each other and enhance the good features of both. Excellence in a coordinated design will increase the usefulness and safety of the highway, encourage uniform speed, and make a positive contribution to the visual character of the road.

The Green Book covers the basic general guidelines for achieving coordination between line and grade. The criteria are of sufficient importance to summarize again as follows:

- The curvature and grades should balance, i.e., flatter curves used with flatter grades, and sharper curves with steeper grades.
- Tangent grade superimposed on tangent line, and vertical curves on horizontal curves, should be strived for at all times.
- Horizontal curves should lead vertical curves when they are superimposed so drivers can clearly see the direction the road is turning. The length of the vertical curve should preferably approach that of the horizontal curve.
- Sharp horizontal curves that are introduced at a pronounced crest or sag in the road grade create hazardous driving conditions, especially at night.
- Both horizontal curvature and profile grade should be as flat as possible at intersections where sight distance along both roads is important and vehicles may have to slow down or stop.
- On two-lane roads, the need for safe passing sections often supersedes the desirability for a well-coordinated line and grade. In these cases, work toward a long tangent section or a very gentle curvature section having sufficient passing sight distance.
- The alignment should enhance scenic views, whether natural or manmade. The highway should head toward, rather than away from, those views that are outstanding. It should descend toward those features of interest at a low elevation, and it should ascend toward those features best seen from below or in silhouette against the sky.

3. Establish Control Points. The designer's approach to balancing horizontal and vertical alignment is essentially the same using aerial photographs, contour maps, quad sheets, or other graphics showing the relief of the topography. The first step in coordinating both alignments is to establish the necessary physical control points that will set the parameters of the location. These control points can be either natural or manmade features such as mountain passes, summits, bodies of water, developed areas, intersecting roadways, archaeological or historic properties, and related constraints. In cases of reconstruction or RRR improvements, the existing right-of-way limits may become a primary control point.

The designer should plot a horizontal alignment through the established control points using splines, curve templates, shop curves, or freehand methods. These preliminary layout stages avoid or limit the use of straightedges and string lines to evaluate a curvilinear design properly.

In rolling or mountainous terrain, it is desirable to plot a rough profile to determine if the preliminary alignment will fit the vertical controls. This consists of scaling stations on the horizontal alignment and picking elevations from the contours.

A rough profile plot on a reduced scale ratio (such as 1:5000 horizontal and 1:500 vertical) is adequate to determine the need for alignment shifts. Several adjustments of the rough line and grade may be necessary before a reasonably good initial line complies with the design speed requirements.

4. Horizontal Alignment. Horizontal alignment is a combination of circular curves, transition curves, and tangents. Horizontal alignment must provide for safe and continuous operation at a uniform design speed for substantial lengths of highway.

The major design considerations in horizontal alignment are safety, functional classification, design speed, topography, vertical alignment, construction cost, cultural development, and aesthetics. These factors, when properly balanced, produce an alignment that is safe, economical, and in harmony with the natural contour of the land.

The following guidelines apply to all alignment projections:

- The line should be as directional as possible, consistent with topography and land use. A flowing line following the natural contours is preferable to one with long tangents slashing through the terrain and causing large construction scars.

- If possible, avoid the use of the minimum radius for the design speed.

- Consistent alignment is the desirable end product. Sharp curves introduced at the ends of long tangents, and sudden changes from flat curvature to sharp curvature are dangerous. When sharp curvature is used, successively sharper transition curves from flat curvature to sharp curvature are applicable. This is necessary since actual operating speeds typically exceed design speeds on long flat curves (radius>450 m) and tangents. The designer may assume 85th percentile operating speeds of 100 km/h approaching curves following tangents or flat curves longer than 500 meters.

- On long high through-fills, use only very flat curvature unless guardrail or other measures such as plantings or reflectors are used to delineate the edge of the roadway.

- Small deflection angles should have long curves to avoid the appearance of a kink. On alignments with long tangents and sight distances, the curve should be at least 150 meters in length for a delta (central angle) of 5°. This minimum length increases 30 meters for each 1° decrease in delta. For curves located on a crest vertical curve, decreasing the above lengths will still provide a pleasing transition.

    Deflections of 15 minutes and less do not require the use of a curve, but it is preferable to locate slight breaks in grade at these angle points to minimize the visible effect to the road user.

    For aesthetic reasons and driving comfort, the preferable minimum length of curve should be between 1.5 to 3 times the design speed.

- Avoid abrupt reversals in alignment by providing enough room between curves for superelevation runoff or for spirals. See Section 9.4.A.4.d on transition curves and Figure 9-3 for instructions on locating the flat section between reversing curves with short intervening tangents.

- Broken-back curves (adjacent curves in the same direction with short intervening tangents) violate drivers' expectations. Drivers expect a curve in the opposite direction of the one they just negotiated. When broken-back curves are visible for some distance ahead, they present an unpleasing appearance, even with tangents as long as 400 meters. It is desirable to introduce a reverse curve between them to eliminate the broken-back effect. In some cases a single long curve or compound curve may replace the broken-back curve.

- Use compound curves cautiously because they can surprise the driver. They may be needed to eliminate excessive cuts or fills, encroachments into rivers, or broken-back curves, but avoid their use on open highway alignment. A single curve with minimal additional impact is always preferable to a compound curve.

  Since neither compound or broken-back curves are desirable, it is up to the designer's experience and judgment to determine which to use in an unavoidable situation.

- When compounding curves, the radius of the flatter curve should not be more than 1.5 times that of the sharper curve. If this is impractical, design a partial spiral or a curve of intermediate radius between the main curves. The rate of change of a partial connecting spiral should be equal to or less than the average of the normal spirals used on the curves. Intermediate connecting curves should have a length not less than the runoff length for the flatter main curve as obtained from the superelevation runoff tables (Green Book, pages 167 to 171).

  The arc length of the main curves of any compound curve should be a minimum of 1.5 times the design speed. This provides about 5 seconds of driving time on each curve.

- A single design speed should normally apply for the full length of the compound curve. This requires different superelevation rates, which must be transitioned from one rate to the other over the full length of the partial spiral or the full length of the connecting curve. If neither a partial spiral nor intermediate curve is used, the superelevation transition should take place over a minimum length of 30 meters. Half the transition length should be on each curve.

  After the alignment fits the controls of the highway location, reduce it to circular curves, transition spirals when required, and connecting tangents.

a. Circular Curves. When splines or freehand methods are used to determine the preliminary alignment, the following procedure will approximate the radius of circular curve.

- Select segments of the preliminary line which are uniform in curvature. Measure the long chord (C) and middle ordinate (M) of each alignment segment of uniform curvature.

- Determine the radius (R) of the circular curve using the equation:

$$R = \frac{M}{2} + \frac{C^2}{8M}$$

Select the curve closest to the calculated value.

b. Transition (Spiral) Curves. A transition curve allows for a gradual change in radius from infinity on the tangent to that of the circular curve so centrifugal force also develops gradually. Longer transition lengths can improve the aesthetic quality of the alignment. Spirals improve the appearance of a highway, reduce the lateral drift of vehicles entering curves, and simplify transitioning of superelevation at the ends of curves. It is FLHO policy to encourage the use of spirals for smoother transitions.

The minimum length of the spiral used to connect a circular curve to a tangent shall be the length required for superelevation runoff. A discussion on transition spirals begins on page 174 in the Green Book. The minimum superelevation runoff lengths are provided in Tables III-7 to III- 12 on pages 167 to 171 in the Green Book. The designer should be aware that many States have adopted transition lengths greater than the minimum AASHTO requirements so State criteria applies in these cases. It should also be noted that some States prefer not to use spiral curves.

c. Superelevation. The highway designer must consider design speed, maximum curvature, and superelevation in horizontal alignment design. These design elements are related by the laws of mechanics and involve friction factors, centrifugal force, gravity, etc.

Design speed is based on the terrain, traffic, and functional classification of the highway. Maximum superelevation considers the design speed and climatic conditions. Maximum curvature is a function of design speed and maximum superelevation. Pages 151 to 153 in the Green Book provides guidance on selection of maximum superelevation rates. Where spirals are used, the superelevation runoff is applied uniformly over the full length of the spiral.

Superelevation is not necessary on flat curves because the centrifugal force developed by vehicles even at high speeds is minimal. Design these curves using a normal tangent crown section. See page 166 in the Green Book for a discussion on the sharpest curve without superelevation.

On RRR projects, provide proper superelevation and transitions. When standard superelevation rates are impractical, the highest achievable rate applies, subject to approval through the design exception process. Where exceptions are necessary, speed studies should identify locations for speed and warning sign installations.

In addition to improving superelevation, consider flattening curves when accident data indicates that geometrics are a contributing factor.

Within the constraints imposed by adjacent development (curbs, sidewalks, and arterial streets) urban highways should be superelevated the same as rural highways.

d. Transition Sections. Tangent sections of roadways carry normal crown. Curved sections are superelevated. Transitions make a gradual change from one to the other. Superelevation runoff is the length of roadway used to transition from full superelevation on a curve to a flat section on the outside lane(s) on the adjoining tangent. Tangent runoff is the length of tangent required to transition from the above flat section to full crown. In IHDS, the tangent runoff distance is user defined. Under normal conditions the distance should match the rate of superelevation. A detailed discussion of runoff begins on page 175 in the Green Book.

Where the alignment consists of tangents connected by circular curves, generally the superelevation begins on tangent, and full superelevation is attained some distance into the curve.

Design practice is to place about two-thirds of the runoff on the tangent approach and one-third on the curve. With a short tangent distance between reversing curves, the runoff length may require up to one-half of the length on the curve and one-half on the tangent.

Give special attention to superelevation transition for broken-back curves. Figures 9-1 and 9-2 give guidance in providing an adequate transition between curves in a broken-back situation.

Figure 9-3 shows a method of checking templates for flat sections between reversing curves with a short tangent.

Many vehicles operate at speeds higher than the design speed on long tangents and flatter curves. These vehicles have to slow to the design speed in order to safely negotiate the sharpest curves. In areas of sharp curves, the radius and the superelevation of adjacent curves should limit the difference in design speed between the curves to a maximum of 20 km/h. If the maximum differential is exceeded, the plans shall include advance curve and advisory speed signs for the lower speed curves.

A method for determining superelevation rates for significant changes in curvature is detailed in the example in Table 9-3.

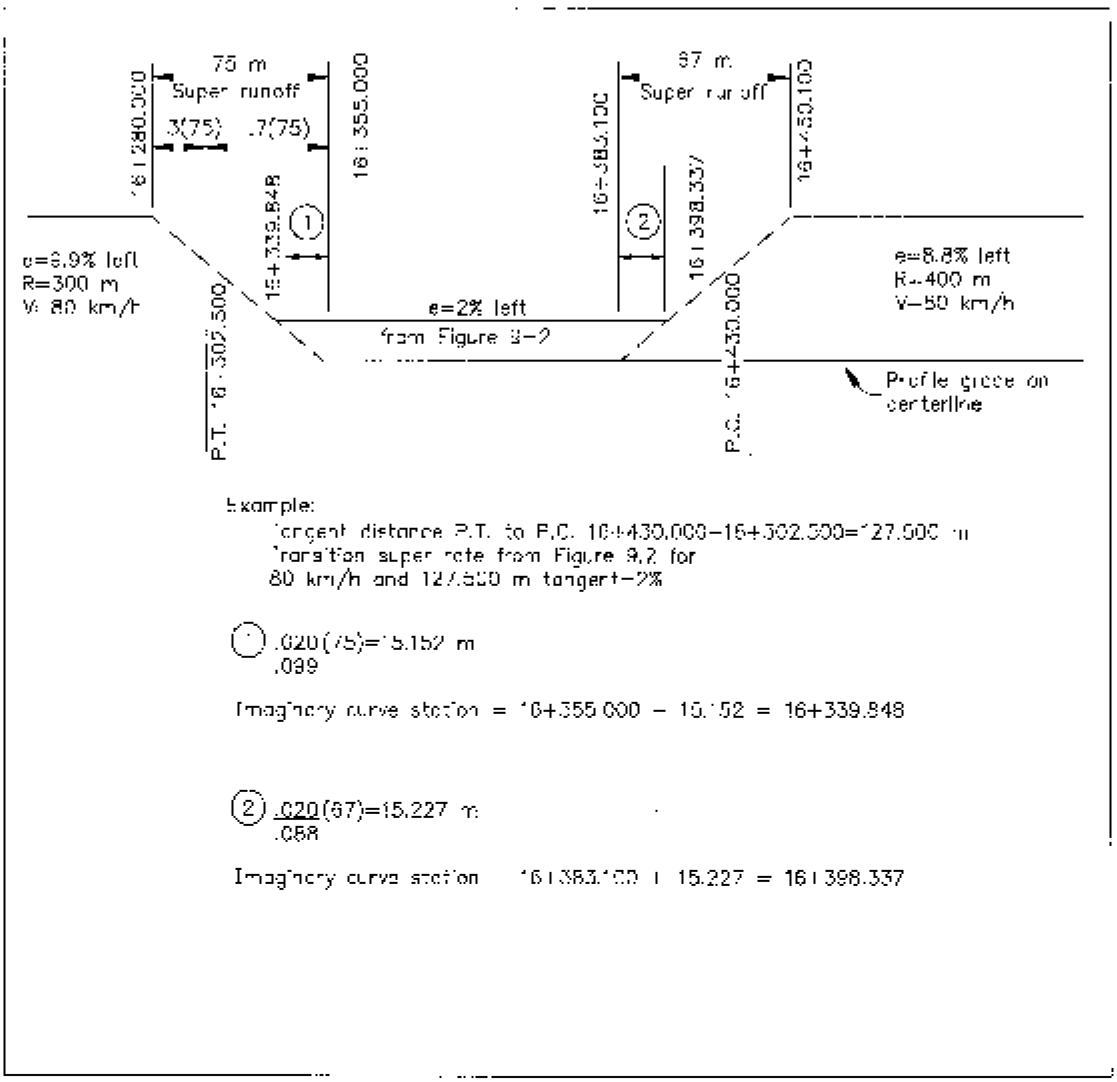


Figure 9-1 Superelevtion Transition on Short Tangents Between Broken-Back Curves

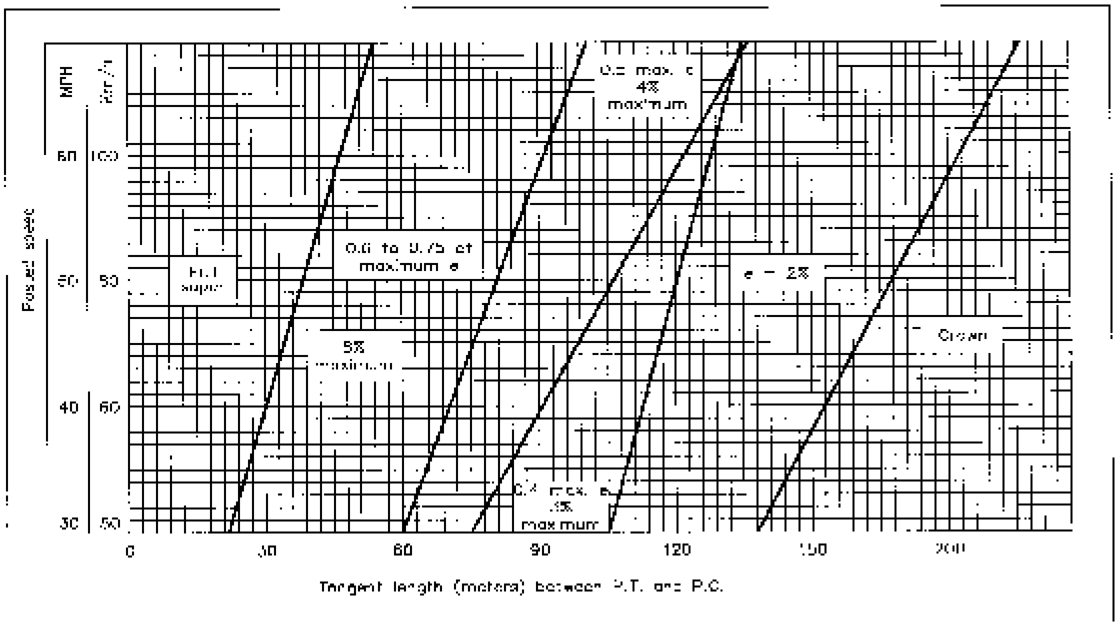


Figure 9-2
Superelevation Transitions for Broken-Back Curves

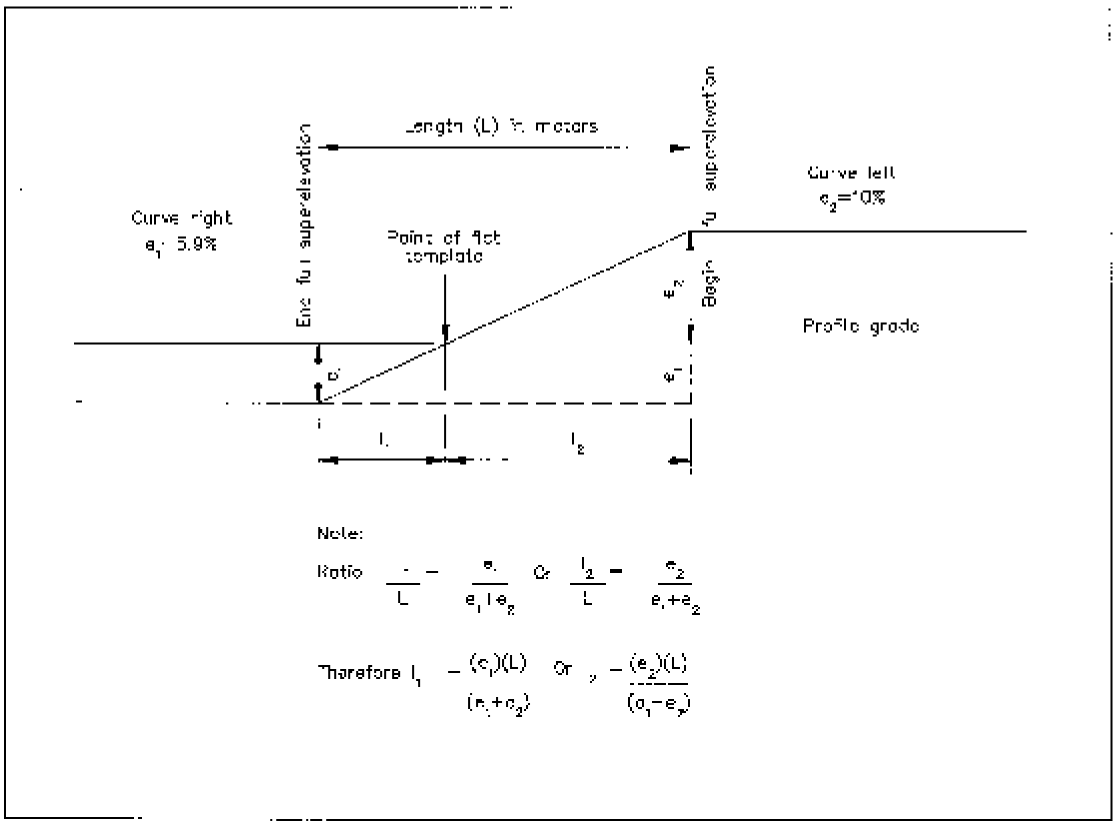


Figure 9-3
Determining Flat Sections Between Reversing Curves with Short Tangents

Example: A 20 km/h maximum differential in design speed is allowed between adjacent curves and between a curve and a long tangent. For a maximum radius curve with a 50 km/h design speed, flatter curves on either side could be superelevated for a 60 km/h design speed. A curve at the end of a long tangent with an expected operating speed of 100 km/h would be superelevated for a 80 km/h design speed. Tangents over 120 meters in length are considered long tangents.

Table 9-3 is an example of how to record design speeds for a project.

The following is a list of the sample design data entered into the table.

Given:

Basic design speed = 60 km/h.
e_{max} = 8%
Road alignment =
190 m tangent, 600 m radius curve right,
98 m tangent, 300 m radius curve left,
84 m tangent, 200 m radius curve right,
73 m tangent, 150 m radius curve left,
80 m tangent, 300 m radius curve right,
93 m tangent, 900 m radius curve left,
97 m tangent.

Table 9-3
Example Listing of a Determination of Superelevation Rates

Tangent / Curve Left/Right (meters)/(radius)	Safe Speed e_{max} 8% (km/h)	Adjusted Design Speed (km/h)	"e" for Adj. Design Speed (percent)	Run Off Length (meters)
	100	100		
190 m Tangent				
600 m Radius Curve Right	120	100	6.9	56
98 m Tangent				
300 m Radius Curve Left	90	80	7.6	55
84 m Tangent				
200 m Radius Curve Right	75	70	7.9	52
73 m Tangent				
150 m Radius Curve Left	67	60	7.8	47
80 m Tangent				
300 m Radius Curve Right	90	80	7.6	55
93 m Tangent				
900 m Radius Curve Left	145	100	5.2	56
97 m Tangent				

NOTE: Enter tangent length in meters and the curve radii in the first column. From Figure III-10 through Figure III-14,Design Superelevation Rates in the 1994 “Green Book”, determine the maximum safe speed at a superelevation rate of 8% for each curve and record in column 2. Now adjust each curves design speed for the maximum 20 km/h differential between curves. Start with the sharpest curve (the 150 and 200 m radius curves) and continue by increasing the design speeds accordingly on the adjacent curves. Leaving a long tangent, the process is reversed. Start with an estimated driving speed for the tangent and reduce the speed by 20 km/h for the adjacent curve. Record the runoff or spiral length actually used in the last column. These are helpful for future checking. Include the analysis in the design study.

If design speeds of horizontal curves are increased, the vertical curvature must meet the standards for these increased speeds. Where there is not enough runoff length between curves, redesign them to provide the runoff length or lower the design speed for one or both curves.

5. Vertical Alignment. Vertical alignment consists of a series of gradients connected by vertical curves. Applicable design controls include safety, topography, functional classification, design speed, horizontal alignment, construction cost, cultural development, drainage, vehicular characteristics, and aesthetics. The terms *vertical alignment, profile grade* and *grade line* are interchangeable.

The topography of the land has an influence on alignment. AASHTO separates topography into three classifications of terrain:

(1) Level or flat
(2) Rolling
(3) Mountainous

A description of these three types of terrain begins on page 226 in the Green Book.

Terrain classifications pertain to the general character of a specific route corridor. For example, routes in mountain valleys and mountain passes that have all the characteristics of level or rolling terrain should be classified as such. The terrain classification determines the maximum allowable grades in relation to design speed.

a. Vertical Alignment (Grade). Once the horizontal line is in the Interactive Highway Design System (IHDS), the designer should obtain a plot of the ground line and establish the vertical control points. Project the profile grade to fit these control points and the standards for percent of grade and vertical curve length. To produce a desirable vertical alignment, the designer should use the following guidelines:

- Use a smooth grade line with gradual changes, consistent with the type of highway and character of terrain. Avoid numerous breaks and short grade lengths.

- Avoid hidden dips. Hidden dips are hazardous on two-lane highways. They can hide approaching or slow moving vehicles or obstructions on the road ahead while deceiving the driver into believing that it is safe to pass or travel at high speed. Use long straight grades or introduce horizontal curves in conjunction with vertical curves to break up unsafe long tangents.

- Long steep grades affect traffic operation. If traffic volume is high, a slow moving vehicle lane or turnout requires study. On long downgrades, consider a truck escape ramp.

On some steep grades, especially on low speed roads, it is desirable to break a sustained grade by making it steeper at the bottom and flatter at the top. Short intervals of flatter grade permit high-powered vehicles to accelerate and pass underpowered vehicles.

- On switch-back curves, flatten the grade to compensate for slower speeds.

- Avoid broken-back grade lines. Two vertical curves in the same direction separated by short tangents is poor design practice particularly in sags where both curves are visible at the same time.

- Sag vertical curves at the ends of long tangents should be several times the length required for stopping sight distance to avoid the appearance of an abrupt change in grade.

- When at-grade intersections occur on roadways with moderate to steep grades, it is desirable to reduce the grade through the intersection.

- In swampy terrain and areas subject to overflow and irrigation, the low point of the subgrade should be at least 0.5 meters above the expected high water. For roads located along main streams and rivers, refer to Chapter 7 for the appropriate hydraulic controls.

b. Maximum Grade. The designer should know the functional classification of the project from the planning and programming process (see Chapter 2). Consider this data, pages 227-241 of the Green Book, and the type of topography to determine the maximum allowable grades in relation to design speed.

Example:

- Rural Area.
- Highway Functional Classification is Rural Collector.
- 60 km/h Design Speed.
- Rolling Terrain.

According to the Green Book (Table VI-3, maximum grades, page 463), the maximum grade for this example is 8 percent.

When analyzing maximum grades, note that superelevation transitions will increase the effective grade on the edge of the traveled way. This increase is significant particularly to trucks and recreational vehicles. To minimize this effect on long continuous runs of near maximum grades, the designer has two options:

(1) Flatten the grade throughout the curve.

(2) Carry profile grade on the right edge of the traveled way going upgrade.

This is especially important when the design contains climbing lanes or scenic pulloffs.

c. Minimum Grade. Flat and level grades on uncurbed pavements are not objectionable when the pavement is adequately crowned to drain the surface laterally.

A flat grade (0.00 percent) is acceptable in through-fill sections where the highway has sufficient crown. Minimum grades (0.5 percent) are applicable only for drainage of roadway ditches in cut sections, drainage of curb sections, and to ensure pavement drainage on superelevation transitions. This requirement particularly applies where flat grades on crest and sag verticals have substantial lengths that are essentially flat. It also applies where superelevation transitions introduce sags in the ditch or gutter line. Computer plots of the ditch or gutter profiles will highlight any drainage problems for correction as the design progresses.

See Section 9.4.A.7, Geometric Cross Section, for details on design of drainage.

d. Vertical Curves. Vertical curves provide a gradual change between tangent grades. (See Figure III-38 on page 281 in the Green Book.) For simplicity, the parabolic curve with an equivalent vertical axis centered on the vertical point of intersection (VPI) is common in roadway profile design. On certain occasions, critical clearance or other controls require the use of unsymmetrical vertical curves. Either situation is easily handled in IHDS.

Figure 9-7 shows a method of determining the low point on a vertical curve when the grades are unequal. This will identify locations for the installation of pipe culverts, catch basins, or other such drainage facilities.

Figure 9-8 shows a way to eliminate a series of broken-back curves.

e. Critical Lengths of Grade. Maximum grade, in itself, is not a complete design control. The length of a particular grade in relation to desirable vehicle operation requires analysis. The critical length of grade is the maximum length of a designated upgrade on which a loaded truck can operate without an unreasonable reduction in speed. Studies show that regardless of the average speed on the highway, the greater a vehicle deviates from this average speed, the greater its chances of becoming involved in an accident. A 15 km/h reduction in truck speed determines critical lengths of grade. The Green Book has a discussion on this subject and recommendations for different conditions starting on page 234.

6. Sight Distance. Sight distance is the continuous length of roadway ahead that is visible to the driver. Of prime importance is the arrangement of geometric elements so that adequate sight distance exists for safe and efficient operation.

On horizontal curves the sight distance available depends on the radius of the curve and the location of obstacles to the line of sight across the inside of the curves. Obstacles such as cut slopes, tall grass on cut slopes, trees and shrubs, farm crops, buildings, bridge abutments and walls, bridge railing, and guardrail may limit the sight distance. To provide for safe operation, horizontal sight distance must equal or exceed the safe stopping distance for the selected design speed. These distances are listed on page 120, Table III-1 in the Green Book. To obtain the required sight distance, the designer may flatten curves or provide for the removal or relocation of obstacles.

Crest vertical curves may also limit the horizontal sight distance, especially in cut sections. The designer must take this into consideration when crest vertical curves coincide with horizontal curves and there is a substantial change in grade. This case may require a longer vertical curve, flatter horizontal curve, wider and deeper ditch, additional clear area beyond the ditch or shoulder, or a combination of these.

Three sight distances are considered in design:

- Stopping Sight Distance (SSD).
- Decision Sight Distance (DSD).
- Passing Sight Distance (PSD).

Minimum stopping sight and passing sight distances directly relate to the design speed of the road.

Sight distances for at-grade intersections, including railroad crossings and private road approaches, are a separate topic covered under Intersections at Grade, Section 9.4.C.

a. Stopping Sight Distance. A roadway design requires minimum stopping sight distance at all points, and where economically justified more liberal stopping distances are desirable.

Minimum stopping distance is the least distance required to bring a vehicle to a stop under prevailing vehicle and climatic conditions. It depends on the initial speed of the vehicle, the perception and reaction time of the driver, and the coefficient of friction between tires and roadway for the prevailing conditions. The coefficient of friction is much lower for wet pavements; therefore, wet rather than dry pavement conditions apply for establishing minimum values.

Design controls for SSD are in the Green book, pages 117 to 125, 219, 223, and 283 to 293. Also see Tables 9-4 and 9-5 in this chapter.

b. Decision Sight Distance. Decision sight distance is the length of road a driver needs to receive and interpret information, select an appropriate speed and path, and begin and complete an action in a safe maneuver. This distance is greater than the distance needed to simply bring a vehicle to a stop, and provides for a reasonable continuity of traffic flow.

If possible, provide decision sight distance in advance of any feature requiring increased driver awareness and action. This includes intersections, lane changes, congested areas, pedestrian crossings, or other features. When decision sight distance is unavailable and relocation of the feature is not possible, the designer shall provide suitable traffic control devices.

See design controls for DSD in the Green Book, pages 126 to 127. Also see Table 9-4 in this Chapter.

c. Passing Sight Distance. Passing sight distance is generally applicable only to two lane, two-way roads. It is important for reasons of safety and service to provide as many passing opportunities as possible in each section of road. The designer should try to ensure there are no long sections where passing is not possible. The available passing sight distance has considerable influence on the average speed of traffic, particularly when a road is operating near capacity.

The economic effects of reduced speed are indeterminate, but there is no doubt that road users benefit considerably when operating at or near design speeds with minimal traffic interference. The designer should consider these economic effects when setting horizontal and vertical alignments.

Passing sight distance seldom applies on multilane roads. However, passing sight distance at the end of truck-climbing and passing lanes where traffic must merge requires consideration.

The designer should increase the sight distance in areas where vehicles operate above the design speed.

Standard minimum passing distances for all classes of two-lane roads are given in the Green Book, pages 128 to 136.

Design minimum passing sight distance requirements should not be confused with values provided in the MUTCD for determining no-passing zone pavement striping (MUTCD 3B-5).

Table 9-4
Sight Distance Standards[1]

Design Speed km/h	Assumed Speed km/h	Sight Distance (meters)				
		Stopping (SSD)		Decision (DSD)		Passing (PSD)
		Minimum	Desirable	Maneuver C	Maneuver E	Minimum[2]
30	30-30	29.6	29.6			217
40	40-40	44.4	44.4			285
50	47-50	57.4	62.8	145	200	345
60	55-60	74.3	84.6	175	235	407
70	63-70	94.1	110.8	200	275	482
80	70-80	112.8	139.4	230	315	541
90	77-90	131.2	168.7	275	360	605
100	85-100	157.0	205.0	315	405	670
110	91-110	179.5	246.4	335	435	728
120	98-120	202.9	285.6	375	470	792

NOTE:
[1]Based on passenger cars operating on wet pavement on grades <3%. For grades $\geq$3%, the values for SSD should be adjusted to the lengths shown in Table 9-5. Because truck and bus drivers are higher above the highway surface than car drivers and can see the road further ahead, the values in the table are considered adequate for trucks and buses.

[2]The PSD values shown are minimum to allow one vehicle to pass and are based on a speed differential of 15 km/h between the passing and passed vehicle. Longer lengths are desirable to allow more vehicles to pass.

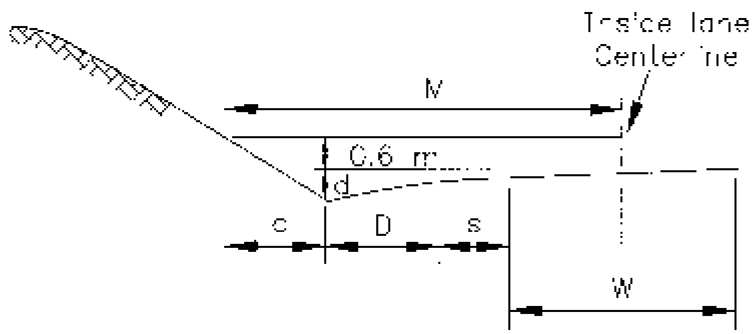
Table 9-5
Effect of Grade on Stopping Sight Distance

Design Speed (km/h)	Stopping Sight Distance (m) for Downgrades:			Assumed Speed for Condition (km/h)	Stopping Sight Distance (m) for Upgrades:		
	3%	**6%**	**9%**		**3%**	**6%**	**9%**
30	30.4	31.2	32.2	30	29.0	28.5	28.0
40	45.7	47.5	49.5	40	43.2	42.1	41.2
50	65.5	68.6	72.6	47	55.5	53.8	52.4
60	88.9	94.2	100.8	55	71.3	68.7	66.6
70	117.5	125.8	136.3	63	89.7	85.9	82.8
80	148.8	160.5	175.5	70	107.1	102.2	98.1
90	180.6	195.4	214.4	77	124.2	118.8	113.4
100	220.8	240.6	256.9	85	147.9	140.3	133.9
110	267.0	292.9	327.1	91	168.4	159.1	151.3
120	310.1	341.0	381.7	98	190.0	179.2	170.2

d. Restrictions. Sight distance on horizontal curves is proportional to the radius of the curve. Manmade objects or naturally occurring conditions can restrict the line of sight across the inside of a curve. Typically, vegetation or a cut slope restricts sight distance.

Provide adequate sight distance on horizontal curves by selecting the proper curve radius and arranging for the removal or relocation of obstacles.

Stopping sight distance (SSD) for the design speed of the highway must be provided on all horizontal curves as a minimum. The SSD is measured from the eye height of a passenger car driver, 1070 millimeters above the center of the inside lane, to an object 150 millimeters high on the center of the inside lane on the highway ahead. If the grade and superelevation are uniform throughout the SSD, then the midpoint on the line of sight is (1070+150)/2 = 610 millimeters above the center of the inside lane. This dimension determines the offset (M) on a cut slope at the midpoint of the SSD. See Figure 9-5.



Offset (M) = c + D + s + 0.5W

Where:

c= the drop (c) from the center of the inside lane to the bottom of the ditch plus 0.6 meter multiplied by the cut slope ratio.

D= the total ditch width from bottom of ditch to edge of shoulder.

s= the shoulder width

W= width of the inside lane

Note: When vegetation is expected to grow on the cut slope, the drop (d) should be reduced by the estimated depth of the vegetation. On crest vertical curves, (c) should be reduced appropriately. On sag vertical curves, (d) should be increased.

When vegetation is not controlled on the cut slope, reduce the c distance to zero.

Figure 9-5 Lateral Clearance for Stopping Sight Distance

Checking the computed offset (M) against Figure 9-6A or 9-6B will determine if the design provides adequate SSD for the design speed and the radius of curve. The designer must provide at least the minimum SSD or reduce the design speed for a portion of the highway. When reduced speeds are used, permanent advance warning signs are mandatory.

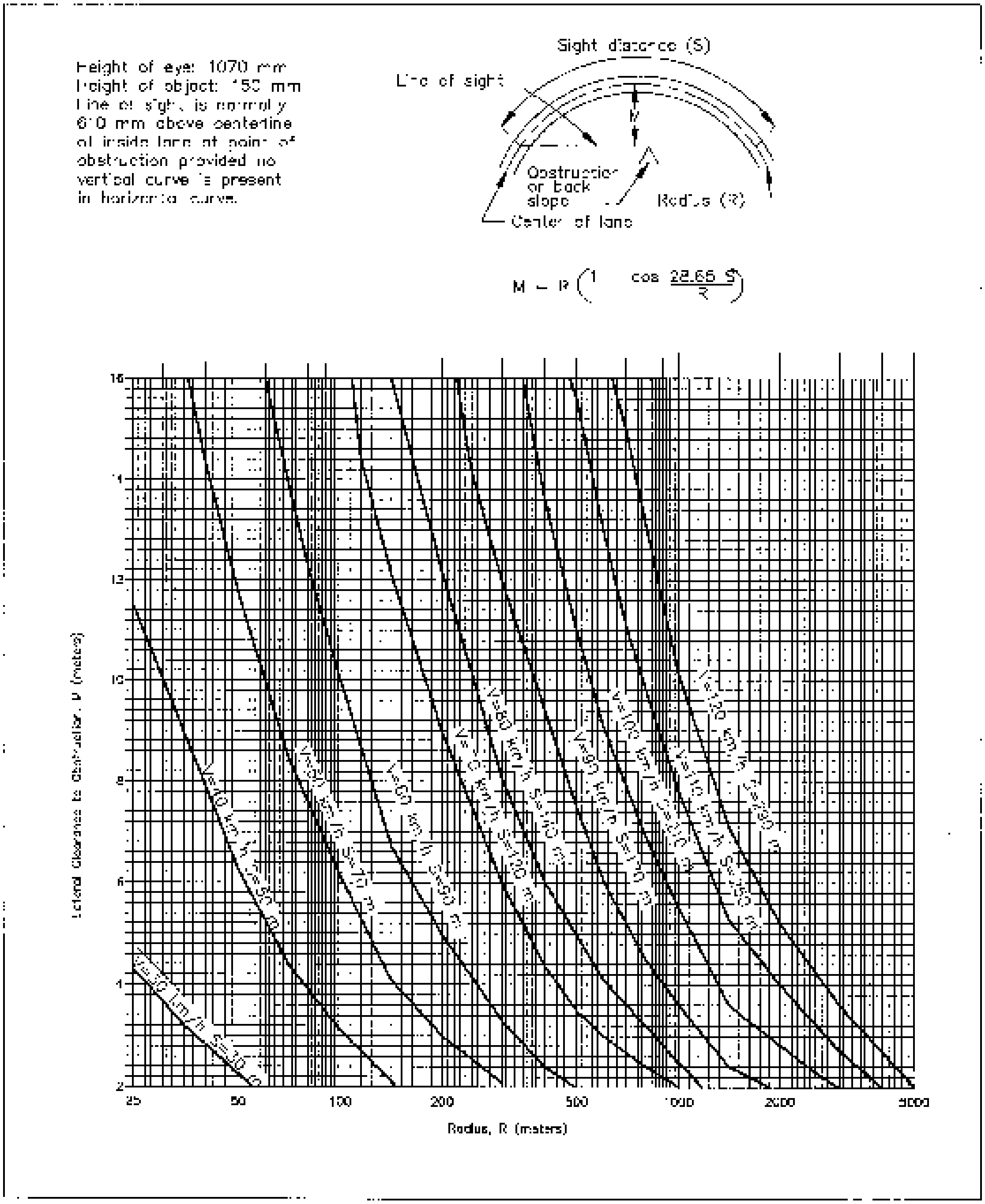


Figure 9-6A
Desirable Horizontal Stopping Sight Distance

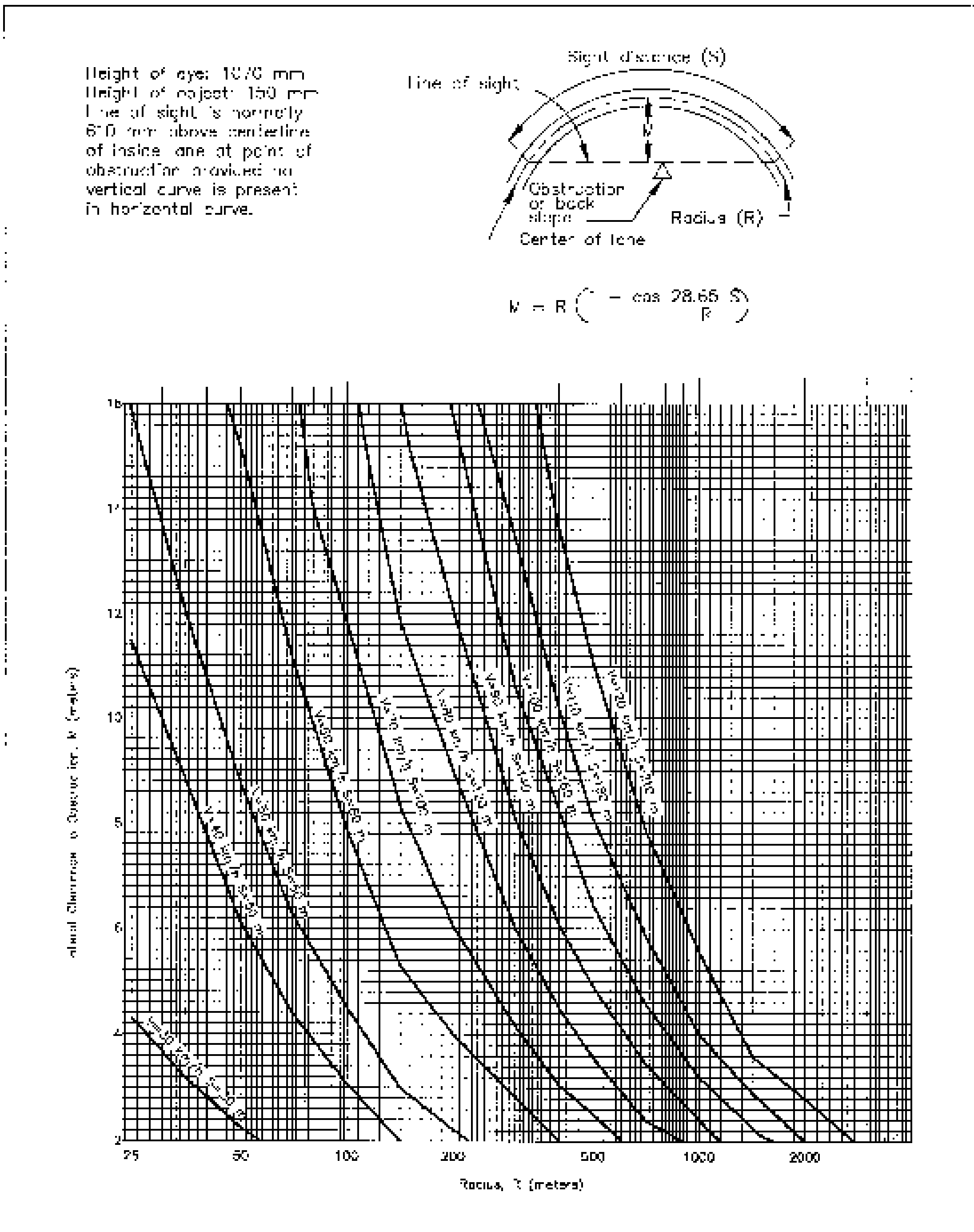
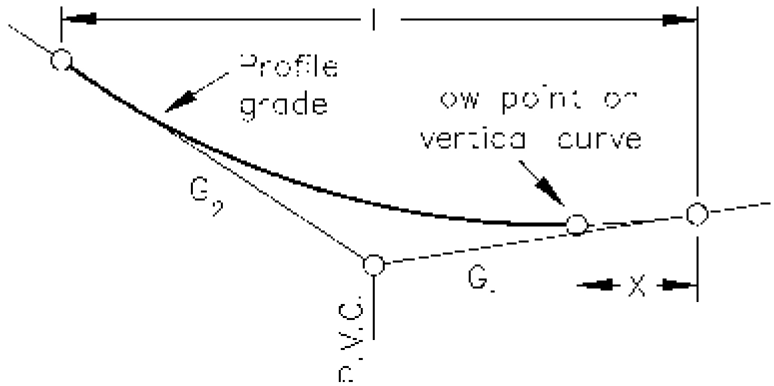


Figure 9-6B
Minimum Horizontal Stopping Sight Distance



Where:

G_2=Steeper grade in percent

G_1=Flatter grade in percent

L=Length of vertical curve in meters

$X = \frac{G_1(L)}{G_2+G_1}$ Distance in meters from end of vertical curve of flatter grade to low point on vertical curve.

Example:

Let G_2=4% and G_1=2%

L=300 meters

$$\text{therefore } X = \frac{(+2)(300)}{4+2} = \frac{600}{6} = 100 \text{ m}$$

Figure 9-7 Determining Low Points on Vertical Curves With Unequal Grades

9.4.A. Geometric Design. (continued)

The minimum lengths of vertical curves used in design are determined by the following formula:

$$L = AK$$

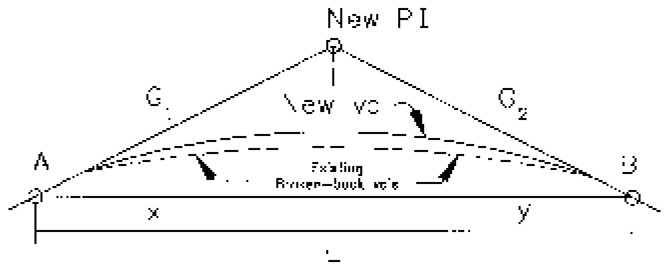
Where:

L = Minimum length of vertical curve in meters. (Round up to even tens, fifties, or hundreds.)

A = Algebraic difference in grade in percent.

K = Rate of change of grade (a constant value for a particular design speed and type of sight distance). Obtain value from Table 9-6.

NOTE: For small changes in grade (A) or for small values of (K), the computed lengths of vertical curves may be very short. For these conditions, use the minimum lengths specified in Table 9-6 instead of the calculated length, provided it is longer. When practical, it is desirable to design vertical curves of 150 meters or more in length, in order to create a pleasing appearance.



VC=vertical curve

To determine the station and elevation of a new PI by extending existing grades to intersection:

1. Select a random even station for point A and determine the elevation for it from the old grade PI. Elevation of Point B=Elevation of Point A.

2. Determine the station of Point B from the old grade PI.

3. Distance L equals difference in stations between A and B in meters.

G_1=Ascending grade in percent

G_2=Descending grade in percent

$$x = \frac{G_2 L}{G_1 + G_2}$$

$$y = L - x$$

$$\text{Elevation of new PI} = \text{Elevation point A} + \frac{G_1 x}{100}$$

$$= \text{Elevation point B} + \frac{G_2 y}{100}$$

Figure 9-8 Eliminating Broken-Back Vertical Curves

Table 9-6
(K) Values for Determining Lengths of Vertical Curves

Design Speed km/h	Crest Vertical Curves					Sag Vertical Curves		Minimum Lengths of Crest or Sag Vertical Curves (m)
	Based On Stopping Sight Distance		Based On Decision Sight Distance		Based On Passing Sight Distance	Based On Stopping Sight Distance		
	K Minimum	K Desirable	K Minimum	K Desirable	K Minimum	K Minimum	K Desirable	
30	3	3			50	4	4	18
40	5	5			90	8	8	24
50	9	10	52	99	130	11	12	30
60	14	18	76	137	180	15	18	36
70	22	31	99	187	250	20	25	42
80	32	49	131	246	310	25	32	48
90	43	71	187	321	390	30	40	56
100	62	105	246	406	480	37	51	60
110	80	151	277	468	570	43	62	66
120	102	202	348	547	670	50	73	72

Note: The minimum PSD shown in Table 9-6 is significantly less than shown in Table 9-4. The PSD in Table 9-4 assumes the passed vehicle is operating at or near the design speed. The distances in Table 9-6 allow opportunities to pass slower moving vehicles.

7. Geometric Cross Section. The highway cross section is defined as the finished or the proposed finished section between construction limits. (See Figure 9-9.)

Roadway section configurations depend on functional classification criteria. The criteria show the cross-section characteristics of the roadway section based on the Green Book, State developed and approved classifications, NPS standards, or other applicable agency standards.

Most Federal roads have an asphalt concrete surface. Some highways are graded under several contracts and the ultimate pavement is placed when a long section of the route is ready. Under the grading contracts, the base courses may be placed and then surfaced with an interim asphalt surface treatment. Occasionally, a roadway with gravel surfacing is requested by the client agency.

a. Pavement Structure. The pavement structure refers to the material and depth of base and pavement placed on the finished subgrade. The pavement structure design should use the minimum depth of material necessary to carry the projected loads over the design life of the pavement. The design shall also provide for a smooth-riding, skid-resistant surface.

A normal pavement structure design has a 10 to 20-year life. The geotechnical staff bases the design on soil samples and the predicted volume and type of traffic using the highway during the design life. The pavement structure thickness varies with climatic conditions and the type and strength of subgrade material used (usually in the top 300 to 600 millimeters of subgrade).

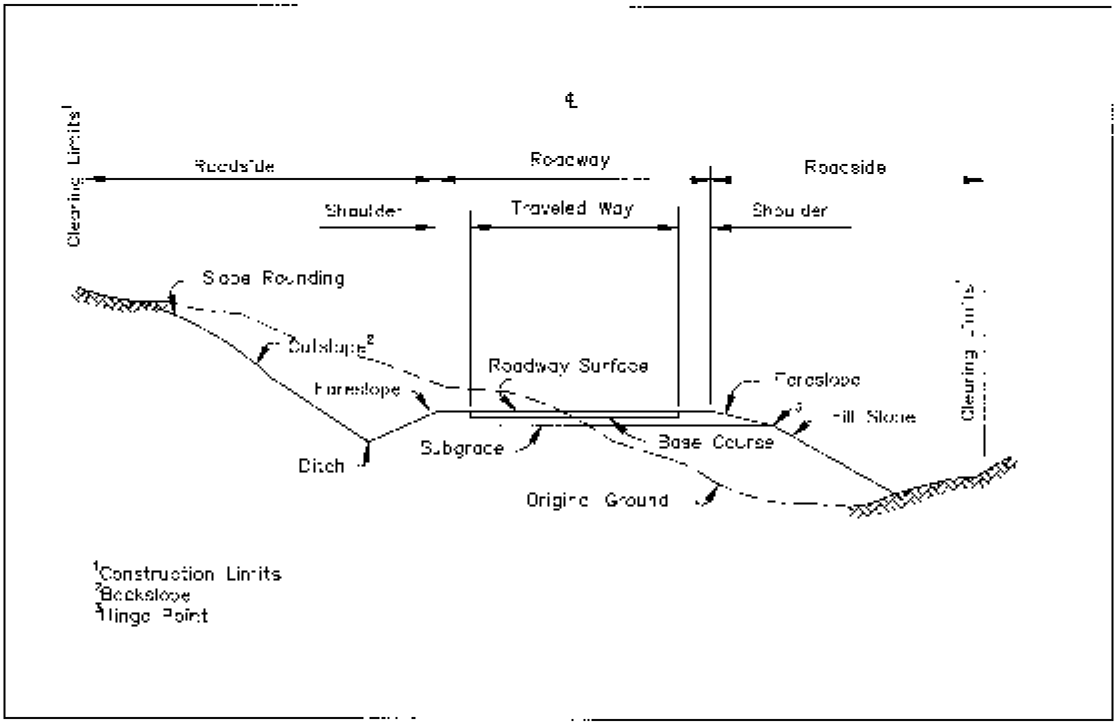


Figure 9-9
Typical Road Cross Section Elements

Generally, free-draining, high-strength materials require less thickness than low strength materials containing clay or silt. See Chapter 6 for the design of structural overlays including minimum thicknesses.

At the beginning of a design, the depth of the pavement structure may be arrived at by an assumption based on experience or by comparing with the depths used on an adjacent project. Following a geotechnical investigation, the designer will adjust the assumed depth accordingly. The geotechnical investigation usually takes place after a line and grade have been established.

For RRR projects, the riding quality of an asphalt surface may be improved by providing a leveling course. This additional depth may increase the pavement structure capabilities and merits consideration in the final pavement design when leveling is relatively uniform over the length of the project. If a field review of the project is not practical, the designer should increase asphalt concrete pavement quantities by 20 percent for use as leveling material. See Chapter 6 for additional details on the design of asphalt and concrete pavements.

b. Profile Grade Location and Cross Slope. The standard location of profile grade on the highway cross section is at centerline or low side of the superelevated section for all two-lane highways.

The cross slope on tangents on paved highways shall be from 1.5 to 2.0 percent.

Normally, the cross slopes on gravel surfaced roads shall be 3 to 4 percent.

The shoulder cross slope should be the same as the adjacent traffic lane. With curb sections or when the shoulder surface is an asphalt surface treatment, aggregate, or turf, increasing the slope helps to facilitate drainage. In these cases, consider cross slopes of 4 to 6 percent. On super elevated curves, the roll-over in cross slope on the outside of the curve should not exceed 8 percent.

The cross slope on the tops of base courses and the subgrade is usually the same as on the finished pavement. In some cases it is desirable to have a reverse slope on the subgrade (on the high side of curves and outside the edge of the pavement) to prevent moisture from entering the base.

c. Lane and Shoulder Widths. The Green Book and other agency standards show lane and shoulder widths for each functional classification for various design speeds and traffic volume ranges.

When the percentage of trucks or recreational vehicles is high in comparison to the ADT, consider increasing lane widths.

d. Foreslopes. Foreslopes ensure the stability of the roadway and provide a reasonable opportunity for recovery of an out-of-control vehicle. The foreslope, the slope from the edge of the surfaced shoulder to the edge of the subgrade shoulder, should not be steeper than the slope ratios shown in Table 9-7, unless guardrail is placed (Detail designs should be in accordance with the *Roadside Design Guide*, AASHTO, 1996).

The slope from the edge of the subgrade shoulder to the bottom of the ditch should normally be an extension of the foreslope.

Table 9-7
Foreslope Ratios

Guidelines for Foreslopes Including Ditch Sections

Design Volume (ADT)		**Design Speed (km/h)** 30	40	50	60	70	80	90	100	110
Less than 250		1:3*	1:3*	1:3*	1:3*	1:3*	1:3*	1:4	1:4	1:5
250 to 500		1:3*	1:3*	1:3*	1:3*	1:4	1:4	1:4	1:4	1:5
501 to 1000		1:3*	1:3*	1:3*	1:3*	1:4	1:4	1:5	1:5	1:5
1001 to 3000	1:3*	1:3*	1:3*	1:4	1:4	1:4	1:5	1:5	1:6	
Greater than 3000		1:4	1:4	1:4	1:4	1:5	1:5	1:6	1:6	1:6

*Slopes steeper than 1:4 are traversable but are not considered recoverable and should be avoided.

On RRR projects, the proposed work on the roadway may affect the foreslopes from the edge of pavement to the hinge point of the fill slope and ditch foreslopes.

The following points should also be noted:

- When the existing roadway geometrics are retained and the foreslopes are steeper than 1:4, reshaping to provide a flatter foreslope is desirable.

- There are cases where the roadbed width will not accommodate foreslopes of 1:3 or flatter. There also may be restrictions on filling of ditches to provide width or widening of embankments. When this occurs, consider strengthening the existing pavement structure through a recycling-in-place process rather than overlaying the project. A narrower pavement width to maintain a 1:3 foreslope and prevent an undesirable edge drop-off is also a reasonable solution.

- It is desirable to flatten crossroad/road approach foreslopes to 1:10. Provide at least a 1:4 minimum slope. Move the crossroad/road approach drainage away from the mainline to maintain the integrity of the clear zone and reduce the length of pipe required.

e. Roadway Ditches. The ditch cross section must be adequate to accommodate drainage of the pavement and cutslope. Chapter 7 covers the details of hydraulic design.

Ditches should have a streamlined cross section for safety (Chapter 8) and ease of maintenance. Wide ditch bottoms are used in rock fallout areas as well as in projects designed with side borrow.

Generally, roadway ditches have a "v" shape formed by the foreslope from the subgrade shoulder and cut slope. The depth of the ditch is dependent on hydraulic needs. It should normally be from 150 to 300 millimeters below subgrade for safety and maintenance purposes. When hydraulic needs dictate ditches of greater capacity, a flat bottom ditch takes precedence over deepening the v-ditch.

The designer should obtain computer plots of the roadway ditch profiles to check for sags in the ditch line. These profiles will show where the installation of culverts or the construction of special ditch grades will eliminate ponding.

At the ends of cuts, it is normal to widen ditches for rounding purposes as shown in Figure 9-10. Using

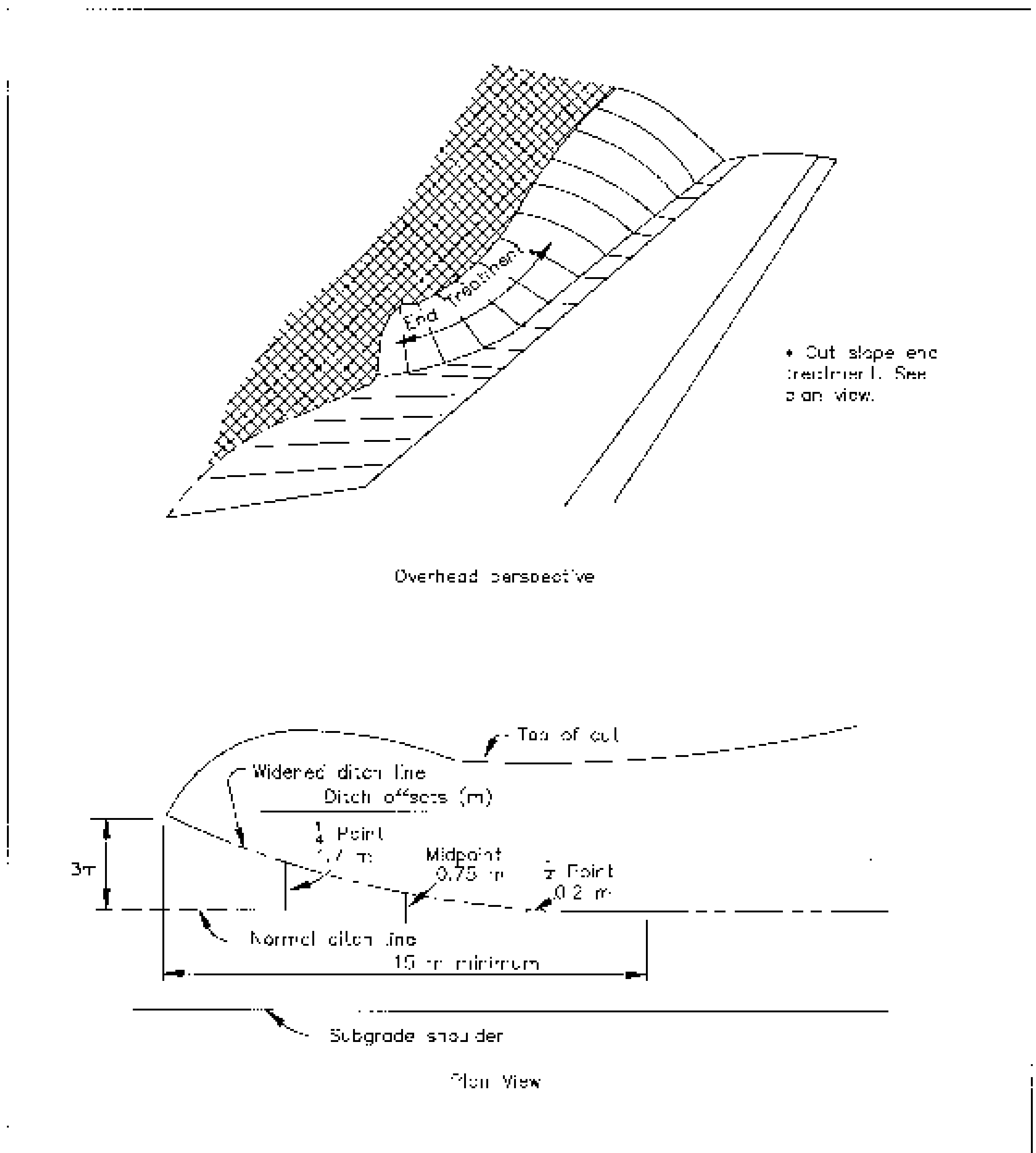


Figure 9-10
Typical Cut Slope End Treatment

the special ditch grade criteria files in IHDS will accomplish this objective.

f. Cut and Fill Slopes. The design of cut and fill slopes is a compromise between aesthetics, safety, stability, and economics. Generally, low cuts and fills are economical to construct on relatively flat slopes and will enhance aesthetics, safety, and maintenance. Slopes 1:3 are generally traversable by a vehicle that has run off the road but do not provide for vehicle recovery. Slopes 1:3 and flatter are also traversable by self-propelled mowers, and should be used at locations where the grass will be regularly cut. High cuts and fills normally have steeper slopes.

Cuts have a high visual impact, therefore, the design of cut slopes requires careful consideration. In some cases, it is desirable to use the same slope throughout the cut, while in other situations a constant distance to the catch point stake and a continuously varying slope may be appropriate.

In steep terrain, the slopes may be varied slightly from standard slopes in order to better fit the topography or eliminate high "sliver" cuts or fills. Transition slopes between common material and rock require special consideration. Blend the ends of cut slopes into the natural terrain by rounding, flattening, or otherwise shaping the ground line.

Transition fill slopes from the main portion of the fill into the cut section. Transitions between flat and steep slopes should be sufficiently long to provide a pleasing appearance. A transition from a 1:4 slope to a 1:1.5 slope may require a distance of 50 meters or more to appear natural.

Table 9-8 lists commonly used slopes for cuts and fills in earth materials. Use this table as a guide, along with the recommended slopes in the geotechnical report, to design the slopes on the project. All fill slopes steeper than 1:4 should be evaluated for safety. (See Chapter 8.)

Geotechnical reports may not be available for the project when beginning a design. If this is the case, design cut and fill slopes based on available survey or field review data. When a geotechnical report becomes available, the designer must review the slopes initially used and make any necessary adjustments in the earthwork design.

Table 9-8
Desirable and Maximum Slopes

Cut and Fill Slope Ratios for Soil Materials

Height (meters)	Slope Type	Flat Desirable	Flat Maximum	Rolling Desirable	Rolling Maximum	Mountainous Desirable	Mountainous Maximum
0-1	Cut	1:6	1:4	1:6	1:4	1:6	1:3
	Fill	1:6	1:4	1:6	1:4	1:6	1:4
1-3	Cut	1:4	1:3	1:3	1:2	1:3	1:2
	Fill	1:4	1:4	1:4	1:4	1:3	1:3
3-4.5	Cut	1:3	1:2	1:3	1:2	1:3	1:2
	Fill	1:4	1:3	1:4	1:3	1:3	1:1.5
4.5-6	Cut	1:3	1:2	1:2	1:2	1:2	1:1.5
	Fill	1:3	1:2	1:3	1:2	1:2	1:1.5
Over 6	Cut	1:2	1:1.5	1:2	1:1.5	1:2	1:1.5
	Fill	1:3	1:2	1:3	1:1.5	1:2	1:1.5

NOTE: Cut and fill slopes steeper than 1:2 should be avoided in clay or silty soils subject to erosion. Fill slopes steeper than 1:1.5 may be used in critically tight areas with geotechnical guidance when the fill material is composed of quality rock.

g. Rock Cut Slopes. Generally, rock slopes vary from near vertical to 2:1, depending on the type and quality of rock, joint patterns, fractures, cross bedding, etc. Rock slopes dipping toward the roadway may require flatter slopes.

High cuts, particularly in weathered or weak rock, may require fallout ditches for stability and safety. A fallout ditch at the bottom of high rock cuts keeps falling rock from encroaching on the highway. A geotechnical investigation will determine the need for fallout ditches, their width, and necessary configuration.

When soil or highly weathered rock overlays the solid rock, overburden benches at the top of the solid rock may be desirable. The overburden slope should range from 1.33:1 to 1:2, depending on the type and depth of overburden and the steepness of the topography. When the rock surface is known, compound slopes work very well.

From a safety viewpoint, rock cuts should be vertical or nearly vertical if the rock will stand on these slopes. Under these conditions, falling rocks seldom roll once they hit the ditch. Rock cuts on the inside of curves designed on 5:1 or flatter slopes prevent the appearance of an overhang to drivers.

Figures 9-11 and 9-12 provide guidance for designing rock cuts and fallout ditches. However, the final design shall rely on the recommendations in the geotechnical report. Typical sections for rock cuts should be shown on the plans.

The normal rockfall protection is provided by the typical V-ditch with the minimum width shown in Figure 9-11. Rock slopes higher than 10 meters from shoulder grade may require wider fallout ditches and the geotechnical staff should be consulted. Cuts less than 6 meters in height generally do not require a fallout ditch.

The added rock protection features shown in Figures 9-11 and 9-12 may be applicable on higher volume highways experiencing falling rock. The geotechnical unit should recommend or approve these features before inclusion in a project.

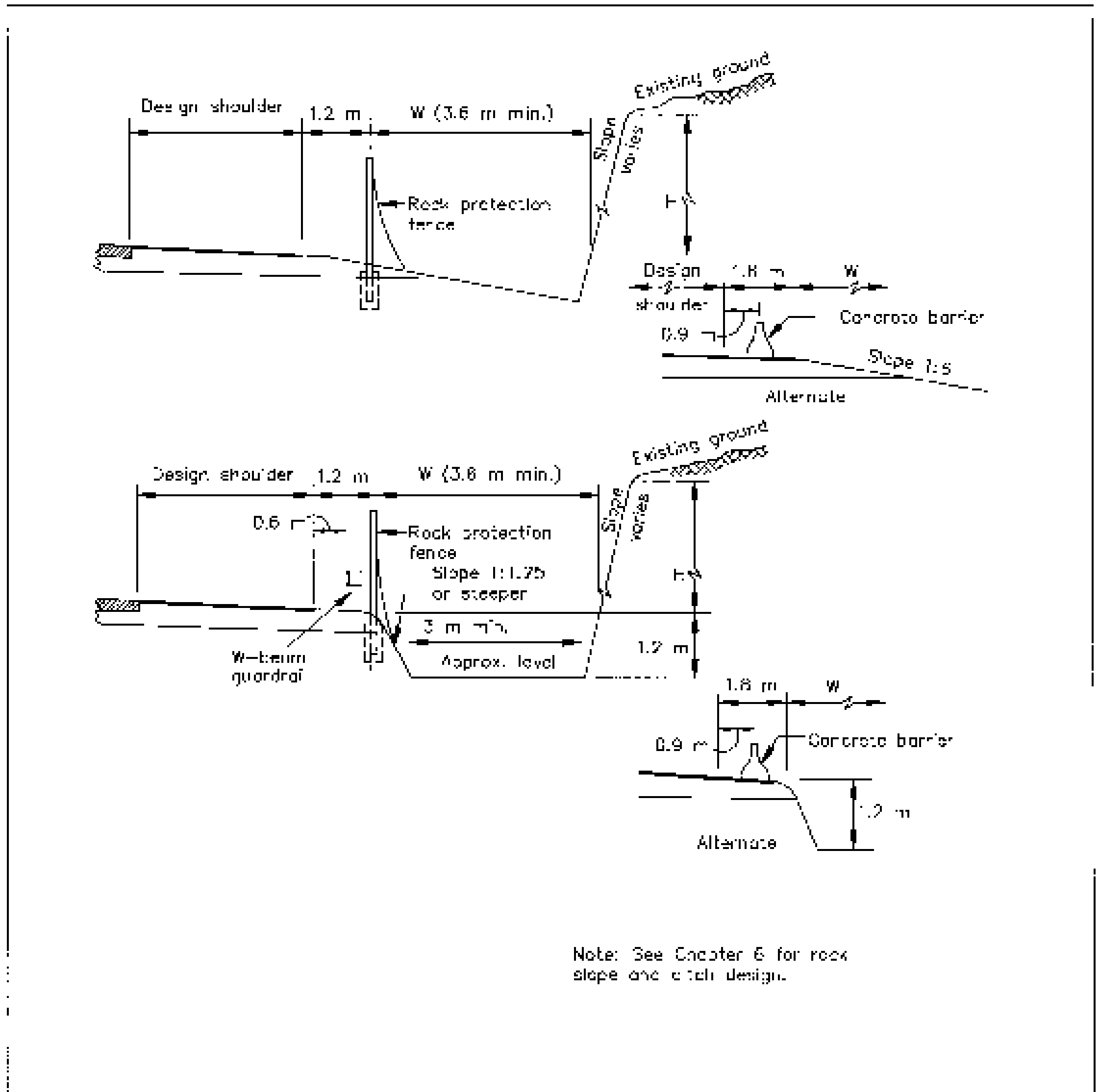


Figure 9-11
Falling Rock Control

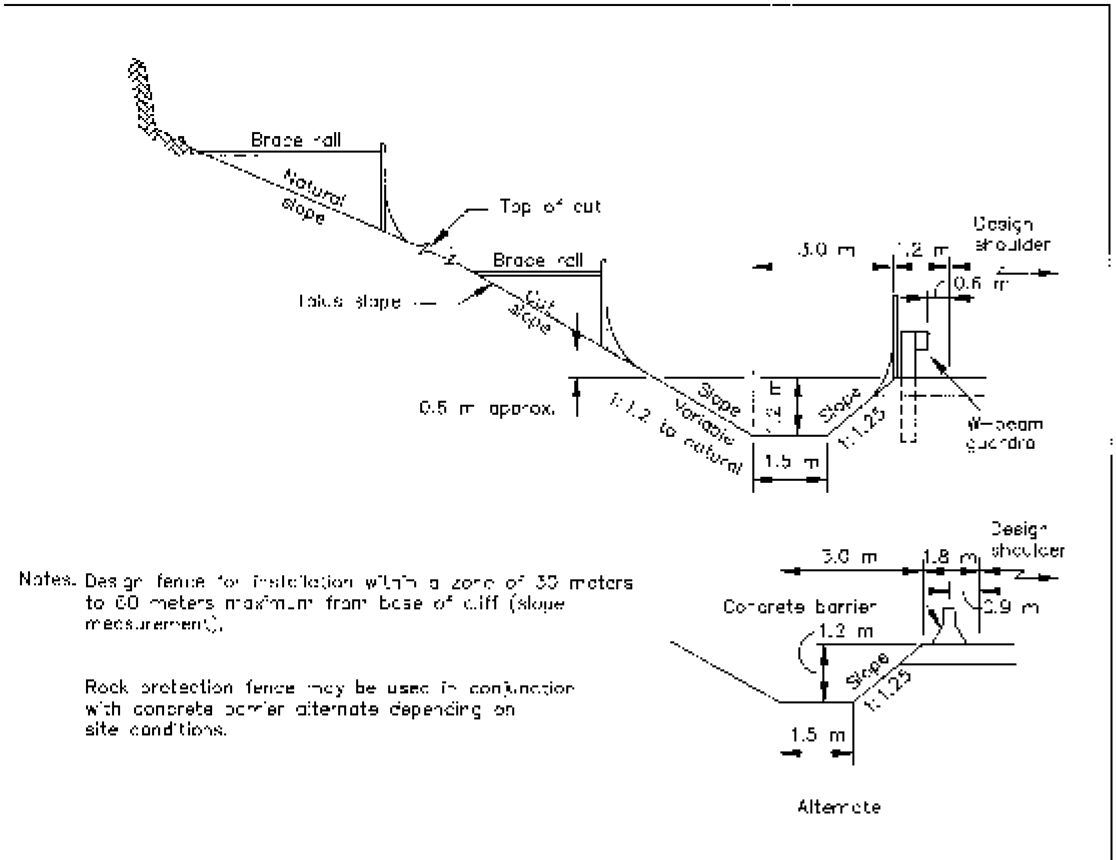
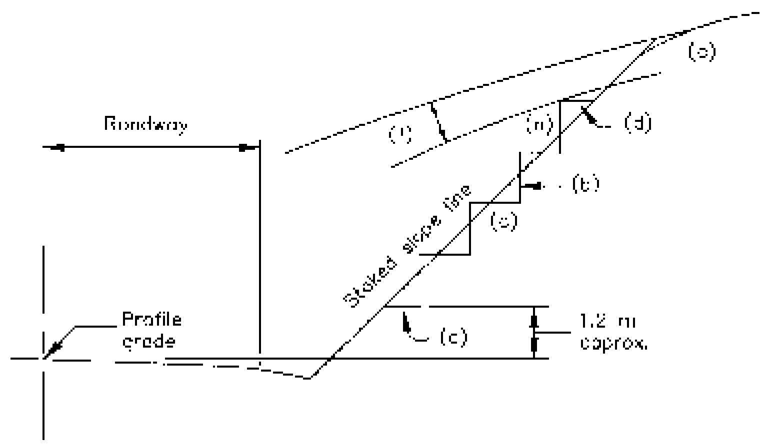


Figure 9-12
Rolling Rock Control

h. Serrated Slopes. Serrated slopes are a series of small steps in soft rippable rock cuts having slope ratios between 1.3:1 and 1:2. The steps allow weathering and decomposing rock to accumulate to provide a growing medium for plants. The flat steps also retain moisture for use by the growing plants. When using serrated slopes, take into consideration local environmental conditions, soil, and plant growth potential. Figure 9-13 shows a typical section of a serrated slope.

Include a drawing in the plans showing step tread and rise dimensions. Generally, the step rise varies from 0.5 meters for easily ripped rock to 1.5 meters for harder rippable rock. The step tread width is equal to the rise multiplied by the cut slope ratio.



Notes:
(a) 1:0.75 maximum slope.
(b) Step rise variable from 0.5 to 1.5 meters.
(c) Step tread = (a)(b)
(d) Ending step width = 0.5 (c).
(e) Normal slope rounding.
(f) Overburden area—variable slope ratio.

Figure 9-13
Serrated Slopes

I. Slope Rounding and Clearing Limits. Rounding at the top of cut slopes is especially important to reduce erosion and ensure long term stability and revegetation of cut slopes. It also adds to the aesthetics of the finished project by blending the slope into the natural terrain. The amount of rounding may depend on the environmental impact and on the desires of the agency having jurisdiction.

It is FLHO policy to encourage the use of slope rounding on all projects.

For low fills, it is desirable to have a clearing width beyond the edge of the travel lane that provides a clear zone for vehicles that may run off the road. This applies to daylighted sections and low cuts except in guardrail locations. Refer to Chapter 8 for information on determining clear zone widths.

In some cases the horizontal sight distance near intersections and on the insides of horizontal curves requires wider clearing than normal. Figures 9-5 and 9-6 will aid in determining widening needed to provide adequate site distance. When wider clearing is necessary, it shall show on the plans.

There are special cases where it is desirable to widen the clearing to create openings and irregularities in a long straight clearing line. The treatment will depend on the type, size, and density of the trees and ground cover and on the terrain. Each case merits consideration on an individual basis.

8. Miscellaneous Roadway Widening. Roadways often require special consideration for additional widening for curves, auxiliary lanes, turnouts, etc.

a. Curve Widening. The rear wheels of longer vehicles do not follow or track the front wheels on horizontal curves. To accommodate this, it is good practice to increase traveled way widths on curves, particularly when lane widths are less than 3.6 meters.

Traveled way widening values are shown in Table III-22 on page 217 in the Green Book. Place the widening on the inside of curves and transition it throughout the length of the superelevation runoff. The final centerline striping should split the pavement to provide equal widening to both lanes.

b. Auxiliary Lanes. Auxiliary lanes adjoin the traveled way and provide for parking, speed change, turning, weaving, truck climbing, passing, or other purposes supplementary to through-traffic movement. They also maintain lane balance and accommodate entering and exiting traffic.

(1) Parking Lanes. The design of arterial or expressway facilities should only permit emergency stopping or parking. Within most urban areas existing and developing land uses require on-street parking. This may also be true of small rural communities located on arterial highway routes.

When land use development requires parking lanes, consider only parallel parking. Do not use diagonal or angle parking without a careful analysis of operational characteristics of the facility.

The width of parking lanes can vary from 2.1 to 3.6 meters depending on the use of the lane for purposes other than parking automobiles. Refer to the Green Book, pages 411-413, 474, 521, and 539 for criteria on design of parking lanes.

(2) Speed Change Lanes. Vehicles use acceleration and deceleration lanes, including tapered areas, when entering or leaving the through traffic lanes. There are no definite warrants for providing speed change lanes. The Green Book provides guidance on the use of these lanes on pages 749-751, 781-782, 952-957. Figures 9-14 and 9-15 in this chapter provide distances for deceleration and acceleration lengths required for automobiles.

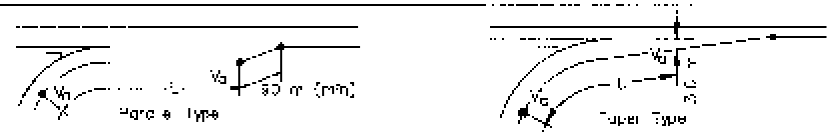
For Right-turn corner design, see Exhibit 9.9

Highway Design Speed, V (km/h)	Average Running Speed, Va (km/h)	Deceleration Length, L (meters) For design speeds of exit curve, V' (km/h)							
		Stop Condition	20	30	40	50	60	70	80
		For Average Running Speed on Exit Curve, V'a (km/h)							
		0	20	28	35	42	51	63	70
50	47	75	70	60	45	–	–	–	–
60	55	95	90	80	65	55	–	–	–
70	63	110	105	95	85	70	55	–	–
80	70	130	125	115	100	90	80	55	–
90	77	145	140	135	120	110	100	75	60
100	85	170	165	155	145	135	120	100	85
110	91	180	180	170	160	150	140	120	105
120	98	200	195	185	175	170	155	140	120

Adjustment Multiplier
For Grades of 3 percent or more

Percent Grade	Upgrade	Downgrade
3% to less than 5%	0.9	1.2
5% or More	0.8	1.35

Figure 9-14
Right Turn Deceleration Lanes for Non-Controlled Access Highways



For right-turn corner design see exhibit 9.9.

Highway Design Speed (km/h)	Highway Speed Reached, V_a (km/h)	Acceleration Length, L (meters) For Entrance Curve Design Speed (km/h): Stop Condition	20	30	40	50	60	70	80
		And Initial Speed, V_a: 0	20	28	35	42	51	63	70
50	37	60	–	–	–	–	–	–	–
60	45	100	85	70					
70	53	145	125	110	85	50	–	–	–
80	60	195	180	165	135	100	55	–	–
90	67	275	280	240	210	175	130	50	
100	75	370	345	330	300	265	220	145	55
110	81	430	405	390	360	330	285	210	120
120	88	520	505	500	470	445	400	335	245

Note: Uniform 50:1 to 70:1 tapers are recommended where lengths of acceleration lanes exceed 400 meters.

Adjustment Multiplier for Grades of 3 percent or more						
Highway Design Speed (km/h)	Ratio of Length at Grade to Length at Level for Design Speed of Turning Roadway Curve (km/h): 40	50	60	70	80	All Speeds
	3 to 4 percent upgrade					3 to 4 percent downgrade
60	1.3	1.3	–	–	–	0.70
70	1.3	1.4	1.4	–	–	0.70
80	1.3	1.4	1.4	1.5	–	0.65
90	1.4	1.5	1.5	1.5	1.6	0.65
100	1.4	1.5	1.5	1.5	1.6	0.60
110	1.5	1.6	1.7	1.7	1.8	0.60
120	1.5	1.6	1.7	1.7	1.8	0.60
	5 to 6 percent upgrade					5 to 6 percent downgrade
60	1.5	1.5				0.60
70	1.5	1.6	1.7	–	–	0.60
80	1.5	1.7	1.9	1.9	–	0.55
90	1.6	1.8	2.0	2.1	2.2	0.55
100	1.7	1.9	2.2	2.4	2.5	0.50
110	2.0	2.2	2.6	2.8	3.0	0.50
120	2.3	2.5	3.0	3.2	3.6	0.50

Figure 9-15
Right-Turn Acceleration Lanes for Non-Controlled Access Highways

(3) Turning Lanes. The designer will find criteria for left-turn lanes and right-turn lanes under *Intersections at Grade* in Section 9.4.B.

(4) Weaving Sections. The Green Book covers weaving sections on pages 84 and 91-93 and 909-910.

(5) Climbing Lanes. Normally, climbing lanes are synonymous with truck traffic and steep grades. They should also be considered in recreational or other areas subject to slow-moving traffic.

Steep downgrades have a negative effect on capacity and safety when used on facilities with high traffic volumes and numerous trucks.

There are instances when providing a truck lane for slow moving downhill traffic (such as trucks, vehicles with trailers, or recreational vehicles) is appropriate. Design climbing lanes independently for each direction of travel. Consider climbing lanes on two-lane highways under the following circumstances:

- The upgrade traffic volume exceeds 200 VPH.
- The upgrade truck volume exceeds 20 VPH.
- The level of service E or F exists on the grade.
- A reduction of two or more levels of service occurs when moving from the approach segment to the grade.
- Trucks will experience a speed reduction of 15 km/h or greater.

For anyone unfamiliar with the *level of service* concept, it is difficult to visualize the operating conditions that characterize levels of service A through F. Table II-5 on pages 88-89 of the Green Book presents a brief description of the operating characteristics for each level of service and type of highway.

Refer to pages 241-264 in the Green Book for details on designing climbing lanes on two-lane highways. The *Highway Capacity Manual* contains sample calculations on pages 8 through 21 inclusive.

For justification and design criteria for climbing lanes on multilane highways, read Chapter 3 in the *Highway Capacity Manual* and the text in the Green book beginning on page 281.

(6) Passing Lanes. Refer to the Green Book and the *Highway Capacity Manual* for information on the design of passing lanes.

c. Slow Moving Vehicle Turnouts. Technically these turnouts are not auxiliary lanes. They do provide room for a slow moving vehicle to pull safely off the roadway, then re-enter the through lane after faster moving vehicles pass.

Generally, the need for a turnout occurs on paved roadways (1) with limited passing opportunities, (2) when slow-moving vehicles are prominent but do not warrant climbing lanes, and (3) where the cost of an auxiliary lane is prohibitive.

Figure 9-16 provides guidance for width and length of turnouts. The riding surface of a turnout should be similar to the adjacent travel way. Provide adequate sight distance so the vehicle can re-enter the traffic stream safely. Sign all turnouts to identify their presence.

9. RRR Considerations. RRR projects primarily involve work on an existing roadway surface and/or

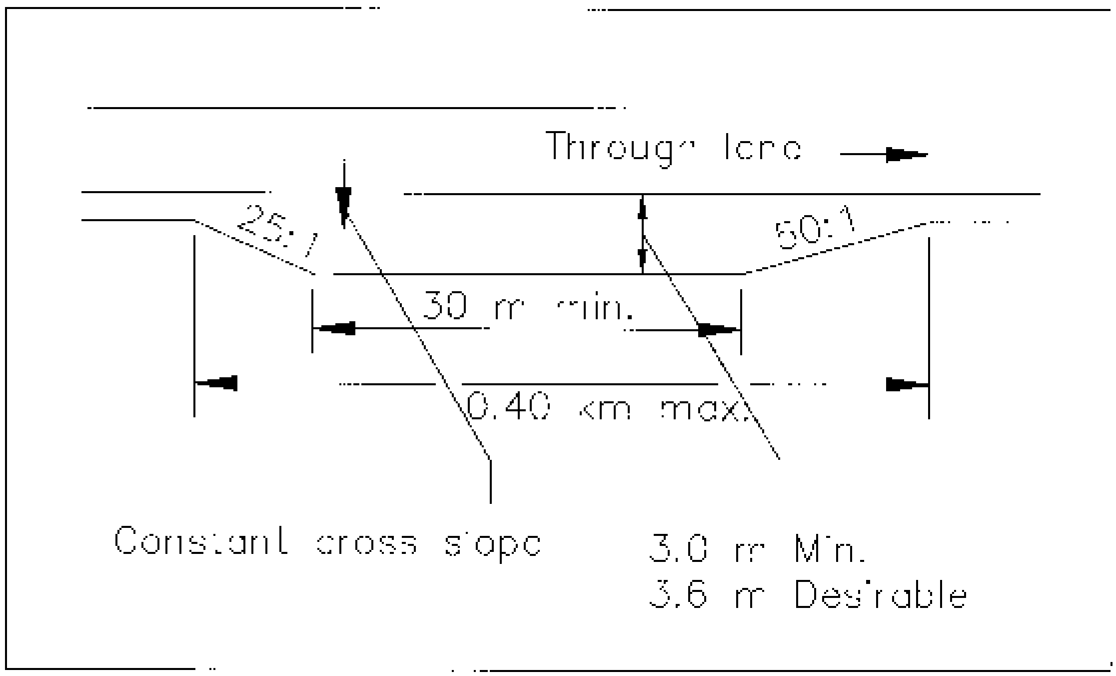


Figure 9-16
Slow Moving Vehicle Turnout

subsurface. Their purpose is to extend the service life, provide additional pavement strength, restore or improve the original cross section, improve the ride of the roadway, and enhance safety. An RRR project should not decrease the existing geometrics of the roadway section. See TRB Special Report 214, *Designing Safer Roads* for additional information.

Funding restrictions may prevent improvement of existing highways to the desirable standards. Therefore, when the pavement condition reaches minimal service level, there is a need for cost effective pavement and improvement projects.

RRR projects reflect and emphasize the economic management of the highway system. Therefore, economic considerations will largely determine the scope of work.

Many factors influence the scope of a RRR project, such as the following:

- Roadside conditions
- Funding constraints
- Environmental concerns
- Changing traffic and land use patterns
- Pavement condition
- Accident data

Acquisition of additional right-of-way to construct RRR improvements is sometimes necessary. Horizontal and vertical alignment modifications, if any, should be minor.

The Designer should review the project in the field and include those items that will be practical enhancements to the project. These items may include the following:

- Roadside obstacle removal
- Drainage improvements
- Slope rounding or flattening
- Traffic barrier
- Traffic control devices
- Shoulder improvements
- Minor widening
- Bridge rails
- Intersection improvements
- Railroad-crossing improvements
- Illumination

Many of these work items will enhance the project by providing the broadest scope of improvement possibilities.

Carefully establish project limits, particularly where widening occurs. Avoid ending the project at potentially hazardous locations, such as a narrow structure or a severe vertical or horizontal curvature. Provide the appropriate safety measures when these conditions are unavoidable.

All safety elements of an RRR project merit specific consideration. Collect and analyze accident numbers, types, and rates for the project to identify safety problem areas. In addition, field reviews can identify potentially hazardous conditions.

While an analysis may indicate deficiencies in one or more of the following areas, each needs examination:

- Horizontal and vertical alignment
- Cross-sectional geometrics
- Traffic control
- Access
- Railroad crossings
- Pedestrian/bicycle facilities
- Bridges
- Illumination
- Signing
- Channelization
- Skid-resistant surface texture

Improvements to the roadway surface may result in increased operating speeds. To maintain an acceptable level of operational safety, examine the geometrics and modify them if necessary.

Horizontal and vertical curvature and stopping sight distance directly relate to the speed of vehicles. As a consequence, major deviations from the standards may cause speed related problems.

When curvature is the cause of accidents, consider some corrective action. This can range from positive guidance (such as placement of additional warning signs and markings) to reconstruction. Often, existing horizontal and vertical alignments are adequate, and an analysis will show they only require signing and marking.

Consider alignment improvements when accident experience is high and previously installed warning signs, markings, or other devices have been ineffective.

When the design speed for a horizontal or vertical curve is less than 20 km/h below the design speed of the adjacent sections, and has a low accident history, signs and marking may be applicable instead of reconstruction. When the difference is 20 km/h or more or the design speed of the horizontal or vertical curve is less than 30 km/h, corrective action is essential. If improvement is not possible, provide the appropriate signs and markings and other provisions to obtain proper speed transition.

Sight distance improvement on horizontal curves and at intersections consists of flattening cut slopes, selective clearing, or both. On completion of this work, measure the actual sight distance, determine the maximum comfortable speed, and sign and mark the location.

As a rule, grades cannot be flattened on RRR projects. However, steep grades and restricted horizontal or vertical curvature in combination may warrant corrective action.

It is desirable to provide a roadside recovery area as wide as practical using the guidelines in Chapter 8. Make an evaluation to determine the consistency of the clear zone throughout the project limits. Following this, determine the severity of each situation. Give particular attention to the clear zone at identified high roadside accident locations (fixed object accidents). Perform a cost analysis of appropriate measures (e.g., do nothing, remove, protect) to mitigate the hazardous conditions. On the basis of these analyses, select the appropriate remedial action. An adequate clear zone on horizontal curves at the end of a downgrade merits special attention.

Consider widening to provide additional clear distance through short sections of rock cuts. In longer rock cuts, protrusions are cut back or protected where warranted. A review of accident data will help to define dangerous obstructions. Good engineering judgment, cost effectiveness, and consideration of environmental and community impacts may also influence decisions.

Under urban conditions, the minimum setback for obstructions should be outside the paved shoulder or 600 millimeters behind the curb. Where there will be sidewalks, it is desirable to locate the obstructions behind the sidewalk.

Safety items reduce the severity of run-off-the-road accidents. These items include traffic barriers (including bridge rails), flattening slopes to eliminate the need for barriers, crash cushions, breakaway or yielding sign supports, and breakaway luminaire supports.

Refer to section 10.3.F in Chapter 10 for a discussion on bridges on RRR projects.

All RRR projects should consider the following safety enhancements:

- Upgrading all rail and end treatments to current standards. Evaluate existing traffic barrier rail, bridge rail, guardrail, and end treatments for need and compliance with standards.

- Extending cross pipes outside of the clear zone if practical, or

- Installing beveled pipe ends or end sections for both parallel and cross-drain structures located in the clear zone.

- Relocating, protecting, or providing breakaway features for sign supports and luminaries.

- Protecting exposed bridge piers and abutments.

- Modifying raised drop inlets that present a hazard in the clear zone.

Sign and mark all RRR projects according to the MUTCD.

B. Intersection Design. This section sets the basic guidelines to use in the design of at-grade intersections. The designer should also be familiar with "At-Grade Intersections", Chapter IX of the Green Book. For information on intersections with grade separation and interchanges, see Chapter X of the Green Book.

Intersections at grade are a critical part of highway design. The efficiency of a road network depends on the effectiveness of the intersections. The number of possible conflicts at intersections is very high compared to normal roadway operations. Good design practice will minimize these areas of high accident potential. Traffic, driver characteristics, physical features, and economics influence the design of channelization and traffic control measures.

It would be ideal to design every intersection based on an engineering analysis using traffic data and accident records, but this is seldom practical. When an engineering study is appropriate, it should include recommendations for channelization, turn lanes, acceleration and deceleration lanes, intersection configuration, and traffic control devices.

The speed at which vehicles approach and move through the intersection and the size of the design vehicle govern the minimum dimensions of an effective intersection. Such features as minimum sight distance, curve radii, and lengths of turning and storage lanes directly relate to speed and design vehicle. (See paragraph 9.4.B.2.)

1. Intersection Types. The three-leg, four-leg, and multileg configurations are the three basic types of intersections. (See Exhibit 9.3.)

- The three-leg configuration is generally referred to as either a tee or wye intersection. The tee intersection has three legs intersecting so the angle between the stem of the tee and the remaining legs is 60° to 120°. It is desirable to keep this range between 75° and 105° with 90° being the ideal. The tee shape provides better driver visibility than the wye shape. It is preferable to have the minor traffic movement on the stem of the tee.

  In the wye intersection, the angle between two of the intersecting legs is less than 60°. The wye shape can cause driver confusion when two legs diverge from the stem and thus requires careful signing.

- The four-leg intersection is the most common type of intersection and may be right angled, oblique, or offset. The desirable angle between any two respective legs is between 75° and 105° although the Green Book will allow a range from 60° to 120° with 90° preferred.

  The right-angled crossing is easily signed and signalized, provides good visibility, and is the safest to negotiate by drivers and pedestrians. The oblique crossing creates problems with driver visibility, pedestrian safety, and vehicle turning angles. The offset intersection has low intersection capacity, is difficult to negotiate and comprehend, and is difficult to effectively sign and signalize. The through traffic movement on the major roadway should have the straight alignment.

- The multileg intersection has more than four intersecting approach legs and can form several configurations. For purposes of this discussion, the rotary intersection is considered to be a multileg. These intersections have visibility problems and poor turning angles, confuse the road user, and are difficult to sign, mark, and signalize. This type of intersection occurs when a highway diagonally cuts across a street grid system or when more than four approach legs intersect. The multileg configuration is not appropriate for new highways, and the reconstruction of existing multilegs to the four-leg type intersection is very desirable.

- The "roundabout" intersection, a small radius version of a rotary intersection/traffic circle has worked well on some low-speed routes as replacements for intersections with 4-way stops. It has been very successful in reducing accidents, but failures have shown that site selection is critical to successful performance.

2. Design Vehicle. Design vehicles have selected dimensions and operating characteristics. Each represents a class of vehicles that establish design controls for specific conditions.

The design vehicle for any intersection depends on the roadways involved, the location of the intersection, and the types and volume of vehicles using the intersection. Table 9-9 provides a guide to determine the design vehicle appropriate for various intersections.

Design an intersection so the design vehicle can make all turning movements without encroaching on adjacent lanes, opposing lanes, curbs, or shoulders. Using a taper at the exit end of the right-turn corner will reduce the radius and the pavement area. For the recommended right-turn corner design see Section 9.4.B.8, Right-Turn Lanes.

Table 9-9
Intersection Design Vehicle

	Design Vehicles		**Radius (meters)**	
Intersection Type	**Desirable**	**Minimum**	**Desirable**	**Minimum**
Junction of Major Truck Routes	WB-19	WB-19	35	30
Junction of State Routes	WB-15	WB-12	30	23
Ramp terminals	WB-15	WB-12	30	23
Other Rural	WB-12	SU	23	17
Urban Industrial	WB-12	SU	23	17
Urban Commercial	SU	P	17	11
Residential	SU	P	17	11

Note:

P = Passenger car, including light delivery trucks.
SU = Single unit truck.
WB - 12 = Semitrailer truck, overall wheelbase of 12 meters.
WB - 15 = Semitrailer truck, overall wheelbase of 15 meters.
WB - 19 = Semitrailer truck, overall wheelbase of 19 meters.

3. Alignment. When the gradient of an intersecting roadway exceeds the cross slope of the through pavement, it is desirable to adjust the vertical alignment using suitable grades and vertical curves. Any adjustment should maintain sight distance.

To determine the maximum grade of a minor road at an intersection refer to Exhibit 9.4. In areas of ice or snow conditions it is desirable to use a 3 percent maximum grade, but the grade should not exceed 5 percent. A minimum grade of 0.5 percent will provide for adequate drainage at an intersection.

When the desirable criteria is not attainable for an intersection, suitable curves introduced into the horizontal alignment of the less important road will reduce the angle of the intersection. Exhibit 9.5 shows some examples of intersection horizontal realignments.

Often the cross slope of a road is in the same direction as the intersecting cross road. In this case adjust the vertical alignment of the cross road to meet the pavement cross slope of the highway.

If possible, avoid or eliminate intersections where the cross slope of the curving road is not in the same direction as the grade of the intersecting cross road. If this is unavoidable, adjust the vertical alignment of the cross road far enough from the intersection to obtain a desirable alignment. (See Exhibit 9.4.)

4. Sight Distance. The operator of a vehicle approaching an at-grade intersection needs an unobstructed view of the entire intersection and a sufficient length of the intersecting roadway. Under some conditions, when it is impractical to provide adequate site distance for cross road traffic to safely enter the main road, it may be necessary to install traffic signals. (See Part IV of the MUTCD.)

Many intersections use stop signs on the minor road for traffic control. In this case, the driver stopped on the minor road must see enough of the major highway to safely cross before a vehicle on the major highway can reach the intersection.

See Exhibit 9.6 for minimum sight distance along the major road for level conditions. In Exhibit 9.6, the time for acceleration value (t_a) multiplied by the applicable adjustment factor from Table 9-10 will adjust the minimum sight distance to reflect grades of the minor road approach.

Table 9-10
Sight Distance Adjustment Factor

Design Vehicle	**Cross Road Grade (percent)**				
	- 4	- 2	0	+ 2	+ 4
P	0.7	0.9	1.0	1.1	1.3
SU	0.8	0.9	1.0	1.1	1.3
WB- 15	0.8	0.9	1.0	1.2	1.7

Within the sight triangle, remove, adjust or lower cut slopes, hedges, trees, signs, utility poles, or anything large enough to constitute a sight obstruction (see the Green Book, pages 696-721). Eliminate parking and offset signs to prevent sight distance obstructions.

The SU vehicle serves as the design vehicle for most rural highway conditions, including most recreational roads. If there is significant semi-truck traffic, use the WB-15 or WB-19 vehicles. In areas where SU or WB vehicles are not prevalent, and ROW restrictions prohibit adequate sight triangle clearing, the P design vehicle may be applicable.

At some intersections the turning volume from a stop-controlled minor roadway is significant enough to conflict with through vehicles on the major roadway. In these instances, sight distances shown in Table 9-11 are recommended. The distances shown in the table for P or SU design vehicles are the sight distances required for P vehicles to turn onto a two-lane highway and attain an average running speed without being overtaken by a vehicle going the same direction. The distances shown in the table for the WB-15 and WB-19 design vehicles are the sight distances required for them to complete a left turn. Using sight distances less than that required for the P or SU vehicle will require the through traffic to reduce speed.

For additional information on sight distance and for sight distance across divided highways, refer to Chapter IX of the Green Book.

Table 9-11
Sight Distance for Turning Vehicles

Design Speed (km/h)	**Design Vehicle** P or SU	WB - 15	WB - 19
30	110	130	150
40	120	155	180
50	145	195	225
60	160	235	270
70	235	270	315
80	315	315	365
90	395	395	405
100	475	475	475
110	565	565	565

5. Channelization. Channelization separates traffic into definite paths of travel using pavement markings or raised islands. Channelization facilitates the safe and orderly movement of vehicles, bicycles, and pedestrians.

Pavement markings used to delineate travel paths generally consist of painted stripes reflectorized with glass beads. Raised Pavement Markers (RPM), reflectorized and nonreflectorized, may supplement pavement striping when increased visibility is desirable. RPM may replace painted stripes when climatic or traffic conditions warrant. (See Chapter 8).

Curbing is permissible for channelization under the following conditions:

- Prevention of mid-block left turns.
- Raised divisional and directional islands.
- Raised islands with luminaries, signals, or other traffic control devices.
- Pedestrian refuge islands.
- Landscaped areas within the roadway.

Curbing is undesirable at any location where painted pavement markings with or without reflective lane markers attain the same objective.

Try to limit the use of curbing to urban and suburban highways with a design speed of 60 km/h or less. On these types of highways, drivers expect to encounter confined facilities and raised channelization works well.

The two general classifications of curbing for channelization are mountable curbs and barrier curbs of the types shown in Figure IV-4 on page 346 of the Green Book. For safety considerations, use mountable curbing whenever possible. Use barrier curb for raised islands with luminaries or traffic control devices and for pedestrian refuge.

Table 9-12 shows the minimum offset distances recommended for barrier curb. For mountable curbing installations, the left offset distance is optional.

Table 9-12
Offset Distances for Barrier Curb

Lane	**Left**		**Right**
Width (m)	**Rural (m)**	**Urban (m)**	**Rural and Urban (m)**
3.6	0.3	0.3	1 minimum
3.3	0.6	0.3	1 minimum
3.0	1.0	0.6	1 minimum

6. Traffic Islands. A traffic island is a defined area between traffic lanes for control of vehicle movements, pedestrian refuge or traffic control devices. The use of raised traffic islands should be limited to those urban and suburban highways with a design speed of 60 km/h or less.

Traffic islands perform these major functions:

- Channelization islands control and direct traffic movement.
- Divisional islands separate opposing or same direction traffic streams.
- Refuge islands provide safe haven for pedestrians.
- Miscellaneous islands provide for proper placement of traffic control devices.

Divisional and refuge islands are normally elongated and should be at least 1.2 meters wide and 6 meters long.

Channelization islands are normally triangular. In rural areas they should contain an area of at least 7 square meters with 9 square meters as a desirable minimum. In urban areas where speeds are low, islands about two-thirds this size may be acceptable. Islands with traffic control devices or luminaries and islands crossed by pedestrians require 18 square meters as a minimum area.

Design triangular shaped islands as shown in Exhibit 9.7. The offset distances illustrated apply to islands constructed with mountable curbs. For painted islands in rural areas, these offset distances are desirable but not mandatory. With barrier curbing provide the minimum offset distances shown in Table 9-12 but not less than those shown in Exhibit 9.7. Increase the offsets of the approach noses of the islands when the minimum offset distance shown in Exhibit 9.7 is increased.

Avoid offset distances wider than 1.5 meters as this gives the appearance of an added lane. Reflective RPMs may supplement island markings.

Raised islands at crosswalk locations require barrier-free access for the handicapped. (See Section 9.4.F.6.)

Design approach ends of islands to provide adequate visibility and advance warning of their presence. Islands should not cause a sudden change in vehicle direction or speed. Transverse lane shifts should begin far enough in advance of the intersection to allow gradual transitions. Avoid introducing islands on a horizontal or vertical curve. When islands on curves are unavoidable, adequate sight distance, illumination, and/or the extension of the island must be considered.

See Part V of the MUTCD and the Green Book for additional design criteria for islands.

7. Left-Turn Lanes. A left-turn lane is an auxiliary lane on the left side of a one-directional pavement for use as speed change and storage of left-turning vehicles. Left-turn movements result in more critical traffic conflicts than do right-turn movements. Design left-turn channelization with enough operational flexibility to function under peak loads and adverse conditions. Left-turn lanes are an economical way to reduce delays and accidents at intersections.

At unsignalized intersections on two-lane highways, use Figure 9-17 for guidance on the need for left-turn lanes. Left-turn lanes are appropriate at locations where accidents involving left- turning vehicles are high. Refer to Figures 9-18 through 9-20 and Table 9-13 to determine the storage length required. The minimum storage length should be 30 meters. At signalized intersections the left-turn storage length is dependent on capacity and level of service criteria found in the *Highway Capacity Manual*.

Exhibit 9.8 shows typical left-turn geometrics to accommodate a left-turn lane. Offsets and pavement widening should be symmetrical about centerline or baseline. Widen on one side only when right-of-way, topography, alignment restrictions, or other circumstances prevent symmetrical widening. See the Green Book for additional design guides and for left-turn treatments on multilane facilities.

8. Right-Turn Lanes. Right-turn corner designs should allow the design vehicle to turn without encroaching on adjacent lanes, curbs, shoulder edges, or opposing traffic lanes. Exhibit 9.9 shows typical design for the design vehicles using a taper at the exit end of the right-turn corner. For a simple radius without the exit taper, the values in Table 9-9 apply, however, this will increase the pavement area. At signalized intersections some encroachment on adjacent lanes of the approach leg is usually acceptable to obtain an adequate radius.

Where larger radii than those given in Table 9-9 or Exhibit 9.9 are desirable, compound curves may reduce the need for additional pavement area. See the Green Book for a discussion of compound curves and other guidelines for corner radius returns.

Right-turn movements at intersections influence intersection capacity, although not usually to the same extent as left-turning movements. Conflict between the opposing traffic and the right-turning vehicle is not a factor. Right-turning vehicles are affected by pedestrian movements, especially those in the crosswalk of the leg into which the turn is being made.

Consider right-turn lanes at unsignalized intersections when:

- Approach and right-turn traffic volumes are high. See Figure 9-21.
- Presence of pedestrians requires right-turning vehicles to stop in the through lanes.
- Restrictive geometrics require right-turning vehicles to slow considerably below the speed of the through traffic.
- The decision sight distance is below minimum at the approach to the intersection.
- Accidents involving right-turning vehicles are high.

At signalized intersections, a capacity analysis using the *Highway Capacity Manual* will determine if right-turn lanes are necessary to maintain the desired level of service.

Where adequate right-of-way exists, providing right-turn lanes is cost effective and can provide increased safety and operational efficiency.

Table 9-13
Additional Left-Turn Storage for Trucks at
Unsignalized Two Lane Highway Intersections

Standard Storage Length	Trucks in Left-Turn Movement				
	10%	20%	30%	40%	50%
	Additional storage length to be added to standard values of left turn lengths.				
(meters)	(meters)	(meters)	(meters)	(meters)	(meters)
30	7.5	7.5	15	15	15
45	7.5	15	15	22.5	22.5
60	7.5	15	22.5	30	30

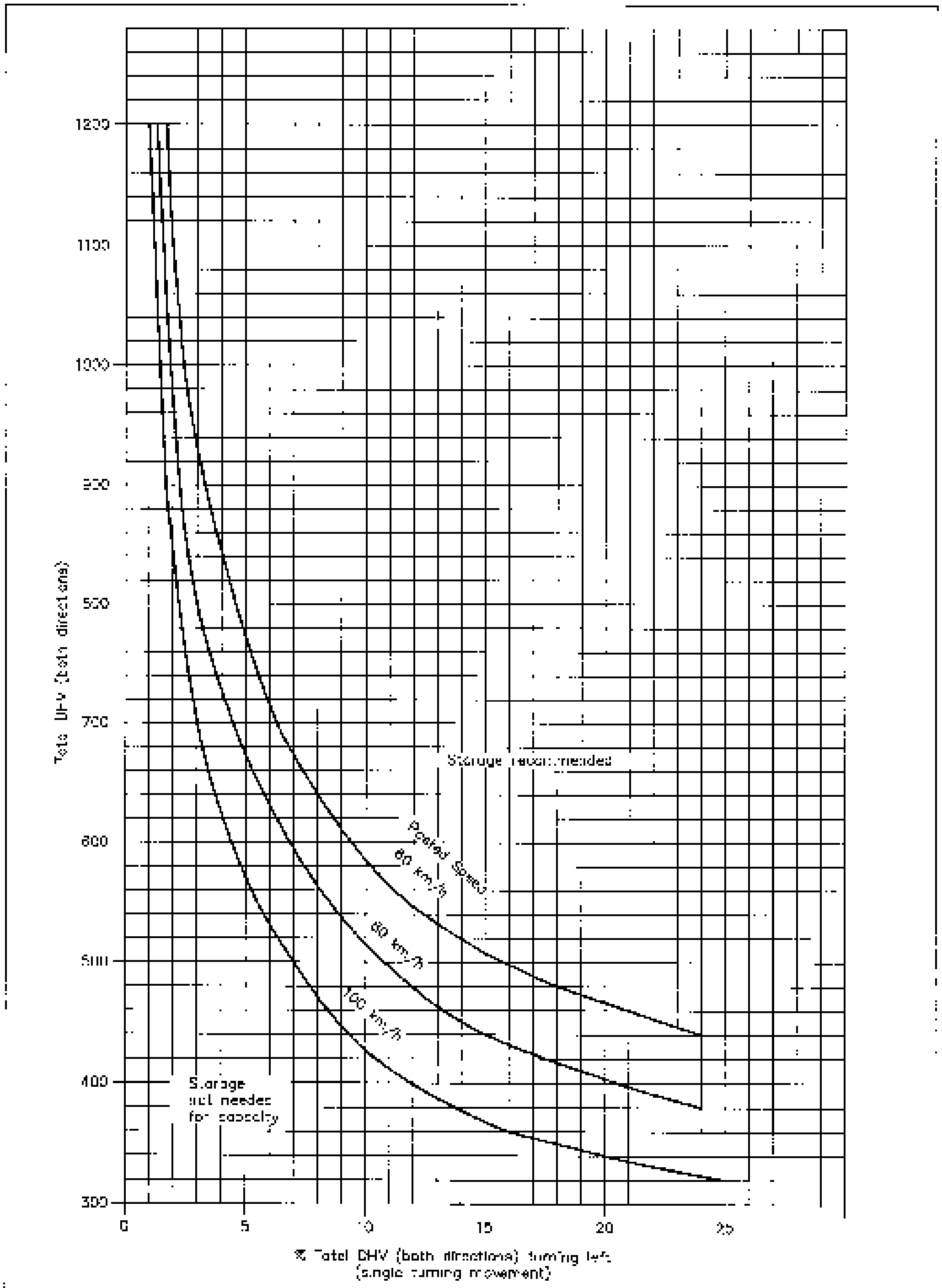


Figure 9-17
Left Turn Storage Guidelines for Unsignalized Two-Lane Highway Intersections

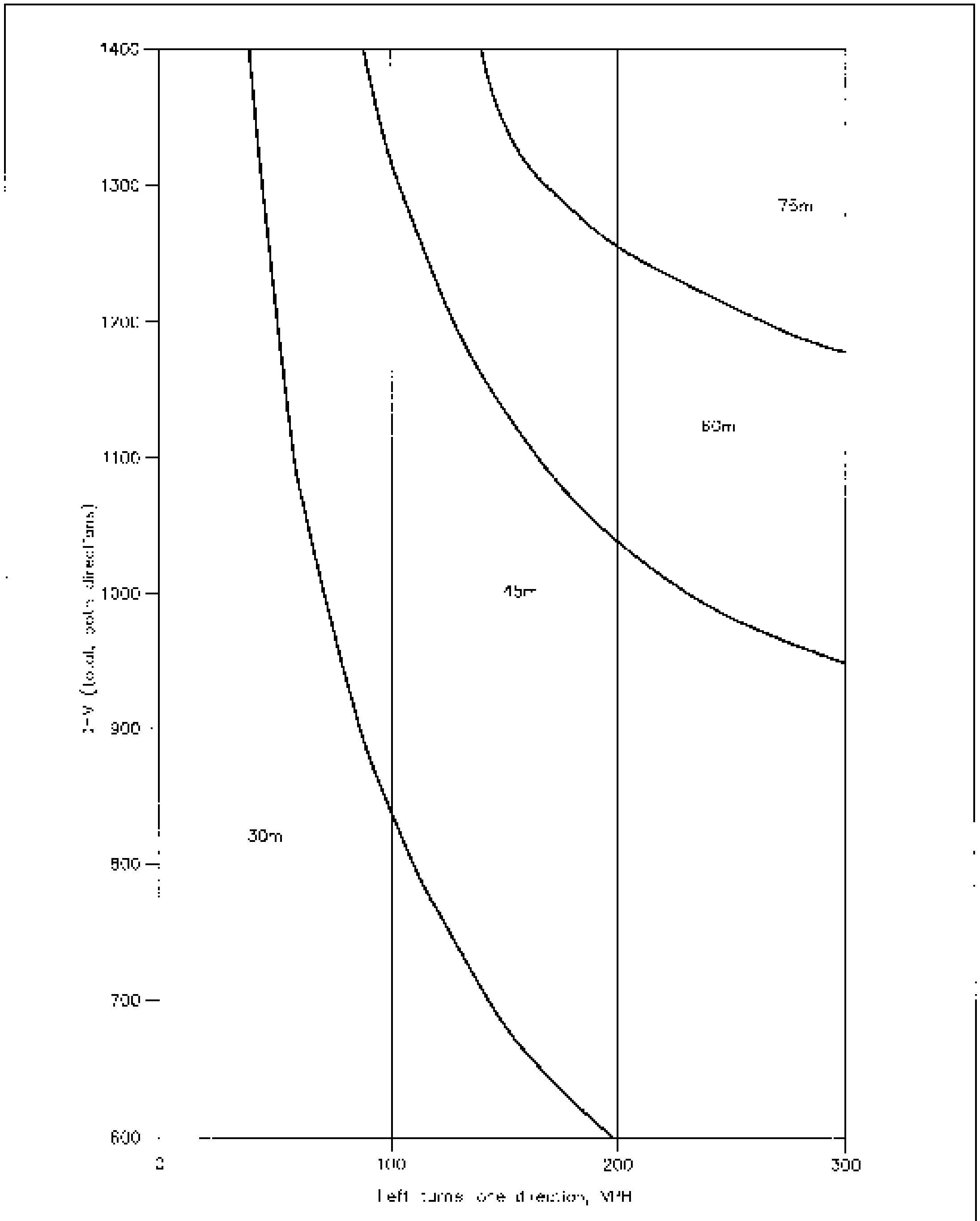
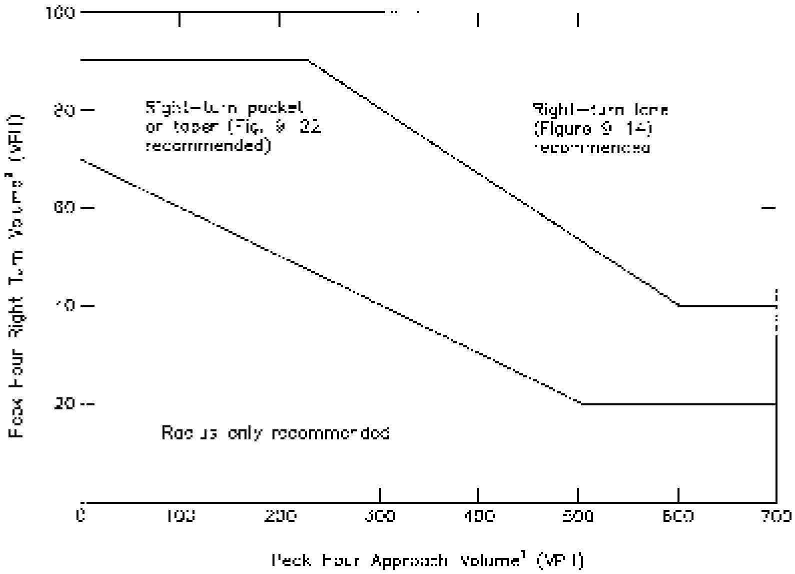


Figure 9-18
Left-Turn Storage Lengths for Unsignalized Two-Lane Highway Intersections
60 km/h Posted Speed



Note:

1. For two-lane highways use the total peak hour approach volume. For multilane, high speed (posted at 70 km/h or above) highways use the total peak hour approach volume per lane.
2. Reduce peak hour right turn volume by 20 VPH when all three of the following conditions are met.

- Posted speed ≤ 70 km/h
- Right-turn volume > 40 VPH
- Total approach volume < 300 VPH

Figure 9-21
Right-Turn Lane Guidelines

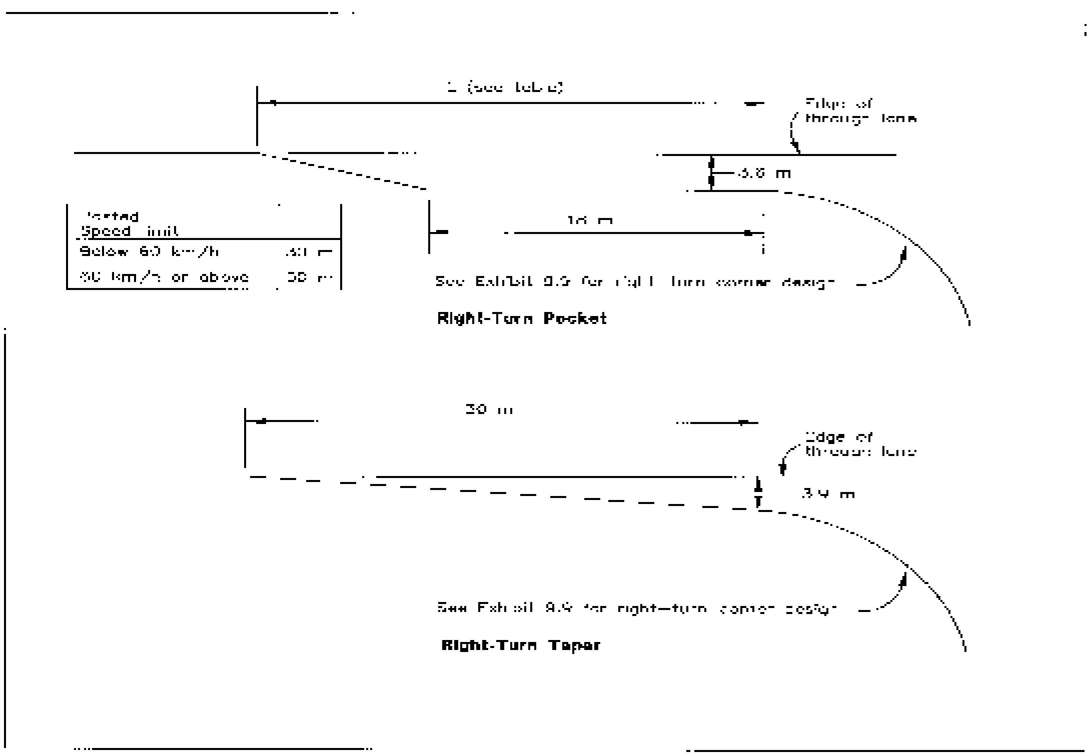


Figure 9-22
Right-Turn Pocket or Taper

C. Earthwork Design. Earthwork design includes the following:
- Clearing and grubbing.
- Additional clearing and grubbing.
- Removal of structures and obstructions.
- Excavation and embankment.
- Rock blasting.
- Watering.
- Earthwork geotextiles.
- Structure excavation and backfill for selected major structures.
- Structure excavation and backfill.
- Drainage layer.
- Roadway obliteration.
- Linear grading.
- Subgrade stabilization.

1. Clearing and Grubbing. Clearing widths should extend 1.5 meters beyond the outer limit of slope rounding for cuts and 1.5 meters beyond the toe of fill. Additional clearing and grubbing includes the following:

- Additional clearing or selective thinning of vegetation at the top of high cuts.

- Additional clearing for scalloping and vistas to improve visual appearance.

- Additional clearing required for the accommodation of utilities.

- Additional clearing to allow for southern exposure to assist in melting snow in high elevations.

Clearing and grubbing widths may be limited under the following situations:

- Decreased clearing allowance in sensitive areas, such as National Parks or areas where the preservation of existing vegetation is critical.

- Decreased clearing because of limited Right-of-Way (R/W).

Clearing and grubbing quantities are normally computed using IHDS except for isolated areas of special clearing outside the normal section. Clearing quantities are usually not computed until the earthwork runs are completed.

2. Removal of Structures and Obstructions. This work consists of the removal and disposal of all buildings, fences, structures, old pavements, abandoned pipelines, and other obstructions that cannot remain in place.

3. Classification of Roadway Excavation. Classification of roadway excavation for design purposes includes the following types:

- Common material. Common material is largely earth or earth with detached boulders less than 0.5 cubic meter.

- Rippable rock. Rippable rock refers to material ready for excavating after it is loosened by a ripper.

- Solid rock. Solid rock includes hard rock in place, ledge rock, and boulders requiring drilling and blasting equipment for removal. Any blasting work will be performed according to the rock blasting section specifications.

In addition to the excavation for the construction of roadways, there may be excavation for drainage ditches, culverts, bridges, and grade separation structures. Still another type of excavation includes dredging operations for hydraulic fills.

Using data furnished by the geotechnical staff, the designer shall check the characteristics of the material to be excavated or placed in embankments. The excavation used for embankments will range from rock to earth and have shrink/swell factors assigned for design purposes.

4. Shrink and Swell Factors. Roadway excavation, however classified, is commonly but not always measured in the original, undisturbed position. The specifications must carefully state the place and method of measurement because almost all materials change volume in their movement from cut to fill.
Excavated earth will expand beyond its original volume in the transporting vehicle but will shrink below the excavated volume when compacted into the fill. To illustrate, 1 cubic meter of earth in the cut may use 1.25 cubic meters of space in the transporting vehicle, and finally occupy only 0.65 to 0.85 cubic meters in the embankment. This, of course, depends on its original density and the compactive effort applied. This difference between the original volume in a cut and the final volume in a fill is the shrink.

Excavated rock placed in a fill occupies a larger volume. This change in volume is the swell. When the voids in the rock embankment become filled with earth or other fine material, the volume in the fill will just about equal the combined volumes in the two source locations.

For light soil excavation and for fills constructed on swampy ground subject to settlement, the shrink may range from 20 to 40 percent or even greater. For moderate soil excavation, the shrink ranges from 10 to 25 percent. For heavy soil excavation with deep cuts and fills, expect a range of about 15 percent shrink to 5 percent swell. Shrink generally includes the slight waste in transporting material from cut to fill and the loss for material which escapes beyond the toe of slopes.

A swell of 5 to 25 percent is anticipated in rock excavation depending upon the proportion of solid rock and upon the size of the rock placed in the fill.

When available, the design should incorporate actual field shrink and swell factors for like material used on adjoining projects.

The shrink factor is determined as follows:

$$\text{Shrink Factor} = \frac{1}{1+\frac{\%\ shrinkage}{100}}$$

Thus, if the percent of shrink is 25 percent, the shrink factor would be:

$$\frac{1}{1+\frac{25}{100}} = \frac{1}{1.25} = 0.8$$

The swell factor for rock excavation is determined as follows:

$$\text{Swell Factor} = 1+\frac{\%\ \ swell}{100}$$

Thus, if the percent of swell is 25 percent, the swell factor would be the following:

$$1 + \frac{25}{100} = 1.25$$

See Table 6-12 in Chapter 6 for additional information on shrink/swell factors used for commonly specified materials.

The shrink/swell factors are applied to the excavation quantities to arrive at the adjusted quantities.

Settlement results in shrinkage, but one is not directly proportional to the other. Do not confuse shrink with subsidence. Subsidence is settlement of the entire embankment due to unstable foundation conditions such as placing heavy fill on swampy soil.

5. Design Cut and Fill Slopes. The design of cut and fill slopes depends upon the characteristics of the material. The designer should refer to the geotechnical report for recommended slope ratios. (See Section 9.4.A.)

6. Slides. When the geotechnical report identifies potential areas for slides, the earthwork excavation quantities may require adjustment to cover potential slide removal. Provisions to dispose of excess slide material are necessary.

7. Balancing Earthwork. The earthwork is balanced when the volume of excavation (with the appropriate allowances made for shrink and swell) equals the volume of embankment. The designer shall consider the quantity of subexcavation removed and disposed of and the quantity of topsoil reserved for slopes in the balance quantities.

It frequently happens that the material from the adjacent cuts is not sufficient to make the intervening fill. In this case, material is borrowed from outside the construction limits.

When there is an excess of excavated material, it may be necessary to dispose of the material. Instead of long hauls, it may be more economical to dispose of the material by widening shoulders or placing the material in disposal areas than to pay hauling costs.

If the earthwork is not in balance, the designer should try to adjust grade line or centerline so it is in balance. When a balanced project is not practical or desirable, the designer either disposes of excess material or borrows material to obtain a balance. Designated disposal or borrow areas require clearance for proper ownership, rights-of-use, environmental concerns and applicable permits.

Waste areas for the disposal of excess material and/or borrow areas should be shown on the plans.
The geotechnical unit should evaluate the sites and provide recommendations on classification of borrow material or slopes and depth of embankment allowed in disposal sites. Appropriate environmental considerations apply to reclamation or rehabilitation plans for the disposal sites.

The designer can use the added quantities feature of IHDS to add or subtract cut or fill from the quantities computed for the roadway.

8. Haul. Haul consists of transporting material from its original position to its final location. The cost to haul material is required to estimate the unit price of various items of work.

Haul costs are based on hauling on cubic meter of material a distance of one kilometer or one metric ton of material a distance of one kilometer using the shortest practical route. Haul costs are generally based on a rate per unit of time for the hauling equipment multiplied by the actual time needed to move the material. This is quite simple when calculating costs to haul from crusher sites to the middle of a project. It becomes more complicated when estimating costs to haul material between balance points on a grading project. The use of a mass diagram as described below will provide the quantity of haul within balance points as well as other helpful information. It is up to the designer to determine cost estimate based on historical data and the equipment needs and work rates to move the material.

9. Mass Diagram. A mass diagram is a continuous curve showing the accumulated algebraic sum of the excavation and embankment (cuts + fills -) from some initial station to any succeeding station. The points of the mass curve are plotted to a horizontal scale of distances (same as profile) and a vertical scale of cubic meters (such as 1 millimeter = 50 cubic meters).

The designer can prepare a mass diagram using IHDS to arrive at haul quantities for cost estimating purposes. The steps necessary to generate and interpret mass diagrams are explained in Part IX, Chapter 15 of the GEOPAK Users Manual.

The characteristic properties of a mass diagram (or curve) are as follows:

- The ordinate at any point on the mass curve represents the cumulative cubic meters to that point on the profile.
- Within the limits of a single cut, the curve rises from left to right. Within the limits of a single fill, it falls from left to right.
- Sections where the cumulative cubic meters changes from cut to fill correspond to a maximum. Sections where the cumulative cubic meters changes from fill to cut correspond to a minimum.

- Any horizontal line cutting off a loop of the mass curve intersects the curve at two points. Within this area the cut is equal to the fill (adjusted for shrinkage). Such a line is called a balance line.

- The loops that convex upward show that the haul from cut to fill is to be in one direction. Loops that concave upward indicate a reverse direction of haul.

A mass diagram can assist in balancing cuts and fills and showing the best distribution of materials. The mass diagram shows the most economical procedure for disposing of excavated material. It also shows which part to move forward or backward, and whether borrowing and wasting are advisable. It presents a graphic picture of the distribution of materials and the haul involved in the placement.

10. Computing Structural Excavation Quantities. To determine the quantity of structure excavation for pipe culverts, box culverts, or other drainage structures, plot a cross section at the location of the structure, plot the roadway template, and draw the grade line of the structure. Calculate the average end area and compute the excavation quantity.

Round the structure excavation for each pipe to the nearest cubic meter and show this quantity on the Drainage Summary sheet of the plans.

Structure excavation for foundation trenches for riprap, walls, etc., is calculated by average end areas and lengths and is shown on the plans where the work is to take place.

11. Subgrade Treatment. The geotechnical report should identify the location of and propose a solution for any subgrade problems, such as the following:

- Subexcavate unsuitable subgrade materials and use special backfill.

- Stabilize poor quality subgrade materials in-situ with additives such as lime, fly ash, or cement.

- Place special subgrade topping material.

- Use geotextiles to increase support values.

- Install special drainage systems.

- A combination of any of the above.

The designer is responsible for incorporating the appropriate corrective measures to be taken into the design and for including any special contract requirements and special drawings into the PS&E package.

12. Roadway Obliteration. Roadway sections no longer needed for traffic and located outside the cuts or fills are often obliterated. Obliteration consists of restoring the ground to approximately the original contour to produce a pleasing appearance by forming naturally rounded slopes.

The designer should evaluate the obliteration work and consider salvaging existing base rock or other surfacing materials for incorporation into the new construction.

Material from the old roadway used in the new roadway, and material from the new roadway used in obliteration of the old roadway, is paid for under Section 204 or other sections of the Standard Specifications. The designer may obtain topsoil or other recyclable materials in this manner.

13. Design Steps Using IHDS. The guides listed below represent the more commonly used portions of the IHDS. The designer should refer to IHDS manuals for details in the preparation of input to obtain specific output data.

Obtain the roadway template, cross-section, and other miscellaneous design information from the approved standards for input into the IHDS. See Subsection 9.4.A.7, Geometric Cross Section.

(1) Refer to Section 9.4.A in this manual for guidelines on the following topics:

- Aesthetic Consideration in Highway Design.
- Horizontal and Vertical Alignment Relationship.
- Establishing Control Points.
- Horizontal Alignment.
- Vertical Alignment.

Usually more than one horizontal or vertical alignment is studied. These studies deal with cost, alignment, safety, encroachment on waterways, right-of-way, aesthetics, maintenance, and operation. After the completion of the studies, one line is selected for further enhancement and refinement of design.

(2) Position the design line over the survey data provided using the controls and guidance mentioned above.

(3) Compute the station and coordinates of curve and PI points, bearings, tangent lengths, curve lengths, radii, tangent distances, and delta angles using the IHDS horizontal alignment program. Spiral functions are computed for spiraled curves.

Unless otherwise required, bearings computed to the nearest minute are acceptable. The arc definition for curves is used with few exceptions.

(4) Obtain a plot of the design profile.

(5) Using recommended design speed for the route, prepare a progressive listing of each tangent/curve, and determine the standard safe speed from charts found in the Green Book. Then adjust this standard safe design speed for local requirements such as snow and ice conditions, relatively steep grades, and specific requirements of the cooperating agency.

The IHDS program will automatically assign a superelevation rate and runoff length using criteria from the Green Book, pages 167 to 171. The designer may have to adjust these rates and lengths to comply with the safe speed guidance.

(6) Use the IHDS proposed cross section input file to obtain cross sections. Use input files to obtain end areas, catch points, earthwork volumes, accumulated cut and fill volumes, and the mass ordinates.

The IHDS uses the average end area method of determining volumes. The total volume of earthwork is the sum of the volumes of the prismoids formed by adjacent cross sections.

When using the average end area method, the prismoid is treated as a prism whose cross section is the mean of the two end areas of the prismoid.

$$V = L\left(\frac{A_1 + A_2}{2}\right)$$

Where:

V	=	Volume (cubic meters).
Al and A2	=	Cross sectional end areas (square meters).
L	=	Distance between the cross sections (meters)

This formula is approximately correct. Due to its simplicity and substantial accuracy in the majority of cases, it has become the formula in common use. It gives results, in general, larger than the true volume.

If desired, IHDS will adjust excavation volumes for curvature. Normally, this is not necessary, but in cases where there is a preponderance of curvature in one direction, consider adjustment.

Use the added quantities feature to add or subtract miscellaneous excavations for such work as subexcavation, road approaches, etc.

(7) Make any adjustments to the line or grade to balance the earthwork quantities. If a line change achieves this, repeat Steps (2) through (4). For a grade change repeat Steps (2) through (7).

(8) Compute the clearing quantities using the clearing program. The quantities should include the rounding shown on the standard plans or any other limiting parameters requiring adjustment to clearing distances beyond the slope stakes.

(9) Use the seeding program to compute the areas of seeding. The quantities for seeding should include the rounding shown on the plans.

D. Earth Retaining Structures.

1. Design:

a. Determination of Need: The first step in the earth retaining system design process is to determine that a retaining structure is needed. The determination may be needed early in the environmental/location stage of design, or it may come later, at the preliminary design stage. The Project Manager shall make this determination of wall need in consultation with other involved disciplines and agencies. The Project Manager shall consider environmental and historic constraints, as well as physical constraints.

The Project Manager shall determine if a retaining wall is the best choice to provide the needed function to meet the constraints established. Retaining wall systems shall be considered with other alternates, such as fills, cuts, changes in alignment, and mechanically stabilized earth (MSE) slopes. The decision process is too site specific to be completely defined, but the Project Manager should document the project conditions and constraints that were considered in the analysis.

b. Alternative Wall Systems: When a retaining wall is determined to be needed, the FLH shall permit all retaining wall system alternatives that are determined to be technically suitable, and aesthetically acceptable to land-owning agencies. The recent changes in technology have rapidly increased the number of retaining wall systems available, which has made determining the most suitable wall alternatives more difficult. This has highlighted the need for consistent design guidance to help Project Managers select and design appropriate wall types to be permitted at each site.

The Project Manager shall decide which alternative systems will be designed and included in the contract, and which wall systems will be permitted as alternative Contractor designs. Options the Project Manager may consider include:

- FLH to prepare designs for all competitive alternatives
- FLH to prepare designs for the most likely 1 to 3 alternatives
- FLH to list acceptable alternatives and the final selection and designs are prepared by the Contractor
- FLH to prepare designs for the most likely alternative(s) and permit additional alternatives which could be designed by the Contractor

Any of the four approaches may be appropriate depending on project conditions and constraints. On large projects the third option should generally be provided. On smaller projects the fourth option may be necessary. The final number of complete alternative designs included in the contract shall be determined by the Project Manager. The alternatives permitted for design by the Contractor shall normally include all remaining wall systems which the Project Manager determines to be technically suitable, economically competitive, and aesthetically acceptable to the land-owning agencies.

The Project Manager shall avoid permitting only one retaining wall system, if the system is proprietary. The Project Manager will insure that contracts specifying a proprietary wall system have at least one other reasonably competitive proprietary or non-proprietary wall system permitted as an alternative.

c. Design Guidelines: All alternatives permitted in FLH contracts shall be designed in accordance with the *Guidelines for the Design of Retaining Wall Systems*. These guidelines are a summary, mainly by reference, of acceptable design criteria and other information for each wall system which may be considered for use in FLH contracts. These guidelines assure consistent FLH designs and encourage competition by permitting as many Contractor designed alternatives in the contract as possible. These guidelines shall be used by the FLH in its designs, by A&E firms in designs done for FLH, and by the construction Contractor for alternative designs.

In addition to design criteria, the guidelines contain other information, including wall system limitations, materials specifications, and construction specifications necessary for a construction contract. A checklist of all retaining structure geometric and design data (original and final vertical profiles, beginning and ending stations, foundation capacity, backfill criteria, soils $\varnothing$ angle, etc.) needed for the design of each alternate wall system is included in the guidelines. This checklist will help insure the Project Manager provides all design data for consultant and Contractor designed wall systems in the contract package. The FLH guidelines permit consistent design and review of retaining walls. The guidelines will be updated as new retaining wall systems are added to the list of alternative wall systems which may be considered for use on FLH projects.

Each FLH division shall have a process to insure that any wall used on FLH projects is designed using the procedures in the design guidelines. The process must include a review of designs of proprietary walls and those prepared by A&E firms to insure the procedures in the *Guidelines for the Design of Retaining Wall Systems* have been used.

d. Selection of Wall Types: Once it has been determined that a wall is needed, the Project Manager shall determine which wall system alternatives shall be permitted. The Project Manager shall coordinate with the land-owning agency and a Federal Lands Highway (FLH) inter-disciplinary team. The team shall normally be made up of Geotechnical, Highway Design, and Bridge Design Engineers. The level of involvement of the individual team members will vary depending on the type and function of the wall. The Project Manager shall consider spatial, behavioral, and economic factors in determining the alternatives to be permitted. These evaluation factors include: 1) Constructability, 2) Maintenance, 3) Schedule, 4) Aesthetics, 5) Environment, 6) Durability or proven Experience, and 7) Cost.

The Project Manager shall document the selection process. The documentation may be especially useful when selection and non-selection of proprietary retaining wall systems are challenged. The Project Manager may limit the number of alternative wall systems to be permitted based upon an analysis of the specific constraints and conditions. The analysis shall consider the complexity of the site, and the estimate of the cost of the wall system in addition to the technical suitability of the wall system to the site.

The Project Manager normally will consider only retaining wall systems included as part of the *Guidelines for the Design of Retaining Wall Systems*, unless an unusual situation, or an experimental wall system is proposed by the interdisciplinary team. In these situations, the Project Manager must insure the design guidance and specifications are made available. The wall systems which are normally considered are listed in the *Guidelines for the Design of Retaining Wall Systems*. This list shall be updated as new wall systems are added, as provided in Section 9.4.D.5.d. below.

e. Retaining Wall Systems: A description of the retaining wall systems is included in the *Guidelines for the Design of Retaining Wall Systems*. Generally, all of these systems have design guidelines included in the *Guidelines for the Design of Retaining Wall Systems*. However, some systems described below may not be listed in the guidelines.

1) Design Considerations: A retaining wall is a structure built to provide lateral support for a mass of earth or material and a variety of dead and live load surcharges. See Exhibit 9.10 for examples of some general types of retaining walls. The layout, design specifics, and construction details of a wall consider the following:

- Highway geometrics.
- Topography and subsurface conditions
- Traffic characteristics.
- Length and height of wall required.
- Type of material to be retained.
- Type of foundation support available.
- Presence of ground water.
- Routine and special loading conditions.
- Visual appearance of the completed structure.

Retaining structures resist applied loads by a variety of methods including structure weight, structural stiffness and load transfer, and internal and external restraining elements.

Walls installed near the edge of a traveled way can serve as traffic barriers if they have an approved traffic barrier design incorporated into the wall details.

The wall selected must be capable of supporting the temporary loads which occur during retaining structure construction. The design surcharges for standard walls shall be shown on the standard drawings.

The design of a retaining structure consists of an analysis of loads that will act on the structure and the development of a structure to withstand these loads safely. In addition, the structure and adjacent soil mass must be stable as a system, and vertical and horizontal deformations anticipated must be within acceptable limits.

A primary cause of retaining wall failure is the additional load imposed by hydrostatic pressure due to saturated soils behind the wall. The design must provide adequate drainage facilities for the site to prevent entrapment of water.

Designs should use native soil for backfill if it meets the requirements for the particular wall system.

All retaining walls require an investigation of the underlying soils by the geotechnical unit. Chapter 6 provides details on conducting and reporting the investigation.

Where conditions warrant, retaining walls shall be designed with an aesthetically pleasing appearance compatible with other structures in the area and the surrounding terrain. Although economics generally dictate wall selection, an aesthetic wall facing treatment could be an overriding selection factor. Consistent architectural treatment and economy of scale will frequently result in the same wall type being used throughout any given project.

Aesthetic requirements may include the wall's material, the top profile, the terminals, and the surface finish for texture, color, and pattern. Short sections of walls should be avoided if possible.

The Project Manager shall give land-owning agencies, cooperators, and resource agencies an opportunity to provide guidance and recommendations for wall selections.

When the design includes proprietary wall systems, the designer shall contact the company representatives during the design stage to obtain general information on timeframes, detailing, oversight responsibility, and other factors necessary to complete the design and construct the wall. The wall companies will require specific site information such as typical cross sections, plan and profiles, soils and foundation criteria, and special design parameters.

All retaining walls not included in standard plans shall be designed by a structural or geotechnical engineer experienced in the wall type being designed. Hydraulics engineers shall review any wall designs potentially threatened by flood waters or located in a floodplain. Geotechnical engineers shall prepare external stability analyses and prepare or review all special foundation designs.

Information on wall design may be found in Chapter 10, Section 10.4.K (safety design factors and other criteria applicable to retaining walls) and Chapter 6, Section 6.4.C (wall foundation and backfill criteria).

2) Retaining Systems Types: There is a wide variety of retaining wall types available to the designer within each system. Each type has its limitations and usefulness. The following walls are commonly used in highway construction. Families of retaining wall systems have similar characteristics, advantages and disadvantages; yet each wall product within the family generally has some unique design and construction features. The general descriptions and advantages and limitations of each system are discussed.

Gravity Walls. Gravity walls are usually most cost effective for smaller wall areas and lower heights since they are relatively expensive because they are materials and labor intensive. They are generally most suitable for fill and widening applications.

- **Mass concrete walls.** The economic overall height of mass concrete walls is about 1.2 meters. Short sections with heights up to 2 meters are acceptable. Mass concrete gravity walls can be used in conjunction with cantilever walls if long stretches of design heights less than 1.2 meters are necessary.

- **Reinforced Concrete Cantilever and Counterfort Walls.** Cantilever walls have standard design heights up to 10 meters but are most economical below 6 meters. They lend themselves readily to a variety of aesthetic facial treatments.

  A concrete, L-type cantilever may be suitable where site restrictions do not allow for a footing projection beyond the face of the wall stem. This wall and counterfort walls require special designs. The major disadvantage of these walls is their low tolerance to settlement. Piling can provide adequate foundation support, but greatly increases the overall wall cost.

  Counterfort walls are economical compared to cantilever walls for wall heights less than 6 meters and for long wall lengths. The intricate forming required generally causes higher costs for counterfort walls than for cantilever walls above this height. Counterfort walls may also prove economical over MSE walls where base width considerations require a minimum width.

- **Buttressed Walls.** A buttressed wall is relatively expensive. It is frequently constructed where right-of-way is unavailable for other wall types. Historically these walls have been used in the 9 to 15 meter height range; however, more recently developed systems such as ground anchors and reinforced soil have reduced their application significantly.

- **Gabion Walls.** Gabion walls consist of compartmented metallic mesh containers filled with select 100-150 millimeter backfill. They have been successfully constructed to heights of 12 meters with adequate foundation support. The walls are somewhat flexible and tolerate some settlement. The walls are aesthetically pleasing because they blend well into areas of rugged terrain. Gabion walls are relatively inexpensive if a source of rock is locally available and labor is inexpensive.

- **Crib Walls.** Crib walls are somewhat flexible and will tolerate some differential settlement along the axis of the walls. Crib walls not constructed on tangent alignments usually require special detailing, particularly when the wall face is battered. Because open crib wall faces can be climbed, they are not recommended for urban sites where they will be accessible to the public. Project topography and cost of select backfill and labor significantly influence the cost-effectiveness of crib walls. Crib wall are constructed without structural foundations and are not suitable where marginal foundation soils exist.

  Concrete crib walls have been constructed up to heights of 15 meters, but a 6-meter height is probably the limit of economic consideration. Concrete crib may be closed face and, therefore, useful where impinging drainage is a problem. Concrete crib may also be precast modules of various sizes and shapes. Some walls have planters incorporated in their faces to grow shrubs and vines to conceal the walls.

  Metal crib walls have standard design heights of up to 11 meters. The wall elements are light in weight, easily transported and installed, and therefore suited for relatively inaccessible installations and emergency repairs.

  Timber or log crib walls have standard design heights up to 6.7 meters. This wall system has a rustic aesthetic value that makes it popular for use in locations such as parks, National forests, or primitive areas. It is also well suited for use on detours or for stage construction. When all of the wood members are pressure preservative treated, the service life of a timber wall is comparable to that of concrete or metal crib walls.

- **Slurry Walls.** Slurry walls are used when a wall is needed before the surrounding soil is excavated or where ground water is a problem. A trench is excavated for the wall and simultaneously filled with a bentonite or other type of slurry. The slurry restricts the ground water flow and holds the trench sides in place. This is followed by placement of reinforcing steel in the slurry-filled trench and then by placement of concrete by tremie or a concrete pump. After the concrete has cured, the excavation can proceed.

  When one of these walls is exposed to view, some form of facing (precast, cast-in-place, or shotcrete) will provide a more pleasing appearance. In general, slurry walls are designed as cantilever walls without footings. Tiebacks are compatible with this type of wall. Slurry walls are seldom used in transportation applications, other than large urban projects, due to their unique features and extremely high unit costs. Slurry walls are only applicable for retaining walls in cut situations.

- **Rock Walls.** Rock walls consist of stacked large rock, used primarily in cut sections where very good soil exists. These walls provide erosion protection and limited earth support. They are generally 5 meters or less in height for cut sections and less than 3 meters in fills.

- **Modular Precast Concrete Walls.** This wall system consists of precast, interlocking, reinforced concrete elements of varying size depending upon the application. Most of these wall systems are proprietary and are typically available and cost competitive on a regional basis. Each element is rectangular in shape . Once the units are in place and locked together, they are backfilled with free draining material.

  These wall systems have been constructed to heights of 18 meters, but are seldom competitive above 9 meters. Unlike metal crib walls, these walls are always used in conjunction with structural footings and require a deep foundation in marginal and poor soils. Wall designs over 12 meters in height, walls designed to support bridge abutments on spread footings, and walls designed to be installed in locations of excessive foundation settlement shall be approved by the geotechnical and structural staff before using.

  Modular precast concrete walls are easy to install and quickly placed. Exposed aggregate finishes or other surface textures can aesthetically enhance the wall face.

Cantilever Pile Walls. These walls include cantilever, sheet, anchored, or soldier pile walls. The walls consist of sheet or soldier piles made from concrete, steel, or timber; either driven or placed in drilled holes and backfilled. The walls commonly have concrete facing or timber lagging.

These walls are suitable where horizontal deformations are not critical, but are costly and become impractical at heights of 5 meters or more. The net wall cost is also significantly influenced where the embedded portion of the wall requires significant rock excavation.

In embankment sections, a cantilever pile wall may be an appropriate solution for roadway widening where design heights are relatively low. They are also practical for correction of slope instabilities depending on design height, loadings, and site conditions.

Anchored Walls. These walls are also referred to as tieback walls. Routine wall designs go up to heights of 15 meters. These walls are practical in cut sections where a wall is needed before the soil is excavated and are appropriate where cantilever walls are not cost effective. Anchored walls require a specialty contractor and are not suitable in certain soil types. These walls generally require some type of facial treatment for aesthetic purposes. These walls are commonly utilized in conjunction with temporary excavation support based on the need for deformation control and economics.

One advantage of a tieback wall is that it causes minimal disturbance to the soil behind the wall and to any structures resting on this soil. At a wall height of about 5 meters, the walls may become economical compared with cantilever construction. The number of tieback rows, spacing and loading is project specific. Tiebacks offer the advantage of construction confidence, since each tieback is tested beyond it's design load as the basis of acceptance. Geotechnical and structural expertise is essential for all wall designs of this type. Tieback walls can be built in a fill side situation. However, difficulties with construction of the fill over the ties, and control of the face deflections, must be considered in the design before using this wall type in fill side situations.

Mechanically Stabilized Earth (MSE) Walls. MSE walls consist of facing elements, metallic or polymeric reinforcing elements, and a cast in place or precast facing. Many of the available systems are proprietary. MSE walls offer cost-effective alternatives for fill-type retaining structures in the height range of 5 to 15 meters. MSE earth retaining systems work best used in embankment situations and will tolerate considerable magnitude of horizontal and vertical deformations.

The walls work on moderately poor foundation soils and are flexible enough to accommodate some settlement. Transitions in the foundation material along the base of the wall require special attention. These walls have considerable economic advantage for temporary applications and detours.

During construction, the proprietary wall company should be required to furnish the wall materials and/or arrange for their production. Periodic technical assistance is also usually available to the wall installation contractor at the project site.

Several types of MSE walls use a welded wire mesh, a polymer mesh, or fabric. Some examples of these types of MSE walls follow:

- **Welded Wire Walls.** Welded wire walls are a patented system marketed by the Hilfiker Retaining Wall Company. These walls use metallic welded wire mat units that serve as both the soil reinforcement and facing element.

- **Geotextile and Geogrid Walls.** Geotextile wall systems use geotextile for the soil reinforcement and can use a variety of facing elements depending on project requirements. They are not proprietary and can be designed in-house without infringing upon a patent. The face can remain exposed if the geotextile is treated to prevent decay from ultra-violet rays. Concrete panels, mortarless masonry, tar emulsion, or shotcrete coatings make good facing materials. Consider this type of wall for temporary wall installations.

  Geogrid walls use a high tensile strength plastic grid as the soil reinforcing element of the wall. The geogrid can be precast into concrete facing panels, can be used with precast segmental block facing elements as the wall is constructed, or attached to precast face panels after wall construction. Some wall facing details permit the construction of battered walls and walls which permit the development of vegetation (a "green wall"). All designs shall be approved by the geotechnical and structural staff. Geogrid walls are proprietary wall systems.

- **MSE Slopes.** The MSE Slopes use geogrid or geotextile for soil reinforcement. They may be used as alternatives for retaining walls in some situations. The MSE Slope is constructed similar to MSE Walls, except the slope does not have a structural facing and is designed using slope stability methods. MSE Structures with slopes between 70 and 90 degrees are classified as retaining walls and are designed using retaining wall design procedures. When applicable, MSE slopes will typically be more cost-effective than MSE walls.

- **Soil Nailing.** This type of wall uses grouted metal bars as soil reinforcement. Soil nailing is a cost-effective wall system suitable for use either as temporary shoring or for new wall construction in cut applications, grade separation, widening, and rehabilitation of existing retaining walls. The fundamental concept of soil nailing is to reinforce and strengthen the existing ground by installing closely spaced grouted steel bars, called "nails", into a slope or excavation as construction proceeds from the "top down". Similar to tieback walls, this top down construction technique offers the significant advantages of continuous support of the excavation (and adjacent structures if there are any), cost savings through elimination of the need for structural excavation and imported wall backfill (as for conventional gravity cut walls), and reduced environmental impact.

  The typical soil nail wall construction sequence includes a progressive repetition of 1 to 2-meter high vertical to near vertical excavation lifts, followed by installation of nails and application of a reinforced shotcrete facing. The reinforced shotcrete facing stabilizes the excavation face between the nails. When required due to local instability of the excavation cut face, the order of nail and shotcrete installation can be reversed. On permanent walls, a cast-in-place concrete facing is usually constructed over the shotcrete facing.

The nails are typically grouted into predrilled holes. The nails are typically referred to as "passive" inclusions. The term "passive" means that the nails are not pre-tensioned, as are tiebacks, when they are installed. The nail bars are forced into tension as the ground deforms laterally in response to the loss of support caused by continued excavation. Therefore, lateral deformation of the ground immediately behind the top of wall is typically greater with a soil nail wall (typically 0.001 H to 0.004 H, where H = wall height), than with a tieback wall. Several alternatives are available where existing structures: 1) cannot tolerate such deformations; and 2) are located within a lateral distance of up to 1.5 times the wall height (H) behind the top of proposed wall. Either a tieback wall should be used, or 1 or 2 rows of tiebacks should be used in the upper part of the nailed wall in addition to the nails, to limit deformation.

In cases where either tiebacks or soil nails are appropriate, soil nails are typically more economical. This is due primarily to; 1) elimination of soldier piles, 2) faster construction, and 3) smaller equipment is required with soil nailing.

Soil nail walls cannot be used in all types of ground. For soil nail walls to be most economical, they should be constructed in ground that can stand unsupported on a vertical or steeply sloped cut of 1 to 2 meters, for at least one to two days. Soil nail walls are not suitable in loose cohesionless soils (eg. "caving" sands) or below the water table.

2. Contracting Procedures: The contract frequently will include end result specifications, furnishing only line diagrams, design criteria, and an estimate of wall area or other pay item unit. The contract may include all construction details for all acceptable alternative retaining wall systems, or it may include one or more complete designs and permit other contractor furnished designs. The Project Manager shall make this determination with input from the inter-disciplinary team and the Construction Engineer, considering the project size and the number of retaining walls involved.

Guidance on information needed by bidders is included in FHWA's Geotechnical Engineering Notebook, Geotechnical Guideline No. 2. The information needed by bidders includes the following detailed geometric information, subsurface investigation, structural requirements, and geotechnical design data:

Geometric:
- Beginning and ending wall stations
- Profile elevation of top of wall and roadway and cross-sections.
- Horizontal alignment.
- Construction details of appurtenances in the area.
- Right of way limits.
- Stage construction sequence and traffic control needs.
- Foundations elevations and locations of unsuitable materials.
- Estimated wall area.

Subsurface:
- Shear strength and consolidation properties of foundations materials.
- Shear strength and unit weight of backfill.

Structural and Geotechnical:
- Design life (minimum service life) - normally 75 years.
- Safety factors for overturning, sliding, and stability of temporary slopes.
- Allowable foundation bearing pressure and minimum embedment depths.
- Maximum tolerable differential settlement.
- MSE internal design requirements.
- External loads.
- Drainage requirements.
- Backfill requirements.
- Facing requirements.

In addition, the Notebook provides guidance on information and requirements which should be included in supplier prepared designs and plans.

The bid advertisement period shall be extended from 30 to 45 days, or longer, if the Project Manager determines projects with alternative bids and Contractor designed walls require additional bid preparation time.

One advantage of the development of the *FLH Guidelines for the Design of Retaining Wall Systems* is the reduction or elimination of the need to review and analyze complex proprietary wall systems under tight contractual time constraints. The Project Manager should insure that special contract requirements are included in projects which prohibit submission of value engineering change proposals (VECPs) which propose to change the basic wall system alternatives permitted. This restriction is possible since the use of the design guidelines insures that all suitable wall systems have been considered and are included in the contract. However, VECPs may be permitted on the components of the wall systems, such as facing and connection details.

The contract specifications shall identify the procedures for the FLH review of designs and working drawings submitted by the Contractor, similar to the bridge process for reviewing and approving falsework drawings. The information which will be required from the Contractor for review of wall submittals shall be specified in the contract, along with the amount of time required for FLH reviews. The contract should include provisions for additional time needed to permit the working drawings to be reviewed by the A&E firm which did the original design, if appropriate. The specifications shall define when the time count begins for both the review of initial submissions, and for subsequent reviews when changes are required. The contract shall specify the number of sets of drawings needed by FLH.

The pay unit for contractor designed alternative walls shall be identified. The impacts of alternative wall types on the units of measurement should be considered if a common measurement, such as wall face area is used. If alternative wall systems require different pay item measurements, alternative bid items shall be required. The contract shall include a method for adjustment of quantities for field changes if a lump sum payment is used.

Specifications: All wall systems permitted as alternatives shall have construction and materials specifications available to the designers. Construction and materials specifications are referenced or included in the FP-96 of the *Guidelines for the Design of Retaining Wall Systems* for all wall systems which may be considered for use on FLH projects. The applicable portions of these specifications shall be included as part of contracts for all wall systems which do not have specifications covered in the latest FP.

Review Procedures: The Construction Operations Engineer (COE) shall be responsible for initiating the review of Contractor designed retaining wall systems and working drawings. The working drawings will normally be reviewed by the Geotechnical Engineer for MSE systems, and by the Structural Engineer for tie-back and cantilever systems. The Geotechnical Engineer will be the lead for all wall system reviews. The Geotechnical Engineer will insure the approval is made within the time limits specified in the contract, and shall keep the COE informed of the status of the review. Any communications which must pass directly between these reviewers and the Contractor shall be documented and provided to the COE.

3. Consideration of New Retaining Wall Systems: The FLHO shall keep a current list of retaining wall systems which may be considered for use on FLH projects. This list shall be for general guidance of designers in determining retaining wall systems which may be considered for use on FLH projects, and is not a blanket endorsement of the retaining wall system.

The retaining wall system review process will identify the general design concepts used, and will determine if these concepts are acceptable for use on FLH projects, or if they must be modified to be acceptable. Also, the wall system review will determine the availability, durability, and constructability of new systems. In addition to possible modifications to the supplier's design process, the review shall generate any materials and construction specifications needed for inclusion in the *Guidelines for Design of Retaining Wall Systems*. Finally the review process will determine any limitations in the use of the system, such as maximum wall heights, and special materials or construction requirements.

FLHO will not directly solicit data from suppliers and manufactures to determine if newly developed wall systems are acceptable. Periodically the FLHO will solicit information from selected partner agencies (state,federal, and professional engineering organizations) concerning their evaluation and approval of wall systems. The FLHO will review the partner agencies design approval process and will adopt those wall types which meet *Guidelines for Design of Retaining Wall Systems*, and other criteria specified below. FLHO, working with the divisions, will update the list as new walls are determined to be acceptable for use on FLH projects.

Information which shall be requested from Partner agencies includes:

- Size and capacity of the supplier.
- Geographical availability of the system.
- Theoretical basis for the design, including when and how the theory was developed.
- Practical basis for the evaluation of the design by FLH Engineers, including any design manuals, charts, or software needed for the design.
- Laboratory and field experiments which support the theory.
- Practical applications with descriptions and photos.
- Limitations and disadvantages of the system.

- List of owner agencies using the system, including contact names, addresses, and phone numbers. The list shall include documentation that the system has a successful "track record" of several installations. The actual number of successful installations required will depend on the FLH reviewers' concerns, but normally will be between 2 and 10 installations.

- Details of wall elements, analysis of structural elements, design calculations, factors of safety, estimated life, corrosion design procedure for soil reinforcing elements, procedure for field and laboratory evaluation including instrumentation, and special requirements, if any.

- Sample material and construction control specifications showing materials type, quality, certifications, field testing, acceptance and rejection criteria, and placement procedures.

- A well documented field construction manual describing in detail, with illustrations where necessary, the step by step construction sequence.

- Typical unit costs supported by data from several actual projects.

- A certification of the product and procedure by an independent Professional Engineer.

- Types of architectural facing treatments available or possible.

Normally the Division Geotechnical Engineers will be responsible for coordinating the review. The principle reviewer shall determine if the system warrants further review. The reviewer shall insure all information needed from the above list has been provided.

The principle reviewer shall determine if additional reviews by Geotechnical Engineers, Bridge Engineers, and other technical expert within FLH, the FHWA, or outside consultant firms are needed.

Much of the information requested from the suppliers is needed to determine the acceptance of the design procedure. However, some of the data is to permit the reviewers to develop additional information for designers and Project Managers:

Constructability
Versatility/suitability for varying site conditions
Suitability for Architectural Facing
Limitations on usage (Maximum Fill Heights, etc.)

The principle reviewer shall send copies of the review package they determine to be acceptable to FLHO and the other FLH divisions for concurrence. All retaining wall systems considered for use on FLH projects shall be included in the *Guidelines for Design of Retaining Wall Systems*. A new retaining wall system shall not be added to the list until all design guidelines, wall system limitations, and materials and construction specifications have been developed and approved for inclusion.

E. Drainage Design. Drainage facilities convey both normal surface and subsurface waters (and within reasonable limits, expected flood and storm waters) across along, or away from a highway. The designer considers the most cost efficient and practical manner to do this without undue damage to the highway, the drainage facility, or adjacent stream channels and property. Various types of drainage methods will accomplish this, including the use of open channels, riprap and channel lining, bridges, culverts, storm drains, underdrains, and related appurtenances. Some installations require provisions for fish passage.

Chapter 7, Hydrology/Hydraulics, contains information, references and methods for designing drainage facilities.

The designer shall include all of the drainage facilities in the contract plans and make certain the specifications contain provisions for these facilities.

The designer is responsible for the design of drainage facilities and for submitting requests and data to the hydraulics engineer, the bridge unit, and the geotechnical unit. The designer normally designs all minor drainage structures and appurtenances, such as small culverts (1200 millimeters and smaller), end sections, catch basins, and inlets as well as minor drainage channels and ditches.

Large culverts and channels are usually sized by the hydraulic engineer or by the designer with the assistance of the hydraulic engineer.

Bridge design (layout, minimum opening under bridge, pier placement, etc.) is the co-responsibility of the bridge unit and the hydraulics engineer.

The geotechnical unit is responsible for specialized design of underdrains, horizontal drains, drainage blankets, and subdrainage systems using geotextile fabrics. They are also responsible for obtaining pH values of soils and waters and for determining foundation materials for bridges and large culvert installations.

Refer to Chapter 7, Section 7.1 to determine responsibilities of drainage design.

The designer shall furnish lines, grades, cross sections, detail maps, and vicinity maps to the hydraulics engineer and the bridge and geotechnical unit for design.

The designer often adjusts grades (and lines) to provide adequate cover for culverts, minimum clearance under bridges, or for other constraints imposed by drainage facility designs performed by others.

Early in the design process, the designer should consult with the hydraulics engineer, the bridge unit, and the geotechnical unit where any special needs are foreseen. Also, early in the design process, the designer should discuss the need for various Federal, State, and local permits and approvals with the hydraulics engineer.

The designer must review the environmental documents and correspondence with fish and wildlife agencies and review all permits to ensure that all drainage requirements are in the contract.

The hydraulics engineer or the bridge unit designs the larger and more complicated drainage facilities. However, the designer must have familiarity with the design principles and methods to supply adequate information so others can design these facilities. The designer should know the minimum vertical dimensions of structures to adjust the highway grade, and should be aware of alternative designs that could affect the line and grade of a highway.

To design any drainage facility, the quantity of flow that the facility must pass has to be determined. Various methods as explained in Section 7.4.A.1, Floods, will accomplish this. This quantity of flow or discharge is designated by the letter "Q" in hydraulic equations and charts. The discharge is the number of cubic meters per second (m^3/s) of water flowing into or out of a drainage facility or a segment of the facility. (See Section 7.4.B.)

1. Channels and Ditches. (See Section 7.4.C, Open Channels). Drainage channels, other than normal roadway cut ditches and channel changes of streams generally require a design by the hydraulics engineer when the discharge is significant. The designer shall furnish approximate lines and grades, existing site conditions, and cross sections for the channel design. Include provisions for fish habitat and aesthetics in the design. Good fish habitat includes pools, riffles, boulders, logs and gravels in the stream bed, and brush and shade on the stream banks. In order to design channel changes properly, the hydraulics engineer needs to know which features to include. The designer shall include typical sections and detailed drawings of drainage channels and channel changes in the plans.

Roadway cut ditches shall meet AASHTO, State, or county minimums for depth requirements and foreslopes. The minimum depth should be 150 millimeters below the subgrade shoulder. Cut ditches serve two primary purposes:

(1) To keep the ground water level below the subgrade.

(2) To drain surface runoff and small streams into culverts and cross drains.

The amount of water the ditch can carry and the depth of flow vary with the grade of the ditch line. On very flat grades, the water may not drain fast enough to prevent saturation of the subgrade. This situation may cause pavement failures. The designer can alleviate this problem by using deeper or flat bottom ditches, steepening the ditch grade, decreasing the distance between cross drains, paving the ditch, or using slotted drains. Give first consideration to the ditch grade. Use a minimum ditch grade of 0.5 percent. Consider special design for grade lines of ditches on long crest and sag vertical curves and in superelevation transition areas where ditch grades may be flat for substantial lengths.

In soils subject to erosion, consider lining the ditches with rock or some other suitable material especially on grades steeper than 3 percent. Consult the hydraulics engineer when ditch erosion is a possibility. (See Section 7.4.H.)

2. Culverts. (see Section 7.4.D.). For design purposes, there are two categories of culverts:

Category (1) - Minimum sized culverts used for cross drains to carry off intermittent roadside ditch water or water from very small drainage areas.

Category (2) - Culverts sized to carry perennial streams and large runoffs.

Category (1) culverts normally range in size from 300 to 600 millimeters in diameter. The design of these culverts consists of locating them on the cross sections, determining the end treatment (beveled ends, end sections, catch basin, etc.), establishing grades, cover, structural excavation, and showing the locations on the plans.

Category (2) culverts require hydraulic design procedures to determine size. The sizing of these culverts is either done by or checked by the hydraulics engineer.

The designer locates the culverts on the detail map and produces plotted cross sections to determine the length of culvert invert, inlet and outlet elevations, and available depth for headwater. After sizing the culverts, determine the maximum cover of fill over the culverts and calculate the structural excavation.

To locate culverts for a project, obtain a plot of the ditch profile and study the cross sections and the detail map. Streams crossing the alignment, draws, and low spots in fills and ditch lines are the obvious sites for culverts. In long cut sections between the obvious culvert sites, space the cross drains so water does not build up in the ditch line and infiltrate the subgrade or cause erosion problems. There is no set rule for minimum spacing between cross drains because of various types of soil encountered and the wide differences in rainfall in different geographical areas. Consult with the hydraulics engineer on a project-by-project basis for minimum spacing of culverts.

After locating the culverts on plotted cross sections and determining the maximum cover, prepare a drainage summary sheet for the plans. The maximum cover of each culvert determines the culvert wall thickness for alternative metal culvert pipe materials and corrugations or the reinforcement class for concrete alternatives. Select the wall thicknesses and reinforcement classes from the standard drawings.
Any required or optional special coatings on metal pipes shall be shown in the contract. (See Section 7.4.D.15 for details.)

3. Downdrains and Pipe Anchors. Downdrains work well in high fills. Their use may prevent the excessive excavation required to install a new culvert at the bottom of an existing fill. Also consider downdrains where the outfall of a culvert will be on erodible soils. Pipe anchors should be specified for all above ground downdrain installations. Buried downdrains may require an anchoring system depending upon specific site conditions. For tongue and groove concrete pipe, use concrete anchor blocks on grades steeper than 10 percent. For bell and spigot concrete pipe and metal pipe culverts on grades steeper than 30 percent, use pipe anchors as detailed on approved standard drawing.

When specifying pipe anchors for a project, list them on the drainage summary.

4. Catch Basins and Inlets. (See Section 7.4.E., Roadway Drainage). Catch basins and inlets are generally associated with curb and gutter sections, storm drains, depressed medians, and ends of bridges. They may also be used as a safety measure in roadway ditch lines. In this case, maintain the normal ditch depth at a culvert inlet and provide a traversable grate at the top of the catch basin or inlet.

In curb and gutter sections, space the catch basins and inlets close enough together so water will not spread on the traveled way and create a traffic hazard. Spacing will depend on the gutter grade and cross slope of the road or gutter. Consult with the hydraulics engineer on spacing requirements.

At the lower ends of bridges, design catch basins or inlets to prevent runoff from the bridge gutters eroding the fill slopes at the corners of a bridge.

At culvert inlets, determine the need for catch basins on an individual basis. However, they serve no purpose if slides and siltation will plug them.

5. Storm Drains/Storm Sewers. (See Section 7.4.E, Roadway Drainage). Storm drain systems and urban drainage systems require design by or in consultation with the hydraulics engineer. The designer shall furnish layouts, lines and grades, and culture and land features for each drainage area. The designer shall include detailed drawings of the system in the plans.

6. Underdrains and Horizontal Drains. The geotechnical section should design underdrain systems and horizontal drains based on field observations and exploration of subsurface conditions. The designer will have to incorporate them in the plans and provide detailed drawings for their construction.

7. Riprap. (See Section 7.4.C.3, Channel Stabilization). The Hydraulics engineer determines the class, thickness, and cross section of riprap for slope protection along streams and lakes and for ditch and channel lining. The roadway designer incorporates the data in the plans. The class, thickness, and typical section must show in the plans and specifications.

Place riprap around culvert inlets and outlets to prevent erosion and undercutting.

8. Energy Dissipators and Outlet Basins. (See Section 7.4.D.10). In areas of erodible soils, consider energy dissipators at the outlet of downdrains and culverts with high outlet velocities and in channels at points where the grade flattens. Energy dissipators may be in the form of riprap outlet basins, stilling wells, weirs, or concrete structures.

9. Erosion Control. (See Section 7.4.H). Determine the need for various items of erosion control and include the items in the contract. The type and extent of erosion control measures will depend mostly on the soils and streams on a project.

F. Other Design Elements. Many components go into the preparation of a completed design for a proposed highway facility. This section will establish basic guidelines and direction for the many elements not already covered but essential to complete the design package. Such elements include culverts, catch basins, curbs, gutters, sidewalks, special ditches and channels, slope protection, erosion control, cattleguards, fencing, etc.

1. Highway Lighting. The purpose of highway lighting is to provide illumination for an orderly flow of traffic and to improve road safety during the hours of darkness. Properly designed and maintained fixed roadway lighting allows the motorist and pedestrian to quickly, accurately, and comfortably recognize all significant details in the traffic occupied space.

This section provides warrants, standards, and other information on highway lighting installations. An engineer experienced in lighting design should review all highway lighting designs. Generally, the maintaining agency should be contacted to ensure compatibility in lighting hardware and components.

a. Warrants. Lighting warrants relate to the need for roadway lighting and the benefits derived. Factors such as traffic volume, speed, nighttime road use, night accident rate, road geometrics, and general night visibility are important when considering highway lighting. Economic returns for lighting are measurable by the reduction in personal injuries, fatalities, property damage, and other societal costs. More effective usage of the road and the possible increase in its capacity also affect the warrants.

Roadway lighting is warranted for the following:

- Urban expressways and arterials, urban collectors having ADT (20) exceeding 5000, and urban intersections having a combined ADT (20) exceeding 10 000.
- Rural interchanges and intersections where the average number of nighttime accidents (N) per year exceeds the number of daytime accidents (D) per year divided by three. (Illuminate when N is greater than D/3).
- Major rest areas located near urban areas or located near available power sources.
- Tunnels where driver's visibility requirements (or needs) during daylight hours require illumination and where the approach roads to tunnels are lighted.
- Pedestrian underpasses and highway underpasses used by pedestrians.
- Underpasses on lighted highways.
- Overhead signs along urban expressways and arterials; and overhead signs at interchanges on roads approaching urban areas.

b. Design Values. FHWA's Roadway Lighting Handbook gives the levels of average maintained horizontal illuminance and uniformity of illuminance, as well as levels of average maintained luminance and uniformities of luminance for various classes of roadways.

(1) Urban Intersections. Illuminate intersections of arterials and collector roads with other roads in urban areas to a level equal to the sum of the illuminance levels of the intersecting roadways. If only one of the intersecting roads has lights, the intersection requires lighting to a level at least 40 percent higher than the lighted roadway.

(2) Rural Intersections. Where warranted, illuminate rural intersections to provide visibility of other traffic and physical features that are potential collision objects. Place a minimum of two luminaries, and preferably four, per intersection. Maintained average illuminance of the roadway between luminaries shall be 10 to 12 lux with a maintained minimum between luminaries not less than 3 lux.

(3) Overhead Signs. The level of lighting required for easy recognition and good legibility of overhead signs depends on the ambient luminance behind the sign. There is no approved method for determining ambient luminance.

The following explanations of low, medium, and high ambient luminance apply in selecting the recommended design range of average maintained illuminance levels for signs.

- Low Ambient Luminance. Rural areas with no lighting or with very low levels of lighting. This would include background of mountains, deserts, fields, trees, and rural roads.
- Medium Ambient Luminance. Urban areas with small commercial developments, lighted roadways, and lighted intersections.
- High Ambient Luminance. Areas with high street lighting levels, and brightly lighted advertising signs. An expressway through or adjacent to a highly developed downtown area could experience high ambient luminance.

When warranted, illuminate overhead signs to the following levels of average maintained illuminance:

Ambient Background Luminance	Sign Illuminance (lux)
Low	100-200
Medium	200-400
High	400-800

Maintain a minimum to maximum uniformity ratio of 1:6 over the entire sign surface.

While the recommended values will provide good sign recognition and legibility for painted or enameled sign surfaces, the highly retroreflective sign materials require special care. In this case use luminaries especially designed for these materials, and strictly follow manufacturer's installation recommendations. In addition, a field test of such equipment before accepting it for construction is desirable.

(4) Rest Areas/Parking Lots. Rest area lighting installations shall not adversely affect the vision (by glare or spill light from the rest area) of traveling motorists along the main roadway. Motorists on the highway passing the adjacent rest area should be able to discern any vehicle leaving the rest area as well as the traffic traveling along the main roadway.

Recommended average maintained horizontal illuminance levels and uniformities of illuminance are as follows:

Entrance and Exit Gores and Interior Roadways	6-10 lux	G_1 = 1:3
Parking and Activity Areas	12-16 lux	G_1 = 1:3

(5) Tunnels. Daytime tunnel lighting assists the driver's eyes to adjust from high levels of luminance outside the tunnel to a low level of luminance inside the tunnel. Drivers' eyes adapted to high outside ambient luminances will not see obstacles just inside the tunnel unless the tunnel is very short and straight. When approaching a very short and straight tunnel, vehicles and other objects show in silhouette against the light of the exit portals. Such tunnels normally need no daytime lighting.

Tunnels are classified as short or long. A short tunnel has a portal to portal length equal to or less than the minimum stopping sight distance for vehicle operating speeds within the tunnel. A long tunnel has a portal to portal length greater than the minimum stopping sight distance.

A tunnel zone is a length of tunnel roadway equal to the minimum stopping sight distance. A short tunnel will have one tunnel zone and a long tunnel will have two or more. The first tunnel zone in from the entrance portal defines the entrance zone.

The visibility within this entrance zone shall be adequate so motorists can recognize vehicles and objects on the tunnel roadway while the driver is still outside the portal entrance. Adequate visibility occurs when the luminance level is at least seven to ten percent of the ambient luminance outside the entrance portal. This ratio applies only to the luminance or brightness level the motorist observes in the entrance zone. The ambient brightness outside the portal will depend upon the sun's path and the surrounding entrance environment.

Although the sun may produce illuminance levels exceeding 100 000 lux on the earth's surface on a clear day, the entrance zone is not automatically illuminated to 10 000 lux to meet the ten percent criterion. Evaluate the actual approach roadway and entrance portal and determine the correct ambient brightness and the anticipated degree of eye adaptation. On facilities not yet constructed, use model simulation to duplicate the anticipated tunnel approach conditions.

The driver's field of view of the adapted brightness shall be evaluated at a location along the approach roadway equal to the minimum stopping sight distance in advance of the entrance portal. Design the entrance zone lighting levels for the highest ambient brightness expected at the location.

For a short tunnel, continue the entrance zone lighting level throughout its entire length. However, lighting beyond the minimum stopping sight distance in long tunnels must be progressively reduced to an established minimum level. Beginning at the end of the entrance zone lighting, reduce the levels by steps to not less than seven to ten percent the previous higher level. Minimum daytime levels in long tunnels should not be less than 50 horizontal average maintained lux on the roadways. Each stepped zone should have a length at least equal to the minimum stopping sight distance.

Since visual adaptation from low to high luminance levels presents no problem, special exit portal lighting is not required unless there is traffic reversal or two-way traffic in one tube of a two-tube tunnel. Such cases justify the installation of symmetrical lighting systems at both ends of the tunnel.

Nighttime illuminance levels and uniformities of tunnels shall be about equal to those on adjacent roadways. If, because of mounting height and spacing restrictions, these recommended uniformities are not achievable, exceed the recommended illumination levels somewhat to meet the uniformity requirements. Such increased illumination levels, however, should not exceed twice those recommended for the adjacent roadways.

(6) Underpasses. An underpass is defined as a portion of a roadway extending through and beneath some natural or manmade structure, and having a length to height ratio not exceeding 10:1. Because of its limited length to height ratio, it will not, under normal conditions, require supplementary daytime illumination.

Nighttime illumination levels and uniformities applying to tunnels also apply to underpasses. If warranted, underpasses located on unlighted roadways are lighted to the minimum levels recommended for the roadway types adjacent to such underpasses.

(7) Bridges. When bridges are a part of a lighted highway or roadway, illuminate them to at least the same levels and uniformities as the adjacent highways or roadways. Under normal conditions, do not light individual bridges on unlighted roads.   When lighting is required, use overhead luminaries. Luminaries located at ground level or in the railing (parapet lighting) make it difficult to achieve and maintain the required lighting levels and uniformities.

Poles, luminaries, and lamps mounted on bridge structures are subject to more severe vibration than those located on conventional roadways. Take precautions to minimize luminaire and lamp damage of such installations. This requires special resilient pads inserted between pole base and foundation, a spring loaded lamp holder located opposite the lamp socket to provide two-point lamp support, etc.

Luminaries shall be shielded to minimize glare emitted toward motorists using roads located near and below the illuminated bridge. Such shielding may be especially desirable on bridges crossing navigated waterways. For complex and/or multilevel bridge structures, consider high mast lighting.

c. Lamps and Luminaries. Lamps and luminaries shall be standardized to provide the most economical roadway lighting. Standardization also reduces inventories and simplifies design and procurement of materials for maintenance and repair work. Coordinate with the maintaining agency to verify lamp type selection.

(1) Lamps. Generally all highway lighting, including the lighting of overhead signs, shall use high pressure sodium lamps. There are situations, however, that make the spectral energy distribution (color) of this light source unacceptable. For such exceptions, use metal halide lamps.

All lamps shall be first-line, high-quality products. The outer envelopes shall be heat-resistant glass. The structural design of the arc-tube support shall be suitable to withstand the mechanical vibrations expected during a lamp's normal life cycle without moving or damaging the arc-tube.

(2) Luminaries. A luminaire is a complete lighting device, less lamp, consisting of a housing, support clamps, or a fitter for attachment to the support structure, reflector, refractor or lens (as specified), lamp socket, terminal block, lightning arrester (when specified), an integral or external ballast (as specified), and an integral photo control receptacle (as specified). The luminaire shall be capable of operating the specified lamp at the line voltage specified in a completely sealed optical system. The seal of the optical system shall be of such design and materials as to minimize entry of dirt, dust, sand, and other contaminants into the optical cavity. The luminaire, including all its electrical components, shall be capable of operating satisfactorily at ambient temperatures covering the range from -5°C to +55°C.

To keep glare to an absolute minimum, use luminaries meeting the Cutoff type Vertical flux distribution (per ANSI/IES RP-8, 1983). "Semicutoff" type luminaries may, under certain conditions, be allowable. Do not use "Noncutoff" type luminaries.

d. Pole Location. The primary consideration in locating light poles is safety. The designer shall minimize the hazards of these poles by reducing their number, increasing the offset distance, locating them behind barriers, installing frangible or slip base supports, and installing poles in areas with low incidence of vehicles leaving the road.

Use higher lumen output lamps at greater mounting heights to reduce the number of poles. Use high mast lighting on very wide multilane facilities and at interchanges.

If at all possible, install the lighting system in the median. This results in a reduced number of poles, only one run of electrical conductors, and usually better use of the light emitted by the luminaries compared to a lighting system installed on both outside edges of the roadway. If the median is wide, use a breakaway or yielding pole located in the center of the median. A wide median width is greater than twice the pole offset (distance between outside edge of pavement and property line) of an installation along the outside edge of the road. Since most medians on urban freeways are narrow and provided with a barrier, it is often possible to locate the poles on or within these barriers, provided that the following is true:

- The barrier is rigid and considered unmountable by passenger vehicles.
- The barrier is semirigid with enough clearance between barrier and pole to permit deflection.
- The barrier is semirigid but stiffened in the vicinity of the pole to increase beam action and reduce vehicle pocketing.
- Sufficient space is available for safe and proper maintenance of the lighting equipment.

Existing utility poles may be used for attaching luminaire's mast arms. If the highway is in a depressed section having retaining walls, the mast arms may also be attached to these walls.

Increasing the pole offset distance from the traveled way reduces the hazards of light poles. It is desirable to have luminaries positioned over the outside traveled lane and, as a minimum, positioned over the shoulder.

The offset will depend upon the lengths of standard mast arms. Do not use nonstandard mast arms.
Locate light poles without breakaway bases and high masts outside the clear zone. If high mast poles are designed within this zone, install crash barriers (impact attenuators) around them.

Conventional poles located within the clear zone shall have frangible or slip bases unless falling poles would create greater hazards.

The hazard of light poles can be further reduced by placing them outside of ramp gore areas and on the inside instead of the outside of curves.

Require frangible or slip base poles in the clear zone and in medians (12 meters or wider) or along the outside of the traveled way.

Frangible bases are not appropriate on poles located along sidewalks or other locations where they could fall into heavily traveled roads, on pedestrians, or where a falling pole would create a greater hazard. This is especially applicable to those poles located on narrow sidewalks separating frontage roads form the main roadway.

Select pole locations so the luminaire's brightness will not produce excessive glare in the driver's view or cause reflected glare on adjacent overhead signs.

2. Fencing. Fence is usually installed to protect a highway facility from unsafe encroachment by pedestrians, livestock, etc. Generally, fencing replaces existing fence, and is usually constructed on the right-of-way (R/W) line through private lands. Some states have laws requiring fence for all State R/W. The designer needs to check the applicable regulations during the design process. The type of fencing and its location shall agree with the R/W documents or be agreed to during the plan-in-hand or other reviews of the project.

When the R/W line has many abrupt irregularities over short distances, fencing runs should have continuous alignment. This means some R/W corners or monuments will remain outside the fence line. Fencing on a continuous alignment has a cleaner appearance and is more economical to construct. In rural areas, the designer should contact the property owners to determine locations for the fence line. In many instances, the landowner will request a fence outside the R/W line for ease of maintenance. Attempt to hold the number of fence types to a minimum on any particular project for convenience of construction.

Chain-link fence may be warranted for the following:

- Through industrial areas.
- At residential developments.
- Through military reservations.
- At schools and colleges.
- At recreational and athletic areas.
- At other locations where maximum protection to prevent encroachment on the right-of-way is necessary.

Generally, an 1800 millimeter high chain link fence provides protection from encroachments. Sometimes a 1200 millimeter height is adequate if conditions are noncritical.

Wire fencing warrants apply in all rural areas and in some suburban and urban cases. The fencing may consist of barbed wire, hog wire, and other types of metal fabric.

The height of fence can be variable depending on the primary purpose of the fence, such as controlling cattle, sheep, wild animals, etc. Some wire fencing can be 2 to 3 meters high when used to control elk and deer. In some western states, the clear distance from the ground to the first wire is important for antelope crossings. Metal right-of-way fencing can interfere with airport traffic control radar. When fencing in the vicinity of an airport, review the FAA permit to determine if the fencing will create radar interference. An alternate type of fencing may be appropriate in this case.

Some projects require lograil, jackrail, and other types of wood fences on projects for aesthetic and other reasons. Examples of these types of fences can usually be found in Division office files.

It is not unusual to require fencing at stockpile sites, borrow sites, and ponded areas. In such cases the degree and type of fencing depends on the requirements of each site.

Fence measurement is taken along the slope of the fence. The design quantities should reflect this measurement.

Provide gates, when required, at the locations stated in the right-of-way agreements or as agreed to during the plan-in-hand review of the project. The type and size of gates shall be shown on the plans.

3. Cattleguards. Cattleguard substructures shall be concrete, timber or steel. The width and type shall agree with the R/W document or be agreed to during the plan-in-hand review of the project.

Cattleguard widths should be shoulder to shoulder or traveled way widths plus 2.4 meters, whichever is greater.

4. Pedestrian Facilities. Pedestrian facilities consist of sidewalks, hiking or walking trails, and pedestrian separation structures. Sidewalks are generally located immediately adjacent to the highway or parking area. Walking and hiking trails are independently aligned and usually serve recreational activities such as paths from parking areas to scenic overlooks. Pedestrian separation structures are not discussed here. Pages 389 to 399 in the Green Book cover pedestrian structures.

a. Sidewalks. Sidewalks shall have all-weather surfaces. Provide sidewalks along both sides of urban area highways when there is a need for pedestrian access to schools, parks, commercial areas, and transit stops. In suburban residential areas, provide a sidewalk on at least one side of the highway and locate it close to the right-of-way line, if possible.

In lightly populated suburban areas and in rural areas, consider sidewalks only at points of community development such as schools, businesses, industrial plants, and transit stops.

In urban and in major residential areas, sidewalks are usually raised. In many suburban and most rural areas, pedestrians use the roadway shoulder. Sidewalks in residential areas shall have a minimum width of 1.2 meters. To provide a planting strip between the sidewalk and curb allow a minimum of 0.6 meters. When constructing a sidewalk adjacent to the curb, widen the sidewalk 0.6 meters to accommodate open doors of parked vehicles.

Sidewalks in areas of high pedestrian traffic such as schools, businesses, industrial areas, and transit stops should be wider than the minimum and paved to the curb in most cases.

Raised sidewalks should slope toward the roadway at 2 percent.

In most cases where pedestrians use the roadway shoulder for walkways, there are no markings or signs for pedestrian use. In areas of known heavy pedestrian use, an additional 1.2 meters of shoulder width will satisfy the purposes of a sidewalk. An 200 millimeter solid white stripe should mark the edge of the traveled way at these locations.

Pedestrian crosswalks are regularly marked in urban areas. In residential and rural areas, marked crosswalks are normally not necessary. In the vicinity of schools, convalescent centers, local parks, or community centers, marked crosswalks may alert vehicle operators of an unusual situation. For additional details see MUTCD and Traffic Control Handbook.

All sidewalk designs shall accommodate persons with disabilities.

b. Walking and Hiking Trails. These pedestrian facilities usually provide connections with existing trails, lead to roadside points of interest, allow access to streams, or permit leisurely walks. They often have a natural surface, except high use locations require paving to protect existing environmental conditions.

The following guides for walking and hiking trails apply when persons with disabilities do not require accommodations.

- The clear area around walking and hiking trails should be 2.4 meters laterally and 3 meters vertically. Any trees or brush removed from this area shall be flush cut at ground level and intruding branches trimmed flush with the tree trunk.

- Walking trails should be a minimum of 1.2 meters wide and have a maximum grade of 10 percent. The trail should have independent horizontal and vertical alignment. Always locate a trail outside the clear recovery zone or behind guardrail when it parallels the main roadway.

- Hiking trails should have a minimum surface width of 0.6 meters and a maximum sustained grade of 10 percent. The grade may be up to 20 percent for short distances. A hiking trail constructed in a riprap slope, talus slide, or other rock slope should have all voids filled at least 600 millimeters below the rock surface. Provide a 75 millimeter cover of soil or small rock for a final surface.

c. Bicycle Trails. Consider bikeways in the overall design of a highway when bicycles would interfere with or jeopardize the safety characteristics of the highways. See 23 CFR 652. The AASHTO publication Guide for Development of Bicycle Facilities provides the criteria for the design of bikeways.

5. Parking Areas. On FLH projects, parking areas are most often constructed for the scenic, recreational, and cultural enhancement of the highway facility. Parking area design is coordinated with the client agency to determine geometrics, capacity, design vehicle type, and other related requirements. Special design considerations are necessary to accommodate recreational vehicles at intersections within the parking area to provide safe traffic movement. Parking areas shall be designed to accommodate persons with disabilities.

The basic design for parking areas can be found on pages 54 and 55 in the FHWA publication Safety Rest Area Planning, Location, and Design.

6. Accommodation of the Disabled. The *Americans with Disabilities Act (ADA) Accessibility Guidelines* contains most of the applicable standards. The Green Book contains information on curb-cuts beginning on page 393.

The following accessibility requirements apply to the design of parking areas and loading zones:

- Parking spaces for disabled persons and accessible passenger loading zones shall be the spaces or zones located closest to the nearest accessible entrance on an accessible route.

- Parking spaces for disabled persons shall be at least 2.4 meters wide and shall have an adjacent access aisle at least 1.5 meters wide. Parking access aisles shall be part of an accessible route to the facility and shall comply with width and slope requirements for accessible routes.

- Accessible routes shall have a minimum width of 0.9 meters and no running slope greater than 5 percent.

- Parking spaces and access aisles shall be level with surface slopes not exceeding 2 percent in all directions.

- The surface of all accessible routes shall be stable, firm, and slip resistant.

- Changes in the level of accessibility lanes up to 6 millimeters may be vertical and do not require edge treatment.

- Changes in level between 6 millimeters and 12 millimeters shall be beveled with a slope no greater than 1:2. Changes in level greater than 12 millimeters require a bevel at the slope of 1:12.

- Parking spaces shall be reserved for the disabled by a sign showing the symbol of accessibility. The signs must be visible, even when a vehicle is parked in the space.

7. Landscaping and Roadside Development. AASHTO defines roadside development as follows:

The treatment given to the roadside to conserve, enhance, and effectively display the natural beauty of the landscape through which the highway passes.

Throughout the manual, there are references to aesthetic considerations for incorporation into the final design. Aesthetic consideration is not something added onto the project at the last moment to make it look good. Owner agency input at an early stage is vital toward ensuring that all environmental concerns are satisfactorily incorporated into the final design.

Consider the highway as an essential element of the total environment, not as a separate entity apart from or in conflict with the environment. All highway-oriented disciplines should collaborate at all stages of the corridor selection, location, and design. Only in this manner will the functional aspects of highway geometrics be an integral part of the aesthetic quality as it relates to the highway user and the immediate environs.

Employing as many of the following landscaping treatments as possible into the final design will enhance and emphasize the natural beauty of the roadside.

a. Landscape Treatment. In a rural environment, the most successful treatment is one that imitates the existing landscape elements. A motorist going 80 km/h is not going to see detailed landscape patterns. In parking areas, such as overlooks or vistas (and in some cases areas of slower moving traffic), a more concentrated effort is desirable to properly relate landscape details to the viewer.

The best landscape approach is one intended to completely eliminate change points by modifying vegetation clearing lines, cut slope lines, and even ditch lines. Blend all treatments with existing or planted features to simulate natural forms.

The extent of landscape treatment will vary according to the amount of landscape manipulation and area visibility. The most visible areas should receive the greatest attention. Suggested possible treatments for these sites are plantings, slope molding, and rock cut sculpturing, etc.

To achieve the necessary blending, concentrate much of the landscaping effort near the base of the fill and the top of the cut lines. When planting larger trees, specify them to be placed near the top of the cut slopes or the toe of the fill. Keep them beyond the clear zone and, if required, beyond the snow storage area in snow plowing areas.

On the higher speed rural roadways, plant groupings of one or two tree species can provide adequate treatment. More species diversity along with appropriate groundcover shrubbery is typical in urban planting situations.

b. Earthwork. Design cut and fill slopes not only to satisfy slope stability and balance material quantities but also to improve the appearance of the final project.

Use variable slope ratios for both cut and fill slopes. Avoid using constant slope ratios. The use of slope rounding at the top of cuts is commonplace. Round the ends of cuts and blend the ends of fills into the cut slopes. See Figure 9-10.

When practical, include in the design some slope molding techniques to imitate the existing landscaping elements. Slope molding goes beyond variable slope and rounding concepts. With slope molding, a deliberate attempt is made to break up the uniformity of a finished slope.

On long cut slope faces, lay back the draws and accent the ridges. Warp slopes around existing large boulders and rock outcrops.

In areas of natural draws, lay back or flatten the cut slope to match that of the draw. This only generates a small amount of additional material and greatly enhances the appearance of the cut slope. This material can be used to flatten fill slopes or mold then into natural land forms common to the project area.

Accent ridges by steepening the slopes and rounding to the maximum extent practicable. Naturally, stable slopes are a basic consideration on any slope treatment so the steepening should not exceed geotechnical recommendations.

On large cuts, the lay back the draws and accent the ridges technique may not work. The use of false draws and ridges to break up the slopes may be required, although this technique could cause a substantial increase in the roadway excavation unless the material is stable at relatively steep slopes.

c. Rock Work. On many projects with long, high rock slopes, the cooperating agencies may not permit presplitting along one face or along a number of benched faces. The demand is for a more natural appearing rock face that will be compatible with the natural existing rock faces in the area.

Rock cuts can be designed to produce a staggered bench effect which will reflect natural terrain and accent natural fracture lines in the rock. When presplitting is necessary to stabilize the rock slopes, the use of staggered benches will break up the vertical drill scars.

Where slope stability is not a factor, nonpresplit blasting techniques will expose the natural rock fractures. In some instances, this produces the most pleasing results.

Where practical, design planting pockets or benches in the slopes for the introduction of plant material. It is desirable to spread topsoil on all rock benches to encourage grass growth and minimize the visual scar through revegetation. The planting of trees and shrubs will aid in reducing the size and scale of the rock cuts.

d. Clearing Techniques. In heavily forested areas, usual clearing techniques may leave a vertical wall of vegetation at the tops of cuts and toes of fills. In these cases, selective thinning methods will produce a softer edge by cutting out taller old trees in favor of younger ones. The object is to produce a natural forest edge effect.

Selective thinning methods combined within scalloped clearing lines and vista clearing to promote and frame scenic views will enhance the natural beauty of any project. There is, however, a point where excessive clearing is not beneficial. In some areas, the emphasis should be on bringing the forest as close to the roadway as safety permits. A balance is needed that emphasizes vegetation patterns above and below the highway slope.

e. Revegetation. Revegetated slopes are not only pleasing to view but are stabilized and require little or no maintenance. Re-established vegetation is also important as cover and food for wildlife.

Select grass seed that is native to or adaptable to the area. The seed mixture should satisfy criteria for elevation and slope exposure changes. Several seed mixtures may be required to satisfy all conditions on a relatively long project. Use soil mulches and netting to stabilize and protect the ground until grass is established.

Where practical, conserve topsoil from the project limits and replace it on the finished slopes. The topsoil not only provides needed fertility and a growing medium for grasses, it contains an abundance of native seeds. These forbs, weeds, and grasses usually grow fast and dense and will blend in with the undisturbed vegetation which effectively brings the background vegetation onto the cut slope.

Shrubs and trees can be planted to primarily beautify the disturbed roadside areas and blend them into the undisturbed areas. Using hydrophilic shrubs, such as willow and birch, grouped in areas of excess soil moisture will aid in stabilizing the area. Locate all plant groupings in areas most visible to the motorist.

It is FHWA and FLHO policy that at least one-quarter of 1 percent of funds expended for landscape projects be used to plant native wildflowers, except in ornamental landscapes, or unless a waiver is granted by the Division Engineer.

An ornamental landscape is one that is irrigated, has barked shrub beds, and has irrigated grass that is routinely mowed.

Requests for waivers can only be granted for the following conditions:

- Wildflowers cannot be satisfactorily grown.
- The available right-of-way is to be used for agricultural purposes.
- There are no suitable available planting areas.
- The planting poses a threat to endangered or rare plant species.

A waiver shall be documented with adequate justification in support of all findings and conclusions.

Erosion control seeding is not a landscape item although wildflower seeding associated with the erosion control seeding mix can satisfy wildflower seeding requirements in a landscape project.

In order for wildflowers to perpetuate themselves, they must be permitted to go to seed and become dormant. Identify on the plans all areas to be seeded with wildflowers. Provide in the contract for the installation of suitable markers to identify the wildflower seed beds for roadside management and maintenance personnel.

f. Slope Treatment. This technique consists of placing boulders, stumps, and old logs on cut and fill slopes to represent existing conditions beyond the clearing limits. These items are generally available on the project. Logs and stumps can be randomly staked to approximate a natural scattering on an adjacent slope. Boulders can be placed individually or in clusters. They are usually worked into the slopes to appear as natural outcroppings.

G. Right-of-Way and Utilities. This section ideals with determining right-of-way needs, acquisition of right-of-way, provisions for moving or accommodating utilities, right-of-way and utility plans, and acquisition of material sources.

Since the Federal Lands Highway Division offices work with so many different roadway owners and operating agencies, only general guidelines are provided. It is not practical to prescribe detailed procedures and methods applicable to all situations relating to right-of-way, utilities, and material sources.

1. Right-of-Way. The land that a highway occupies is the right-of-way (R/W). It consists of the land owned by the operating agency or land that the operating agency has a right to use for roadway purposes.

The right-of-way plans are official documents used to acquire real estate and property rights. The plans are often references for legal instruments such as deeds or other documents conveying land or interest in land to various parties. The R/W staff assembles data and prepares plans for the acquisition of R/W, including easements, permits, or any other substantiating documentation necessary. The final plans must be correct from the engineering standpoint and meet FHWA legal requirements and those of the highway agency acquiring the right-of-way.

a. Determining Needs. There is a basic conflict between the use of land for right-of-way and other uses. The R/W should provide for maintenance, control of access, utilities, future widening, and control of adjacent drainage and vegetation for ensuring sight distance and aesthetics. The same land is often desirable for dwellings, farming, commercial, or recreational purposes. Hence, a right-of-way is seldom ideal but is usually a compromise.

Establishing right-of-way widths can usually begin as soon as the earthwork design is substantially completed. The minimum R/W width is the horizontal distance from the centerline to the edge of clearing. It is always desirable to provide some additional area to accommodate minor changes in construction and to provide space for normal maintenance operations.

The clear zone recovery area should receive consideration when establishing new R/W limits. Good engineering judgment is essential in this area to determine when taking a prudent right-of-way equals the need for a portion of the theoretical recovery area.

It is not mandatory to provide right-of-way for new utilities. However, it is the usual practice to accommodate them when they do not conflict with the primary function of the roadway. Construction often causes the relocation of utilities located within the existing right-of-way. It is a requirement that the new right-of-way must provide areas for their relocation.

Poles or other surface utility relocations should be beyond the clear zone area or behind guardrail. Place underground utilities in the road shoulder, beneath the ditch, or preferably outside the right-of-way line. Pole lines usually require a minimum of 5 meters of width to accommodate the cross arm and anchor systems and to provide for control of vegetation under the wires.

Sometimes there is a need to have drainage control structures, channel changes, riprap, stilling pools, etc., constructed above or below the roadway. It is desirable to have these structures within the right-of-way so there is no question of the right to maintain or rebuild them. The R/W should extend at least 3 meters beyond these facilities. It is preferable to obtain right-of-way to cover these installations but in some cases a construction easement may suffice.

States, counties, and other cooperating agencies generally have standard widths for highway right-of-way. Contact the highway operating agency to determine the standard minimum widths and any other applicable criteria.

b. Right-of-Way Widths. Following the placement of slope limits on the detail map, work can begin on setting R/W limits. This assumes the designer knows the standard minimum widths and the desirable distance from the clearing limit to the R/W line.

The designer should keep the following in mind when establishing the final limits:

- It is desirable to have a uniform R/W width through each ownership for ease in locating fences and describing R/W.

- It is desirable to keep changes of R/W width to a minimum. Consider keeping the minimum length of constant width along centerline to 60 meters. Change widths when the right-of-way width needs changes by more than 5 meters over a length of 60 meters.

- Change R/W widths at property lines, if practical, to simplify legal description of right-of-way.

- Change R/W widths at even stations or at curve points. To make a symmetrical fence line, it may be necessary to change widths at 20 meter points or other odd stationing.

- Changes in width should taper from point to point except at property lines. Use a minimum of 15 meters, preferably 30 meters, along the centerline to avoid abrupt angles in the right-of-way line. This makes it easier to build and maintain right-of-way fences, and to mow and care for right-of-way plantings.

- Provide stopping sight distances at intersecting road approaches and provide R/W to maintain these sight distances. This is mandatory at all grade crossings of railroads.

c. Right-of-Way Plans. A State or cooperating agency acquires almost all right-of-way for Federal road projects. As such, the format for right-of-way plans varies between the different acquisition agencies.

In some instances the cooperators prefer to prepare their own right-of-way plans and only require a completed detail map with slope limits and all known property ties. In other areas, Federal Lands Highway Division offices are responsible for preparing complete and detailed plans in the precise format required by the agency responsible for the acquisition of right-of-way. The following guidelines and recommendations cover the preparation of plans.

Before developing the R/W plans, obtain title reports, copies of deeds and any other documents about existing right-of-way. In some cases the acquisition agency will perform this function.

Examine the documents for easements or other encumbrances to reveal the existence and location of waterlines, conduits, drainage or irrigation lines, or other features affecting construction.

The relocation plan prepared during the conceptual stage is available to the right-of-way designer for information and implementation when it is applicable to the project. If the plan is outdated or significant changes have occurred within the project corridor, it may be necessary to prepare a supplemental relocation study. The study should show how occupancy needs are to be correlated with specific available and suitable housing. Usually the R/W designer can request this information from the State or cooperator by working through the appropriate FHWA Federal-aid Division Office.

Resolving the right-of-way plan format and obtaining current title reports and other documentation opens the way to preparation of the actual right-of-way plans. Completed right-of-way plans generally consist of 4 elements (see Exhibits 9.11 through 9.14):

- Title Sheet.
- Tabulation of Properties.
- Vicinity Map and/or Ownership Map.
- Right-of-Way Plan Sheets.

The basic information required on all R/W plans is found in FAPG NS 23 CFR 630.B. The following supplements the instructions in the FAPG.

A standard construction type of title sheet, modified to reflect R/W criteria, may be used provided it is acceptable to the acquisition agency. All the information that normally shows on a construction title sheet can appear on the R/W title sheet.

Most projects require a vicinity map or total ownership parcel map. The map scale used should be suitable to show the entire project on one plan sheet. It should also show general information to depict the project in relation to surrounding communities, public and private road systems, and other local features.

Many States use the vicinity map to show ownerships and parcel numbers. This is often shown in tabular form with column headings as follows:

- Parcel Numbers.
- Recorded Owner.
- Total Assessed Ownership.
- Right-of-Way Required.
- Existing Right-of-Way.
- Remainder (Left and Right).
- Easements (Permanent and Temporary).

Minor variations of this tabular format will occur depending on the acquisition agency's practices, but the column headings shown seem to be consistent with most agency policies. It is usually permissible to place the parcel tabulation on a separate plan sheet if the vicinity map becomes too detailed. Some agencies show the parcel tabulation on the individual plan sheets rather than the vicinity map. It is difficult to go wrong if the vicinity map follows the format of the applicable agency manual. (This is essentially true if the project is on a county road system or a State system.)

In addition to the requirements of the vicinity map and other right-of-way documents, the following data shall show on the right-of-way plan sheets.

- **Alignment.** Show the base line that legally describes the right-of-way as a continuous solid line for the full length of the project including alignment data. Existing or additional centerlines show as dashed lines with or without alignment data as appropriate. Tie the existing stationing to the new centerline by station and/or bearing equations.

- **Control Features.** In addition to the culture tie requirements of Chapter 5, identify on the plans all Government subdivisions, platted subdivisions, donation land claims, National Park or Forest boundaries, Indian reservations, or farm units.

Show a minimum of one tie from the new highway centerline to an existing and recorded monument or government subdivision, particularly the monument from which the title report originates. Compute the tie to a centerline intersection along the section subdivision line with a station, bearing, and distance to the monument.

Frequently it is necessary to resolve the issue of appropriate evidence of property lines for purposes of right-of-way activities. The property line could be a fence, ditch, partial section boundary (1/16), or the line described in the property deed. Locate, reference and show on the plans all topographic features such as fences, ditches, roads, etc., relating to property usage and boundaries. These topographic features shall be shown on the plans as they actually exist in the field. The property line is determined and designated from this data for right-of-way requirements.

(1) Right-of-Way Details. Right-of-way lines are continuous. These lines cross city streets, county roads, rivers, railroads, etc. and must match adjoining projects.

Show enough detail to describe the R/W for its entire length from a centerline or from a metes and bounds description. Tie any existing R/W retained for the new project and describe it from the new centerline or by metes and bounds description. Ties to a previous center line are not acceptable.

Only deeded land for R/W is always supportable in a court of law. Right-of-way by usage or prescription is in many cases not legally supportable. Therefore, when deeded right-of-way does not exist, neither the existing R/W nor the centerline of the existing road need be tied to the new road alignment and/or the new right-of-way.

Right-of-way widths and centerline stationing shall show at the beginning and ending of each plan sheet, and at all points of change in R/W width. Any easements required outside the R/W must show permit descriptions. These easements will accommodate intersecting roads and streets, land service, access and temporary roads, drainage areas, material storage areas, slope widenings, utilities, railroads, and other special uses.

Show centerline station at the beginning and end of each easement. Mark each easement as temporary (T) or permanent (P). If the easement is irregular in shape, include distance and bearings for writing a description.

Temporary construction easements give permission to use the land for a brief time, such as during construction, etc. Use permanent easements where parties other than the owner need to maintain a right to the land such as a pipeline or an access road.

Assign a parcel number to each recorded ownership for properties involved on each project. This includes all units of government. As a rule, number parcels starting with the first tract crossed by the project and then continue in sequence through to the end of the project.

(2) Access Control. The highway operating agency regulates control of access between a highway facility and all other property. When acquiring access rights, access control lines and all approved points of entry or exit from the traffic lanes must show on the plans. An access control line may or may not be coincident with the right-of-way line. Several types of access control, ranging from minimal to full control, may exist within the project limits.

When the access control agency permits individual road approach entries from adjacent properties, identify them on the plans by symbol or type including stationing, width, and grade.

d. Coordination with Acquisition Agency. Every highway agency responsible for acquiring right-of-way has a format and style that suits their method of operation. The R/W staff should meet with the acquisition agency early in the design process to determine the format and style acceptable to all parties.

The following general topics also merit discussion and resolution during the preparation of the right-of-way plans.

- How should property lines and ownerships show on the plan sheets?

- Can construction plans and R/W plans be combined? For separate right-of-way plans, is it necessary to have profile grade plan sheets? Are Federal-aid plan and profile sheets adequate or are separate sheets necessary?

- What is the policy for need, type, placement, and installation responsibility for R/W fencing?

- When the agency acquiring the right-of-way is also responsible for utility relocation agreements, what additional requirements are necessary to complete the plans?

- What is the process for modifying R/W plans after the acquisition agency has given final approval to the plans?

Sometimes the cooperating agency requests FHWA to furnish descriptions of the R/W needed. Sometimes the request is for a metes and bounds description. See Exhibit 9.15 for a sample description for parcel No. 9 shown on the R/W plans (Exhibits 9.12, 9.13, and 9.14).

e. Right-of-Way through National Forest Lands. In those cases where the acquisition agency and the Forest Service request that FHWA prepare right-of-way plans over National Forest Lands, the above plan preparation instructions apply. When the cooperator is a State highway agency, the R/W plans should comply with the memorandum of understanding between the State and the Forest Service. When the acquisition agency is a county or other local government entity, the State Highway Agency may assist the county in obtaining the appropriate easement deeds for the highway construction. The process will be expedited and function quite smoothly if the designer coordinates the procedures through the appropriate FHWA Federal-aid Division right-of-way office.

Monumentation of the final right-of-way through National Forest Land, if requested, should be in conformance with the memorandum of understanding between the State and Forest Service.

f. Right-of-Way Acquisition. Right-of-way acquisition shall be in accordance with the Uniform Relocation Assistance and Real Property Acquisition Policies Act of 1970.

Send the final right-of-way plans and supporting documentation to the agency responsible for acquiring the right-of-way and request them to proceed with the acquisition process. Although not mandatory, it is desirable that the plans and request for acquisition be sent through the appropriate FHWA Division Administrator.

It is also desirable to hold a field review of the right-of-way as proposed. All attending parties should resolve responsibility and timing for the various R/W clearance activities. Discuss the schedule for clearances, monitoring activities, contact personnel, delegation of authority, and related matters and record the decisions from the field review.

Upon receipt of the right-of-way agreements from the acquisition agency, the right-of-way designer shall see that all negotiated items such as fences, cattleguards, road approaches, building relocations, etc. are properly noted on the construction plans and rough draft special contract requirements prepared.

When the State or other cooperating agency cannot obtain the R/W by purchase, it is often obtained by condemnation under the right of eminent domain. This is a time-consuming procedure as well as one having some legal ramifications. Therefore, when the State or cooperating agency reports that condemnation is likely, the designer shall review the plans for possible line shifts or other modifications to eliminate the need for condemnation.

When right-of-way is condemned, the usual procedure is to get a right-of-entry to the land by a court ordered declaration of taking so construction can proceed. The court will determine (1) if the need for the right-of-way exists, (2) if its use will serve a public purpose, and (3) that the landowner receives payment for the land. The court requires the taking agency to post funds with the court equal to the estimated value of the property. At a later time the court, usually by jury trial, determines the value of the right-of-way and requires the taking agency to pay this sum to the landowner. The court then transfers title of the right-of-way to the taking agency by court order.

In these cases the designer will record the status of the R/W as being under condemnation and will not approve the project for construction without at least a right-of-entry document.

For projects requiring a housing or business relocation, obtain a statement from the State or cooperating agency that relocation assistance was provided or tendered. This procedure is mandatory and is normally part of the right-of-way certification furnished by the acquiring agency.

Construction easements grant the right to construct supporting elements of the project outside the normal right-of-way on private land. The State or cooperating agency acquires them in the same manner as right-of-way.

Often there is the need for a construction easement after the project is underway. In these cases the project engineer may work with the designer to document the need for the construction easement and to locate it. The designer prepares a description of the construction easement and requests the State or cooperating agency to obtain it.

FHWA may obtain some construction easements (such as for temporary haul roads, stockpile sites or material sources) directly from a landowner. These are special cases and are done only when the cost to FHWA would be the same or less than if obtained by the State or cooperating agency.

2. Utilities. FAPG CFR 645A and FAPG CFR 645B provide policy and guidelines on adjustments to utilities. The highway operating agencies have various degrees of authority to designate and to control the use of R/W acquired for public highway purposes. Their authorities depend upon State laws or regulations. Utilities also have various degrees of authority to install their lines and facilities on the R/W.

The general policy is that utilities can occupy the right-of-way if they do not conflict with the integrity, operational safety, or functional and aesthetic quality of the highway facility.

The term utility shall mean all privately, publicly, or cooperatively owned lines, facilities, and systems for producing, transmitting or distributing communications, power, heat, petroleum products, water, steam, waste and storm water not connected with highway drainage. Other services that directly or indirectly serve the public and are also considered utilities include cable television, fire and police signal systems, and street lighting systems. It shall also mean the utility company inclusive of any wholly owned or controlled subsidiary.

When irrigation districts or companies do work at Federal expense, treat them as utilities.

a. Determining Relocation Need. The initial contact made with the utility company by the R/W staff is in the form of a letter shortly after the design work begins. The letter must outline the proposed construction project, its length, termini, and other pertinent information that could affect the utility company, such as a tentative construction schedule. In some cases a small scale map may be helpful for describing project limits.

The utility companies should provide, when requested, plat maps of the project area showing the location of all existing facilities above and below the ground level. The letter of request should also state that the utility company will receive construction plans later, showing existing utility facilities.

The designer will note the following types of utility conflicts during the design:

- Those utilities that are in the way of actual road construction. These could be poles or buried facilities within the construction limits or buried lines exposed or damaged by construction operations.

- All hazardous utility objects above groundline within the desirable clear zone. Those objects within the clear zone but located in back of nontraversable cut slopes, behind guardrail or impact attenuators, or having breakaway features may not require relocation.

- Any utility installation not conforming to the aesthetic quality desired in the appearance of the highway and its environment.

b. Determining Responsibility for Utility Relocation. When the alignment and grade are firm, the designer shall check the plans and outline the utilities that may require relocation or adjustment.

The plans indicate responsibility for the utility adjustments. This could be Government, utility, or a combination.

When determining the responsibility for utility adjustments, identify each utility conflict on the preliminary plans. Color coding and/or symbols can be helpful in making proper identifications. A tabulation sheet showing conflicts by utility companies will help the designer as shown in Exhibit 9.16.

Determine financial responsibility using these guides:

- When the utility occupies the existing highway right-of-way, the Government's share of relocation cost is set out in applicable State law. This ranges from zero percent in most states to up to 100 percent in a few States.

- When the utility occupies Government land such as that administered by the Forest Service, National Parks, Bureau of Land Management, etc., all relocation cost is usually borne by the utility. This requires checking with the land management agency as there are cases when the utility has occupancy rights that require the Government to share in the cost of adjustment.

  After establishing financial responsibility, the designer shows on the preliminary plans the method used to make the required utility adjustment. One way to accomplish this is to show on the plans at each location where conflict exists, the following information:

- Identify who is to move the facility (utility company, FHWA, State, etc.).

- Identify location (stationing, left or right of centerline).

- Identify who will pay for the relocation (utility company, FHWA, State, etc.).

A system of symbols can show the same information. In addition, some method of noting joint use of utilities (i.e., power and telephone lines on the same poles) is desirable for use on the plans.

There will also be cases where the utility move will be a combination of utility and Government expense. This covers instances where the utility is on existing R/W and would only need to move a short distance for construction purposes. However, FHWA wants them to move a greater distance for other purposes such as aesthetics or clear zone requirements.

The plans developed for construction or R/W may be adequate for utility plans. The essential information needed on utility plans includes the following:

- Centerline.
- Construction limits.
- Existing and proposed right-of-way.
- Edge of existing road.
- All utility installations.
- Easement, permit, and utility ownership data.
- Depths of underground facilities and elevations of all crossing wires less than 13 meters in height from the proposed grade line.
- The proposed utility construction necessitated by the highway improvement project.

Send a letter and plans to the utility companies inviting them to a field inspection. See Exhibit 9.17 for a sample of a letter to a utility company.

It may be prudent to provide the utility companies with a copy of FAPG CFR 645A and FAPG CFR 645B along with the preliminary plans. This is particularly true if the utility is a local entity and not familiar with their rights and obligations under FHWA policy and procedure.

In each letter inviting the utility companies to a field inspection, insert the following paragraph:

> Your company's preliminary engineering costs for plan preparation and estimating costs of the utilities to be removed, adjusted, or relocated at FHWA expense are eligible for reimbursement after date of this letter.

At the field review with the utility company's representative, discuss the following areas of mutual interest and resolve any conflicts (such as the following) to the extent possible.

- Are all the utilities requiring adjustment shown on the plans?
- Has the financial responsibility for the utility adjustment been mutually determined?
- Will the utility build the new relocated facility before cutting the existing one or can service be discontinued until the existing facility is moved to its new location?
- How long will it take to move the utility?
- What advance notice does the utility require before it performs the work? (The ideal situation is to have all utility adjustments completed in advance of roadway construction.)
- Do requirements for traffic control plans conform to the applicable standards in the MUTCD ?
- Is there evidence of the utility company's right-of-occupancy?

The designer shall document oral agreements made at the field review. The report should note the name and organization of those in attendance, the names of contacts during development of the utility plan, and any problems pertaining to facility relocations. The utility should receive a copy of the report.

Invite the highway agency responsible for permitting the utility to use a portion of the right-of-way to all field reviews and keep them informed of all developments. When the utility is on government land, involve the administrating agency in the utility relocation.

Following the field review, work with the utility's representative to determine the adequacy, practicality, and economic reasonableness of the portion of the relocation eligible for reimbursement by FHWA. This involves checking the utilities' relocation plans and reviewing their work estimate for accuracy and cost effectiveness.

The evidence of the right of occupancy submitted by the utility requires a check to determine its validity. The evidence may be a letter giving the numbers and/or identifying the use permit or a statement that the utilities are on private right-of-way or easements. If there is any question, check the permits through the applicable agency. The utility right-of-way easement over private property can be checked through the county records of deeds or assessments.

On approval of the utility relocation plan, the designer will transfer the information onto reproducible plan sheets to make copies for the utility agreement, if applicable.

The Government requires a utility agreement when any portion of the relocation costs are eligible for reimbursement. When the relocation costs are borne by the utility, the R/W staff will furnish plans, coordinate activities, and review the utility's proposal for compatibility with construction and safety requirements.

A utility agreement is a three part document consisting of the following:

- Utility Project Agreement Form
- Cost Estimate
- Plan Sheets

See Exhibit 9.18 for a sample format of a utility project agreement. The sample covers most types of relocation possibilities. Select those clauses applicable to the project specific relocation work.

When the rough draft of the agreement is complete, obtain the contract number from Planning and Coordination and request that they obligate the required funds. When notified that funding is clear, complete the preliminary agreement including cost estimate and plans.

Send a copy of the utility package (include occupancy permits, when applicable) to the cooperating agency with responsibility for its use. The responsible agency is usually the State highway organization or the county. When the relocated utilities fall within the Forest Service boundaries, send a copy to the Forest Supervisor's Office for review. The FHWA Division Office may want the opportunity to review the package to ensure that the proposal does not conflict with policy agreed to with the State.

When all the review comments are resolved, complete the final agreement package. The original and two copies of the final agreement requires signatures before they can be forwarded to the utility. The utility should return two signed copies. Distribute the signed copies and all necessary confirmed copies in accordance with office procedures.

Prepare a utilities packet for the project engineer consisting of the following:

- A copy of the agreement with exhibits.

- Copies of letters or memoranda dealing with the utilities.

- Copies of reports of field trips or meetings.

- Discussions of procedures or actions needed, such as traffic control, disruption of service, coordination of contractor and utility company operations, safety, etc.

The utilities packet is given to the appropriate construction staff for forwarding to the project engineer.

The construction unit is responsible for verifying the utilities work. When the utility performs the work before the award of the contract, the R/W unit is responsible.

After completion of the utility relocation and Government verification of the work, make final payment to the utility company, and record the work.

c. Location. Locate facilities to minimize the need for utility adjustment on future highway improvements. Avoid interference with highway maintenance and permit access to the facilities for their maintenance with minimum interference to highway traffic. Always consider clear zone requirements when making utility adjustments.

Locate facilities on uniform alignment as near as practical to the R/W line. On frontage roads, locate the facilities so that servicing may be performed from the frontage road.

Place facilities crossing the highway approximately at right angles to the highway alignment whenever possible--and preferably under the highway.

d. Retention of Existing Facilities. Under certain conditions, AASHTO policy permits existing facilities encountered during highway construction to remain in place. Facilities deviating from this policy may remain on the highway right-of-way when it is in the public interest and will not adversely affect the highway or its users. Any such retention will be with the understanding that compliance is mandatory when the facility is reconstructed.

When accident history or safety studies show that existing facilities are hazardous, relocate or shield them regardless of prior agreements with the utility. Changes in operating conditions of existing facilities, other than for routine maintenance, require a new permit from the highway operating agency before initiating such work or change.

e. Aesthetic Controls. If practical, place cluttered overhead facilities underground. The design of facilities should minimize any adverse visual impact and should be planned to preserve attractive landscapes.

New utility installations, including those needed for highway purposes, are not permitted on highway right-of-way or other lands acquired by or improved with Federal funds within or adjacent to areas of scenic enhancement and natural beauty. Such areas include public park and recreational lands, wildlife and waterfowl refuges, historic sites as described in 23 USC 138, scenic strips, overlooks, rest areas and landscaped areas.

New underground utility installations must not cause the extensive removal or alteration of trees visible to the highway user or impair the visual quality of the area.

Avoid new aerial installations unless there is no feasible and prudent alternative to the use of such lands and only if the following can be established:

(1) Other utility locations are not available, are unusually difficult, are unreasonably costly, or are less desirable from the standpoint of visual quality.

(2) Underground installations are not technically or economically prudent or are more detrimental to the visual quality of the area.

(3) The location and installation of the proposed facility will not significantly detract from the visual qualities of the area being traversed. The facility will employ suitable designs and materials to enhance aesthetic values.

No service connections shall cross freeways when a distribution line is available within a reasonable distance on the same side of the highway as the premises being served. Keep crossings of other highways and streets to a minimum.

Facilities to be located on or across highways having easements, such as through Forest Service land, Bureau of Land Management land, railroad land, etc., require the approval of those agencies.

f. Utility Installations on Highway Structures. Avoid utility attachments to bridge structures whenever possible due to a potentially negative effect on safe traffic operation, efficiency of maintenance, and appearance. In those cases where alternate locations are not practical, the method of attachment should meet the following requirements:

- Make sure the bridge design is adequate to support the additional load and accommodate the utility without compromise to highway features, including maintenance.

- Do not allow manholes in the deck.

- Locate the utility beneath the deck between outer girders or beams or within a cell in a position that provides adequate vertical clearance. Avoid any attachments to the outside of bridges.

- Attachments made by support rollers, saddles or hangers are acceptable when padded or coated to muffle vibration noise. Make attachments below the deck but do not allow bolting through the bridge floor. The design of the attachment device requires review and approval before installation by the bridge unit.

- Pipes and conduits carried through abutments should be sleeved and tightly sealed with mastic. Upon leaving the bridge, align the utility to the outside of the roadway in as short a distance as practical.

- Provide for linear expansion and contraction due to temperature variation by use of line bends or expansion couplings.

- Provide for shut-off valves, either manual or automatic, at or near ends of structures to provide a means of control in case of emergency.

- Provide suitable protection to prevent corrosion.

- When a pipeline is cased, vent the casing at each end to prevent possible buildup of pressure and to detect leakage of gases and fluids.

- When a pipeline attachment to a bridge is not cased, additional protective measures should be taken. Such measures include using a higher factor of safety in the design and construction and testing of the pipeline than would normally apply for cased construction.

- Communication and electric power line attachments should be suitably insulated, grounded, and preferably carried in protective conduit or pipe from the point of exit from the ground to the point of reentry. Carrier pipe and casing pipe should be suitably insulated from electric power line attachments.

g. Overhead Power and Communication Lines. In rural areas or on urban highway sections having the same design standards and other characteristics of rural highways, above ground facilities shall be located outside the clear zone. When circumstances warrant a lesser distance, facilities installed closer than other roadside appurtenances are not acceptable. It is ideal to locate all fixtures as near as possible to the right-of-way line.

A variance to maintain a reasonably uniform pole alignment is allowable when irregularly shaped portions of the R/W extend beyond the normal R/W limits. Excepted from these controls are poles or other ground-mounted appurtenances required for highway lighting. However, where possible, such poles and appurtenances shall be serviced by underground cable and designed to include a breakaway pole.

Where R/W is not sufficient to allow installation beyond the clear zone, place the facilities to minimize the hazard to an out-of-control vehicle (such as behind the guardrail).

On urban sections with posted speed limits of 35 mph or less, it may not be practical to locate poles and ground-mounted appurtenances beyond the curb or to protect them with guardrail. However, locate the facilities as far as practical behind the curb or outside the shoulder and/or parking area if there is no curb.

Minimum vertical clearance for conductors shall meet the requirements of the National Electrical Safety Code or applicable local codes. When codes conflict, use the code requiring the greater clearance.

h. Underground Electric Power and Communication Lines. Longitudinal installations located within the foreslope limits are acceptable. This is true only if an installation outside the ditch line would be extremely difficult or costly; or if the highway traverses a scenic area where an aerial installation would detract from the view; or if placing buried cable beyond the ditch line would require removal of trees and shrubs.

Locate installations placed within the foreslope limits a uniform distance from the pavement edge and as near as practical to the inside edge of the ditch. Do not place buried cable within 600 millimeters of a ditch line. The installation shall normally be as near to the right-of-way line as practical while maintaining a uniform distance from the highway centerline.

Locate all crossings as normal to the highway alignment as practical. Avoid crossings in deep cuts, near footings of structures, at-grade intersections or ramp terminals, at cross drains, and in wet rocky terrain.

Pedestals or service poles installed as part of a buried installation generally are placed 300 millimeters from the right-of-way line. Never locate pedestals within the highway maintenance operating area (including mowing operations).

Lines (cables) without encasement require a minimum bury depth of 750 millimeters, except to clear an obstruction such as a drainage facility. Then the depth may be reduced to 600 millimeters. Encased lines buried less than 600 millimeters are acceptable provided the encasement does not protrude into roadway base course materials. Encasement and installation shall conform to the applicable cooperator and/or utility company provisions.

Identify all buried cable locations by placing standard warning signs (markers) at the R/W lines for the crossings. Longitudinal installations require markers at appropriate intervals; however, for electric power cables, this interval shall not exceed 150 meters. The markers shall be offset as near the R/W line as practical.

i. Irrigation and Drainage Pipes, Ditches, and Canals. Bury irrigation line and pipe siphon crossings from right-of-way line to right-of-way line or from edge of clear zone to edge of clear zone, whichever is greater.

When crossing a roadway, water canals and irrigation ditches can pass through culverts or bridges. Open canals or ditches should not parallel highways within the clear zone. It is preferable to locate these outside the right-of-way limits.

3. Railroad Encroachments. The processing of railroad agreements and the preparation of plans for railroad encroachment projects usually are time consuming operations. The designer should initiate this process at an early stage to avoid delaying the development of the project.

Railroad agreements are three party documents between the cooperating highway agency, the affected railroad company and Federal Lands Highway Division. The responsibilities and obligations of each party must be spelled out in detail in the jointly signed agreement. There is no rigid format for preparation of the agreement but items needed in every agreement are spelled out in FAPG 23 CFR 646B.

In general, R/W is not acquired in fee from a railroad company. Instead, the highway operating agency acquires easements, access rights, temporary easements, encroachments, etc. for highway construction.

The cooperating highway agency or the affected railroad may prepare the actual agreement. However, it requires review and approval by all three parties. When it is agreeable to all parties, the construction may proceed on the basis of a right-of-entry permit with the actual details of formal agreement being resolved during the construction phase.

Each State usually has a procedure and guide to clear their projects through the appropriate railroad channels. The designer should contact the cooperating highway agency for additional guidance.

a. Pre-Survey. It is best to define the scope of the project by conducting an on-ground joint inspection of the site with railroad engineering staff, the State or highway operating agency, and other interested parties before starting a survey.

If possible, obtain a recent railroad map of the site indicating railroad right-of-way for the meeting.

This review should clarify other railroad company policies on these topics:

- The closest encroachment to the centerline of tracks permitted.
- Sight triangles.
- Traffic maintenance (detours).
- Drainage, bank protection, or other conditions to be encountered on the proposed highway location.
- Railroad work schedules.

b. Cross Sections. When a highway encroaches on railroad right-of-way, extend the cross sections across the railroad tracks at sufficient intervals to show the relationship between the finished highway grade and the railroad tracks. Have the cross sections taken in critical areas of the greatest encroachment and elevations taken at the top of rail.

Cross section each railroad structure and record the type of structure, the opening length, and other information for comparison with railroad map. This information will help determine whether the structure needs extending or replacing.

The survey should tie all railroad or other utility poles and any facilities located on the railroad right-of-way that could affect the design. Proposed utility adjustments shall show along with their ownership. Show all utility poles and vertical clearance of utility lines at grade crossings.

c. Horizontal Alignment. The designer locates highway centerline in the same manner as any other location with the following modifications.

- Show ties to the centerline of the railroad company's main track at each end of the encroachment area and at the beginning and the ends of the curves on the railroad. With this information, compute the bearings of the railroad tangents using highway data.

- Accurately locate railroad facilities such as head blocks, front face of buildings (depot, etc.), drainage structures, and bridges so that stationing will check with railroad plans.

- When the proposed highway crosses over the railroad centerline, make a tie showing highway station reference and railroad station reference with the angular tie between the two. Take a cross section at the intersection of the highway and railroad centerlines.

d. Vertical Alignment. In most cases the profile of the highway project will satisfy railroad requirements. However, at crossings take the top of the rail elevation at centerline and edge of proposed roadway for each rail. This allows easy correlation between highway finished grade at the centerline of the railroad with the railroad elevation at the intersection.

For a highway grade separation structure located above a railroad, obtain the following data:

- Railroad alignment data (all tracks).

- Elevation of top of rail for each track system at centerline of highway.

- Profile of each rail (top) for 150 meters each side of highway centerline.

e. Plan and Profile Sheets. The railroad stationing and curve data (including beginning and ending of the curves through areas affected by encroachment or crossing) shall show on the highway plans.

Show on the plans all railroad and highway right-of-way lines and widths, including easements. Compute the ties at right angles from the highway centerline and show all intersecting corners of the right-of-way. Show the ties at the beginning and the end of each encroachment and at the points of maximum encroachment.

Show all railroad drainage structures and other topographic data pertaining to railroad buildings, head blocks, and other points of control.

Furnish profiles for proposed special drainage or waterway channels to give the railroad company a more complete picture.

An adjustment in the railroad line, such as raising or lowering tracks to accommodate highway construction, is occasionally necessary. In this case a special profile along the railroad alignment will show the full extent of the raising or lowering of tracks. Carry the profile a sufficient distance outside of the adjusted area to give a complete picture of the proposed adjustment.

For a new crossing of the railroad tracks, prepare a special profile on either side of the crossing along the track centerline for several hundred meters.

f. Cross Section Plots. Cross section plots prepared in elaborate detail are not necessary. However, for highways encroaching on railroad property, it is advisable to show all the data obtained in the field.

Computer generated plots are acceptable with the possible exception of partial sections for drainage and approach design. For drainage sections, furnish elevations for inlets and outlets of pipe as well as channel elevations upstream and downstream. Show size and length of all drainage or other type structures in existence and proposed on the new construction.

Show railroad and highway information, including superelevation and widening where applicable.

The cross sections are usually plotted on standard reproducible cross-section paper. Maintain ample space between cross sections to ensure legibility.

Show the railroad right-of-way lines on all cross sections. Make sure the distance shown on the cross section from the encroachment line to the railroad right-of-way will check the field ties shown on the plan sheet.

Show the railroad and highway culverts on the cross sections and include the flow line elevations. This allows the consideration of extensions rather than relaying an existing pipe or installing a new one.

Some projects require slope permits or ditch easements in addition to the regular encroachment. In these cases, the cross sections shall show the railroad right-of-way line, the easement line, and the sloping permit or channel change line.

When raising or lowering a railroad track is necessary for highway construction, plot cross sections along the centerline of railroad tracks through the area affected.

g. Final Assembly. Forward the completed plans, profiles, cross-section rolls, and structure clearance, if applicable, to the owner agency and request their review and comments. A request to begin preparation of the formal agreement can accompany this submittal.

The final PS&E package review should ensure that the contract contains all conditions listed in the approved railroad agreement.

4. Railroad Grade Crossings. Before designing improvements of existing crossings or new crossings, arrange for a field inspection of the crossing site. The review should involve appropriate Federal, State, local, and railroad representatives.

The review should resolve financial responsibility, scheduling, and authorization to proceed with the work. The type, number and location of railroad signals to be installed should also be determined.

All utilities (both aerial and buried) in possible conflict with the proposed installation shall be noted, including facilities interfering with the proposed railroad signals or gate installations requiring adjustments. In some instances it may be preferable to adjust the location of the railroad signals. Consider any proposed future highway widening project when determining placement of the signals.

Photographs taken during a field inspection are very helpful during the design phase of the project.

The function of traffic control systems is to permit safe and efficient operation of railroad and highway traffic crossings.

A Passive Traffic Control System includes signing, pavement markings and grade crossing illumination. Signing used at railroad grade crossings should include the following:

- A railroad crossing sign, commonly identified as the crossbuck sign. The railroad is responsible for placement and maintenance of crossbuck signs.

- An auxiliary railroad crossing sign of an inverted T shape mounted below the crossbuck sign to show the number of tracks when two or more tracks are between the signs.

- An advance railroad warning sign.

- An exempt railroad crossing sign as a supplemental sign (when authorized by law or regulation) mounted below the crossbuck and railroad advance warning signs.

- A "do not stop on tracks" sign.

Pavement markings placed in advance of a grade crossing on all paved approaches shall consist of railroad pavement markings, "no passing" markings (two-lane roads), and stopping lanes (if needed).

Illumination of railroad crossings supplements other traffic control devices for nighttime railroad operations. Consider lighting where train speeds are low, where crossings become blocked for long periods, or where accident history shows that motorists experience difficulty in seeing trains or control devices at night.

Signals consist of post mounted flashing light signals and cantilever flashing light signals, and, where warranted, the addition of automatic gates. Any of the foregoing may or may not include a bell.

There is no single standard system of active traffic control devices universally applicable for grade crossings. An engineering and traffic investigation determines the type of active traffic control system that is appropriate.

Determine from Table 9-14 the level of crossing protection needed. Use these guides unless they conflict with State standards.

Signal installations will use the signals shown in the current edition of the MUTCD and the Railroad-Highway Grade Crossing Handbook. The locations of signals and automatic gates are shown in the MUTCD.

A railroad signal may be a point hazard that warrants the use of a traffic barrier or a crash cushion. Install all traffic barriers or crash cushions outside the minimum railroad clearance as shown in the MUTCD.

Truck and bus stopping lanes may be required at railroad grade crossings except for the following:

- Any railroad grade crossing where a police officer or a duly authorized flagger controls traffic.

- Any railroad grade crossing where a traffic control signal regulates traffic.
- Any railroad grade crossing protected by signals, with or without an automatic gate.
- Any signed railroad grade crossing exempt under State law.

The stopping lane geometrics shall consist of the following:

- The approach taper to the stopping lane shall be 50 meters long and the width may vary from 0 to 3.6 meters.
- The length of the full width stopping lane shall be 30 meters in advance of the centerline of the first set of tracks to 25 meters beyond the last set of tracks.
- The acceleration taper shall be 60 meters long and the width shall vary from 3.6 meters (full width) to 0 meters.
- The shoulder along the stopping lane shall be a minimum of 0.9 meters.

The decision to add stopping lanes is made on an individual project-by-project basis after review of the site and after determining legal requirements under the applicable State regulatory authority.

A good smooth surface is an important part of any railroad-highway grade crossing contributes to the safety of crossing vehicles. Typical types of crossing surfaces for railroad/highway grade crossings follow:

- Asphalt concrete.
- Concrete.
- Steel.
- Timber.
- Rubber (elastomeric) panels.
- Linear high density polyethylene modules.
- Epoxy-rubber mix cast-in-place.

Any highway grade crossing lacking a demonstrated need should be obliterated and all traffic control devices and tracks removed.

On the design plans show the basic roadway dimensions of shoulders, medians, traffic lanes, stopping lanes, and acceleration lanes, including pavement marking requirements. Show the angle of crossing, number of tracks, location of signals, and other railway facilities such as signal power lines, signal control boxes, switch control boxes, etc. The name of the railroad and whether the track is a mainline or branch line should be noted.

Sight distance is of primary consideration at grade crossings. The condition at a railroad grade crossing is comparable to that of intersecting highways where a corner sight triangle must be kept clear of obstructions. The desirable corner sight distance arrangement allows a driver approaching the grade crossing to see a train at such a distance that if the train proceeded without slowing down, it would reach the crossing about the time the highway vehicle can brake to a stop in advance of the crossing.

Plan and profile on both the railroad and highway should show for a minimum of 150 meters on both sides of the crossing. Extend the roadway profile as necessary to show all important vertical alignment data. Also show other important features that may affect the design of traffic operation of the crossings. These features include proximity of crossroads or city street intersections, nearby driveways or entrances, highway structures, vehicular ADT (including percentage of trucks and number of school buses), and train ADT.

If the railroad track is superelevated, the highway profile must conform closely to the grade across the top of the rails.

The plans shall show the type of signals proposed, the length of gates and/or cantilever required, and the number of signal heads and their facing direction. Also show the exact location of the signal supports in relation to the railroad and highway centerline. Signal cantilever arms and gates are normally located perpendicular to the roadway centerline. Show all railroad facilities, signal controls, switch boxes, and utility poles on railroad right-of-way in addition to those along the highway right-of-way. Pedestrian gates may be desirable in certain urban areas and need consideration in the design reviews.

Cantilever arms for signals are normally prefabricated in 600 millimeter increments. Determine the arm length for a four-lane road by measuring from the center of the inner lane to the desired support location. Have the end light units on the cantilever and on the pedestal installed back-to-back. Two-lane roadways do not normally require cantilevers except for unusual sight distance problems. All post-mounted lights on two-lane roadways with truck and bus stop lanes should have a cantilever with light units installed back-to-back over the main traffic lane and on the pedestal.

Wooden gate arms are available in lengths up to 13 meters. Fiberglass arms up to 10 meters and aluminum arms up to 12 meters in length are also available. Longer lengths require prior approval by the railroad company involved.

Gates should end 0 to minus 300 millimeters from the centerline of undivided roadways or from the near edgeline of the median on divided roadways.

Never paint two-way turn bays across railroad tracks. They shall end 30 meters from each side of the railroad tracks with barrier striping across the tracks.

A typical section on the plans shall show roadway and lanes widths, pavement markings for centerline, and edge and lane lines. Simple lines for poles, arm, and gate with circles for the required signal heads are acceptable on the typical section. Show the location of signal heads over center of lane, height of cantilevers above roadway, and distance of signal pole from centerline of travelway. Use only approved symbols.

The review of the preliminary plans and the procedure for requesting the cooperating highway agency to obtain the formal agreement for the proposed work is similar to the procedure discussed in 9.4.G.3.

Table 9-14
Guidelines for Railroad Crossing Protection

Type of Highway	Exposure Factor[1]	Type of Railroad Facility: Non-Mainline	Single Mainline (under 100 km/h)	Double Track or High Speed Single Mainline
Two Lane	Under 1500	Reflectorized Signs	Flashing Lights	Flashing Lights
	1500 to 5000	Flashing Lights	Flashing Lights	Flashing Lights
	5000 to 50 000	Auto. Gates[2]	Auto. Gates[2]	Auto. Gates[2]
	Over 50 000	Separation	Separation	Separation
Multilane	Under 50 000	Auto. Gates	Auto. Gates	Auto. Gates
	Over 50 000	Separation	Separation	Separation
All Fully Controlled Access	In all cases	Separation	Separation	Separation

Note:

1. Exposure Factor = Trains per day x vehicle ADT.
2. Automatic Gates to be used in urban areas and flashing lights in rural areas, unless conditions warrant otherwise.

5. Material Source Reclamation Plans. On FLH projects, all government designated material sources, except established commercially operated sources, require rehabilitation under an approved reclamation plan.

The reclamation plan shall set forth measures to return the land to the most appropriate function following use of the source. The site may be reclaimed in a series of stage reclamation efforts when several projects designate the same source. Side borrow sites within the right-of-way do not require a reclamation plan.

The reclamation plan provides that reclamation measures, particularly those relating to control of erosion, be conducted simultaneously with surface mining. When this is not possible, initiate reclamation measures at the earliest possible time after completion or abandonment of mining on any segment of the site area.

The plan would normally include some or all of the following:

- Vicinity map describing site boundaries as shown on the right-of-way or sundry site boundaries and enough information to locate the site on quadrangle or county maps.

- Existing water forms and ground contours. Existing contours are optional unless the design or permit process requires them.

- Proposed finished ground contours and cross sections needed to show finished slopes.

- Statement of the proposed subsequent use of the land. Include any local zoning and planning requirements, any indications of whether the site is intended for use by other contractors or maintenance forces in the future, and whether or not stage reclamation applies. For stage plans, provide interim reclamation measures that ensure an orderly depletion and restoration of the site. Schedule staged use to reclaim the largest possible surface area under the final reclamation plan.

- Manner and type of revegetation and other surface treatment of disturbed areas.

- Preservation or establishment of visual screening and vegetative cover to screen the view of the operation from public highways, public parks, and residential areas.

- Proposed practices to protect adjacent surface resources. This includes prevention of slumping or landslides on adjacent lands.

- Slopes that are blended with adjacent terrain to meet future use requirements. In all cases, provide for adequate safety.

- Method of preventing or eliminating conditions that create a public nuisance, endanger public safety, damage property, or are hazardous to vegetative, animal, fish, or human life in or adjacent to the area.

- Method of controlling contaminants and disposing of surface mining refuse.

- Method of diverting surface waters around the disturbed areas.

- Method of restoring stream channels and stream banks to a condition minimizing erosion, siltation, and other pollution.

- Planned lakes, ponds, or other bodies of water that would be beneficial for residential, recreational, game or wildlife purposes.

- Restoration of any borrow, quarry or pit site. Sites resulting in a lake or wetland shall involve careful planning and shall take into consideration all factors impacting the fauna and flora.

- Proposed stockpiles of 10 000 metric tons or more.
- Permanent buildings and any protective stipulations required.
- Photographs whenever possible.

Federal Lands Highway Division will cooperate with other governmental and private agencies to provide land reclamation of the sites used for the described purposes.

Reclamation plans for sources located on Federal Lands require coordination with and approval by the agency responsible for administration of the land in accordance with the appropriate Memorandum of Understanding.

Reclamation plans for sources on private lands usually require coordination and approval by a State and/or local agency with responsibility for issuing and administering material removal operating permits.

H. Reviews. PS&E development involves various stages of review. The objective of a field review/plan-in-hand inspection is to ensure to the maximum extent practical that the location and design reflect and are consistent with Federal, State and local goals, objectives, and standards.

All cooperating agencies and appropriate Federal Lands Highway Division staff should be invited to each field review. These reviews give the designer the opportunity to present the proposed design to the cooperating agencies and to solicit comments to ensure that the design is being developed in compliance with the intended scope, and social and environmental commitments.

It also gives the designer the opportunity to verify data and check office proposals against field conditions to minimize construction concerns.

Field reviews give cooperating agencies a medium for free and open discussion that encourages early and amicable resolution of controversial issues that may arise during the development of the PS&E package.

The need for a field review to fulfill the stated objective depends on a wide variety of factors that cannot be predetermined even on a project-by-project basis.

The reviews may range from multi-disciplinary and multi-agency inspections to specialized on-the-ground meetings with a single discipline to resolve a specific problem. In all cases, the conclusions reached at the field reviews require documentation and distribution to the interested parties.

The designer will usually be involved in at least three design reviews as follows:

(1) The first review covers the preliminary design and results in approval of the major design features for a project, e.g., horizontal and vertical alignments, typical section, access control, etc.

The information available for this first review ranges from very little to completed detail maps and profiles showing preliminary alignments and plotted cross sections. This strictly depends on the scale of construction proposed, (e.g., RRR to new construction).

At these early reviews, concentrate on resolving roadway geometrics, safety considerations, environmental mitigation efforts, and cost effectiveness of the proposed improvement.

Emphasize any exceptions to standards along with the associated hazards so that the highway operating agency is aware of the ramifications of the decisions.

(2) The second or plan-in-hand design review is to review preliminary plans and specifications for the proposed project. On some projects an intermediate review may not be necessary to complete the design. The primary purpose of this review is to finalize the design elements and other special conditions for inclusion in the PS&E package.

At this second stage the preliminary design should conform with the governing criteria, including input from geotechnical and hydraulic reports, environmental documents, safety requirements, and other matters pertinent to the project. Discuss those items affecting the plans or special contract requirements and make arrangements for obtaining the necessary data.

Following the intermediate design stage, the designer should prepare the final plans, special contract requirements, and complete the engineer's estimate for the project.

(3) The third stage in the process consists of the final plan-in-hand or PS&E review phase. After revising the plans and special contract requirements to show changes from the previous reviews, the PS&E package shall be distributed internally for a final review by staff specialists to ensure consistency with programming, environmental, geotechnical, hydraulics, bridge, or other project requirements. The PS&E package is also to be forwarded to interested agencies for their review and comment. Depending on the thoroughness of the previous reviews, an on-site inspection may or may not be required.

In either case, resolve all comments received concerning the proposal. The end result of this final review phase is the solicitation of the contract package.

I. Plans. Plans consist of a series of drawings containing engineering data about the location, character, and dimensions of the work, including layouts, geometrics, cross sections, structures, and related details. The plans, together with the specifications, shall contain all of the data required for the contractor to submit a bid, stake, and construct the project.

The overall size of plan sheets shall be 864 by 558 millimeters. The standard size plan sheets provide a 70 millimeter margin for the binding on the left edge, a 14 millimeter margin on the right edge, and a 14 millimeter margin on the top and the bottom. This provides an effective sheet size of 780 by 530 millimeters.

Reduced plans should be one-half the full size, or about 432 by 279 millimeters. Reduced plans are generally accepted throughout the highway industry. In some cases plan sheets may be as small as 216 by 432 millimeters.

The organization of a normal set of construction plans is outlined in Section 9.6.A.2. The format for abbreviated plans is not detailed. The designer should consider the expected work and arrange the format accordingly.

1. Bridge Plans. The designer will usually receive a complete set of bridge plans and accompanying draft special contract requirements for insertion into the PS&E assembly. The bridge plans and plan-profile sheets shall be cross-checked to ensure that stationing, gradients, elevations, and other geometric details are identical. The designer shall review the notes on the bridge plans and the draft special contract requirements to eliminate any conflict with other provisions of the contract. Transfer quantities on the bridge plans to the summary sheet and assign item numbers as appropriate. Resolve any differences found during the review and number the bridge plans for insertion into the final package.

2. Standard Drawings. Standard drawings are designed for repetitive use and to provide uniformity of design and construction where the construction details are the same from project to project. Use standard drawings for culverts, minor drainage structures, guardrail and other items as appropriate. Local State Highway Agency standard drawings may be used where Divisions deem their use is more appropriate.

The Federal Lands Highway Office (FLHO) issues standard drawings for use in the Federal Lands Highway programs. Standard drawings, together with the specifications, contain all appropriate information that is necessary to describe the details of the proposed work. The FLHO maintains the standard drawings and supersedes or withdraws those drawings which become obsolete or ineffective.

When a Division office must modify standard drawings for specific projects, they become special drawings and they no longer have typical standard drawing title blocks. To prevent confusion, title blocks for special drawings shall be completely dissimilar to the standard drawing title blocks.

A Division office or FLHO may propose new standard drawings or revisions to existing standard drawings at any time. Division offices shall submit their proposals to the FLHO for consideration as summarized below. When it is determined standard drawings should be developed, adopted, or revised, the FLHO and Divisions will agree upon a responsible Division to perform the preparatory work.

The responsible Division shall develop or modify standard drawings on the CADD system. The responsible Division will then submit proposed new or revised standard drawings to the FLHO. Any special contract requirements for the standard drawings should accompany the distribution. Normally, the submission to the FLHO should include five copies of special contract requirements and five copies of half-size plans. The responsible Division shall also send two copies of each directly to the other FLH Divisions. The memorandum shall request the FLH Divisions to send comments to the FLHO with copies to the other FLH Divisions.

The following process shall be used for approval of proposed new standard drawings and revisions to approved standard drawings:

- The FLHO will make distribution of the proposed new or revised standard drawings to the appropriate headquarters offices and industry with a request for comments.

- Each Division shall furnish comments to the FLHO, with informational copies to the other Divisions.

- The FLHO will consolidate and review the comments from the Divisions and other offices and forward them to the responsible Division with any recommendations.

- Upon disposition of comments, the responsible Division will resubmit the standard drawings to the FLHO. The submissions should include a summary of the disposition of comments. If needed, additional distributions shall be made by the FLHO in accordance with these procedures. If additional distributions are not required, approval shall be given to the responsible Division to finalize and date the title block of the standard drawings. The approval date or revision date to be included on standard drawings shall be provided with the FLHO approval.

- The responsible Division office shall distribute electronic versions for the CADD systems to each Division The responsible Division shall also send the FLHO 2 copies of the 279 mm by 432 mm standard drawings, and an electronic version in a format compatible with WordPerfect.

- The FHLO will distribute a complete list of the standard drawings with the latest appproval or revision dates with the approval memorandum noted above. Each Division shall insure that latest approved standard drawings are identified in their CADD files.

In standard drawings the lettering will be equivalent to upper/lower case FONT 23 excluding titles and subtitles which will be FONT 1. Standard letter size will be equivalent to standard Leroy size 200. Minimum letter size will be equivalent to standard Leroy size 140. Use minimum letter size sparingly to insure clear and readable plans at the reduced scales proposed for one-half size plans and letter sized abbreviated plans. Additional information is available in the CADD users manual.

J. Engineer's Estimate. An engineer's estimate of cost is prepared for each project as part of the PS&E assembly. The estimate serves as the basis of probable construction cost and as a guide to evaluate bidders' proposals.

The estimate is a listing of all items of work in the contract, showing quantity, unit of measurement, unit cost, and total cost of each. The total amount of all items of work, including appropriate incentive payments, makes up the Construction Estimate. Contingencies, construction engineering, project agreement costs, and other costs added to the construction estimate makes up the Program Amount.

When a contract is financed by multiple funds, and expenditure of a fund is limited to a particular section, a separate estimate, summary sheet, and bid schedule are necessary for each section. When a contract is financed by more than one type of fund, but expenditures are not limited to a particular section, only one bid schedule is necessary, supported by a combined estimate and summary sheet.

Each item of work listed in an estimate needs a description and a unique number. Each Federal Lands Highway Division office maintains a current listing of contract items with their respectively assigned descriptions and unique numbers. When the listed contract items are not applicable to the anticipated work, new items with descriptions and unique numbers will be established by the responsible party and furnished to the designer.

The unique numbers assigned to the items of work serve as input into the engineer's estimate program. This program uses the unique numbers as a basis for other related programs such as bid schedule, tabulation of bids, average bid prices, and the construction progress estimate. A unique number, once assigned to an item, should not be changed.

Bridge items may not be applicable to more than one bridge or structure. Only those items physically incorporated into the bridge structure are considered bridge items. For coding purposes, the following are not considered bridge items: detours, detour structures, loose riprap, slope protection, and the removal of existing bridge structures.

The FLH Engineer's Estimate System software program is used to prepare the engineer's estimate. The designer is responsible for entering the initial pay item names, quantities, and unit bid prices into the system to obtain the engineer's estimate. On-screen directions for entering the data makes the program relatively easy to use. The engineer's estimate is the data base for preparation of the bid schedule, bid tabulation, progress, and final construction estimates using other features of the Engineer's Estimate System. A bid history data base is also developed that maintains current unit bid prices for use by the designer. The designer must evaluate the bid history data to help determine the most likely low bid for the item.

1. Computation of Quantities. The designer determines the contract items needed for the work. All computations for estimating quantities are a part of the supporting data. Keep the computations in support of a contract item together and the items listed in numerical sequence.

The Designer may specify that some work will not be paid for directly. This work consists of small quantities that would be difficult or uneconomical to measure. Limit the no-payment work to an absolute minimum and clearly define it on the plans and in the Special Contract Requirements so bidders can adequately include it in their cost estimates under other contract items.

A lump sum item can is used where the work required consists of a number of inter related, small quantity items to obtain a specified end result or the work can be described in complete detail in the Special Contract Requirements. Show a complete breakdown of the work required on the plans when a number of items are included in the lump sum item.

The Designer determines the work to be included in a contract, but the Construction Branch determines the method to be used to measure the work. A little early coordination can save a lot of last minute adjusting.

The following paragraphs cover many of the bid items commonly used in road and bridge construction contracts under the Standard specifications, FP-96. Guidance is also provided on items where it is difficult to separate quantity and payment. In addition, miscellaneous information is included to assist the designer in selection of items and how to place the items on the plans.

a. Division 100 General Requirements

This part of the FP-96 contains general contract requirements applicable to all projects. No direct payment is made under Division 100. Within this Division, Section 109.— Measurement and payment, covers most of the details the designer should become familiar with to compute quantities.

b. Division 150 Project Requirements

This part of the FP-96 contains project requirements applicable to all projects. Work under Division 150 will be paid for directly when there is a pay item in the bid schedule for it. When there is no work item, no direct payment will be made.

- **Section 151.— Mobilization.** On large projects, use 6 to 8 percent of the construction estimate rounded to the nearest $5,000 or $10,000. On small projects, use 9 to 10 percent of the construction estimate rounded to the nearest $1,000 or $5,000. Do not rely totally on the Engineer's Estimate system to calculate the mobilization amount. Adjust the amount by rounding off so it is reasonable for dollar value of the contract.

- **Section 152.— Construction Survey and Staking.** Determine the bid price of this work can be determined on the basis of crew size, survey requirements, and equipment to estimate hours and cost. When using average bid prices from previous contracts, make sure the survey requirements are essentially the same or the comparison will be flawed. The basis of payment under this section is lump sum, kilometer, each, hour, or other appropriate units.

- **Section 153.— Contractor Quality Control.** This work is not measured for payment. Even though there is no payment for this work, it does cost a contractor money. It is assumed that the contractor's bid price for work under Section 154 includes the costs of the work under this section.

- **Section 154.— Contractor Sampling and Testing.** The cost of the work under this section is usually based on average bid prices. Although there is considerable variance in average bid prices, an amount equal to 2 to 2.5 percent of the construction estimate will usually cover the work involved. Determine if the project requires a minimal amount or an extraordinary amount of testing in relation to the construction estimate before applying the 2 to 2.5 percent rule. The basis of payment is lump sum although other units could be used in unique and unusual circumstances.

- **Section 155.— Schedules for Construction Contracts.** Base the cost of the work under this section on average bid prices.

- **Section 156.— Public Traffic.** The work described in this section is measured for payment under other sections of work with one exception. If a detour is constructed and maintained under a lump sum item, include the work should under this section. If there are extraordinary complications with public traffic, adjust the prices in the appropriate section to cover the work or add additional items of work in the sections.

- **Section 157.— Soil Erosion Control.** Work under this section covers the erosion control plan for the project. It also provides items of work necessary for the Storm Water Pollution Prevention Plan which is included in most construction contracts.

  Most projects will have several items in the bid schedule to cover this work. A very simple project where the erosion control features can be completely detailed on the plans and described in the Special Contract Requirements may be a lump sum item. The use of an item for Soil erosion control, using a contingent sum pay unit is not permitted. In addition to lump sum, pay units of meter, each, square meter, hectare, kilogram, hour, and other related units are acceptable.

  The past practice for developing erosion control is no longer adequate for today's requirements. The current emphasis is to retain all sediments within the construction limits and stabilize them in place.

  Evaluate every cutslope, embankment, stream crossing, or other disturbance, and determine what effort and devices are required to stop sediment from escaping beyond the construction limits. Transcribe this evaluation to the erosion control plan. If a stage construction concept is being considered, evaluate each stage of the work to arrive at an adequate erosion control plan.

  Consider the items in the FP as a good beginning for erosion control devices. Do not hesitate to propose additional methods of controlling erosion and sedimentation. Not all temporary and permanent erosion control features need to be addressed under Section 157. They can be incorporated into other sections of work if it is more appropriate.

c. Division 200 Earthwork

- **Section 201.— Clearing and Grubbing.** The design program computes quantities for clearing and grubbing and provides subtotals as desired by sheet total, or 350 meter intervals or as user defined. These subtotals are placed on the profile part of the plans or on a separate tabulation of quantities to the nearest 0.01 hectares. It may be necessary to round the subtotals so the total shown on the plans equals the design program output. Compute the acreage of any isolated areas and road approaches of significant size or measure the areas by planimeter. Show this quantity on the plans with the mainline roadway quantities using an appropriate note.

  On the supporting data sheet, show the design program total plus any manually computed hectares. The total of these hectares is the plan quantity shown on the Summary of Quantities sheet of the plans. Add an allowance so the bid schedule quantity reflects the next tenth of a hectare. If there is a large number of hectares, rounding up more than a tenth of a hectare is appropriate. If lump sum is used as a payment, show the number of hectares used for the lump sum calculations on the Summary of Quantities sheet or other plan sheet.

- **Section 202.— Additional Clearing and Grubbing.** Although the design program can be used to compute hectares under this section, it is seldom worth the effort. Manual computations are usually faster and easier. Follow the rounding guidance under Section 201 for hectare pay units.

  Plan and bid schedule quantities are usually the same. Quantities for removal of individual trees and individual stumps are usually estimated during one of the field reviews.

  If a field estimate is not available, allow 5 square meters for removal of individual trees in sparsely forested areas, and 10 square meters on projects in heavy timber areas where large numbers of leaning trees and snags exist. These figures are appropriate for a 6 to 8 kilometer grading project.

- **Section 203.— Removal of Structures and Obstructions.** Computations of quantities under this section generally come from the survey notes or from measurement taken at the field reviews. If average bid price data is not available for the work proposed, use equipment rental rates, labor rates, and overhead and profit margins for the estimate. There is a tendency to underestimate the time to remove structures and obstructions so be somewhat liberal in estimating the number of hours to perform work.

  Use this section where the work consists of salvaging, removing, and/or disposing. If the work consists of removing and reincorporating or resetting an item on the project, put the work under the applicable section, e.g., removing and resetting guardrail is provided for under Section 617.

- **Section 204.— Excavation and Embankment.** The design programs provide a listing of the mainline quantities for a project. Manually compute or estimate additional quantities outside the normal roadway prism. Insert these quantities into the design program run as an "added quantity" so they can be included in the mass figures. Show excavation quantities on the plans and show the totals on the Summary of Quantities sheet.

  Show the design program total on the supporting data sheet total plus any added quantities. This total is the plan quantity shown on the Summary of Quantities Sheet. Add about 10 percent to obtain the Bid Schedule Quantity. The allowance used should round the bid schedule amount to an even 1000 cubic meters.

  When computing quantities for borrow, topping, or embankment, use an appropriate shrink or swell factor to arrive at the quantity required to make the computed volume in the roadway. For borrow and topping, add about a 5 percent allowance to obtain an even 500 cubic meter bid schedule quantity. The plan quantity and bid schedule quantity for embankment construction, furrow ditches and rounding cutslopes does not usually require an allowance.

- **Section 205.— Rock Blasting.** Although few projects have a pay item for this work, it is still necessary to estimate the amount of controlled blast hole required to arrive at the correct unit price analysis for roadway excavation. Use the average height of the rock face times the length, and 1 meter spacings to arrive at the estimated meters of blast hole. Round the figure to the nearest 50, 100, or 500 meters depending on the quantity. Rounding within the original computations so the plan and bid schedule quantity is the same.

- **Section 206.— Watering for Dust Control.** Estimate the number of expected days requiring dust control and multiply by an appropriate number of cubic meter units per day. Climate, traffic volumes, and soil conditions have major effects on this item. Construction records from previous projects in the area are very helpful in estimating quantities. The plan quantity and bid schedule quantity should be the same. Round within the original computations.

- **Section 207.— Earthwork Geotextiles.** Compute the square meters of coverage required. For small quantities of less than 3000 square meters, add about 10 percent to round to the nearest 100 square meters. On quantities over 3,000 square meters, add 5 percent and round to nearest 500 square meters.

- **Section 208.— Structure Excavation and Backfill for Selected Major Structures.** Compute the quantities of structure excavation, foundation fill, structural backfill, and structural backfill for walls as detailed in the FP. Add a small allowance to obtain an even 10, 50, or 100 cubic meters for the bid schedule quantities.

  In many instances, it is the Structures Section's responsibility to compute these quantities. The quantities are usually shown as contract quantities. The Structures Section will provide quantities needed for shoring and bracing, and cofferdams.

- **Section 209.— Structure Excavation and Backfill.** Although there is no pay item for work under this section, it is necessary to compute the quantities for bidders to use in estimating costs. This is particularly true with culverts where the estimated excavation is shown on the Drainage Summary Sheet.

- **Section 211.— Roadway Obliteration.** Compute areas by any acceptable method including planimeter. Add about 10 percent and round to 100, 500, or 1000 square meters depending on quantities. When using a lump sum pay unit, show the approximate square meters of obliteration on the plans.

- **Section 212.— Linear Grading.** The measurement unit for this work is station. However, show the design earthwork quantity in cubic meters on the plans for the bidders information. Without a good history of average bid prices, use the cubic meter quantity to determine the unit price which is then converted to stations. Round this item to the nearest 0.001 station. It is almost always a contract quantity.

- **Section 213.— Subgrade Stabilization.** Compute quantities by the square meter or metric ton as appropriate. Round square meter computations to 100 or 500 square meters. Round metric tons to 10 metric tons.

d. Division 250 Structural Embankments

- **Section 251.— Riprap.** Measurement of riprap is cubic meter or metric ton. Add at least 10 percent allowance to obtain an even 50, 100, or 500 cubic meters or metric tons in the bid schedule. Show the class of riprap on the plans by one or all of the following methods.

  - By tables
  - On special typical sections for riprap
  - On the drainage summary if riprap is associated with culvert work

Excavation for toe trenches is seldom paid for directly; however, show quantities on the plans for informational purposes. Where toe trenches are excavated under an existing structure or adjacent to piers, etc., that involve structural excavation under Section 208, it may be appropriate to include toe trench excavation for payment under Section 208.

The supporting data sheet should have a list or table of riprap showing locations, elevations of top of riprap, class, quantity of riprap, and quantity of the trench excavation.

- **Section 252.— Special Rock Embankment and Rock Butress.** The measurement of rock embankment is cubic meter or metric ton. Add at least 10 percent allowance to obtain an 10, 50, or 100 cubic meters or metric tons in the bid schedule. Show the rock embankment on the plans by one or all of the following methods.

  - By tables
  - On special typical sections for rock embankment
  - On the drainage summary if rock embankment is associated with culvert work.

Excavation for toe trenches or embedment is not paid for directly; however, show quantities on the plans for informational purposes.

- **Section 253.— Gabions.** Measurement of gabions is square meter or cubic meter in place. Only minor rounding of about 50 square meters or 10 cubic meters is required.

  Show gabion elevation and cross section views on the plans. Plan views are helpful where there are variations in the face of wall distance to a reference line. Tables on the plans showing station to station, wall quantities, and excavation are appropriate.

- **Section 254.— Crib Walls.** Follow the guidance for gabions.

- **Section 255.— Mechanically Stabilized Earth Walls.** Follow the guidance for gabions.

- **Section 257.— Alternate Retaining Walls.** Although the measurement for this work is lump sum, provide the estimated square meters for informational purposes.

e. Division 300 Aggregate Courses

- **Section 301.— Untreated Aggregate Courses.** The method of measurement under this section is cubic meter, metric ton, or square meter.

  Compute the compacted volume of the material to be placed on the roadbed by using the dimensions shown on the Typical Section Sheet. In addition, compute the compacted volumes for widened areas, approach roads, parking area, and tapers for channelized intersections.

  To determine the hauling vehicle volume, multiply the compacted volume by 1.33. To determine metric tons:

  (1) Multiply the compacted volume by 1.33, then
  (2) Convert to metric tons by multiplying (1) by 1.65 metric tons per cubic meter (If the material is pugmill mixed, compensate for the mixing water by multiplying (2) by 1.06).

The 1.65 metric tons per cubic meter factor applies to aggregate with a specific gravity of around 2.70. For sources with significantly different specific gravity, it is appropriate to multiply the 1.65 factor by the known specific gravity divided by 2.70.

The quantities for crushed aggregate base usually show on a Tabulation of Quantities Sheet in the plans. Show the rate of application in metric tons or cubic meters per kilometer or per square meter for the bidder's information. Also, specify if the quantities include the 6 percent water additive.

Aggregate by the cubic meter = (Average W)(D)(L)(1.33)

Aggregate by the metric ton = (Average W)(D)(L)(1.33)(1.4*)(1.06**)

Where: W = Width in meters
D = Depth in meters
L = Length in meters

* Metric tons per cubic meter
** 6 percent allowance for mixing water where a pugmill is required.

When the maximum dry density is available from the lab reports, multiply the compacted volume by the dry density and convert to metric tons.

Aggregate by the square meter = (W)(L)

If square meter measurement is used, show the exact limits used to arrive at the quantities on the typical section. Where measurement is by the square meter, compute the cubic meters or metric tons to provide bidders with an application rate.

Add a 5 to 10 percent allowance to quantities measured by the metric ton or cubic meter so the bid schedule quantity is an even 500 or 1000 cubic meters or metric tons. Square meter measurements require very little allowance as the limits are pretty well predetermined on the Typical Sections. Round up to an even 1000 square meters for the bid schedule.

- **Section 302.— Treated Aggregate Courses.** Compute quantities for this section similar to Section 301 for metric tons or square meters.

- **Section 303.— Road Reconditioning.** Measurement under this section is kilometers or square meters. Use kilometers for mainline work and side roads where widths are relatively constant. Use square meters for parking areas and other oddly shaped areas or for very small quantities of work.

  Round kilometers to the nearest 0.01 km for the bid schedule. Add 5 to 10 percent to the square meters to obtain an even 100 or 500 square meters in the bid schedule.

- **Section 304.— Aggregate Stabilization.** Measurement for aggregate stabilization is kilometers or square meters. Follow the guidance under Section 303 to compute quantities.

  Provide an allowance for chemical additives so the bid schedule quantity comes out to an even 10, 50, or 100 metric ton quantity.

- **Section 305.— Aggregate-Topsoil Course.** Measurements under this section include metric ton, square meter, cubic meter, or meter. Provide an allowance to round the bid schedule amount to an even 10, 100, or 500 units as appropriate.

- **Section 306.— Dust Palliative.** Measurement for the dust palliative application is the kilometer or square meter. Very little allowance is needed. The dust palliative material is measured by the metric ton. Add a 5 to 10 percent allowance to get an even 10, 50, or 100 ton bid schedule quantity.

- **Section 307.— Stockpiled Aggregates.** Measurement for stockpiled aggregate is the metric ton or cubic meter. Usually the amount has been predetermined and no allowance is necessary.

  The preparation of stockpile sites is measured by the hectare. Provide an allowance so the bid quantity shows a whole hectare.

- **Section 308.— Minor Crushed Aggregate.** Measurement is based on cubic meter or metric ton. Be liberal in estimating quantities so only minimal, if any, rounding is required for the bid schedule quantity.

- **Section 309.— Emulsified Asphalt Treated Base Course.** The measurement for this section is metric ton or square meter. Compute metric tons according to the guidance under Section 301. For square meters, use length times width. Show the exact limits used in the computations on the typical section. Only a minor allowance should be used with square meters. Round up to an even 1000 square meters for the bid schedule.

f. Division 400 Asphalt Pavements and Surface Treatments.

- **Section 401.— Hot Asphalt Concrete Pavement Through Section 407.— Open-Graded Emulsified Asphalt Pavement.** Measurement under these sections is the metric ton. Compute the compacted cubic meter volume of the material to be placed on the roadway using the dimensions shown on the Typical Section Sheet. In addition, compute the volumes for widened areas, approach roads, parking areas, and tapers for channelized intersections.

  For dense graded mixes, multiply the volumes by 2.30 metric tons per cubic meter to obtain tonnage. This factor assumes a plant mix mass unit weight of 2300 kg/m^3.

  Asphalt Pavement (Metric tons) = (Average W)(D)(L)(2.30*)

  Where: W = Width in meters
  D = Depth in meters
  L = Length in meters

  * The maximum density obtained from the lab reports may be substituted for this factor in the equation.

  For open-graded mixes, multiply the volumes by a metric tons/cubic meter factor obtained from the Materials Section. The unit mass density of a cubic meter of open-graded mix is considerably less than dense graded-mix.

  To the total of the above quantities, add an allowance of 3 to 5 percent to obtain an even 500 or 1000 metric tons in the bid schedule.

  When the asphalt is a separate pay item, use 6 percent of the metric tons of asphalt base or pavement mix for dense-graded mixes. Check with the Materials Section for any significant differences on a particular project. For open-graded mixes, the Materials Section will provide recommendations on percentages. If asphalt quantities are based on rounded quantities of base or pavement quantities, very little additional rounding is necessary. Rounding to an even 5 or 10 metric tons is usually sufficient.

- **Section 408.— Cold Recycled Asphalt Base Course.** The measurement for this section is metric ton or square meter. Compute metric tons according to the guidance under Sections 401 through 407. For square meters, use length times width, and show the exact limits used in the computations on the typical sections. Only a minor allowance should be used with square meters. Round up to an even 1000 square meters for the bid schedule.

- **Section 409.— Asphalt Surface Treatment.** Measurement is by the metric ton or cubic meter under this section. Compute the quantities on the basis of the application rates listed in the FP. Round aggregate quantities up to an even 100 or 500 metric tons or an even 50 or 100 cubic meters for the bid schedule. Round asphalt to the even 10 metric tons for the bid schedule.

- **Section 410.— Slurry Seal.** Measurement is by the square meter. Round quantities according to Section 408 above. The quantities of aggregate and asphalt should be calculated for the unit price analysis unless there is a good bid history of average bid prices.

- **Section 411.— Asphalt Prime Coat.** Measurement under this section is metric ton, liter, and cubic meter. Compute the quantity of asphalt using an application rate of 0.1.5 L/m^2 for cut-back asphalt, and 1.1 L/m^2 for emulsified asphalt. To convert liters to metric tons, use 1040 L/t for cut-backs and 1000 L/t for emulsion. Round to an even 10 metric tons or 5000 L for the bid schedule.

  For blotter material, use 10-14 kg/m^2. If an inverted prime is desired, use 19 kg/m^2. Round to an even 10 or 100 metric tons for the bid schedule.

- **Section 412.— Asphalt Tack Coat.** Measurement is based on metric ton or liter. Use an application rate of 0.35 L/m^2 for plan quantities. Round to an even 5 or 10 metric tons or 5000 liters for the bid schedule.

- **Section 413.— Asphalt Pavement Milling.** Measurement is based on square meter or kilometer. Round square meter up to an even 1000 in the bid schedule. Round length to 0.01 kilometer.

- **Section 414.— Asphalt Pavement Crack and Joint Sealing.** Measurement is based on liter, kilogram, and meter. It is difficult to estimate the exact amount of work that will be required in the field under this section. Be liberal in making the estimate of work so only minimal, if any, rounding is required for the bid schedule quantity.

- **Section 415.— Paving Geotextiles.** Measurement is based on square meter and metric ton. Be liberal in estimating the quantities of work so only minimal, if any, rounding is required for the bid schedule quantity.

g. Division 500 Portland Cement Concrete Pavement.

- **Section 501.— Portland Cement Concrete Pavement.** Measurement is based on the square meter. Compute quantities fairly accurately for this work so rounding should be minimal.

- **Section 502.— Portland Cement Concrete Pavement Restoration.** This is a catch-all section for repair of concrete pavement. There is a tendency to be conservative in estimating this type of work. Therefore, assume a generous amount of work and use only minor rounding for bid schedule quantities.

- **Section 503.— Portland Cement Concrete Base Course.** Follow the guidance under Section 501.

h. Division 550 Bridge Construction.

- **Section 551.— Driven Piles Through Section 565.— Drilled Shafts.** This portion of the FP-96 contains the bridge construction work items. The Structure Section generally determines bridge work items and their respective quantities. The Structure Section will provide the items of work, the quantity of work, and the estimated cost for the work for inclusion into the contract package.

  Insert the costs provided by the Structure Section into the engineer's estimate system. Allowances are not usually added to bridge items.

i. Division 600 Incidental Construction.

- **Section 601.— Minor Concrete Structures.** For cubic meter measurement, compute the volumes either from rates on standard plans or manually compute the quantities to the nearest 0.1 cubic meter. Add an allowance to round the bid schedule amount to an even cubic meter. Round square meter measurements to the nearest 1, 5, or 10 units.

  Where concrete is not measured for payment directly, estimate the quantity and show it on the plans for the benefit of the bidders. With footings, uniform height walls, etc., showing concrete quantities per meter to 3 decimal places will assist bidders.

- **Section 602.— Culverts and Drains.** List all culverts on the Drainage Summary Sheet. Show the pipe sizes, lengths, and sections, bevels, structure excavation, acceptable alternates, etc. Add a cross section to the plans for pipe larger than 1200 millimeters in diameter or equivalent diameter showing inlet and outlet elevation, design Q, end treatments, flow grade line, energy dissipators, etc.

  Small size culverts for approach roads and for cross-drains should have an allowance due to normal changes that occur in the field during staking and construction. The allowance depends on the type of construction, terrain, and rainfall in the area, so use engineering judgement. No allowance is necessary for larger culverts.

- **Section 603.— Structural Plate Structures.** These structures have site specific designs. The design is the responsibility of the Hydraulics Unit and their criteria should be incorporated into the plans. No allowance is necessary under this section.

- **Section 604.— Manholes, Inlets, and Catch Basins.** The location, size, type, etc., should show on the plans and on the Drainage Summary. These items require special drawings or standard plans. In many instances the roadway owning agency will request that their standards be used for consistency with their highway system. No allowance is necessary under this section.

- **Section 605.— Underdrains, Sheet Drains, and Pavement Edge Drains.** The pay item for perforated underdrain may be modified to include the geotextile and the backfill. An allowance is appropriate for underdrain.

- **Section 617.— Guardrail.** Compute lengths of W-beam guardrail for individual locations in multiples of 3.81 meters. Round the quantity to an even 5, 10, or 25 meters. Guardrail is generally shown in a table on a separate plan sheet but it is permissible to show it in a straight line diagram along the top of the profile section of the plan sheets.

  Prepare a table for the supporting data showing station to station, guardrail left or right, lenght in meters, terminal section type, etc.

- **Section 618.— Concrete Barriers and Precast Guardwalls.** Compute cast in place or slip form barriers to the nearest meter and round for the bid schedule. Precast barriers should be computed in multiples of the length specified for the precast unit; normally 3 meters. Show this work should show on the plans and in the supporting data as indicated under Section 617.

- **Section 619.— Fences, Gates, and Cattle Guards.** Measurement of fencing is generally by the meter of slope measurement. Compute the horizontal length of fencing along the proposed fence alignment and adjust this length for the average slope of the ground.

  Fencing usually shows on a tabulated format or on a separate plan sheet. The proposed fence may also show on the plans by a straight line at the top of the profile on the plan-profile sheets, with the type and length of fence labeled.

  The supporting data sheet should have a table showing fencing by station to station, left or right, and horizontal length.

  To the plan total, add an appropriate allowance to bring the bid schedule to an even 10, 50, or 100 meters.

  Show proposed gates on the straight line with the fence at the top of plan-profile sheet or tabulated on a separate plan sheet.

  Show cattle guards on the plan with a note indicating station, type, length, and the appropriate references to standard plans.

- **Section 622.— Rental Equipment.** Approach the work under this section similar to work under a lump sum item. Determine what work is required under equipment rental and then determine the size and type of equipment needed to do the work. Try to specify equipment type and size that is common to the work required for the remainder of the contract.

- **Section 623.— General Labor.** Determine the work required under this section and estimate the number of hours that it takes to accomplish the work. The Means Heavy Construction Cost Data Book provides crew sizes and hours to perform several hundred different tasks. It is a good reference if there is no history for the specific work desired under this section. The cost data book is on file in the Technical Services Engineer's office.

- **Section 624.— Topsoil.** Usually the design quantity depends on the availability of topsoil on the project within cut and fill limits. This is often an insufficient quantity to topsoil the whole project, so the plans should show which slopes are to receive topsoil. The topsoil is normally placed in 75 to 100 millimeters loose depth on flatter slopes (flatter than 1:1.75) Specify the depth on the typical section sheet or on a special landscape drawing.

  Where conserving topsoil from roadway excavation or beneath embankment areas, remember to replace the material removed and used for topsoil by roadway excavation. Make the appropriate grade or slope changes to compensate for the removed topsoil.

- **Section 625.— Turf Establishment.** The Design programs compute quantities for areas to be seeded on the mainline. For isolated areas and areas of old roadway obliteration, manually compute the areas by multiplying average widths (m) by average lengths (m) and dividing by 10 000 to obtain hectares. Where using slurry units, assume 10 slurry units per hectare. Seeding may be shown on the plans at the bottom of the profile at regular intervals, by sheet total, or by tabulation on separate plan sheets. Plan quantities should be shown in even units. Round the plan total by adding a small allowance to bring the bid schedule to an even hectare. Round slurry units to 10 units.

- **Section 633.— Permanent Traffic Control.** Show sign location, MUTCD number, legend, size, area (square meters), and post size on the plans. Tables summarizing sign quantities should show on the plans. The supporting data sheet may refer to the tables on the plans.

  Delineators are generally shown with a straight-line diagram or a computer plot of the alignment on a scale that will fit on a plan sheet. Use symbols to indicate locations of posts left and right. The diagram used is acceptable as the supporting data sheet. To determine the spacing of delineators, refer to standard plans or to the MUTCD section on traffic markings. Little or no allowance is added to the plan total for delineators.

- **Section 634.— Permanent Pavement Markings.** Show traffic markings on the plans either by line diagrams for the entire project or by tables. Specify the beginning and ending stations of no-passing stripes and the total quantities of broken and solid striping. Round plan totals by adding an allowance that is appropriate to cover connections and intersections. The supporting data sheet may refer to the plans.

- **Section 635.— Temporary Traffic Control.** Show all 635 items on traffic control plans. Identify the locations for installing construction signs and specify the uses for the barricades, cones, and warning lights shown. Quantities for traffic control devices are summarized on the traffic control plans or on separate plan sheets.

  See Chapter 8 for traffic control plan details. Where extensive detours are required, show the design alignment, grade, and surfacing requirements on the plans.

  After determining the contract time and number of days for major work, compute flagging hours and pilot cars hours. Supporting data sheets for other traffic control items may refer to the plans and show on one sheet.

These guidelines do not cover all the sections of the FP. Do not hesitate to ask for directions on any work involved in the contract, including acceptable methods of computation of quantities.

2. Computation of Contract Time. Designers must allow reasonable times for completion of construction projects. Factors that determine contract time include materials, equipment, manpower, costs, and constraints (such as weather, regulations, traffic, utilities, and user convenience).

Under the current standard specifications, contract time may be based either on a calendar day or be a fixed completion date. Generally specify contract time on a calendar day basis.

There are four basic methods of determining contract time that are in general use throughout the highway industry. They are as follows:

a. Construction Season Limits. The contract time ends at, or shortly following, the end of the construction season. This is a very effective approach on surfacing and paving projects, small bridges, and similar types of construction. The contract time must begin early in the year to ensure materials are available and time frames are reasonable.

b. Quantity or Production Rates. This method determines contract time by allowing a daily production rate for each controlling item of work in the contract that significantly affects the project time. The concept could allow time for every item of work, but this is generally not necessary as many minor items are completed concurrently with the more costly items of work. Experience and past data from completed projects helps in establishing the production rates used.

c. Work Flow Techniques. Determining contract time under this method involves preparation of a bar or progress chart on normal projects to developing full critical path method (CPM) analysis on large, complicated projects. A CPM plan requires extensive coordination of materials, equipment, personnel, and administrative support. The more complicated this technique becomes, the more dependent it is on experience, judgment, and data sources.

d. Estimated Costs. Under this method of determining contract time, the contract costs relate to time or working days (e.g., contractor expected to earn $15,000 per working day over life of the contract). Using this method requires an accurate and current data base.

Any or all of the above methods are acceptable. It is not unusual to combine a bar time chart with production rate analysis on a project. The designer should use the method or combination of methods that are most practical using the data bases available.

3. Development of Prices. The engineer's estimate shall reflect the actual cost to the contractor of doing business, including a reasonable profit. There are two methods commonly used to determine this cost; historical costs (bid based estimating) and actual costs (cost based estimating). With either method, the designer shall strive to target the expected low bid.

a) Bid-Based Estimating. This method uses historical bid data as a basis for estimating current costs. Low bids received for projects (within the past 2 to 5 years) under similar conditions usually represent the contractor's cost plus a reasonable profit for those projects. The low bid is generally the best indicator of the expected actual cost for a project. The average of the low bids received on previous projects in similar locations should be the basis for current projects.

Each Engineer's Estimating software in each Federal Lands Highway Division office provides a listing of unit bid prices on contract items from previous projects. Generally only the low bid on each similar project should be used to develop unit prices (average bids inflate prices above the low bid). However, the bids from the lowest three bidders are generally considered to insure the low bid is reasonable. The designer should use these prices and modify them to fit the conditions on the project. Allow for any factors that may have a direct bearing on the prices. These would include such factors as availability of construction material; proximity of access roads; railroads, distance from towns, traffic, time of construction, inflation, quantities etc. The historical bid price approach, tempered with engineering judgment, works quite well with almost all the minor items of work on a project.

b) Cost-Based Estimating. Some items of work that may not lend themselves to the average bid price approach are major items of work such as roadway excavation, base and plant mix material, and bridge material. These items require a supporting analysis to ensure that all factors that bear on the cost of the item receive consideration. Cost based estimating uses current labor, equipment, and materials costs as well as overhead and profit to develop unit prices.

The following are important steps in developing prices for cost estimating:

- Determine if the proposed unit prices are realistic for the location, time of year, and characteristics of the work to be performed. Support unit prices for major items of work by an analysis prepared in sufficient detail to ensure that all factors that bear on the cost of the item have been considered. Estimated unit prices are generally based on historical data such as the unit prices used for previous estimates and the corresponding bid prices on previous contracts. Review these prices at regular intervals to determine if pricing changes are needed to reflect current trends.

- Consider factors that can affect the estimated cost of a project, such as labor rates, equipment rates, unusually large quantities, interest rates, time allowance, competition levels, and material shortages. Adjust any historical prices accordingly.

- Confirm that the bid data prices to be used are current. Update if necessary.

- Document the methods and assumptions used to establish each unit price. The bid evaluation process will rely heavily upon this documentation to determine if all factors effecting the reasonableness of the bid have been considered.

K. Specifications. Specifications are the compilation of directions, provisions, and requirements about the quality and performance of the work. They should describe the work with clarity and precision and have a clear logical format.

Specifications should not specify impossibilities, near impossibilities, or contain unenforceable requirements. When ideal conditions cannot be obtained, specify tolerances to permit acceptable variations in the work.

All specifications fall into three general categories:

- Performance or end result specifications. These specifications give the contractor the entire responsibility for supplying an item or a product for construction that meets the specification requirements. The specification generally places no restrictions on the materials used or the methods of incorporating them into the completed work. This type of specification is suitable for use when the end product is measurable, when a quick method of testing is available, and when deficiencies are correctable by reprocessing or reworking.

- Materials and methods specifications. These specifications are suitable for use when the end product characteristics are unknown or are not measurable. They also apply when no quick method of acceptance test is available, or it is impractical to remove and replace the defective work. Use of these specifications directs the contractor to combine specified materials in definite proportions using approved equipment or to place a specified material or product in a specified way. Normally, the operations are always under Government supervision and control.

- Restricted performance specifications. These specifications are the most widely used type. They allow the contractor the fullest possible latitude in obtaining the desired end result as stated in the contract. However, they contain certain restrictions to ensure an acceptable level of quality and prevent the construction or production of a large quantity of defective work. In most cases, restrictions on a performance specification shall not relieve a contractor of all responsibility. These specifications ensure a minimum acceptable quality and they also give the contracting officer (CO) some basis on which to administer the contract and accept the work.

1. Types of Specifications. Under the three general categories, there are three distinct types of specifications used by Federal Lands Highway Division offices for contracts, and each has its place in the hierarchy of contract documents.

- Standard Specifications. The Standard Specifications for Construction of Roads and Bridges on Federal Highway Projects approved for general application and repetitive use.

- Supplemental Specifications. Additions and revisions to the standard specifications.

- Special Contract Requirements. Additions and revisions to the standard and supplemental specifications applicable to and individual project.

See the glossary in Chapter 1 for their definitions, relationship with each other, and interaction with the other parts of a contract.

The FLH Specification Coordination Group (SCG) is responsible for the maintaining and updating of the Standard Specifications (current edition is the FP-96). FLHO will issue supplemental specifications, which are to be incorporated in all applicable FLH contracts until such time as the supplemental specifications are included in a standard specification update. The designer is responsible for the initial preparation of all special contract requirements relating to conditions peculiar to an individual project. Special contract requirements are specifications which add to, delete, modify or revise the standard or supplemental specifications. This section will describe the methods and techniques for developing and writing special contract requirements.

The contract specifications will sometimes refer to a specification, standard, or test method adopted by a recognized technical association. Some of the recognized associations follow:

- American Association of State Highway and Transportation Officials (AASHTO).

- American National Standards Institute (ANSI).

- Association of Official Agricultural Chemists (AOAC).

- American Road and Transportation Builders Association (ARTBA).

- American Society for Testing and Materials (ASTM).

- American Wood Preservers Association (AWPA).

- American Welding Society (AWS).

- American Water Works Association (AWWA).

Occasionally a contract may use State transportation agency specifications. This can range from total use of State specifications to allowing some State-specified methods or products to be acceptable alternatives to Federal requirements.

Government specifications and standards used by reference include the following:

- Federal specifications and standards approved for use by the General Services Administration.

- Voluntary products standards published by the National Institute of Standards and Technology, U.S. Department of Commerce. Standards published before 1966 are referred to as "Commodity Standards" or "Simplified Practice Recommendations."

- Military standards approved for use by the U.S. Department of Defense.

When the contract lists or refers to a specification, standard, or test method of an accepted association or other government agency, the specification, standard, or test method cited becomes a part of the contract. Citing such documents has the same legal effect as though every word of the specification, standard, or test method had been written in the contract.

Make sure that specifications incorporated into the contract by reference do not conflict with other contract documents.

2. Developing Special Contract Requirements. These requirements cover additions and revisions to the standard or supplemental specifications. Begin by making a thorough analysis of the material, process, or work proposed in the contract.

Assemble existing specifications prepared for the same or similar subject, and obtain specifications for materials and processes prepared by standardizing organizations or State agencies. A study will reduce the time needed for research and preparation of the specifications.

If possible, do not specify brand name or proprietary products. When brand names or proprietary items have to be specified, list a minimum of three acceptable sources for the material or product desired. Sole source procurement is to be avoided. Cover the important properties of materials but do not load the specifications with minor restrictions which may be difficult or impossible to meet.

Specifications from national technical associations are a valuable source of authoritative information. When specifying standards or test methods, identify them by their identification number such as ASTM A 307, AASHTO T 27, AASHTO M 31M, or Federal Specification TT-P-641. Do not include the year portion of the identification number. (Example: When specifying AASHTO T 27-87I use AASHTO T 27 and drop the 87I which says the specification is an interim specification adopted for use in 1987.) An "M" after the standard number indicates a metric specification and should be included in the reference.

A reference made to a specification, standard or test method adopted by AASHTO, ASTM, GSA, or other recognized national technical association, means the approved procedures that are in effect on the date of the contract solicitation.

When adopting requirements taken from other specifications, make sure they are appropriate for the conditions in the current project. The use of a specification on a previous project does not mean it will be satisfactory for the present project. Check the criteria to make sure it is relevant, realistic and applicable for the proposed project. Study every specification to eliminate nonessential requirements and to permit the use of new types of materials, methods or equipment. Do not repeat specification requirements for emphasis. State them firmly and only once.

Do not specifically exclude recycled materials. Recycled materials should be allowed to compete with virgin materials at least on an equal basis. In some cases, recycled materials may be encouraged by providing incentives or relaxed specification limits.

3. Writing Special Contract Requirements. Use the general format for the standard specifications when writing specifications for a new item. Most standard specification sections (except Divisions 100, General Requirements and Division 700, Material) have five major subsections.

- Description. This contains a short condensed statement of the work required. It may include a list of designations, which may be specified in the pay items. Do not use words such as "in accordance with these specifications and in reasonably close conformity with the lines, grades, thickness, and typical cross section shown on the plans or established by the CO."

- Material. Use this subsection to list the materials for the work and their applicable specifications. Wherever possible the Materials subsection should simply consist of an alphabetical listing of materials and references in tabular form. References are usually made to other sections or subsections in the contract specification or applicable specifications for materials as contained in AASHTO, ASTM, etc. The method(s) of sampling and testing and applicable acceptance procedures should be included in the acceptance subsection under Construction Requirements.

- Construction Requirements. Describe the sequence of construction operations, special equipment, controls, limitations, tolerances, and acceptance criteria in chronological order. Use multiple subsections with subheadings.

  Use imperative mood, active voice whenever possible. Instead of saying, "The Contractor shall build the road." or "The road shall be built." say "Build the road." In sentences using the imperative mood, the subject, the Contractor, is implied. Actions of the Government should be written in the active voice using the work "will." For example, " The Government will approve the road." Subsection 101.01 of the FP makes this interpretation a part of FLH contracts.

  Use sufficient specification requirements to ensure quality of workmanship and satisfactory completion of the work. Minimize specific requirements about methods and equipment to permit improved equipment and to encourage contractors to apply new and advanced ideas and methods in construction. Specify the allowable tolerances and applied penalties, if any, for exceeding these tolerances.

  The last subsection under Construction Requirements is used to describe how the work under that Section will be accepted. This usually includes references to the following four methods of acceptance: Subsection 106.02, Visual Inspection; subsection 106.04, Certification of Compliance; Subsection 106.04, Measured or Tested Conformance; or subsection 106.05, Statistical Evaluation of Work and Determination of Pay Factor (Value of Work).

- Measurement. Since the Contractor performs the measurement under FLH contracts, use the active voice, imperative mood. Specify the components of the completed work item to be measured for payment and the units of measurement to be used. Use the measurement terms and definitions contained in Subsection 109.02 of the FP. Establish where, when and how to measure the work item. List any exception that will or will not be included in the measurements.

- Payment. This subsection should consist of the following wording: "The accepted quantity, measured as provided above, will be paid at the contract price per unit of measurement for the pay items listed below that are shown in the bid schedule. Payment will be full compensation for the work prescribed in this Section. See Subsection 109.05." followed by a list of the pay item numbers, names, and corresponding pay units.

  Pay items with their unit bid prices subject to adjustment under Subsection 106.05 should be included as exceptions in the above paragraph. The subsection will also need to describe the method for adjusting the contract unit bid price.

  Subsection 109.05, Scope of Payment, includes the general rules for measurement and payment of work. There is no need to restate these rules in each individual Section. However, all exceptions or needed clarifications of these rules should be stated in the Measurement or Payment subsections of the individual Section.

When writing a special contract requirement which adds to a standard specification, use the following phrase:

Subsection ( ) is supplemented as follows:

When writing a special contract requirement to delete a standard specification for a contract, use the following phrase:

Subsection ( ) is deleted.

When writing a special contract requirement to replace or modify a standard specification, use the one of the following phrases:

Delete Subsection ( ) and substitute the following.

Subsection ( ) is amended as follows:

a. Fairness. Specifications should not place all the risk of construction on the contractor. To do so will, in all probability, result in high bid prices. Omissions, ambiguities, or inconsistencies in the plans or specifications are not the responsibility of the contractor.

Direct reference to proprietary specifications of national, regional, or local trade associations (Western Pine Association, etc.) have no place in the specifications. Proprietary specifications are subject to change without notice to or acceptance by FHWA.

Avoid the use of trade names in specifications and on plans. Instead, formulate specifications to obtain the desired results and assure full competition among equivalent materials, equipment, and methods. The Federal Acquisition Regulations (FARs) do not permit reference in specifications and on plans to single trade name materials (also refer to 23 CFR 635.411). In exceptional cases, however, the use of trade name designations is acceptable. These cases require a listing of all, or at least a reasonable number of acceptable materials or products. Generally, list at least three trade names.

A project may require a specific material or product, even though there are other acceptable materials and products. This is an acceptable procedure if the Division Engineer approves the choice as being in the public interest.

A specification should clearly state the contractor's obligations and known risk. No specification should try to get something for nothing from a contractor by concealing its intent.

b. Clearness. Write all specifications in a simple and concise style. Use short sentences, use words in their exact meaning, avoid multi-syllable words, and be careful in the use of punctuation and pronouns. Avoid the use of indefinite words and phrases. Each word, each phrase, and each sentence in a specification should clearly convey the same meaning to every reader.

The specification shall describe the work with clarity and precision to prevent different interpretations by the contractor and the CO. Never put anything in the specification that you do not expect to enforce.

Avoid expressing more than one thought in a sentence since this leads to confusion. If a good technical word will clearly describe the idea to the contractor, use it exclusively. Do not use synonyms for literary effect. Always use words in their true dictionary or technical meaning. Colloquialisms and slang expressions have no place in specifications. Syntax, the orderly or systematic arrangement of words or phrases in a sentence, is very important and the established usage should be maintained.

Punctuate carefully. Recast the sentence if a change in punctuation might change the meaning. The purpose and effect of the specification should be clear from its language and the language should convey only one meaning.

Use all the words you need to convey clear and correct messages, but use no more. The choice of words is important. They should be plain and well understood.

9.4.K. Specifications. (continued)

Table 9-15 is a listing of words and phrases to avoid when writing specifications.

Table 9-15
Correct Usage of Words and Phrases

Do not use	Use
Any	All
In the event that	If or when
It is intended	Shall
Subsequent to	After
In order to	To
It shall be incumbent upon	Shall
It shall be the responsibility of the contractor	The contractor shall
It shall be the duty	Shall
Is hereby authorized	May
For the purpose of	For
Must	Shall
If the contractor so elects he may	The contractor may
At the option of the contractor	The contractor may
Is hereby amended	Is amended
Is hereby deleted	Is deleted
By means of	By
Absolutely essential	Essential
Enclosed herewith	Enclosed
At a later date	Later
Prior to	Before
In accordance with	by, under, according to
Through the use of	By
Until such time	Until
In order to	To
Engineer	Contracting officer (CO)

In addition to the words and phrases listed in Table 9-15, use the following words in the proper context:

- Shall/Will. Use shall when the contractor is the subject of a command or order. Better yet, use the imperative mood, active voice to avoid the use of "shall." Use "will" when the Government or CO is the subject.

- May. Use may when either the contractor or Government is the subject and either or both have options or alternatives.

- Amount/Quantity. Use amount when money is the subject. Use quantity when volume, mass, or other unit of measurement is the subject.

- Bidder/contractor. Do not use bidder in the specifications. Use contractor exclusively. Bidder is reserved for use in the Notice to Bidders, press releases, amendments, and other similar nonspecification portions.

Do not use the words said, same, aforesaid, hereinabove, hereinafter, former, latter, whatsoever, or similar words of reference or emphasis. Do not use the expressions and/or, as per, or etc.

Avoid such terms as "as directed by the CO", "to the satisfaction of the engineer", or "satisfactory to the engineer". This type of phrase may be used sparingly, such as in unit price items where action taken by the CO will definitely not involve changes in cost to the contractor.

c. Completeness. Each specification must be complete and shall complement and substantiate the applicable typical sections, dimensions, and details shown on the plans. The specification should furnish all information necessary to enable a bidder to prepare a complete and responsible bid and to enable the contractor to construct the project properly. The specification should never fail to give the bidders and the contractor explicit and definite instructions. However, there is no place in a specification for instructions to the CO.

Do not attempt to explain the reasons for requirements. This information or instructions associated with the enforcement of specifications properly belongs in the construction manual or in a design narrative and not in the specifications.

Specifications should specify materials, construction methods, sequence of work, the method of measurement, and the basis of payment. Notes on the plans should explain and clarify the design features. Cover a requirement only once. Information or data that is shown on the plans should not show in the specifications.

There should be no uncertainty by the contractor or CO about the desired quality or acceptability of the work. Use only essential facts, essential words, and essential phrases. Omit needless words and phrases. If a word has the same meaning as a phrase, use the word.

d. Correctness. Specifications should be accurate and factual. Sources of data used in the specification must be reliable and current. Careless statements or statements based on unreliable data are frequently the cause of contract administration problems and contractor's claims. Legalistic words and phrases may shorten or clarify specifications, but be sure that usage is correct and that alternate interpretations cannot contradict the intended meaning.

There are many publications available for providing instruction on the preparation of specifications. The majority of the standard specifications begin as special requirements which gradually change through use until the intent and meaning is the same to both the contractor and CO.

A good guide for determining the success of a specification is to review the bid tabulations for the item in question. When the range of bidding is close, it indicates that all contractors are reading the specification in the same context. Conversely, a wide range of bidding may indicate confusion and ambiguity in the specification.

L. Contract Assembly. The contract assembly, often called solicitation package, is the end product of the designers efforts. The PS&E package is an integral part of this assembly. Before the Federal Lands Highway Division offices can solicit bids for a construction contract, they need to describe the articles, works, or services for a desired bid. This involves preparing plan drawings, (supplemented by specifications and a schedule of quantities) and combining them with appropriate regulations and clauses into a contract assembly.

A contract assembly or solicitation package consists of several main parts:

1. Solicitation, Offer, and Award (SF 1442). This contract form, after being signed by the contractor and CO, consummates the contract and makes it legal and binding on all parties.

2. Solicitation Provisions. The Federal Acquisition Regulations (FAR) define the scope of the contract and sets forth bidding requirements.

3. Bid Schedule. A list of all pay items in the contract to be completed by bidders with their offered bid prices for the work. The bid schedule is prepared from data obtained from the engineer's estimate.

4. Contract Construction Clauses. FAR clauses regulating and controlling contractor construction activities.

5. Labor Standard Clauses. All laborers and mechanics working on the project are covered by Federal regulations (Davis-Bacon Act) that includes a minimum wage schedule.

6. Special Contract Requirements. The amendments and supplements to the standard specifications necessary for the construction of the project.

7. Plans and Drawings. The plans and drawings necessary to detail and identify the work. These include standard plans and special drawings that may be applicable.

The Federal Lands Highway offices use these seven subdivisions in their contract solicitations (advertised or negotiated). The solicitation generally contains all the necessary forms and contract documents that a bidder needs to make the government an offer for the construction of the highway facility.

9.5 APPROVALS

FLHM 1-A-2 outlines the roles and responsibilities of the Federal Lands Highway offices at the Headquarters and Division levels for carrying out the Federal Lands Highway Program. FLHM 1-A-3 establishes the line of delegation for approval authority.

9.6 STANDARD FORMAT

A. Plans. Project plans as described under Section 9.4.I should be prepared using the guidance provided in this section. Following these guides will produce plan sheets that are accurate, neat, presentable, and that will reproduce legibly.

The following sections detail the format, drafting standards, and organization of the plan sheets into a PS&E assembly.

1. Format. All plan sheets should be prepared using a CADD system. There may be some exceptions, e.g., conceptual drawing, architectural renditions, emergency projects, etc., to accommodate special needs of internal sections or cooperating agencies, but these should be few in number. When manual drafting becomes necessary, it should be accomplished in a manner that duplicates the appearance of CADD drafting to the extent possible.

Exhibits No. 9.22A through 9.37 were prepared using MicroStation version 5 software on an Intergraph CADD System. In addition to illustrating an acceptable format for plan sheets, the exhibits show, with the use of a hand-shaped symbol, the recommended fonts (FT), text sizes (TX), line style (LC), and weights (WT) to use in the preparation of the graphics. Lettering is shown in font 23 or 24 italics and font 1 or 2 vertical. Text size in shown in millimeters. Line weights vary from 0 = 0.13 millimeters to 6 = 1.00 millimeters. The exhibits were prepared using italic lettering for instructions and data relating to the construction of the project. Vertical lettering was used to indicate existing conditions. The only exception to this criteria is that streams, rivers, and lakes are always shown in vertical lettering. Backward italic lettering is used to show information about the development of the sheet.

When other software or hardware systems are used, the line weights, line styles, text size, text style, and cell names will vary from that shown on the exhibits. The Intergraph System with MicroStation version 5 and subsequent versions permits many other changes the characteristics of the fonts, sizes, and weights. The plan preparer should match the exhibit plan sheets as closely as possible by following the guidance provided in Table 9-16.

The plan sheets in the exhibits state whether the graphics were prepared on 864 by 558-millimeter plan sheets or 432 by 279-millimeter plan sheets. Using the fonts, text and line criteria shown will result in uniform sizes and weights on the 432 by 279-millimeter plans sent out to potential bidders.

2. Drafting Standards. The use of drafting standards establishes uniformity and quality in the drafting of contract plans.

When a CADD system is used to develop plans, the dexterity of a manual drafter is no longer critical; letter spacing is correct and lines are uniform throughout their lengths. However, a CADD system operator must have the same knowledge of drawing layout and detailing as a manual drafter to produce a good drawing. The CADD operator must use care in laying out details when placing text on a plan sheet. The relationship between the text and what it applies to must be clear.

Notes on plan drawings should clarify the drawing and provide necessary information for a complete understanding of the work. Notes shall be clear, concise, descriptive, and as brief as possible to convey the message. Plan drawings shall not include instructions covered in the specifications.

CADD text shall be in the correct style and at the size specified in Table 9-16. Proper spacing between figures, symbols, and words will assure clarity, improve neatness, and increase accuracy.

In line work, the operator must select the correct line style, and weight and use them in the correct relationship to other lines on the plans. The CADD system will NOT automatically perform this work. The system reacts to instructions. The operator must know what is needed and how to direct the CADD system.

Drafting details that enhance the uniformity and consistency of plan preparation include:

- Do not go overboard on line weights. Make a good, clear delineation of all lines so the proposed work will stand out in contrast to existing features. Do not make line weights so bold that they resemble a border line.

- Do not use "station" as a prefix to station numbers. Any numbering including a plus sign (for example 2+959) is understood to be a station number.

- When placing text on plan sheets, do not crowd other information. Carefully choose a place for the notes that is as close as possible to the point of application.

- Do not use broad triangles instead of arrowheads for cross-section indicators. Place the section letters at the end of the arrows, not on one side.

- Do not use the letters "I," "O," "N," or "Z" as cross-section indicators. I and O resemble symbols shown on drawings and N and Z are the same shape, but oriented 90 degrees. When you reach the end of the alphabet, use AA, BB, etc.

- Do not draw hidden contours under a structure with long dashes. Make dashes 3 millimeters long with 1.5 millimeter spaces between. Show hidden lines of structures with the same symbol.

- Avoid running hatching, lines, or patterning through words or figures. Do not use the border lines of the sheets as a basis for establishing angle of parallel hatching lines. Gradually change the direction of hatching at angle points in the section to maintain a 45 degree angle with the neat line of the structure.

- Use abbreviations on plan and profile sheets only where there is not enough space to spell out the word. In instances where the meaning of an abbreviation appears doubtful, the word should be spelled out.

- Do not capitalize abbreviations unless the word or words represented are ordinarily capitalized, or unless the abbreviation itself has become established as a capital letter, such as N for north.

- A period usually follows each part of an abbreviation that represents a single word. This aids in quick interpretation of an abbreviation, such as "a.m.", not "am". The exception to a period following an abbreviation is with units of measure where periods are not used.

The abbreviations in Exhibit 9.23 have been adopted for use on plan sheets.

Deviations are acceptable provided basic drafting practices are followed, and the deviation will improve the drawings. There are situations where the size and weights need to be adjusted to emphasize or clarify specific information on a plan sheet. For example, centerline stationing along the plan alignment may require a heavier weight for clarity where culture or other background data tends to clutter up a drawing.

Table 9-16
Lettering Sizes And Styles

Subject[1]	**Size**			
	CADD Size & Weight[2]	**Freehand Guide No.**	**LeRoy Guide and Pen No.**	**Style**[3]
Index contours (brown)	3.0-0		120-0	S
Intermediate contours (orange)	2.5-0		100-00	S
Supplemental contours (orange)	2.5-0		100-00	S
Grid values (green)	2.5-0	3	100-00	V
Triangulation & traverse stations	3.0-0		120-0	V
P-lines (red)	2.5-0	3	100-00	S
Bench marks	2.5-0	4	100-0	V
Spot elevations	2.0-0		080-00	V
Highways (U.S., State)	2.5-0	3	100-00	V
Railroads (names)	3.0-0	4	120-0	VU
Major bodies of water (blue)	3.5-1	5½	175-1	SU
Minor bodies of water (blue)	3.0-0	4½	140-0	SUL
State names	6.0-2		240-2	VU
County names	5.0-1		200-2	VU
Township & range nos. along line	3.5-1		175-1	V
Section numbers[4]	3.0-1		140-1	V
Property ownership	3.0-0		140-0	VU
City street names	3.0-1		175-1	VU
Photo center numbers	2.0-0		080-00	V
Additional names & identification	2.5-0	3	100-00	VUL
Curve data (PS, PSC, etc.)	3.5-1	5½	140-1	SU
Bearings	3.5-1	5½	140-1	VU
Centerline stationing	4.5-1		140-1	VU
Culverts	3.5-0	4½	140-0	SUL
Quantities	3.5-1	5½	175-1	V
R/W	2.0-0	4	100-00	S
Forest names (subdivision names)	7.5-3		290-3	V

Note: [1]Color is black unless otherwise noted.

[2]Approximate weights
0= 0.13 mm 1 = 0.25 mm 2 = 0.38 mm 3 = 0.50 mm

[3]Lettering style code:
S = Slant (italics) U = Upper Case V = Vertical L = Lower Case

[4]Section Numbers. When required to delineate a portion of a parcel of land, use 3.5-1 upper and lower case, e.g. "NE 1/2 SECTION 17 North of Highway".

3. Organization of Plans. The FAPG, Subchapter G, Part 630, Subpart B provides guidelines in the preparation of plans, specifications, and estimates. The guidelines are presented in a non-regulatory supplement attachment to Part B.

The guidelines in the FAPG list the following 12 subject areas for the arrangement of plan sheets in the preparation of a set of contract plans.

a. Title Sheet
b. Typical Section
c. Summary of Quantities
d. Tabulation of Quantities
e. Plan and Profile
f. Bridges
g. Drainage Facilities
h. Traffic Control Plan
i. Standard Plans and Special Details
j. Environmental Mitigation
k. Cross-Sections
l. Contiguous Projects

The guidelines permit some latitude in the arrangement of plan sheets provided the intent of the plans is clear and meet the criteria of Section 9.4.I of this manual. Designers should decide on an arrangement that best fits their needs within the guidelines.

Exhibits No. 9.22A through 9.37 referred to in this subsection are not mandatory formats. They show an acceptable format for presenting the required information on plan sheets in reasonable accordance with the guidance provided in the FAPG. The drafting on plan sheets prepared as shown in the exhibits will be acceptable to a Division when prepared by a consultant or another Division Office.

The discussion that follows addresses some of the details needed to complete each of the 12 subject areas listed for the arrangement of the plans. For convenience, the discussion will follow the order as listed above.

a. Title Sheet. (See Exhibit 9.22A & 9.22B). Exhibit 9.22A shows a title sheet layout for a typical Forest Highway Project and Exhibit 9.22B shows a title sheet layout for a typical National Park Service Project.

The title sheet serves to identify the location and limits of the project so bidders can find it in the field. Descriptive terms appearing on the title sheet should be readily identifiable by the topography or culture or by use of State highway maps.

The information detailed on Exhibits 9.22A and 9.22B is the basic information to be shown for all projects. Additional details that help to clarify the limits of the work or provide data needed to conveniently bid the work are encouraged. Examples of additional details that may help the bidders include: locations of material sources described in Section 105, locations of disposal areas, staging areas, stockpile sites, and off-project mitigation work.

The FAPG recommends that the scales used on the plans show on the title sheet. Considering the number of scale variations found in a typical project, a scale legend could be confusing and difficult to cross-check. Therefore, the title sheet exhibits show only a bar scale for the map appearing on that sheet, but no scales for the internal sheets.

A completed title sheet contains the following data:

- Proper title and project designation.
- Statement of the project length.
- The State, county, city or town (and where applicable, the national forest, National park, etc.).
- Key map of the State with designator showing project location.
- The location or route map showing project location with beginning and ending stations or termini.
- Index of sheets comprising the plans.
- Design classifications such as the current average daily traffic (ADT), design year ADT, design hourly volume (DHV), directional distribution (D), percent of trucks (T), design speed (V) and maximum superelevation rate (e).
- Distance from the project to nearest city, town, etc.
- Provisions for dates and signatures of the approving officials.
- Standard specifications applicable to the project.

The location or route map should be prepared using a scale ratio of 1:100 000 or larger and show the project area, the nearest towns appearing on a State highway map, other roads, railroads, major streams. etc. In instances where sufficient information cannot be placed on the route map to adequately identify the project work, additional vicinity maps should be prepared on separate sheets and placed following the title sheet.

The large number of symbols and abbreviations used within FLH prohibits the past practice of placing the information on the title sheet. Therefore, the plan symbols and abbreviations sheet was developed (See Exhibit 9.23) and generally follows the title sheet in a set of plans.

When a special symbol is required that is not included in Exhibit 9.23, show it in a legend on either the first plan sheet where the symbol appears or on the left side of the first plan-profile sheet. Abbreviations not shown may be placed on the plans similar to the way symbols are placed or may be added to the contract as a special contract requirement under Subsection 101.03 Abbreviations.

The symbols and abbreviations should not be changed on a project-to-project basis. When a change is required in Exhibit 9.23 to satisfy a Division's needs, change the master file so all future projects will have the same symbols and abbreviations. This prevents the need to check all the data on the sheet for every project.

b. Typical Sections. (See Exhibit 9.25). The typical section shows the shape of the finished surface and shoulders, and represents the appearance of the completed project. It must be specific enough to describe the proposed work, its location, and the material needed.

For combined roadway and bridge projects, the typical section for the bridge may be shown with other bridge design information. All plans should show typical sections for the project including those for bridges only and those where abbreviated plans are used. On projects requiring more than one typical section, the limiting stations for each section should show. This may require additional plan sheets for clarification of the work.

Identify all functional elements of the typical section to a relative scale. Show widths in meters and show thickness or depth in millimeters. Show the thickness of each element in the pavement structure in millimeters.

Where different pavement structure thicknesses are necessary because of differing soil conditions, use notes or tables on the typical section sheet to cover such variations.

For stage construction projects, identify the ultimate typical section. Clearly distinguish the work to be performed under the contract and the future stage construction work.

Include tables or notes to illustrate curve widening, relationship of slope ratios to cut and fill heights, slope rounding, and other special treatments.

Identify the profile grade on the typical section at the point where it is carried relative to superelevation.

Use supplemental typical sections to show variations in special ditches, clearing widths, rock cuts, etc. Also use supplemental typical sections to detail curbs, median treatments, slope protection, channel changes, etc. Place these supplemental typical sections on the typical section sheet or on a following sheet. List the stations where the typical sections apply. Place a note on the plan and profile sheet describing the site-specific work and referencing the appropriate typical section. On abbreviated plans, supplemental typical sections may be placed on the plan sheet at the locations where the work is proposed. See Exhibit 9.36 for examples.

c. Summary of Quantities. (See Exhibit 9.24). The summary of quantities tabulates, combines, and summarizes quantities of the various construction items. This summary informs prospective bidders of where to locate work within the plan sheets, the difference between plan quantities and bid schedule quantities, if any, and expands on contract bid schedule information. It also serves as a helpful checklist to the designer to ensure that all elements of the design receive consideration.

This is generally one of the last plan sheets prepared in final form. All the pay items are listed in numerical order and identified by appropriate descriptions using the engineer's estimate program. The bid schedule quantities duplicate those in the contract. Show any pertinent information by the use of remarks or footnotes at the bottom of the summary plan sheet. Items of work paid for under the contract quantity provision of Section 109 should be identified when preparing the engineer's estimate.

In the preparation of the summary of quantities sheet or the tabulation of quantities sheets, always spell out the pay unit the way it is shown in the FP-96. For example, use Square meter - not Square Meter or Sq. meter. Symbols for pay units are expressed without periods; e.g., m; m^2; kg, etc. Familiarity with the information shown on the plan symbols and abbreviations sheet will improve the consistency of a set of plans.

d. Tabulation of Quantities. A tabulation of quantities sheet consists of a detailed summary of an item of work or several items of work usually presented in a tabular or table format. It provides bidders with more detailed information on the location and extent of the work required than can be shown on the summary of quantities sheet.

(1) Drainage Tabulation. (See Exhibit 9.26). The tabulation of drainage quantities sheet lists all culvert and related drainage data. Show the location of the drainage installation under the station heading. Show related data in the row across the sheet under an appropriate column heading. Total the figures in the various columns to obtain the quantities to show on the summary of quantities sheet for the appropriate culvert item.

The tabulation of drainage quantities sheet may be developed using a spread sheet format. The designer may modify the sheet layout to address specific project requirements.

Exhibit 9.26 shows a summary of drainage quantities sheet that addresses a relatively simple project. Where maximum cover is the controlling factor in acceptable culvert pipe selection, the format shown on the exhibit works well. Where environmental factors control acceptable culvert pipe selection, it may be necessary to modify the spread sheet layout considerably. For instance, a large portion of the sheet may be required to detail the various coating options or thickness options acceptable for a certain pipe installation. A designer may reserve the right hand portion of the sheet for remarks and list acceptable culvert pipe along the bottom of the sheet. The primary purpose of the summary of drainage quantities sheet is to present all available options for potential bidders to evaluate in preparing their estimate for the project.

Where maximum cover is the controlling factor on acceptable culvert pipe, the designer has the option of specifying the thickness, class, or type of culvert on the summary or simply checking off the acceptable column spaces and having the contractor or supplier determine the thickness, class, or type.

(2) Other Tabulations. (See Exhibits 9.27 through 9.32). A tabulation of quantities sheet should be placed as close to the location or description of the work as possible. Use a separate plan sheet for the tables or place the tables on the same sheet as the details for the work. Separate sheets are required when the tabulation is supported by work detailed on FLH standards or Division standard details.

Placing a tabulation of pavement structure quantities table immediately before or on the typical section sheet groups the required work in one location and is easy to comprehend and check. Placing a tabulation of guardrail locations immediately before the standards used for guardrail installation connects the work and location very nicely.

Tabulation of quantity tables placed immediately before the plan-profile sheets for such items of work as removal of individual trees, roadway obliteration, roadway excavation, and turf establishment aids the bidders in precisely locating the work areas and determining the effort required to perform the work. Tabulations for items of work such as guardrail or fences may be placed before the plan-profile sheets or before the special and standard drawings detailing the installation of those work items.

A sheet tabulating all the items required and placed immediately before the detail sheets for a major parking area, a roadside development area, a scenic overlook, or other special work assists bidders as well as internal checking. This also applies to traffic control plans, signing plans, landscaping plans, and other work.

The items and quantities shown on the exhibits are for example purposes only and do not reflect the work shown on the plans. They are intended to show one of several acceptable methods of tabulating the work. The designer may use any format that presents the work items in a clear and concise manner that can be easily checked and verified. The exhibits are grouped in one location instead of being spread through the remaining exhibits for convenience only.

e. Plan and Profile. Under this subject area, the designer may incorporate either contact plan and profile sheets or abbreviated plan sheets.

(1) Plan and Profile. (See Exhibits 9.33 through 9.36). Plan and profile sheets should be prepared at a scale that is adequate to show the necessary details as governed by the topography and the complexity of the work.

Plans usually have a horizontal scale of 1:1000 when prepared on the 864 x 558-millimeter sheet size. Larger or smaller scales can be used depending on the amount of detail to be shown.

Profiles usually have the same horizontal scale as the plan, but the vertical scale should be 5 to 10 times that of the horizontal scale.

When laying out plan and profile sheets, avoid dividing major structures, highway intersections, interchanges, or grade separations between sheets. Use supplemental sheets as necessary to make these drawings as clear as possible.

Leave about 250 millimeters of blank space before the beginning of the project on the first plan-profile sheet and a similar blank space after the end of project on the final plan-profile sheet. Use the blank space on the first plan-profile sheet for project specific legends, utility information and other miscellaneous information beneficial to the contractor. Except for the first and last sheet, attempt to place 700 meters on a sheet and always break sheets at even 100 meter station numbers. Increasing stationing should run from left to right.

Show a prominent **North arrow** for orientation on each sheet.

Show all boundary lines, State, county, city, township, and section lines. Where ties are shown to section corners that fall off the sheet, break the line and show the corner with tie distance. Describe found corners and show their coordinates. At the bottom of the plan portion of the sheet, show township, range, and meridian. Streams, lakes, swamps, estuaries, etc. shall also be shown.

Show the station coordinates of the beginning of the project and the end of the project on the first and final plan-profile sheets, as appropriate. Identify them as State grid, or assumed.

On the first sheet, show the elevation datum, such as USC&GS, USGS, assumed, etc., used for the project.

Show the designed centerline prominently and comply with the following:

- If the designed line (L line) is not staked, show the preliminary control line (P line) as a light line. Label the P line as "Line as staked" and the L line as "Line to be constructed." Where the preliminary control line consists of a series of control points to be used by the contractor during the construction staking operation, label the control points by number and show the coordinates and elevation.

- If the L line is staked, do not show the P line on the plan and profile sheets. Label the L line as "Line as staked and to be constructed." Where control points are provided for the contractor's staking operation, label the points by number and show coordinates and elevations. The exhibits cover this condition.

- If an L line is staked but later another line is selected for construction, make the staked line dashed and label it as "Line as staked" and make the other line solid and label it as "Line to be constructed."

On all sheets show the cut and fill slope limits, access control lines, easements, and right-of-way lines. Within the right-of-way, show all cultural features requiring relocation, such as utilities and fences. Identify all ownerships for right-of-way purposes. Show all drainage structures. Show any cultural features adjacent to the right-of-way that may be affected by the project.

Curve data consisting of delta angle, radius of curve, tangent length, length of curve, and superelevation should be shown. Curve widening may also be shown at this location. For spiral transitions, the spiral angle and length of spiral should be shown. Identify every 100 meter station along the centerline. Bearings or azimuths of all tangents should be shown.

Show the location of borings, test pits, or other sites where subsurface investigations have been made on the plan portion of the plan-profile sheet. Do not show actual log or test results on the plan-profile. Use separate plan sheets for this data.

On the profile portion of the plan-profile sheets show the profile grade and existing ground lines. Show gradients on the profile to four decimal places, grade elevations to three decimal places, and natural ground points to two decimal places.

Show vertical and horizontal clearances for railroads, highways, and streambeds under proposed and existing structures.

Identify and show type and clearance under and over utility lines within the right-of-way.

In addition to profile data, the quantity and limits of the following items may be shown by arrow diagram at the bottom of the profile sheet.

- Turf establishment.
- Clearing and grubbing.
- Embankment where it occurs.
- Roadway excavation where it occurs.
- Balance points if desired.

At the top of the profile portion of the sheet, the designer may show information such as curbs, fences, guardrail, etc., at the proper stations and identify them appropriately. These items may show instead on separate sheets using tables, tabulations, or other appropriate formats.

Show profiles of connecting roads, waterlines, road approaches, etc., on the profile sheet. Offset their location on the plan if they obscure the main profile or show them on a separate plan sheet.

Show bridges and major structures to be constructed on the plan and profile in outline only, with a note to see the appropriate drawings.

Show irrigation facilities requiring minimum service interruptions during construction of the project.

Show all culverts on the plan and profile sheets.

(2) Abbreviated Plans. (See Exhibit 9.37). Plan-profile sheets are not required for all work in a contract. Abbreviated plans are acceptable on rehabilitation type work, emergency relief work or other types of work where plan-profile sheets would not clarify the required construction.

The work areas can be identified along the route by stations, mile posts, kilometer posts, etc. with a written description of the work to be performed at each site.

The description is used to identify work details, specify quantities, and reference special details or standards elsewhere in the plans. The information may be placed in a tabular format or may be included as descriptive text at the specific work locations as shown on a straight line diagram or graph. Exhibit 9.36 is only one of several ways to show the work. Any plan format that is clear, concise and details the work is acceptable.

f. Bridges. Most bridges and other large structures are designed by the Bridge design units. Number the drawings properly for insertion in the final package. Structure sheets may be inserted into the plan package anywhere following the plan-profile sheets.

g. Drainage Facilities. Plan sheets under this subject area would include details of large culvert installations conforming to the requirements listed in Chapter 7. Headwalls, inlet and outlet treatments, fish passage requirements, energy dissipators, catch basins, manholes, and other drainage installation can also be detailed under this subject area. The drainage plan sheets should be numbered and placed in the plans in logical order as determined by the Designer. The plan sheets may be combined with the Drainage Summary to keep all similar work in one location in the plans.

h. Traffic Control Plan (TCP). The plan sheets for the traffic control plan are special drawings that graphically portray all traffic controls required to assure safe passage of traffic through a specific project construction zone. All pay items related to traffic control may be tabulated on this sheet or have a separate tabulation sheet.

Traffic control plans may range from simple line diagrams for low volume rural roads to complex plan sheets detailing every stage of the project work on high volume urban highways. Guidance on traffic control plans is provided on pages 316 to 318 in the 1994 edition of "A Policy on Geometric Design of Highways and Streets."

i. Standard Drawings, Standard Details, and Special Details. FLH standard drawings are usually incorporated into the contract plan assembly and not issued as a separate booklet. Special detail sheets, including Division Standard Details and project specific details, necessary to properly describe the work, may be placed under this subject area. Arrange the standard drawings, standard details, and project specific special details in an order that best clarifies the work to be accomplished.

(1) FLH Standard Drawings. FLH standard drawings cover various design elements that have been approved by FLHO for use on a nationwide basis. FLH standard drawings have a fixed format and each drawing has its own unique identification number. They cannot be changed by a Division Office and used as a standard drawing. If changes are made, they become special details. See Section 9.4.I.2.

(2) Division Standard Details. These drawings are used on a continuing basis within each division. They should be placed in the plans to clarify the work required.

Standard plans prepared by State DOT's or other outside agencies that are incorporated into the contract should be treated as Division Standard Details for insertion into the plans package.

(3) Special Details. Special details are plan sheets detailing grade crossings, turnouts, retaining walls, dikes and ponds, waste or borrow areas, stage construction plans, permanent striping and signing plans, road approaches, material source locations, and other work.

Many approaches are built using road approach plans adopted by each division. Their location is shown on the plan and profile sheets with a symbol and letter designation. Road approaches are roads that intersect the project on grade without excessive cuts or fills and without restrictive sight distances.

Some road approaches require special drawings to show how they fit into the project. These detail the alignment, profile, right-of-way and/or construction easements, typical section, and drainage for the road approach.

j. Environmental Mitigation. Commitments for environmental mitigation features which are contained in the environmental documentation should be detailed as necessary and included in the project plans as special details and/or shown at the appropriate location in the plans.

(1) Erosion Control Plan. The plan sheets for the erosion control plan are special drawings and/or standard detail drawings that detail the measures required to protect resources and to comply with permit stipulations. The plan sheet details should reflect Best Management Practices (BMP); comply with Erosion and Sediment Control on Highway Construction Projects, FHWA, 23 CFR Part 650, Subpart B.; and be in agreement with the stipulations in the National Pollutant Discharge Elimination System (NPDES) permit.

(2) Wetlands. Plan sheets for wetland replacement or mitigation are special drawings that detail all work required to ensure successful mitigation. These may range from simple sketches to elaborate contour grading and planting plans to conform to the commitments in the environmental document. Pay items may be tabulated on these sheets or on separate sheets.

(3) Other Plans. Additional plan sheets may be required to address issues such as material source rehabilitation, disposal or borrow area restoration, special landscaping plantings and other enhancing features. These plan sheets could be appropriately placed under this subject area.

k. Cross Sections. When cross sections are included in the contract plan assembly, show sufficient information on each of the sections to accurately determine the extent of the proposed work. Use a scale that is appropriate for the work.

l. Contiguous Projects. A general plan or layout of contiguous construction projects may be beneficial to potential bidders in determining the cost of work on FLH projects. This is particularly true where another agency is constructing a project that will affect FLH contractors. It is essential that the relationship between the projects be well detailed on the plans.

There are instances where as-built plans should be included in the contract plan package. If a bridge or other structure is scheduled for salvage, a set of the as-built plans will greatly assist a contractor in determining the most effective method to disassemble the structure.

On occasion, right-of-way plans or utility plans may be too complicated to incorporate on the plan and profile sheets. They could be inserted into the plans under this subject area.

B. Specifications. The designer is responsible for the initial preparation of all special contract requirements relating to an individual project. The special contract requirements shall conform to the format set forth in Subsection 9.4.K.

C. Estimate. The designer prepares the engineer's estimate for each project. The procedures and instructions outlined in Subsection 9.4.J cover the preparation of the estimate.

In addition to the estimated unit costs and total cost for construction, the estimate shall show, as separate line items, the estimated costs for construction engineering, utility relocation, and other anticipated contingencies.

D. PS&E Package. The following items represent the minimum requirements necessary to complete a basic PS&E assembly.

- Contract drawings.
- Special contract requirements.
- Engineer's estimate.
- Contract time.
- Physical data available to the bidders such as RDS listings, hydraulic analysis, geotechnical data and cross sections.

9.7 DIVISION PROCEDURES

Reserved for Federal Lands Highway Division office use in supplementing the policy and guidelines set forth in this chapter with appropriate Division procedures and direction.

LIST OF EXHIBITS

LIST OF EXHIBITS

Exhibit

Federal Highway Administration
Federal Lands Highway Divisions

Design Standards Information

Project Number: ______________________________

Project Name: ______________________________

Description/Termini: ______________________________

____

[ ] New Construction **[ ] Reconstruction** **[ ] RRR**

Highway System: ______________________________

Owner Agency: ______________________________

Functional Classification: ______________________________

Traffic Data:

	ADT			Percent Trucks			
	Year	Average	Seasonal	DHV	DHV	ADT	D
Current							
Future							

Design Speed: ______ **Terrain: [ ] Level [ ] Rolling [ ] Mountainous**

Applicable Standards: ______________________________

____

Design Criteria:	**Standard**	**As Designed**	**Exception**
Horizontal Curvature			
Superelevation			
Superelevation Runoff			
Crown			
Gradient			
Travel Way Width			
Shoulder Width			
Vertical Curvature			
Stopping Sight Distance			
Bridge Width			
Bridge Railing			
Clear Zones			

Description of and reasons for exceptions to standards:___________

____
____
____
____
____

Analysis of risks and design considerations proposed to mitigate exceptions:

____
____
____
____

EXHIBIT 9.1
Sample Documentation of Highway Design Standards

Sheet 1 of 2

Approval

+),
.)- **There are no exceptions to applicable standards.**

+),
.)- **The exceptions noted have been reviewed with client or cooperating agencies and are considered acceptable.**

______________ ______________________
Date **Design Engineer**

______________ ______________________
Date **Design Project Manager**

Approval is recommended

______________ ______________________
Date **Project Development Engineer**

Approved for final PS&E

______________ ______________________
Date **Division Engineer**

CHAPTER 10 - STRUCTURAL DESIGN

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CHAPTER 10 - STRUCTURAL DESIGN

10.1 GENERAL

The purpose of this chapter is to provide guidance and techniques for designing bridges, retaining walls, tunnels, large span culverts and other structural items. The goal of a structural design is to produce a structure that (1) serves the purpose for which it is intended; (2) is capable of co-existing within its immediate environment without causing adverse impacts (either visual or physical); and (3) is economical from both a maintenance and construction point of view. Structural design requires a solid understanding of the techniques of structural analysis and the behavior of a structure under various loading conditions. Structural design also requires knowledge of concrete, steel, and timber material properties.

Awareness of factors related to other engineering fields such as hydraulics and soils is necessary to ensure that the structure functions without affecting or being affected by its environment in a detrimental way. Finally, the importance of aesthetic appeal must be recognized to make the structure an extension of nature rather than an intrusion on nature.

The Federal Lands Highway Division (FLHD) Offices employ a staff of professional structural/bridge engineers who develop plans and specifications for projects and occasionally oversee the actual construction.

Since structural elements do not normally comprise the entire highway project, the structural engineer will generally function as part of a design team.

The roadway designer has the overall responsibility for seeing that all aspects of the project are addressed. However, the structural designer must obtain supporting data from the environmental, geotechnical, survey, and hydraulics staff and coordinate the structural design with these technical units. The structural engineer is responsible for the following:

- Developing bridge type, size and location (TS&L).
- Designing bridges, retaining walls, and other structures.
- Preparing complete PS&E's for structures.
- Providing technical assistance to construction staff.
- Checking contract shop drawings.
- Providing technical assistance to other agencies as requested.

A. Bridges. Bridges are the most common major structure encountered in highway engineering and the most varied in design. Bridges range from simple designs (such as a timber deck on stringers that are supported at each end) to very complex designs (such as segmental, cable-stayed, or suspension bridges). Span lengths can vary from 6 meters to hundreds of meters. Each bridge location is different and in most cases it is necessary to custom-fit a bridge structure into its surroundings. This generally precludes the use of wholly standardized plans and specifications in the design of bridges and requires that each bridge be handled individually.

Structural engineering work consists of designing new structures and repairing or rehabilitating existing ones. Bridges include both simple and continuous span structures constructed of reinforced concrete, prestressed concrete, steel, timber, or a combination of these materials. Span lengths generally range from 6 meters to approximately 60 meters. As a general rule, slab-type superstructures (either cast-in-place or precast, prestressed units) are economical for span lengths up to 15 meters. Superstructures consisting of a deck slab supported by stringers are commonly used for spans up to 30 meters. Structures with span lengths in excess of 30 meters require special consideration.

Bridge rehabilitation most often involves the repair of concrete decks which have been damaged by corrosion of the steel reinforcing in the deck. The type of repair needed depends on the level of concrete and steel deterioration. A deck that is severely deteriorated may have to be entirely replaced, whereas one that is moderately deteriorated could be made usable by removing and replacing all unsound materials. For decks in the initial stages of deterioration, one preventive solution may be to install a cathodic protection system to stop further corrosion.

B. Special Designs. The structural engineers may occasionally become involved with certain types of bridges or other structures which differ from those normally handled and would therefore be considered special designs. This category includes major bridges having exceptionally long spans and/or requiring unique design and construction techniques. Examples are cable-stayed bridges, segmental bridges, and long-span box girder bridges. Designing these types of structures often requires specific expertise. For this reason, the Washington Headquarters Bridge Division often reviews projects of this type and is available to provide assistance upon request.

In general, structures such as retaining walls, box culverts, and sign supports lend themselves to a standardized design. This enables the roadway designer to handle these types of structures with little or no assistance from the structural engineer. Occasionally, standard designs or plans are not entirely applicable to the conditions encountered, and a modified or custom design is necessary.

An example of a modified standard design would be a box culvert that is required to have dimensions larger than what are detailed in the standard plans. The structural engineer would then be responsible for developing plans and specifications for the structure. It is therefore important that the structural engineer understand the principles governing the design of these structures and also that the engineer recognize the factors which influence their design.

In addition to the structure itself, the structural engineer is sometimes called upon to design structural components for guardrails, sign supports, lighting supports, pedestrian screening, etc.

1. Retaining Walls. The retaining wall as a highway structure serves either to maintain the stability of a roadway embankment in fill areas or to prevent unstable material from sloughing off onto the roadway surface in cut areas.

The design of retaining walls is normally carried out by the roadway designer through the use of standard designs. However, this approach is not always practical. If wall height, foundation material, or the material being retained differs significantly from the design criteria on which the standardized designs are based, the structural engineer will custom design the installation.

2. Tunnels. Because of their high construction costs, highway tunnels have limited use and should only be considered when other more cost-effective alternatives are not practical. The successful design of a tunnel is dependent upon a comprehensive geologic study performed by qualified geotechnical engineers to determine the presence of faults, badly fractured rock, seams, water, etc. It is vital that the structural engineer work closely with the geotechnical engineers to determine requirements for lining, drainage, and methods of excavation.

3. Culverts. Culverts with clear spans greater than 3 meters are generally described as large culverts and are in most instances designed for a specific site condition by a structural engineer. While these structures are described as culverts, they are in most cases not used as drainage structures, but are used to pass farm livestock, farm machinery, industrial equipment, or people through an earth embankment. Typically, these large culverts are low profile steel arch superspans with spans from 6 to 12 meters, rigid frame reinforced concrete box structures with spans in the 4- to 5.5-meter range, and precast prestressed concrete low profile arch structures with spans in the 9- to 12-meter range.

10.2 GUIDANCE AND REFERENCES

The FLH program includes a wide variety of bridge types, site conditions, and design loadings. Accordingly, the bridge engineer relies on a wide variety of references for assistance.

A. Professional Assistance. The primary source of professional assistance is the FLHD bridge engineers and senior structural engineers within the design office. These individuals can provide not only technical guidance but also can explain the correlation between theory and specifications.

Additional professional assistance is available from the Bridge Division in the Federal Highway Administration, Office of Engineering, Washington, DC.

On FLH projects that become part of State highway systems upon completion of construction, State highway departments are also a source of excellent professional assistance.

As a matter of good office practice, all outside contacts should be informally discussed with the FLHD Bridge Engineer prior to making contact and the items discussed should be documented in the design notes or in the design files.

B. Design Specifications and Guidelines. The primary design specification for all highway bridges on public roads in the United States is the *Standard Specifications for Highway Bridges* published by American Association of State Highway Transportation Officials (AASHTO). It is also the primary design specification for all FLH bridges.

AASHTO specifications set forth *minimum* requirements that are consistent with current practice and certain modifications may be necessary to suit local conditions. AASHTO specifications apply to ordinary highway bridges, but supplemental specifications may be required for unusual types and for bridges with spans longer than 150 meters.

Interim specifications are published yearly by AASHTO and have the same status as standard specifications. Interim specifications are revisions that have been approved by at least a two-thirds majority of the members of the AASHTO Subcommittee on Bridges and Structures. FLHO policy is to apply Interim specifications to all design projects started after issuance of the specifications. Interim specifications shall not apply to projects retroactively.

The following AASHTO specifications including current revisions apply to all FLH bridge projects:

Standard Specifications for Highway Bridges. AASHTO. 15th ed. 1992 (with all current Interim Specifications).

Guide Specifications for Horizontally Curved Highway Bridges. AASHTO. 1993.

Guide Specifications for Fracture Critical Non-Redundant Steel Bridge Members. AASHTO. 1978 (with all current Interim Specifications).

Standard Specifications for Moveable Highway Bridges. AASHTO. 1988.

Standard Specifications for Structural Supports for Highway Signs, Luminaires, and Traffic Signals. AASHTO. 1985.

Bridge Welding Code. ANSI/AASHTO/AWS D1.5-88. 1988.

Guide Specifications for Strength Design of Truss Bridges (Load Factor Design). AASHTO. 1986.

Guide Specifications for Design and Construction of Segmental Concrete Bridges. AASHTO. 1989.

The following specifications offer insight to and clarification of many of the AASHTO specifications:

Building Code Requirements for Reinforced Concrete and Commentary. ACI 318M-89. American Concrete Institute. 1992.

Ontario (Canada) Highway Bridge Design Code and Commentary. Ministry of Government Services, Toronto, Ontario. 1983.

AISC Specification for the Design, Fabrication, and Erection of Structural Steel for Buildings and AISC Code of Standard Practice. Current edition. (Found in Manual of Steel Construction, 9th ed., American Institute of Steel Construction.)

National Design Specification for Wood Construction and Design Values for Wood Construction. National Forest Products Association. 1991.

Design Standard Specifications for Structural Glued Laminated Timber. AITC 117-93 . American Institute of Timber Construction.

Structural Welding Code-Steel. American Welding Society. 1992.

Manual for Railway Engineering. 2 volumes. American Railway Engineering Association.

C. Design Examples. Previous projects are an excellent source of guidance.

Engineers with minimal experience should rely on the design notes and project plans of previous bridge projects. Care should always be exercised to select projects designed and checked by experienced structural engineers. Also, previous notes should not be followed in a cookbook manner, but rather, they should be used in conjunction with current AASHTO specifications.

Design engineers should always review new projects with the bridge engineer or with senior structural engineers before work is started. At this time, a similar example project to be used for guidance can be selected and discussed.

D. Technical References. State-of-the-art bridge design involves the practical application of the principles of many varied disciplines. The following references are listed to provide entry level structural engineers with theoretical background and assistance in practical bridge design. These references should not necessarily be considered FLHO policy. Experienced structural engineers may also find the listing useful for a personal library.

Structural Analysis

Moments, Shears, and Reactions for Continuous Highway Bridges. American Institute of Steel Construction. 1966.

Timoshenko, S. *Strength of Materials.* 2 volumes, 3rd ed. New York. D. Van Nostrand Company. 1958.

Roark, Raymond J. and Young, Warren C. *Formulas for Stress and Strain*. New York. McGraw-Hill Book Company. 1975.

Wang, Chukia K. *Statically Indeterminate Structures*. Chukia K. Wang. New York. McGraw-Hill Book Company. 1953.

Gaylord Jr., Edwin H. and Gaylord, Charles. *Structural Engineer Handbook.* 2nd ed. New York. McGraw-Hill Book Company. 1979.

Gere, James J. and Weaver Jr., William. *Analysis of Framed Structures*. Princeton, NJ. D. Van Nostrand Company. 1965.

Gere, James M. *Moment Distribution*. Princeton, NJ. D. Van Nostrand Company. 1963.

Continuous Concrete Bridges. 2nd ed. Portland Cement Association.

Handbook of Frame Constants. Portland Cement Association. 1958.

Carpenter, Samuel T. *Structural Mechanism*. Salt Lake City. John Wiley and Sons. 1960.
Ketter, Robert L.; Lee, George C.; and Prawel, Sherwood P. *Structural Analysis and Design*. New York. McGraw-Hill Book Company. 1979.

Reinforced Concrete

ACI Manual of Concrete Practice. American Concrete Institute. 5 volumes. 1994.

Notes on Load Factor Design for Reinforced Concrete Bridge Structures. Portland Cement Association. 1974.
Analysis and Design of Reinforced Concrete Bridge Structures. American Concrete Institute. 1977.

Notes on ACI 318-833. Portland Cement Association. Current edition.

Ferguson, Phil M. *Reinforced Concrete Fundamentals, with Emphasis on Ultimate Strength*. 3rd ed. Salt Lake City. John Wiley and Sons.

CRSI Handbook. Concrete Reinforcing Steel Institute. 1992.

Degenkolb, Oris. *Concrete Box Girder Bridges.* Iowa State University and American Concrete Institute. 1977.

Heins, Conrad P. and Lawrie, Richard A. *Design of Modern Concrete Highway Bridges*. Salt Lake City. John Wiley and Sons. 1984.

Manual of Standard Practice. Concrete Reinforcing Steel Institute. 1990.

Reinforcing Bar Detailing. Concrete Reinforcing Steel Institute. 1990.

Hurd, M.K. *Formwork for Concrete*. 5th ed. American Concrete Institute. 1989.

Structural Steel

Merritt, Fredrick S. *Structural Steel Designer's Handbook*. New York. McGraw-Hill Book Company.

Highway Structures Design Handbook. American Institute of Steel Construction. 2 volumes. 1986.

Fischer, John W. *Bridge Fatigue Guide*. American Institute of Steel Construction. 1977.

Fischer, John W. *Fatigue and Fracture in Steel Bridges*. Salt Lake City. John Wiley and Sons. 1984.

Heins, Conrad P. and Firmage, D.A. *Design of Modern Steel Highway Bridges*. Salt Lake City. John Wiley and Sons. 1979.

Fischer, John W. and Struik, H.A. *Guide to Design Criteria for Bolted and Riveted Joints.* Salt Lake City. John Wiley and Sons. 1974.

Johnston, Bruce G. *Guide to Stability Design Criteria for Metal Structures.* 3rd ed. New York. John Wiley and Sons. 1976.

Troitsky, M.S. *Tubular Steel Structures - Theory and Design*. The Lincoln Electric Company. 1982.

Composite Steel Plate Girder Bridge Superstructures. U.S. Steel Corporation. 1977.

Blodgett, Omar W. *Design of Welded Structures*. The Lincoln Electric Company.

Prestressed Concrete

Lin, T.Y. and Burns, Ned H. *Design of Prestressed Concrete Structures.* 3rd ed. Salt Lake City. John Wiley and Sons. 1981.

Post-Tensioning Manual. Post-Tensioning Institute. 1985 .

Post-Tensioned Box Girder Bridge Manual. Post-Tensioning Institute. 1978.

Precast Segmental Box Girder Bridge Manual. Post-Tensioning Institute and Prestressed Concrete Institute. 1978.

Libby, James R. *Modern Prestressed Concrete*. New York. D. Van Nostrand-Reinhold. 1977.

Prestress Manual. State of California Department of Transportation, Division of Construction. November 1978.

PCI Design Handbook, Precast and Prestressed Concrete. Prestressed Concrete Institute. 3rd ed. 1985.

Timber

Timber Bridges: Design, Construction, Inspection and Maintenance. U.S. Department of Agriculture, U.S. Forest Service. June 1990.

Timber Construction Manual. American Institute of Timber Construction. Salt Lake City. John Wiley and Sons.

Weyerhaeuser Glulam Wood Bridge Systems. Weyerhaeuser Company. 1980.

Western Woods Use Book. Western Wood Products Association. 1978.

Timber Design and Construction Handbook. Timber Engineering Company. New York. McGraw-Hill Book Company. 1956. (Out of print.)

Foundations

Bowles, Joseph E. *Foundation Analysis and Design.* New York. McGraw-Hill Book Company. 1988.

Terzaghi, Karl and Peck, Ralph B. *Soil Mechanics in Engineering Practice*. Salt Lake City. John Wiley and Sons. 1967.

Cheney, Richard S. and Chassie, Ronald G. *Soils and Foundations Workshop Manual.* DOT, FHWA. Office of Highway Operations, National Highway Institute. 1982.

Manual on Design and Construction of Driven Pile Foundations. DOT, FHWA. 1985.

Soil Mechanics. Design Manual 7.1. Department of the Navy, Naval Facilities Engineering Command. 1982.

Foundations and Earth Structures. Design Manual 7.2. Department of the Navy, Naval Facilities Engineering Command. 1982.

Design of Piles and Drilled Shafts Under Lateral Load. DOT, FHWA. 1987.

Steel Sheet Piling Design Manual. U.S. Steel. (Updated and reprinted by DOT, FHWA, July 1984.)

Schnabel, Harry. *Tiebacks in Foundation Engineering and Construction.* New York. McGraw-Hill Book Company. 1982.

Woodward, Richard J.; Gardner, William S.; and Greer, David M. *Drilled Pier Foundations.* New York. McGraw-Hill Book Company. 1972.

Tiebacks. Report No. FHWA/RD-82/047. DOT, FHWA. Office of Research and Development. July 1982.

Permanent Ground Anchors. FHWA-DP-68-1. DOT, FHWA. Demonstration Projects Division. March 1984.

Seismic/Dynamic Analysis

Nathan M. Newmark and Emilio Rosenblueth. *Fundamentals of Earthquake Engineering*. Englewood Cliffs, NJ. Prentice-Hall. 1971.

Weigel, Robert L. *Earthquake Engineering*. Englewood Cliffs, NJ. Prentice-Hall. 1970.

Seismic Design of Highway Bridges - Workshop Manual. DOT, FHWA. Office of Research and Development, Implementation Division. January 1981.

Caltrans SEISMIC Bridge Design Specification and Commentary. California Department of Transportation, Office of Structure Design. 13th ed. 1983.

Miscellaneous Topics/Design Manuals

Bridge Design Practice - Load Factor. California Department of Transportation. October 1980.

California Falsework Manual. California Department of Transportation, Division of Structures. January 1988.

California Trenching and Shoring Manual. California Department of Transportation. May 1977.

Construction Handbook for Bridge Temporary Works. Report No. FHWA-RD-93-034. DOT, FHWA. Office of Research And Development. November 1993.

10.3 INVESTIGATION

In the development of structural design plans and specifications, the structural engineer will be confronted with data and comments obtained from several different types of investigations and reviews. This information may include bridge safety inspection structural condition data reports, bridge site survey information, and several levels of field review.

A. Bridge Site Plans. A bridge site plan is developed when a new or replacement bridge is required. The purpose of the site plan is to provide the structural engineer with a graphic representation of the topography at the site so the required type, size, and length of bridge can be determined for the site.

Bridge site topography can have a significant effect on the method of construction. The structural engineer must be aware of the possibilities and limitations that are presented by the existing conditions. Topographic maps assist the designer in determining quantities of excavation for estimating purposes.

The site plan shows the contours of the terrain as well as roads, streams, or other significant features in the immediate area of the proposed bridge. This data is collected by survey teams taking extensive topographic field measurements. The plans should be drawn using a scale appropriate for the total length of the proposed bridge. Contours are generally drawn at 0.5 or 1-meter intervals.

B. Hydraulic Analysis. In cases where a bridge crosses a river, stream, or flood plain, it is usually necessary to perform a hydraulic investigation and analysis. This is generally accomplished concurrently with the development of the site plan since hydraulic information is needed in deciding what type of structure is practical for the crossing. The structural engineer is interested in the high water elevation and flow velocity for flood conditions with a specified frequency of occurrence.

Typically, bridges are designed to handle a 50 year flood, which is a flood of such magnitude that it is expected to occur no more frequently than once in 50 years. For some large, high-cost structures, the design might be based on a 100 year flood to lessen the risk of flood damage. For detailed information with regard to the hydraulic design of bridges, see Chapter 7.

C. Geotechnical Investigation. Geotechnical investigations should be performed after the site plan has been developed and preliminary determinations have been made regarding the type and length of the proposed structure and the location of the foundations for the structure. The purpose of the investigation is to identify the composition of the underlying stratum, determine whether the preliminary location is acceptable as a foundation site, and determine what type of foundation design is most appropriate.

Most often the investigation consists of extracting and analyzing core samples of the substratum. Core drilling is normally performed to the depth necessary to reach solid rock. For small bridges on flat terrain, a single core is sometimes sufficient. For bridges longer than approximately 30 meters or bridges located on hilly terrain, a more comprehensive study is usually needed. It is desirable to obtain at least one core at each foundation site.

After analyzing the data, the geotechnical engineer should prepare a report containing recommendations for the type of foundation needed along with allowable bearing capacities and any other pertinent information. The structural engineer receives a copy of this report to assist in developing the final design of the foundations. For detailed information with regard to the geotechnical design of bridges, see Chapter 6.

D. Bridge Inspection Program. All bridges located on public roads are required by law to be inspected at regular intervals not to exceed 2 years. The inspections shall be in accordance with the National Bridge Inspection Standards and Guidelines as set forth in Title 23, Code of Federal Regulations, Part 650, Subpart C.

The Federal Lands Highway (FLH) Division Offices administer a bridge inspection program for the National Park Service and other Federal agencies. Bridge structures are reviewed for condition and structural adequacy.

Basic data that can be found in a typical inspection report includes the following:

- Photographs of the roadway and profile view of the bridge.

- A written description and photographs of deficiencies found during the inspection.

- Basic physical dimensions of the bridge.

- A structural load capacity rating, where applicable.

In many instances, data found in these reports is the basis for the development of preliminary bridge repair plans.

E. Deck Survey. A deck survey is performed to assess the structural condition of the bridge deck. The information is used by the structural engineer to determine if the deck can be repaired and the most suitable method of repair.

A deck survey may be composed of several types of investigations, which can be classified as either destructive or nondestructive. Half cell potential readings and delamination readings are non destructive since they provide information without actually disturbing the deck.

Destructive methods such as taking chloride samples and deck cores are generally used only when nondestructive methods yield data that indicates the potential or presence of severe internal deck deterioration. Chloride samples are taken to determine the level of chloride contamination in the deck.

Deck cores allow a visual inspection of the deck condition below the surface. Also, split-tensile tests can be performed on the cores to give an indication of the strength of the existing concrete.

F. RRR Bridges. A decision shall be made to retain or replace any bridge within the limits of an RRR project. See the applicable chapter of the AASHTO Green Book. When a bridge requires replacement, design the new bridge in accordance with AASHTO structural standards for bridges. Select widths consistent with current standards to which the highway may be upgraded in the near future. Review recent bridge inspection reports to determine if the bridge is structurally and functionally adequate.

When a bridge is to remain in place, make an evaluation to determine what treatment, if any, is required for operational and structural adequacy.

No work or only minor rehabilitation is required provided the following are:

- The bridge clear roadway width is equal to or greater than the minimum surfacing or approach traveled way widths.

- The bridge accident records indicate that accident problems do not exist and the approach is gradually narrowed to meet the bridge clear roadway width in advance of the bridge. When accident problems exist, make an analysis to determine the necessary corrective action such as providing improved transitions, rehabilitation, widening, or replacement.

- The bridge railings, including the approach rail, meet or are made to meet adequate strength and geometric standards. In all cases where a structure is to remain in-place, check the bridge rail for adequacy. When the existing bridge rail does not meet the current design standard, and it is not cost effective to bring it up to full standard, then treat it as an exception.

- A reasonable or adequate alternative route does not exist and the load carrying capacity is sufficient to carry school buses and vital service vehicles (M13.5 minimum design loading).

Consider major rehabilitation when:

- Deck replacement, to the extent practical, is designed in accordance with current AASHTO standards for highway bridges (M13.5 minimum design loading).

- Rehabilitation meets current AASHTO safety standards.

- Bridge railing is to be upgraded to current standards.

- The approach roadway width does not meet current AASHTO geometric standards and the bridge is to be widened to meet the geometric standards for the highway if it were reconstructed. The decision to rehabilitate or replace may be decided by established cost guidelines or may be subjective. However, when the total cost of rehabilitation is expected to exceed 50 percent of the cost of reconstructing the structure to current standards, consider replacing the structure.

Vertical clearances at existing underpass structures will require adjustment when the clearance after resurfacing work is less than the minimums required. Do not reduce surfacing depths or eliminate surfacing in the vicinity of the bridge to avoid pavement removal or structure modification. All signing and markings for bridges shall be in accordance with the MUTCD.

G. Field Reviews. Two levels of field reviews are generally required in the development of plans for bridge repair, replacement, or new construction. The first field review is designed to involve the responsible agencies in the design concepts and parameters that will be used in the development of plans and specifications for the given project. Basic information to be supplied by the structural engineer at this review is a proposed bridge type, size, and length (TS&L) drawing for replacement and new bridge projects. Drawings depicting proposed repair methods shall be provided for bridge repair projects.

The second level of field review, commonly known as a plan-in-hand review, should be performed when the bridge drawings are approximately 70 percent complete. The purpose of this review is to verify that all items covered in the drawings will be compatible with the existing field conditions and to confirm that all design, safety, and specific client agency needs are properly addressed in the final design documents.

10.4 DESIGN PROCESS.

The design process involves two stages. The initial or preliminary design effort establishes the proposed structure type and layout. The final design effort develops detailed contract plans to be used to construct the facility. Both of these stages require the skills of a structural engineer.

In the preliminary design process, a structure is selected which economically fulfills the structural, functional, aesthetic, and other relevant requirements of a given site.

The development of the preliminary plan requires the consideration of many different factors. The following are some of the more common of these factors:

- *Economic.* Initial costs; maintenance costs.

- *Site Requirements.* Topography; horizontal and vertical alignment; superelevation; deck geometrics; proposed or existing utilities.

- *Hydraulic.* Stream flow (Q_{50}, Q_{100}); risk assessment; passage of debris; scour; pier and bank protection; permit requirements; deck drainage; culverts (as alternatives).

- *Structural*. Span ratios; horizontal and vertical clearances; limitations on structural depth; future widening; slope treatment; foundation and groundwater conditions; anticipated settlement

- *Environmental.* Aesthetics and, compatibility with surroundings; similarity to adjacent structures; extent of exposure to the public.

- *Construction.* Access to site; time for construction; detours or stage construction; extent of falsework and falsework clearances; erection problems; ease of construction.

- *Safety*. Traffic convenience; density and speed of traffic; approach guardrail type and connection to structure; bridge rail type.

- *Other.* Recommendations resulting from interdisciplinary team studies or special requests by an owner.

In making the recommendation for type of structure, full consideration should be given to the above factors. Economy is generally the best justification for a selection. However, some of the above considerations may outweigh differences in cost. In the final analysis, the owner must be satisfied that the proper structure has been selected.

The final design process begins with the approval, by all interested parties, of the bridge TS&L drawing. Using the information shown on the drawing, and following the design specifications, the structural engineer makes a comprehensive analysis and design of the bridge. This design is then the basis for the preparation of detailed contract plans to be included in the complete project plans.

The final design of bridges requires meticulous attention to details and a high degree of responsibility. Irresponsible design can result in construction difficulties, reduced service life of the structure, and higher maintenance costs. In the extreme case, poor design can result in the collapse of the bridge either during construction or in service.

It is FLHO policy that a complete and independent check be made of all structural design work. (This means that one structural engineer designs the bridge and a second structural engineer performs an independent structural analysis of the bridge.)

The information that follows applies to both preliminary design and to final design.

A. General Features. The FLH program involves a wide variety of bridge types from single lane forest development roads to high volume urban arterials. The general features, including widths, clearances, railings, and approaches of these structures, are normally controlled by the roadway standards of the client agency. All necessary general features should be shown on the bridge TS&L and should be agreed upon before final design begins.

1. Bridge Widths and Clearances. Single lane bridges should be a minimum of 4.3 meters wide, face-of-rail to face-of-rail.

Multiple lane bridges should be as wide as the approach roadway plus the offset to the face of the approach guardrail.

Vertical clearances for interchange structures should meet AASHTO specifications or be consistent with other bridges on the route.

2. Bridge Railings and Approach Railings. Railings meeting both the geometric and structural requirements of AASHTO should be provided for all bridges. When client agencies request that railings be used that do not meet these requirements, take the following action:

- Document on the plans, under the specifications section of the general notes, the criteria that was used to design the railing.

- Document in the design file, the details of the design exceptions and who in the client agency was notified of these exceptions.

The use of approach railing on all bridges shall be encouraged. When approach railing is provided, it should be connected to the bridge railing system with connecting details that will develop the full strength of the approach railing.

All concrete parapet-type bridge railings should be detailed with joints as follows:

- At the point of maximum positive movement of all spans.

- At or near the centerline of all piers.

- In between the above locations such that the length of rail segments does not exceed 7.6 meters.

- At bridge expansion joints.

At these locations, joints should be detailed normal to the rails or radial on curved bridges. Joint filler material should be a minimum 12 millimeters thick. Reinforcement should not extend through the joint.

Joints for special design concrete railings should be located as necessary to control cracking due to flexure or temperature changes.

At the ends of the bridges, between the superstructure and substructure elements, railing joints should be compatible with deck joints, expansion assumptions, etc.

All steel bridge railing should have joints located as described above. Joints should be designed to allow movement that maintains the full strength of the railing.

3. Hydraulic Considerations. Most bridges are designed to pass, without damage, Q_{50} flows. The effects of Q_{100} flows should be evaluated. Normally, there are only minor differences in these two flows and most structures will pass both without damage. For details concerning other hydraulic considerations for scour, clearances, and slope protection, see Chapter 7.

B. Loads. Loads are fundamental to bridge design, having evolved through experience and study over many years. AASHTO has included design loads in bridge design specifications since the mid-1920's. The loads discussed in this manual reflect current bridge design criteria for ordinary highway bridges with spans less than 150 meters . These loads should be supplemented as necessary for unusual site conditions or traffic requirements.

1. Dead Loads. Structure dead loads are the loads imposed on a member by its own weight and the weight of all other structural elements that it supports. In addition to these loads, members must be designed to support the weight of superimposed dead loads such as wearing surfaces, rails and curbs, stay-in-place forms, and utility lines.

Designs should include provisions for an additional 1.2 kilonewtons per square meter of deck surface for future deck overlays.

Normally, the design engineer must make a preliminary estimate of the dead load of a member on which to base the initial design. The actual member weight must then be used to recalculate dead load effects, and the design must be checked. This iteration process converges quite quickly. The design notes should always contain the dead load effects of the final design.

It is possible to arrive at a final value of the dead load for one part of a bridge before proceeding with the design of a supporting part. For example, the deck is always designed before the girders. For this reason, all designs should proceed from the topmost members to the lowest members. (This is exactly the opposite order in which the bridge is constructed.)

2. Live Loads. A highway bridge should be designed to safely support, without permanent damage, all vehicles that might pass over it in its lifetime. In the United States, AASHTO specifies design live loads, and State laws specify the legal weights of motor vehicles. This combination of controls provides safety for our bridges. In addition, the owner of the structure may specify larger design live loads and thus may issue permits for heavier traffic vehicles.

a. M and MS Loads. The four classes of AASHTO loadings known as M13.5, M18, MS13.5, and MS18 were adopted in 1944 (previously referred to as H15, H21, HS15, and HS20, respectively). See *AASHTO Standard Specifications for Highway Bridges,* Article 3.7 Highway Loads. The vehicles are hypothetical and were not selected to resemble any particular existing design. However, any actual vehicle that would be permitted to cross a bridge should not produce stresses greater than those produced by the hypothetical vehicle.

MS18 is by far the most common live loading used today and most projects use this loading. Some NPS bridges are designed for M13.5 or MS13.5 live loading. A few states have adopted MS22.5 loading, which is the same axle spacing as MS18 loading with axle loads increased by 25 percent.

M and MS loadings in AASHTO are presented as both truck loads and lane loads. The MS truck loadings show a variable spacing of the two rear axles of 4.3 to 9.1 meters. The correct spacing is the length that produces the maximum effect.

Only one truck is applied, per lane, on the entire bridge at one time. The lane loadings are simplified loadings which approximate a train of trucks. Lane loadings include a concentrated load that is different for moment than for shear. Only one concentrated load is used in a simple span or for a positive moment in a continuous span. Two concentrated loads are used for negative moment in a continuous span. The uniform load portion may be divided into segments on a continuous span to produce the maximum effect.

Appendix A in the *AASHTO Standard Specifications for Highway Bridges* may be used as a guide to determine if lane or truck loading is the controlling factor.

b. Special Live Loads. Projects sometimes include bridges designed for special live loads. These may be logging vehicles, military transport vehicles, or heavy construction equipment.

Unless otherwise noted, these should be considered overload vehicles, and appropriate overstress or load factors should be used in design. (Details on these procedures are included in appropriate subsections of this manual.) It should be noted that most overload vehicles require careful analysis of the *lateral* distribution of the loads also.

c. Pedestrian Loads. Pedestrian bridges should be designed for a live load of at least 4.1 kilonewtons per square meter (4.1 kilopascals) of walkway. This load may be applied continuously or discontinuously over the length or width of the structure in order to produce the maximum stress in the member under consideration.

Pedestrian loads on sidewalks attached to highway bridges vary depending on the span and are detailed in the *AASHTO Standard Specifications for Highway Bridges*.

d. Impact. A vehicle moving across a bridge at a normal speed produces greater stress than the same vehicle in a static position on the bridge. This dynamic effect is known as impact. From the theory of dynamics, a load applied instantly to a beam causes stresses of twice the magnitude obtained when the same load is static on the beam.

In bridges, the loading is applied over a short period of time, but not instantly. Hence, impacts are less than 100 percent; specifically, they are less than 30 percent.

Impact (I) is determined by the formula:

$$I = \frac{15.24}{L + 38}$$

where:

L = Length of span of loaded portion of bridge, in meters.

Examples of "L" are shown in Figure 10-1.

e. Longitudinal Force. AASHTO specifications provide for longitudinal force for the traction and braking effects of vehicular traffic headed in the same direction.

This force, when combined with other forces, may affect the design of bents. Occasionally, in framed structures where the bents are very stiff, longitudinal force may affect superstructure design.

The application of the longitudinal force for framed bridges should be applied 1.8 meters above the deck. This does not change the girder moments significantly. It is important in the design of bearings and substructure. For bridges other than framed structures, the force should be applied as a shear force at the bearings.

Longitudinal force due to friction at expansion bearings or shear resistance of elastomeric bearings should also be considered. (More information is included in the section on bearings, later in this chapter.)

f. Centrifugal Force. Centrifugal forces are significant in the design of bridges having small curve radii or curved bridges supported by long columns. This force is applied 1.8 meters above the deck at the roadway centerline.

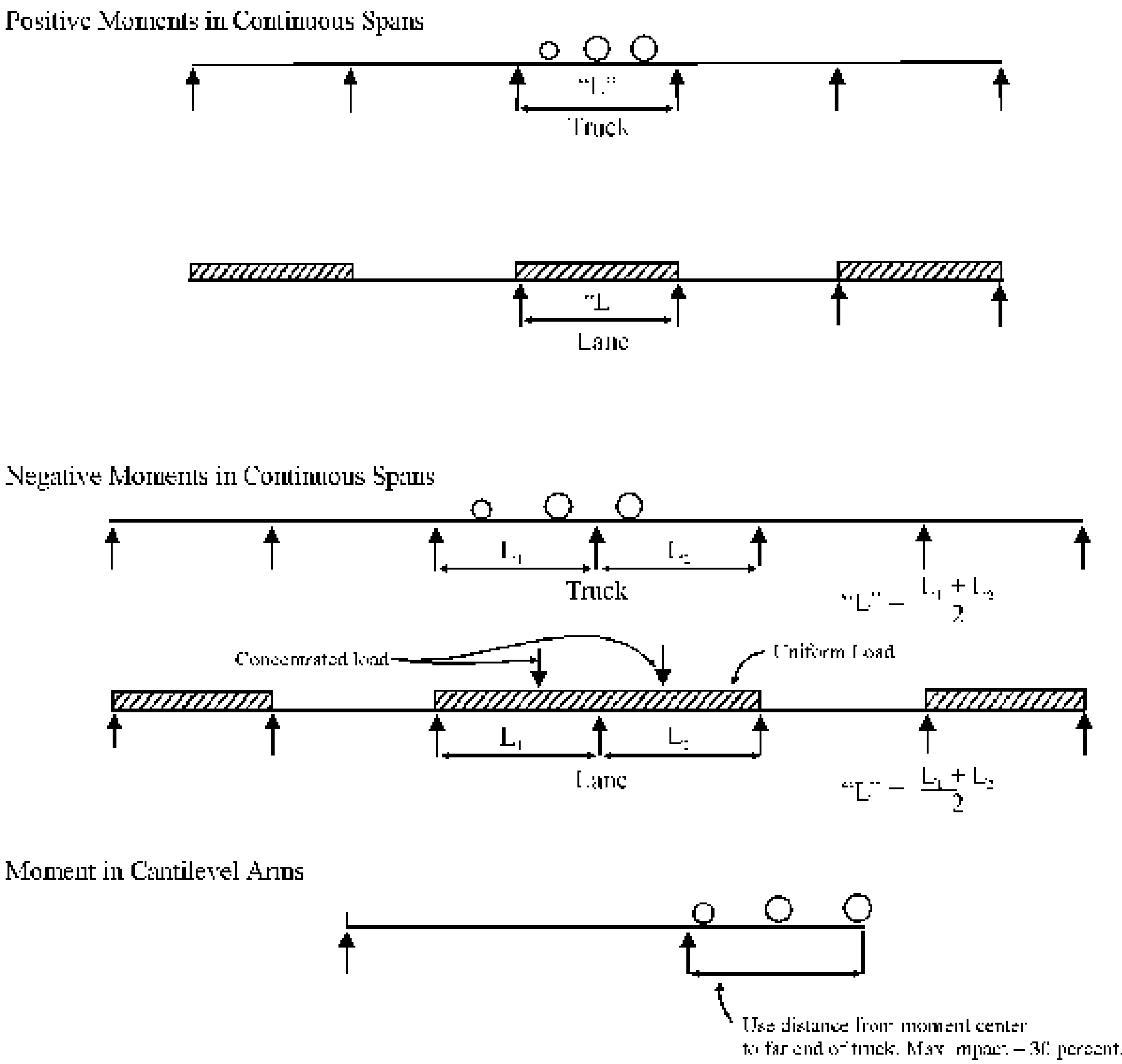

Figure 10-1
Impact Examples

3. Movement Loads. Movement loads include the effects of displacement or settlement of supports, temperature changes, shrinkage of concrete, rib shortening in arch structures, and creep effects. All of these change the geometric dimensions of the structure and many cause large stresses.

a. Displacement of Supports. Possible displacement or settlement of supporting elements of a bridge should be considered in design. If settlements are unavoidable, and of possible large magnitude, provisions should be made in the design to periodically reset bearings to offset the effects of the settlement. Such structures require close coordination of the structural and geotechnical engineers.

b. Temperature. Forces caused by changes in temperature rarely control superstructure design. Forces can become significant and even unmanageable on frame structures with stiff columns. The design range of temperatures for concrete structures represents about one-half of the full air temperature range. This is due to the slow response of concrete structures to temperature changes.

c. Shrinkage. Shrinkage is the volume decrease that occurs when fresh concrete hardens and continues for a period of time thereafter. Shrinkage could be critical in arches (rib shrinkage produces rib and column moments) and in prestressed girders where shrinkage produces loss of stressing force. Shrinkage forces may be reduced by careful placement of mandatory construction joints.

4. Environmental Loads. Environmental loads include the effect of wind, stream and ice flow, buoyancy, and earth pressure.

a. Wind. The basic wind loads are from a high wind of 160 kilometers per hour and a moderate wind of 48 kilometers per hour. In general, the high wind is assumed to act on the bridge when live load is not present. Moderate wind acts on the bridge when live load is present for some load combinations.

Forces are applied in a variety of ways depending on whether one is designing a superstructure or substructure, and whether the structure is ordinary or unusual.

Horizontal wind loads on the superstructure are always based on the side view cross sectional area. They act both longitudinally and transversely. Loads on the substructure can be applied to side or transverse views, or skew angles in between.

The use of engineering judgment is sometimes necessary when considering wind velocities to be used in the design of a structure. Permanent terrain features or precise data from local weather service records may indicate that the basic 160 kilometers per hour design wind should be modified. When modified, the specified wind pressure is changed in the ratio of the square of the design wind velocity to the square of the base wind velocity. The revised design wind must be stated in the general notes of the bridge plans.

The wind effect on the bents and footings needs to be thoroughly investigated for high structures both laterally and longitudinally.

The limiting height of column where wind may control varies with the span lengths, physical makeup of the structure, and the magnitude of other lateral loads such as that due to earthquakes.

When applying lateral loads in continuous structures, consideration should be given to the rigidity of the deck and its ability to transfer wind loads to abutments which might be considerably stiffer than the bents. In these cases, the abutments shall be designed to support these lateral loads.

In addition to moderate wind pressure on the bridge structure when a live load is present, a moderate wind force is exerted on the live load itself. This force is expressed as a live load acting both transversely and longitudinally 1.8 meters above the roadway surface. This offset location is important when designing high piers.

b. Stream and Ice Flow. Stream flow rarely controls the design of bridge piers. Ice flow can result in very large stresses. The maximum ice loading often occurs simultaneously with high water conditions that take place in early spring. The thickness of the ice and the corresponding river level should be carefully determined before starting design. Very large ice loadings should be controlled with piers incorporating icebreaker noses and armor.

c. Buoyancy. Whenever a portion of a structure will be submerged, the effects of buoyancy should be considered in the design. In small structures, its effects are unimportant and no economical advantage can be realized in the footing design. In large structures, buoyancy effects should be taken into account in the design of footings, piles, and piers.

Buoyancy is always a consideration for footings below the water table where cofferdams are necessary. Uplift in piles is limited to an intermittent value of 40 percent of the allowable design load.

d. Earth Pressure. Abutments and retaining walls should be designed so that any hydrostatic pressure is minimized by providing adequate drainage for the backfill.

For level backfill, the minimum active earth pressure is usually taken as an equivalent fluid pressure of 5.7 kilonewtons per square meter (5.7 kilopascals) of height for abutments and retaining walls. This is based on an earth pressure coefficient (K_a) of 0.30 and unit weight (w) of compacted earth of 1900 kilograms per cubic meter. These numbers are used in the design of the following elements:

- Toe pressure or toe piles in retaining walls and abutments.
- Bending and shear in retaining walls and abutments.
- Sliding of spread footings or lateral loads in piles.

For the design of heel piles in retaining walls or abutments, checks should be made using an equivalent fluid pressure of 4.2 kilonewtons per square meter per meter (4.2 kilopascals per meter) of height. This corresponds to a K_a of 0.225.

A trapezoidal pressure distribution is used where the top of the wall is restrained. This provides a more realistic solution than the triangular pressure distribution that applies to typical retaining walls without restraint.

5. Earthquake Loads. Earthquakes and the response of structures to earthquakes, are dynamic events -- events that go into many cycles of shaking. An earthquake of magnitude 8+, such as that which occurred in San Francisco in 1906 and in Alaska in 1964, may have strong motions lasting for as long as 40 to 60 seconds. The San Fernando earthquake of magnitude 6.6 had about 12 seconds of strong motion. During this period of strong motion, a structure passes through many cycles of deflection in response to the motions applied at the base of the structure. The strains resulting from these deflections are the cause of the structural damage.

Structures that may be subjected to earthquake forces shall be designed to survive the strains resulting from the earthquake motion. Three factors that are considered when designing to resist earthquake motions are as follows:

- The proximity of the site to known active faults.

- The seismic response of the soil at the site.

- The dynamic response characteristics of the total structure.

It is FLHO policy to use the AASHTO *Guide Specifications for Seismic Design of Highway Bridges*, Chapter 3 instead of the AASHTO Equivalent Static Force Method since the guide specification contains significant improvements and helps the designer deal realistically with seismic bridge response and design methodology.

The guide specifications provide for different levels of analysis and design requirements for four seismic performance categories (A through D). Each bridge is assigned to one of these four categories depending on its potential seismic acceleration coefficient and an importance classification. No detailed analysis is required for any simple span bridge or any bridge in seismic performance category A; the only requirements pertain to connections and minimum support lengths.

The higher seismic performance categories, B, C, and D, require either a single mode or multimode spectral method of analysis depending on the bridge type and performance category. These methods are dynamic analyses which require the designer to learn both the basic principles in dynamics as well as proper structural modeling for computer analysis.

The single mode spectral method is used to calculate the seismic design forces of a bridge that can be characterized as having its major dynamic response in a single mode of vibration and is limited to the lower seismic structures. This method, although quite rigorous, reduces a complex dynamics analysis to the performance of just two static analyses and on certain, uncomplicated structures, can be done by hand.

The multimode spectral method is required for the higher seismic structures and can only practically be done by computer. It determines many different modes of vibration from a three-dimensional mathematical model of the structure along with response spectrum loadings to produce multimodal contributions to the overall seismic response of the structure.

A computer program currently in use, SEISAB (Seismic Analysis of Bridges), was specifically developed to help bridge designers conduct the guide specification seismic analyses of most conventional bridges with minimal input.

Since the guide specification contains new analysis and design methodologies, it is recommended that new users thoroughly study the guide specification commentary as well as the references listed under Section 10.2.

6. Combination Loads. AASHTO specified ten groups to represent various combinations of the previously discussed loads to which a structure may be subjected. Each component of the structure or the foundation on which it rests, is required to be designed for the most critical group. Allowance for the probability, frequency, and structural effect of these load combinations is made by an allowable overstress (percentage of basic unit stress) for service load design, and the load factors for load factor design. For example, only 30 percent of the full 160 kilometers per hour wind force is applied simultaneously with critical truck or lane live loading.

Group I is the everyday set of loads a structure is expected to resist that consists of dead load, design live load, centrifugal force, earth pressure, buoyancy, and stream flow. Under the Load Factor Design, a 1.67 factor is required for the design live load to ensure adequate strength for overloaded (allowed by permit) vehicles.

Group IA is required to ensure overload capacity for structures designed for live loads less than M18.

Group IB is included to ensure that structures will have adequate resistance to allow passage of normally allowed overload vehicles on a permit basis by the structure owner or regulatory agency. This provides that all structures on a given highway route are capable of meeting the owner's permit policy for transportation of infrequent extralegal overloads. It is FLHO policy to use the owner's permit loading or loading combinations for this group. (For example, Caltrans uses a family of overload vehicles called P-loads which are a set of five trucks, each composed of a steering axle and from two to six pairs of tandem axles at 5.5-meter centers. Each axle weighs approximately 1.5 times legal loads.)

Normally, the controlling loads for superstructure components are dead load and live load plus impact; however, the designer should always verify this. For example, a typical steel plate girder section is normally sized for dead load and live load plus impact. A check must be made for wind and wind on live load under groups II and III for flange stresses when wind bracing is omitted.

For substructure design, normally two groupings of the loads are required:

- A factored set for the load factor design of reinforced concrete columns.
- An unfactored set for the service load design procedure for sizing spread and pile supported footings as well as other foundation units.

Live load distribution to substructure units is done with whole truck or lane loadings rather than girder distribution, since girder distribution could accumulate more wheel lines than would physically fit on the bridge.

The AASHTO list of loads and groupings of loads is not meant to be all inclusive. For example, prestress frame shortening, snow and avalanche pressures, and construction loadings must be calculated and combined with other loads appropriately. An example of a construction loading to be checked during design is the buckling resistance of the composite compression flange of a plate girder during construction of the deck.

When checking foundation stability safety factors against overturning, sliding, etc.) neither load factors nor allowable overstresses should be used.

C. Decks, Rails, Deck Joints, and Drains. The roadway surface of bridges that support and contain vehicular traffic consists of the deck, rails, deck joints, and drains. This surface must not only provide a good riding surface but must also provide durability against abrasive deterioration and repetitive cycles of loading in flexure and shear.

1. Deck Design. Transversely reinforced concrete slabs are the most commonly used bridge deck and are a significant portion of bridge design in terms of dollar investment.

These slabs also make-up the one portion of the bridge that has the most common and expensive maintenance problems. Heavy wheel loads, excessive use of deicing salts, studded tires, and poor construction control are contributing factors to structure damage.

Edge support for transversely reinforced slabs is normally provided by cast-in-place end diaphragms. These diaphragms are often placed only between girders. Caution should be exercised to provide an edge support on slab overhangs where a substantial length of overhang might exist and where moments due to wheel loads might be a major portion of the total moment requirement. Cast-in-place decks on structural steel superstructures is another place where edge support might not naturally be provided. Edge support should be designed for each condition to be capable of carrying a wheel load.

Placement of transverse slab reinforcing on skewed bridges is a subject of some debate. A reasonable rule used by many designers, however, places the reinforcement on the skew for up to 20°, and for 20° or greater, places the reinforcing normal to the roadway with variable length bars at the skewed ends. For reinforcement placed on the skew, the span should be increased to the skewed length and the area of reinforcement increased for the spacing normal to the skew.

The AASHTO specifications require a 50-millimeter cover over the top reinforcing steel and a 25-millimeter cover over the bottom reinforcement in deck slabs. This means that the effective depth for a negative moment is less than that for a positive moment, and because transverse slab spans are designed for the same moment at midspan and at the support, the negative moment top reinforcement is more critical. Therefore, it is common practice to design the top reinforcement and to make the bottom reinforcement the same to avoid confusion during construction.

FHWA Federal-aid Policy Guide 23 CFR 650F, recommends increasing the cover over the top reinforcing steel to 65 millimeters. The purpose is to ensure that a minimum of 50 millimeters of concrete would be provided over all top reinforcing steel. The same FHPM recommends using higher concrete strengths with lower water and cement ratios to increase density and durability of concrete decks. Both recommendations, combined with the use of epoxy-coated reinforcing steel, should be used when appropriate.

Regardless of the grade of reinforcing steel used or the strength of the deck concrete, it is recommended that stresses in transversely reinforced deck slabs should be limited as follows:

- f_s = 140 MPa **or** f_s = 165 MPa

- f_c = 8 MPa when f'_c equals 20 MPa

  or

  f_c = 0.4 f'_c for a f'_c greater than 20 MPa

Note: Stress limits for the reinforcing steel and concrete (f_s and f_c respectively) are to be determined by Division policy and practice.

Designated, infrequent overloads need not meet the above service limits, however, the slab's ultimate capacity must be more than the factored dead load plus overload with live load factor, B_{LL} = 1.0.

The horizontal railing load shall be treated as an infrequent loading. For ease of design, use the following service limits for dead load plus horizontal rail load for curbs, parapets, overhangs, etc.

- f_s = 165 MPa

- f_c = 0.4 f'_c

Many overload vehicles use tandem axles. Current AASHTO specifications do not provide for wheel distribution and moments with tandem axles. The 1957 AASHTO specifications did include tandem axle effects, and these are shown in Table 10-1. The formulas in this table should be used to design slabs for tandem axle vehicles.

Table 10-1
Slab Live Load Distribution and Moment

Distribution of Wheel Loads	**Main Reinforcement Perpendicular to Traffic Formulas for Moments per Meter Width of Slab**	
	Freely supported spans	**Continuous spans**
Single Axle: Spans 0.61 - 2.13 m, E = 0.6S + 0.76 Spans of more than 2.13 m, E = 0.4S + 1.14	$M = +0.25\frac{P_1}{E}S$	$M = \pm 0.2\frac{P_1}{E}S$
Tandem axles: Spans 0.61 - 2.13 m, E = 0.36S + 0.79 Spans over 2.13 m, E = 0.63S + 1.42	$M = +0.25\frac{p_2}{E}S$	$M = +0.2\frac{P_2}{E}S$

S = effective span length defined under "Span Lengths"
E = width of slab over which a wheel load is distributed
P_1 = load on one wheel of single axle
P_2 = load on one wheel of tandem axle

Slab designs occasionally alternate straight bars in the top and bottom of the slab with bent bars (crankshaft bars). This arrangement provides the design area of reinforcement for the critical tension zones for negative and positive reinforcement and one-half of that amount of reinforcement in the compression zone.

The location of bend points as shown in Figure 10-2 will assure safe design. Bent bars should not be used for decks with flared girders or for curved decks supported by straight girders.
Cantilever slabs should be checked for two loading conditions:

- DL + LL + I
  (Wheel 300 mm from the curb or face of rail.)

- DL + RLL

  Where:

DL	=	Dead load
LL	=	Live load
I	=	Impact
RLL	=	Horizontal rail live load

Stresses for these two loading conditions should be limited as previously noted.

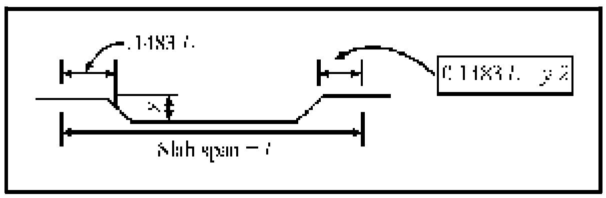

Figure 10-2
Determining Bend Points for Transverse Deck Slab Reinforcement

2. Rail Design. Bridge railings are an extremely important part of any structure and should be carefully designed and detailed . Railing loads are specified in AASHTO *Standard Specifications for Highway Bridges*, Section 2.7.1.3. and the application of these loads to the deck are covered in Section 3.24.5.2.

The method of connection of rails to decks should allow for ease of deck construction, for alignment, and for ease of rail repair or replacement.

3. Deck Joint Design. The designer should carefully consider accommodating all bridge movements for deck joint designs.

These movements include but are not limited to the following:

- Temperature expansion and contraction.
- Concrete shrinkage and creep.
- Live load rotation.
- Effects of prestressing.
- Foundation movements.

Deck joints should be avoided whenever possible since they are often sources of maintenance problems due to leakage of roadway water and contaminants as well as improper performance.

The following are some rough guidelines for providing for superstructure movements at abutments:

- For flexible abutments (such as a single row of piles with cap) with a pin type connection between superstructure and pile cap, allow 23 meters of contributory movement length. Pile flexibility permits structure movement and deck joints are not required.

- For rigid abutments, and for flexible abutments with more that 23 meters of contributory length, allow superstructure movement to occur against the approach fill, but permit movement between superstructure and abutment with an expansion bearing. Limit contributory length to 46 meters; deck joints are not required.

- For abutments with more than 46 meters of contributory length, provide an independent backwall type abutment with deck joint designed for all movements.

The guidelines above are not meant to be used without careful consideration of bearing protection from contaminants as well as provision for approach fill drainage and abutment details.

Deck joints between abutments are not desirable for the reasons mentioned. In general, they should only be used to separate different superstructure types, relieve frame-type restraint forces, or when the designer feels the provision for movement is critical.

For movements of less than 100 millimeters, the designer can select any of a number of proprietary joints according to the manufacturer's recommendations. It is recommended that on skewed joints, an interlocking type strip or gland seal be used. The joint should be detailed so drainage is properly handled at curbs, sidewalks, parapets, etc. On the plans, the joint width setting at the temperature anticipated during construction should be shown as well as adjustments for other construction temperatures.

For movements more than 100 millimeters, a special design is required.

4. Deck Drains. Every bridge should be analyzed for deck drainage considering width of bridge, superelevation or crown, profile grade, wingwalls, rail type, and geographic location. Consideration should be given to locating bridge deck drains between toes of embankments and installing drainage structures, catch basins, etc., off the bridge.

Deck drains over abutment fill slopes should be avoided. These drains have caused severe erosion on many previous projects. Where deck drains must be provided over abutment fill slopes, the plans must include an erosion control measure to be built at the time of bridge construction.

D. Analysis of Bridge Structures. The analysis of bridge structures begins with an approved TS&L drawing and the AASHTO bridge design specifications. Using these two documents, the design engineer begins by making a preliminary estimate of the members and end conditions. This assumed structure is then analyzed for the design loads and only the critical sections are designed. This design is then compared with the assumed (estimated) sections.

If necessary, the structure is modified and the new structure is again analyzed. This process continues until the optimum design is attained. At this point, the entire structure is designed for all sections and the plans can be produced.

Typically, the design is monitored at each stop for consistency, economic feasibility, and practicality of construction. The designer must never forget the original purpose of the structure and the objectives of the client.

1. Preliminary Sizing and Structure Modeling. The preliminary sizing of the bridge members is aided by previously similar designs as well as the depth-to-span criteria listed under Sections 10.4.E through 10.4.H. This is a critical point in the design process since a wise choice here will reduce the analysis/design iterations mentioned. Experience is invaluable at this stage, so assistance from the FLHD bridge engineer and the senior structural engineers is highly recommended. On certain structures, final design of the deck and traffic rails is now possible. This will help to finalize a portion of the dead load.

Structural analysis is the determination of displacements and stresses due to the known loads. For analysis purposes, the bridge structure must be idealized or modeled as to how the various parts interact to carry the loads to the supports.

In all structural analysis, the following three fundamental relationships must be satisfied:

- Equilibrium.
- Compatibility of displacements.
- Consistency of displacements with the respective stress/strain relationships.

The simplest structure type to analyze is the determinate structure which needs only the equations of equilibrium for complete solution.

The indeterminate structure requires compatibility and stress/strain relationships in addition to the equilibrium equations for complete solution. This requires significantly more effort than the determinate structure.

For each member in the bridge structure, the designer must decide which modeling is appropriate: whether a simplified determinate model will be adequate or whether a more complicated, time consuming indeterminate model is required. For example, a pile cap is often analyzed for 0.8 times the simple span moment to approximate the moments from a more difficult indeterminate solution, and the simple span shears are increased by 20 percent to account for continuity. By contrast, a bridge to be built at a high seismic location must be modeled with a sophisticated three-dimensional mathematical model to permit the required dynamic analysis.

Structure modeling for bridge members and complete structures can only be briefly introduced in this chapter. The inexperienced structural engineer is referred to the many excellent references listed in Section 10.2 as well as professional assistance from the sources listed in the same section.

The engineer should always make certain that the modeling assumptions adequately represent the member's or structures' true behavior for the particular design being conducted.

2. Simplified Methods of Analysis (Hand Method). Before the development of computer structural analysis aids, many techniques for hand analysis were developed. These hand analysis techniques continue to be valuable tools for the structural engineer. These techniques serve to train inexperienced engineers in the structural theory behind the computer programs. They also provide a means to check and understand the results of computer analyses.

Moment distribution is a simple, fast, and accurate method of analyzing continuous girders and frames. It was first taught by Professor Hardy Cross in 1924 and continues to be the bridge engineer's most powerful hand analysis tool. Two excellent references are Section 2 of the *Manual of Bridge Design Practice*, 3rd Edition, by Caltrans and *Moment Distribution.* by J.M. Gere. Moment distribution can easily accommodate the frequent variable moment-of-inertia member types encountered by use of aids for stiffness and carryover factors as well as fixed-end moments for various loadings. The analogous column procedure can be used to develop these for members and loadings not covered by the aids.

For computation of deflections, the moment area and conjugate beam procedures prove very useful. Another deflection computation method which can be extended for calculation of buckling loads and beam-column problems is Newmark's method. These methods are described in *Structural Mechanics* by Samuel Carpenter and *Structural Analysis* by Harold Laursen.

Moments, Shears, and Reactions for Continuous Highway Bridges, by AISC provides complete moments, shears, and reactions for certain continuous beam type members. It provides coefficients for determining influence lines that can be used for both dead and live loads.

The elastic center method can be used to analyze arches and rigid frames. It is described in *Structural Mechanics* by Samuel Carpenter, Section 14 of *Manual of Bridge Design Practice*, 3rd Edition, by Caltrans, and *Analysis of Arches, Rigid Frames and Sewer Sections*, by the Portland Cement Association.

For indeterminate frame type structures, the following procedure for hand analysis has proven helpful:

- From assumed member sizes, calculate stiffness and carryover factors.
- Perform moment distributions for unit fixed-end moments at all member ends individually, and tabulate the results.
- Calculate dead-load and live-load moments and shears at critical superstructure sections using the above unit distributions multiplied by the fixed-end moments for dead and live loads.
- Check the critical superstructure sections for adequacy for the assumed member sizes. (If not adequate, a change at this point will not require much effort.)
- When critical superstructure sections are adequate, design the substructure. (Changes at this point to the substructure members will not waste much previous effort and reanalysis can be done.)
- When substructure design is complete, compute dead load moments and shears for the superstructure at all tenth-point locations.
- Develop and draw influence lines for moments at the tenth points. Live load moments and shears can be obtained semigraphically from these.
- Finally, produce the required envelopes of moments and shears for the completion of the superstructure design.

3. Refined Methods of Analysis (Computer Method). The computer has become an invaluable aid to the bridge engineer. It permits better analysis in much less time than hand methods. It provides the engineer more flexibility to change member sizes and investigate different support conditions, various loading conditions, various modeling assumptions, than possible with time consuming hand analyses.

The computer also allows the engineer to do sophisticated analyses that are much too tedious and time consuming to do by hand. Use of this greater analysis power removes the tedium of hand analysis and allows much more flexibility, but demands that the responsible engineer become familiar with each program, its capabilities and limitations, and verify the results of each analysis. This responsible use of computer tools is essential to maintain professional control of a bridge analysis and design project. The computer can not substitute for an engineer's education, experience, judgment, and responsibility.

It is FLHO policy to encourage the responsible use of state-of-the-art computer tools for analysis and design of bridge structures.

Some recommendations for responsible use of these tool are as follows:

- Determine program authors, original purpose, and history of usage and revisions in order to evaluate the authenticity of reliability, available technical support for and the maturity of the program.
- Obtain complete user documentation as well as sample problem input and output.
- Strive to become familiar with and understand the program's flow and internal algorithms to the greatest extent possible.
- Obtain training and technical support from program authors or experienced users.
- Obtain education in unfamiliar program analysis techniques.
- When using very complicated programs for the first time, obtain a check run from the same program by the author or an experienced user.
- Always correlate the program output results (at least at critical sections) to a rough hand analysis in which you have confidence.
- When reasonable correlation does not exist, determine the cause and pursue better correlation or understanding before using the program further.
- Document helpful notes on input, usage, problem areas, correlation results, etc., for aiding novices and repeat users.
- Avoid becoming overconfident with any program and always verify its results.

A very real danger exists in irresponsible computer usage. Engineers should spend their early career development time learning not just the usage of computer programs, but also the structural theory fundamentals.

In the FLH Divisions, engineers are taught the classical hand analysis techniques described previously along with proper computer usage. Development of these hand skills has shown to provide an excellent theoretical as well as practical application base for the development of responsible bridge engineers.

The following are some excellent computer programs:

- **BDS** (Bridge Design System) is an orthogonal plane frame analysis system applicable to a wide variety of bridges. It has interactive capabilities with Direct Federal CADD equipment.

- **ORG** (Oregon Bridge Analysis Program by the Oregon DOT Bridge Design Section) is a general two-dimensional, finite, element-based analysis program for continuous beam or frame-type bridges. It accommodates standard AASHTO live loadings as well as special user specified vehicles and longitudinal loading, axial strain, and prestress. It reports design oriented outputs of conditions envelopes of shears, moments, and axial forces, influence lines, and stress summaries.

- **SAP** (Structural Analysis Program) is a large, general-purpose, elastic finite element program for static, dynamic and nonlinear analysis.

- **SIMON** is an analysis and design program written by United States Steel for steel plate and box girder bridges. It accommodates standard AASHTO live loads as well as optional-user designated, variable wheel loadings up to 20 axles. Both the working stress and load factor methods are allowed.

- **CURVBRG** analyzes horizontally curved steel girder bridges with a finite element grid- type model. It was developed by the University of California at Berkeley and correlated with actual in-service bridge instrumentation results by Caltrans. It incorporates a very helpful automatic live load generation routine.

- **YIELD** is a reinforced concrete column analysis and design program for biaxial bending and axial load by the ultimate strength theory by Caltrans. It easily accommodates many different column shapes and rebar patterns as well as user input by coordinates to handle virtually any solid or voided column shape and rebar pattern.

- **SEISAB** (Seismic Analysis of Bridges) was specifically written to provide the required dynamic seismic analyses of bridges. It incorporates an input generator to greatly simplify the creation of a three-dimensional model of the bridge. It can accommodate sophisticated foundation modeling when required or the use of many default type conditions. It performs static analyses as well as the AASHTO required single-mode and multimode spectral method dynamic analyses utilizing elastic techniques.

- **STDS** (Segmental Time Dependent System) analyzes the time dependent stresses in segmentally constructed prestressed bridges.

- **TANGO** analyzes steel, concrete segmental, composite, and cable-stayed bridges.

- **M STRUDL** is a linear elastic finite element program for static and dynamic analysis.

- **BRASS** (Bridge Rating & Analysis of Structural Systems) analyzes and designs reinforced concrete box culverts; steel, timber, reinforced concrete, or prestressed girders; and, reinforced concrete piers. The program is a comprehensive system for rating simple and continuous truss and girder floor beam stringer type bridges.

E. Reinforced Concrete Design. Almost every bridge designed in the United States today uses reinforced concrete in some element. This may be footings, substructure elements (such as piers and abutments), retaining walls, girders, decks, or rails. Many bridges consist entirely of reinforced concrete. Since its introduction over 150 years ago, concrete has been the most widely used construction material in the history of civilization. The major advantage in the use of concrete for bridges is its ability to be used in a wide variety of configurations and to have variable content.

1. Structural Types. The following is a list of the more common types of reinforced concrete bridge structures. Each design has distinctive characteristics and attributes.

Reinforced Concrete Slab Bridge.

- *Structural*: The depth-span ratio for simple spans is 0.065± and 0.052 to 0.042 for continuous spans. Solid slabs are used for spans from 5 to 14 meters, cored or voided slabs are used for spans from 12 to 20 meters, and recessed soffit slabs for spans from 12 to 25 meters.

- *Appearance*: Neat and simple; desirable for low, short spans.

- *Construction*: Details and formwork simplest.

- *Traffic*: May be impeded by falsework if cast-in-place due to reduced clearances. Guard-rail should protect falsework openings for traffic lanes.

- *Construction time*: Shortest of any cast-in-place construction.

- *Maintenance*: Very little except at hinges. Future widening may be difficult.

Reinforced Concrete T-Beam Bridge.

- *Structural*: The depth-span ratio for simple spans is 0.07±, 0.065 for continuous spans, 0.080 maximum at supports, and 0.055 minimum at midspan for haunched spans. Smaller ratios are possible, but riding qualities are affected by creep characteristics of concrete. Span range is 9 to 25 meters.

- Appearance: Cluttered in view from bottom; elevation is neat and simple.

- *Construction*: Requires good finish on all surfaces; formwork is complicated.

- *Traffic*: May be impeded by falsework if cast-in-place due to reduced clearances. Guard rail should protect falsework openings for traffic lanes.

- *Construction time*: More than for slabs due to forming, but not excessively long.

- *Maintenance*: Low, except that bearing and hinge details may require attention.

Reinforced Concrete Box Girder Bridge.

- *Structural*: The depth-span ratio for simple spans is 0.06±, 0.055± for continuous spans, 0.02-0.03 at midspan, and 0.05-0.08 at supports for haunched spans. Smaller ratios are possible, but riding qualities are affected by creep characteristics of concrete. High torsional resistance makes it suitable on curved alignment. Span range is 25 to 60 meters. For shorter spans, consider recessed soffit, T-beam, or voided slab bridges.

- *Appearance*: Neat and clean lines from all views; utilities, pipes, and conduits can be concealed.

- *Construction*: Rough form finish is satisfactory on inside surfaces; formwork is complicated.

- *Traffic*: May be impeded by falsework due to reduced clearances. Guard rail should protect falsework openings for traffic lanes.

- *Construction Time*: More than for slabs or T-beams due to staging of concrete placement, but still not excessively long.

- *Maintenance*: Low, except that bearing and hinge details may give some trouble. Future widening may be difficult.

Rigid-Frame Bridges.

- *Structural*: Integral rigid negative-moment knees greatly reduce the positive span moment and overturning moment at foundation level.

  Single rigid portal frames will adapt to narrow water channels, railways, subways, and divided or undivided highways underneath.

  Double-span rigid frames suitable for divided multilane highways underneath with sufficient mall or median width for triple-span support rigid frames (with or without side spans) are possible to accommodate multilane, divided highways with a wider center mall or median.

  Advantage of variable moment of inertia can be easily incorporated. Preliminary proportioning can start with a thickness at the knee equal to approximately twice that at the crown.

- *Appearance*: Graceful and clean; well adjusted to stone facing.

- *Construction*: Usually requiring curved formwork for variable depth.

- *Traffic*: May be impeded by falsework due to reduced clearances. Guard rail should protect falsework openings for traffic lanes.

- *Construction Time*: Similar to that of other types.

- *Maintenance*: Low, except for potential backfill settlement. Limited flexibility for future widening.

Arch Bridges.

- *Structural*: Horizontal reactions created by an arch greatly reduce the otherwise large, positive moment in the center. Constant depth for small spans and variable moment of inertia for medium and long spans. Spans as long as 300 meters have been built. Rise-to-span ratio varies with topography. Thickness at spring lines usually is slightly more than twice that at the crown. Filled spandrels are used only with short spans.

  For medium and long deck spans, open spandrels with roadways carried by columns are the rule. In a through-arch, the center deck usually is carried by hangers and side decks by columns. Use long single spans over deep waterways and shorter multiple spans over wide, shallow waters with rock bottoms.

- *Appearances*: Graceful and attractive, especially over deep gorges, ravines, or a large waterway.

- *Construction*: Either falsework or cantilever methods can be used.

- *Traffic*: When traffic cannot be diverted, the cantilever method may be used instead of falsework.

- *Construction Time*: Usually longer than for other structures. Use prefabricated blocks and post-tensioning when shorter time is desired.

- *Maintenance*: Low.

2. General Requirements and Materials. Concrete to be used for nonprestressed structures will normally have a 28-day compressive strength (f'_c) of 20 to 35 megapascals. The strength required will be based on the member use and product availability from local sources. Poor quality local aggregates often limit the strength of available concrete.

All reinforcing steel should be AASHTO 31M, Grade 60 (400MPa minimum yield strength).

Except in very unusual cases, or in designed splices, reinforcing steel should never be welded.

3. Analysis. All members of statically determinate or indeterminate structures should be designed for the maximum effects of all loads as determined by elastic analysis. Instead of elastic analysis, any acceptable method may be used that takes into account the nonlinear behavior of reinforced concrete, when subjected to bending moments approaching the ultimate. The use of these more exact methods of analysis should be approved on a case-by-case basis by the FLHD bridge engineer.

a. Expansion and Contraction. When designing and detailing reinforced concrete structures, the design engineer should always keep in mind the degree of restraint in members of the bridge. Highly restrained members will almost always crack due to shrinkage or temperature changes. Carefully located construction joints can reduce shrinkage stresses. Stresses due to temperature changes can be controlled by adjusting the stiffness of the structure and by the location of joints.

Creep and shrinkage of concrete are time-dependent deformations and must be included in the design of bridge structures. Short-term loading (live loads) on a concrete bridge induces elastic deformations. Dead loads or superimposed dead loads, however, are long-term effects that must be considered.

Creep of concrete is the phenomenon in which the deformation continues with time under constant load. This response can be related to the initial elastic deformation or strain as determined by the following equation:

$$C_t = [\frac{t^{0.60}}{10 + t^{0.60}}]C_u$$

where: C_t = $\frac{creepstrain}{nitialelasticstrai}$

C_u = 2.35

t = time (days)

Creep is also represented by the curve shown in Figure 10-3.

Shrinkage is defined as the volume change in the concrete with respect to time. The associated shrinkage strain can be computed from the following formula:

$$E_{sh} = \frac{t}{35 + t}(E_{sh})u$$

$$(E_{sh})u = 800 \ (10^{-6} mm \ mm^{-1})$$

Shrinkage strain is also represented by the curve shown in Figure 10-4.

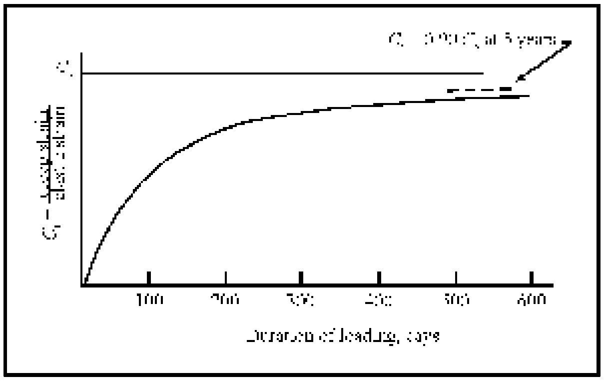

Figure 10-3
Standard Creep Coefficient Curve

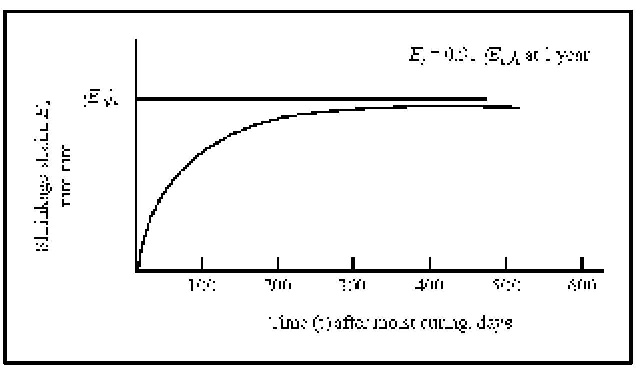

Figure 10-4
Standard Shrinkage Strain Curve

b. Stiffness and Frame. The following guidelines concerning frame analysis with concrete columns, walls, or single shaft piers may be used as a guide to supplement the AASHTO specifications.

For figuring stiffness, include the moment of inertia of the reinforcing steel for all substructure units and use the gross concrete moment of inertia for superstructure units.

The effective height of a pier column or wall should be taken from the centroidal axis of the superstructure to the bottom of the footing or to the top of the footing if an articulated hinge is used. Also, the substructure frame characteristics shall be based on the concrete below the superstructure soffit. If there is a monolithic cap that extends below the superstructure soffit by more than 10 percent of the effective height, the effect of such a cap shall be included in the frame characteristics. The effect of stiffness of footings shall be ignored. In the cases where articulated hinges are used, the moment due to thrust shall be used in figuring footing pressures for such footings.

For stiffness of skewed wall piers up to 20° skew, use the moment of inertia about the axis of the wall. For skews greater than 20°, careful analysis should be made on a case-by-case basis to determine the proper substructure stiffness.

The use of articulated hinges at the bottom of the columns will be restricted to the cases when the size of resulting piers and footings are excessive. When no articulated hinge is used, the pier shall be assumed hinged at the bottom of the footing for allowable soil pressure up to 300 kilonewtons per square meter (300 kilopascals). In this case, proportion the footing area for the uniform footing pressure. Design the footing itself (depth, reinforcement, and shear) for a nonuniform pressure by applying 20 percent of the moment at the column top to the footing.

For allowable soil pressure greater than 300 kilonewtons per square meter (300 kilopascals) and up to 450 kilonewtons per square meter (450 kilopascals), the pier shall be assumed to be 50 percent fixed.

For allowable soil pressure greater than 450 kilonewtons per square meter (450 kilopascals), the pier shall be assumed 100 percent fixed.

The use of a single row of foundation piles shall be considered as a hinge at the bottom of the footings, while the use of more than one row of foundation piles shall be considered as fully fixed at the bottom of the footings.

For skewed walls or single shaft piers, the longitudinal and transverse moments from superstructure (due to any load) should be resolved into components normal and parallel to the axis of the pier.

For circular shafts, the moment should be combined into one resultant depending on the magnitude of the moments.

In nonskewed bridges, the shear load from a span is distributed uniformly into a support by assuming each girder carries its own portion. In a skewed bridge, the load tends to distribute to the supports in a direction normal to the support. This causes a greater portion of the load to be concentrated at the obtuse corners of the span and less at the acute corners.

A graph has been developed to provide adjustment factors for applied shears calculated without considering skew effects. This graph, and examples for its use, are available in the bridge design offices of the Federal Lands Highway Divisions.

For curved bridges having skews greater than 45°, the design should consider a more exact analysis, such as three-dimensional computer programs, that consider torsion.

4. Design. *AASHTO Standard Specifications for Highway Bridges* now permits the designer to choose one of two methods for proportioning reinforced concrete bridge members:

(1) "Service Load Design Method (Allowable stress design)", AASHTO Section 8.15, or

(2) "Strength Design Method (load factor design)", AASHTO Section 8.16.

Service Load Design is a modification of the method used for many years, sometimes called working stress design, since stresses calculated for service load effects are controlled within specified allowable, or working stresses. Strength Design, sometimes called ultimate strength design or load factor design, is based upon providing a member strength sufficient to carry loads that are specified multiples of the service loads.

Exhibit 10.1, at the end of this chapter, contains selected portions of a paper titled *Design Methods and Strength Requirements*, by Ashby T. Gibbons, Jr. of PCA. It is offered to give the design engineer a brief history of these two design methods and to assist in deciding which method to use for design.

It is only a matter of time before service load design will be eliminated from the AASHTO specifications. (The ACI Code did so in 1977 and included it as an *alternate design method* in the appendix of the code.) The use of strength design is highly encouraged for all FLH projects.

5. Specifications, Design Aids, and Policies. In each design office, there are specific policies and design aids that clarify, modify, and guide the usage of the AASHTO specification. These are voluminous and are updated frequently to keep up with the AASHTO yearly interim specifications. The interims are necessary since bridge design is dynamic in nature (i.e., research and development of new technologies force changes in both design specifications as well as construction methods).

Since these policies and aids are voluminous and are frequently updated, it is impractical to include them in this design manual. The designer is referred to the FLH Division Bridge Engineer and Senior Structural Engineers for these policies and aids.

F. Structural Steel Design. Although true structural steel was used for the eye-bars of suspension bridges in the early 1800's, it was not until about 1870 that the first all steel bridge was constructed. Today, there is a wide variety of steels available for bridge design. The bridge engineer needs to have a working knowledge of the physical properties of these steels in order to make a proper selection.

1. Structural Types. The following is a list of the more common types of structural steel bridges. Each design has distinctive characteristics and attributes.

Composite Wide Flange Beam.

- *Structural*: This structure type has low dead load which may be of value when foundation conditions are poor. Depth-span ratio for simple spans is 0.060. Can be used with timber decks for low volume structures or pedestrian bridges. Suitable for spans up to 25 meters. Larger sizes of wide flange beams may not be available in many areas.

- *Appearance*: Can be attractive. Best for simple spans.

- *Construction*: Details and form work simple. Partial length cover plates welded to bottom flange will improve economics.

- *Traffic*: Minimal traffic problems; limited to short periods of time for erection and installation of protection nets if required.

- *Construction Time*: On the job, very short, but procurement of steel may cause delay.

- *Maintenance*: Painted steel structures require routine maintenance depending on environmental conditions. Weathering steel reduces maintenance. Weathering steel should be carefully considered in desert climates, coastal areas, or in areas subject to heavy use of deicing salts. Weathering steel may cause staining of concrete piers and abutments.

Composite Welded Girder.

- *Structural*: This structure type has low dead load, which may be of value when foundation conditions are poor. Depth-span ratio for simple spans is 0.060 and 0.045 for continuous spans. Can be adapted to curved alignment. Suitable for spans 18 to 90 meters. May be competitive when an erected type of superstructure is required. Competitive with precast concrete girders.

- *Appearance*: Can be made to look attractive. Girders can be curved to follow alignment.

- *Construction*: Details and formwork simple. Transportation of prefabricated girders may be a problem.

- *Traffic*: Same as for composite wide flange beam.

- *Construction time*: Short time on the project, but procurement and fabrication of steel may cause delay.

- *Maintenance*: Same as for Composite Wide Flange Beam.

Structural Steel Box Girder.

- *Structural*: Use multiple boxes for spans up to 60 meters and single box for longer spans. Use depth-span ratio for continuous spans of 0.045 and 0.060 for simple spans. Usable for spans 18 to 150 meters. More expensive than steel "I" girder. More economical in the upper range of usable span and where depth may be limited.

- *Appearance*: Generally pleasing. Better than steel or precast concrete girders.

- *Construction*: Very complicated welding and welding details. Because of the many opportunities for welding and detail errors that can give rise to fatigue failures, the steel box should only be used in very special circumstances.

- *Traffic*: Erection requires substantial falsework bents at splice locations.

- *Construction Time*: Procurement of steel and extensive fabrication requires considerable time.

- *Maintenance*: Same as for composite wide flange beam.

Steel Railroad Structure.

- *Structural*: Reinforced concrete deck preferred. Steel plate deck may be used. Deck type structures are more economical than through girder structures. Depth-span ratio is 0.10 for deck type (not including the 0.61 meters from top of rail to bottom of ballast). Through girder structures requires substantial deck thickness from top of rail to bottom of ballast. Depth-span ratio of through girders is 0.13.

- *Appearance*: Can be attractive.

- *Construction*: Details simple. Shop fabricated.

- *Traffic*: Minimal traffic problems.

- *Construction Time*: Same as for Composite Welded Girder.

- *Maintenance*: Same as for composite wide flange beam.

2. General Requirements and Materials. Steel structures shall be designed using the following:

- *ASTM A 36M (AASHTO M 183M) Structural Carbon Steel*. This is the "basic" steel to be used for painted structures where high strength is not required.

- *ASTM A 572M, Grade 345 (AASHTO M 223M) High Strength, Low-Alloy Structural Steel.* This steel is to be used for painted structures where high strength is advantageous.

- *ASTM A 588M (AASHTO M 222M) High Strength, Low-Alloy Structural Steel.* This steel (sometimes referred to as weathering steel) has an increased resistance to corrosion and shall be used for unpainted structures.

The use of structural steel conforming to ASTM A 514M or A 517M should be restricted to only very unusual structures. These very high strength, quenched, and tempered alloy steels require expert design and extreme controls for fabrication due to their critical fatigue and fracture characteristics. Their use on projects will be very rare.

The use of structural steel for main member tension material in excess of 50-millimeter thickness should be avoided.

In general, bolts for structural steel bridges shall be fabricated from ASTM A 325M (AASHTO M 164M) steel - Either type 1 or type 2. ASTM A 325M, Type 3 bolts with weathering characteristics are compatible with ASTM A 588M structural steels.

The use of high strength ASTM A 490M (AASHTO M 253M) bolts should be severely restricted. Like very high strength structural steels, these bolts require extreme construction control.

3. Design. In the past, steel bridge design was relatively simple. Usually, the structure was only required to span an obstacle by the simplest and most direct means. Material stresses were kept quite low. Today, however, steel bridges are required to match the highway alignment, which often results in curved structures. Economic considerations require the use of steels to their maximum, resulting in very high material stresses. This means that the design details for steel bridges are of utmost importance. Current specifications become very complex and should be carefully adhered to for all steel bridge design.

a. Fatigue and Stress Considerations. The fatigue provisions of the AASHTO Design Specifications were developed from research and studies of failures in the field. Details for main load-carrying members, such as cover plates and butt weld of tension flanges, are familiar to bridge designers. The effects of connection to the main members, however, are not as familiar and have been a source of more and more fatigue problems in recent years.

A recent change in the specification is the stress range concept. Research by Dr. John Fisher at Lehigh University has shown that the range of stress is the single most damaging factor in fatigue. Thus, only the live load fluctuation is significant and the stress level does not significantly influence fatigue behavior.

The type of loading, stress category (connection details), and redundancy control the allowable stress range.

(1) Type of Loading. The number of cycles of fatigue life depends on the type-road and the type of live loading. Many projects are low-volume roads in terms of truck traffic and should be designed for 100 000 cycles of loading. There are some projects, (such as major forest highway routes), that may require a design for 500 000 or even 2 000 000 cycles of loading. The number of loading cycles should be determined on a case-by-case basis.

(2) Stress Category. There are several stress categories, A through F. Each of these categories is described in the tables and illustrative examples are shown in Chapter 10, Section 10.3 of the Division I - Design of the AASHTO Standard Specifications for Highway Bridges. Plain plates are in category A and the most severe connection details are in Category E.

(3) Redundancy. Bridge structures where the failure of a member of a single element could cause collapse of the structure (such as a single box girder, truss, etc.) are considered nonredundant structures, and a more severe restriction has been placed on them by shifting the allowable stress range by one loading cycle. This reduction to a lower stress range makes details that fall in category E very uneconomical and, in essence, restricts their use.

(4) Charpy V-Notch Impact Requirements. Main load-carrying member components subjected to tensile stress require minimum supplemental impact properties. These impact requirements vary depending on the type of steel used and the average minimum service temperature to which the structure may be subjected. For service temperatures below -35°C, special values are required.

The basis and philosophy used to develop these requirements are given in a paper entitled *The Development of AASHTO Fracture-Toughness Requirements for Bridge Steels* by John M. Barsom, February 1975, available from the American Iron and Steel Institute, Washington, DC.

(5) Identification of Main Member Components Subject to Tensile Stress. Main load-carrying member components subject to tension or reversal of stress must be identified on the contract drawings as well as the appropriate temperature zone. These are necessary to specify the required charpy V-notch impact properties and the required nondestructive testing of groove welds.

The designer should consult the Federal Lands Highway Division Bridge engineer or a Senior Structural engineer for guidance.

(6) Fracture Control Plan (FCP). The FCP is an AASHTO guide specification for fracture critical nonredundant steel bridge members. The FCP was devised to prevent collapse of steel bridges. Much of the FCP relates to design, welding, and material properties.

The designer is responsible to designate any member or structural component as a fracture critical member (FCM) when failure of the FCM would cause the structure to collapse. The FCP requires the FCM to be fabricated in a qualified shop and inspected by qualified inspectors; requires nondestructive inspection (NDI) by qualified testers; and supplements the current AWS and AASHTO welding specifications, and specified material toughness.

The FCP is a comprehensive plan whose adoption should improve the overall quality of steel structures from design through fabrication.

An excellent source of guidance on fatigue is the *Bridge Fatigue Guide, Design and Details* by Dr. John W. Fisher and published by the American Institute of Steel Construction.

b. Efficient Girder Depths. The first step in the design of a steel bridge is to determine the most efficient web depth. The determination of this depth is based on several parameters. Girders may be classified as either symmetrical or unsymmetrical as shown in Figure 10-5.

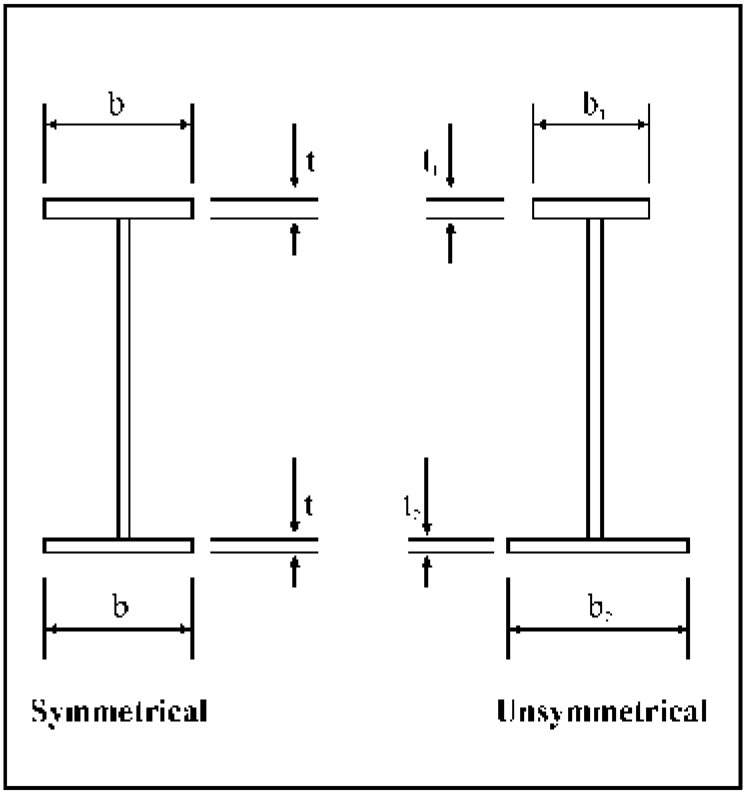

Figure 10-5
Girder Classification

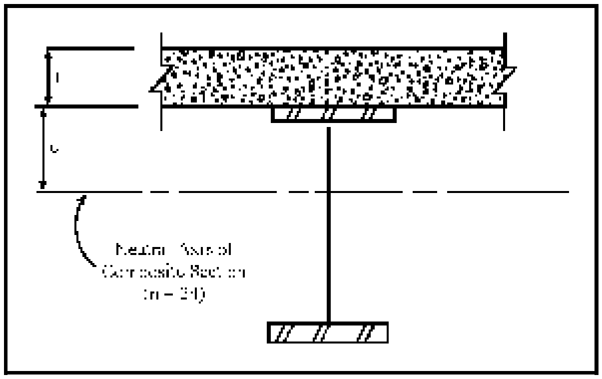

Figure 10-6
Deflection Due to Deck Shrinkage

(1) Shrinkage in Simple Beams. Calculate moment due to shrinkage and apply as a uniform load. Find deflections due to shrinkage using composite section for moment of inertia.

(2) Shrinkage in Continuous Beams. It is assumed that the shrinkage force in the slab takes place when the slab is in compression, such as between points of inflection in interior spans and between end pier and inflection points at end spans.

To calculate deflections, do the following:

1. Find uniform moments along the beam in compression zones (between points of inflection)

2. Calculate fixed end moments together with distribution and carryover factors.

3. Combine 1 and 2 for final moments and find deflections due to these moments using respective moments of inertia.

d. Splices. Field splices should be bolted splices. Field welded splices of primary structural members should be avoided.

e. Diaphragms, Cross Frames, and Lateral Bracing. The AASHTO specifications now include provisions to determine the need for lateral wind bracing for the bottom flanges of rolled beam and plate girder bridges.

The application of these provisions to include the effects of wind loads plus dead and live loads is covered in the pamphlet *Determining the Need for Lateral Wind Bracing in Plate Girder Bridges*, a supplement to Chapter 5, Volume II, USS Highway Structures Design Handbook.

Lateral wind bracing should not be included if not required by stresses.

f. Composite Deck Design. Concrete deck slabs should be made composite with steel girders for the entire length of simple spans and for the positive moment regions only on continuous spans. This is generally achieved with welded stud shear connectors.

4. Specifications, Design Aids, and Policies. Each design office has specific policies and design aids that clarify, modify, and guide the usage of the AASHTO specifications. These are voluminous and are updated frequently to keep up with the AASHTO yearly interim specifications. The interims are necessary since bridge design is dynamic in nature; i.e., research and development of new technologies force changes in both design specifications and construction methods. Since these publications are voluminous and are frequently updated, it is impractical to include them in this design manual.

The designer is referred to the FLHD Bridge Engineer and Senior Structural Engineer for these policies and aids.

G. Prestressed Concrete. The first prestressed concrete bridge in the United States was constructed in 1949. Since 1960, most bridges in the United States with a span range of 18 to 36 meters have been constructed with prestressed concrete. Since the late 1970's, post-tensioned continuous or cantilever bridges with spans of 45 to 200 meters have gained in popularity.

1. Structural Types. The following list of features of the more common structures provides information to assist in the preliminary selection and sizing of members.

Cast-in-place concrete slab.

- *Structural*: Used for spans up to 20 meters. Recommended for conditions where very low depth-span ratio is required. Can be used for either simple or continuous spans. The depth span ratio is: 0.030 for simple and continuous spans. More expensive than reinforced concrete slabs.

- *Appearance*: Same as reinforced concrete slabs.

- *Construction*: More difficult than reinforced concrete slabs.

- *Traffic*: May be impeded by falsework due to reduced clearances. Guide rail should protect falsework openings for traffic lanes.

- *Construction Time*: Shortest of cast-in-place construction; longer than precast slabs.

- *Maintenance*: Very little.

Precast concrete slab.

- *Structural*: Standard plans for corded slabs of spans 6 to 15 meters are available. Not recommended for long multispan structures because of difficulties in camber control resulting in undesirable riding qualities. Economical where many spans are involved or in areas remotely located from concrete batch plants.

- *Appearance*: Same as reinforced concrete slab.

- *Construction*: Details and formwork very simple. Shop fabrication methods employed.

- *Traffic*: Very little interference except during erection.

- *Construction Time*: On site, very short. Very little time required for plant fabrication.

- *Maintenance*: Very little.

Precast Concrete Girder.

- *Structural*: Applicable to spans 9 to 43 meters. Standard sections are available for "I" girders and many other girder shapes to cover complete range of spans. Design analysis to determine prestress force, concrete strength, and camber. Structure depth is girder depth plus necessary slab thickness. Girders longer than 36 meters cannot be hauled over many highways. Depth-span ratio is: 0.055 simple spans, 0.050 continuous spans. Competitive with steel girders, and very economical in areas near precasting plants.

- *Appearance*: Similar in appearance to T-beams. Straight girders on curved alignment look awkward.

- *Construction*: Require careful handling and transporting after fabrication. Fabrication plants nationwide cast a wide variety of sections in addition to standard AASHTO sections.

- *Traffic*: Same as prestressed slabs.

- *Construction Time*: Same as steel girders. Fabrication may require additional time.

- *Maintenance*: Very little except at hinges or joints.

Cast-in-place box girder (post-tensioned).

- *Structural*: Requires detailed stress analysis. Depth-span ratio: 0.040 continuous spans, 0.045 simple spans. High torsional resistance makes it desirable on curved alignment. Dead load deflections minimized. Desirable for simple spans over 30 meters. Long-term shortening of structure must be provided for. About the same as conventionally reinforced box girder. Used for spans up to 180 meters.

- *Appearance*: Better than conventional box girder because of shallow depth. Has all other qualities of conventional box girder. Excellent in metropolitan areas. Can be used in combination with conventional box girders in long structures with varying span lengths to maintain constant structure depth.

- *Construction*: Same as conventional box girder.

- *Traffic*: May be impeded by falsework due to reduced clearances. Guard rail should protect falsework openings for traffic lanes.

- *Construction Time*: Longest for any prestressed concrete structure due to delay before tensioning is allowed to proceed.

- *Maintenance*: Very little except at joints or hinges.

2. General Requirements and Materials. Concrete in prestressed members is subject to higher stress levels than concrete in nonprestressed, reinforced members. Therefore, on all projects under the jurisdiction of FLH, the minimum compressive strength at the time of initial prestress shall be as follows:

- f'_{ci} = 25 megapascals (post-tensioned members).

- f'_{ci} = 30 megapascals (pretensioned members).

Prestressing steel strands are available in diameters from 6.4 millimeters to 15.2 millimeters, in grades of 1.72 gigapascals or 1.86 gigapascals , and as either stress-relieved or low-relaxation. The grade or strand indicates the ultimate strength and the type of strand (i.e., stress-relieved or low-relaxation) and defines the manufacturing process and prestress loss characteristics.

The most common strand used on FLH projects is 12.7 millimeters diameter, grade 1.86, low-relaxation strand. However, some localities may continue to use stress-relieved strand. The specifications should allow a prestressing firm to change the type of strand if desired. Any changes should be redesigned by the manufacturer and checked by the Government. These changes should be shown on the fabrication plans and submitted for approval.

Prestressing steel strands with a 15.2 millimeters diameter should not be used for any precast, prestressed member.

Properties and strengths of seven-wire, grade 1.86 strand are shown on Table 10-2.

Table 10-2
Properties of Prestressing Strand

Seven-Wire-Strand					
Nominal Diameter, mm	9.5	11.1	12.7	14.3	15.2
Area, mm^2 (A*s)	54.8	74.2	98.7	123.9	138.7
Mass, kg/m	0.43	0.60	0.79	0.97	1.12
$0.7f_s'A^*_s$, kilonewtons	71.6	96.5	128.6	161.5	181.0
$0.75f_s'A^*_s$, kilonewtons	76.5	103.6	137.9	173.0	193.5
$0.8f_s'A^*_s$, kilonewtons	81.8	110.3	146.8	184.2	206.8
$f_s'A^*_s$, kilonewtons	102.0	137.9	183.7	230.4	258.4

Note: f_s' = Ultimate strength of 1.86 GPa

3. Analysis. Stresses are introduced into the concrete opposite to the stresses resulting from loads acting on the structure. The stresses are introduced in such a manner that allowable working stresses will not be exceeded. Compressive stresses are induced in the face of the member where tensile stresses tend to develop due to loads. These induced stresses result from a compressive force that is transmitted to the concrete from the prestressing steel.

Prestressed concrete makes full use of the compressive strength of the concrete and the tensile strength of the prestressing steel. Ordinary reinforced concrete does not use the concrete to its full advantage. For comparison purposes (using the same allowable concrete stress), see Figure 10-7. The resulting moment for the reinforced concrete section is calculated in the normal manner, and the resisting moment shown for the prestressed section is approximately the net resisting moment for applied loads after prestressing.

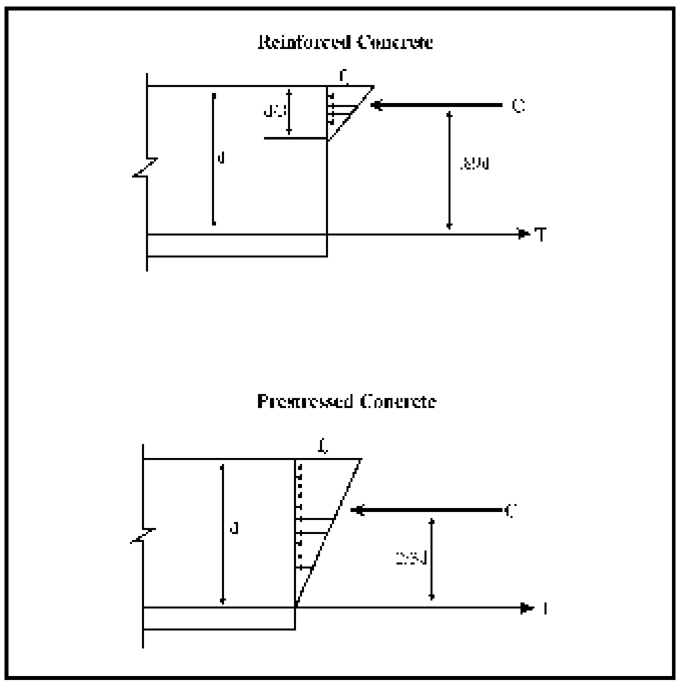

Figure 10-7
Concrete Beam Stresses

As shown in Figure 10-7, a prestressed section with beams of the same depth can resist over twice the moment that the reinforced concrete section can resist. Furthermore, the allowable working stress can be doubled for the prestressed section, thus making the resisting moment over four times that of the reinforced concrete section. The prestressed section makes use of the entire concrete area; however, the reinforced section uses about 1/3 of the area, 2/3 being used to hold the reinforcing steel away from the working section, resist shearing stresses, and develop the bond between the concrete and reinforcing steel.

Two advantages of a prestressed concrete structure are the reduction of both concrete and steel quantities. Other advantages of a prestressed concrete structure are as follows:

- A considerable reduction in depth of section, not only relative to reinforced concrete, but also relative to structural steel.

- A reduction in the cracking of concrete within a known range of load. This results in greater durability under severe conditions of exposure.

- A prestressed structure that has maximum rigidity under working loads and maximum flexibility under excessive overloads.

- The capacity to support a load in excess of the design load in which cracks appear but disappear completely on removal of the excess load.

- A definite reduction in diagonal tension. An important factor in reinforced concrete but often less severe in prestressed concrete.

- Use of pretested structural materials. During the prestressing operations, the steel is tested to a stress that will never again be reached under design loads. The same applies to the concrete, in many cases. This inplace testing is impossible in ordinary reinforced concrete structures.

- Added flexibility for construction.

There are two methods of applying a prestressing force. *Pretensioning* is tensioning of the steel that is done before the concrete is cast in the forms. *Post-tensioning* is tensioning that is done after the concrete has been cast and has attained the required strength. In the former, the force is transmitted by the bond between the steel and concrete. The initial prestress is immediately reduced due to the deformation and shrinkage of the concrete. Gradually, these losses are increased by further shrinkage and creep of the concrete. In post-tensioning, the elastic shortening losses are lower than in pretensioning. Like pretensioning, there is a gradual loss due to the shrinkage and creep of the concrete and the creep of the steel. Consequently for equivalent members, the pretensioning method requires a greater initial prestressing force to compensate for the larger losses.

Pretensioning is practical only within factory or mass production facilities, since permanent anchorages are required to take the reaction of the stressed wires until the concrete attains the required strength.

Several methods of stressing and anchoring "post-tensioned" steel are in use. The methods used most commonly in the United States at present are illustrated in the *Post-Tensioning Manual*.

Design prestressed concrete members to meet the following requirements:

- The prestressing force shall be determined by allowable stress design for service level loads using unfactored MS loads.
- The ultimate moment capacity should be checked by *load factor design* using the ultimate strength theory for factored loads (MS load or design overload, whichever is greater).
- Shear design should be based on strength (load factor design) using the ultimate strength theory with factored MS load or design overload, whichever is greater.

The following assumptions shall be made:

- Strains vary linearly over the depth of the member throughout the entire load.
- Before cracking, stress is linearly proportional to strain.
- After cracking, tension in the concrete is disregarded.

Load factors are multiples of the design load applied to the structure to ensure its safety and are represented by the following formulas:

MS Loads:

$$M_{UA} = \frac{1.3}{\phi}\left[D = \frac{5}{3}(L = I)_{MS}\right] + 1.0M_S$$

Design Overloads (OL):

$$M_{UA} = \frac{1.3}{\phi}\left[D + (L+I)_{OL}\right] + 1.0M_S$$

where

M_{UA}	=	Ultimate moment applied
M_s	=	Secondary moment due to prestress force
D	=	Dead load
L	=	Live load
I	=	Impact
ρ	=	Section strength factor 1.00 for precast members 0.95 for cast-in-place, post-tensioned 0.90 for shear, torsion

Expansion and contraction are important design parameters and require consideration. Bearings and joints for prestressed bridges must accommodate the movement from prestress shortening in addition to temperature changes. In framed structures, the stresses resulting from these movements must be included in the design.

The prestress shortening to be expected can be calculated by use of the equation:

$$\Delta = \frac{PL}{AE}$$

where:

P	=	total prestressing force
L	=	one half of the length between piers
A	=	cross sectional area of the superstructure
E	=	elastic modulus of superstructure concrete

4. Specifications, Design Aids, and Policies. In each design office, there are specific policies and design aids that clarify, modify, and guide the usage of the AASHTO specifications. These are voluminous and are updated frequently to keep up with the AASHTO yearly interim specifications. The interims are necessary since bridge design is dynamic in nature; i.e., research and development of new technologies force changes in both design specification as well as construction methods. Since these policies and aids are voluminous and are frequently updated, it is impractical to include them in this design manual. The designer is referred to the FLHD bridge engineer and senior structural engineers for the policies and aids.

H. Timber. Timber bridges, properly designed and treated with modern preservatives, will give many years of minimal-maintenance service. Their use is normally limited to low-volume, secondary-road bridges and pedestrian bridges.

The following are the most common bridge components that use timber:

- Piling
- Beams or girders
- Decks
- Rails and posts

As can be seen, it is possible to construct entire bridges of timber, however, this is rarely done. Rather, timber is combined with other elements, such as steel girders, concrete substructures, etc., to produce the most economical and maintenance-free structure possible.

With the exception of temporary structures, all exposed timber should be pressure treated. The most common species of timber used are Douglas Fir and Southern Pine. Hardware is normally galvanized.

1. Substructures. Timber pilings are displacement piles that normally function as friction piles. When used as point bearing piles, or when difficult driving conditions are encountered, reinforced pile tips should be considered. AASHTO Section 4.5.7 gives guidance on the design of timber piles as a structural member. Timber piling should not be used in soils where large boulders or cobbles exist. Timber piling is most economical when used for relatively shallow foundations. Timber-pile bents should not be used in streams that carry heavy draft and debris.

2. Superstructures. The most common type of timber superstructure is the longitudinal girder, simple-span bridge. Straight girders are most economical for short spans of 6 to 18 meters. Spans up to 30 meters are possible using glue laminated girders, but may not be economical depending on location, live load, and vertical clearance requirements.

A second common type of timber superstructure is the truss bridge. This may be either a bowstring truss or a parallel-chord truss. Bowstring trusses are of two general types: the pony truss for spans from 15 to 30 meters, and the through span truss for spans longer than 30 meters. Commonly, top and bottom chords are glue-laminated members and web members are sawn timber. Steel rods are used in tension members in the web. When water clearance allows, the parallel chord truss may be used as a deck span, thus enabling pier heights to be greatly reduced. The parallel chord truss may also be used in a through span. The practical span range for either system is 30 to 75 meters.

For long, clear-span timber bridge construction, the deck-arch bridge has been used. With this type of construction, pier height is held to a minimum and yet the bridge is well above high water. The deck arch is practical for spans from 18 to 90 meters, and is particularly suitable when rock canyon walls can reduce the foundation sizes for arch abutments. All present designs for timber-arch bridges should specify laminated construction.

3. Decks. Timber decking is the most common use of timber in current bridge construction. In the past, the most common type of deck was nail-laminated decking using nominal 50 millimeter dimension lumber fastened with through-nailing of the laminations and toe-nailing of the laminations to longitudinal stringers.

Today, most decks are glue-laminated timber systems that allow longer deck spans. These glue-laminated deck systems are plant fabricated in panels and may be designed for either transverse or longitudinal decking. This has necessitated the development of improved connection systems to connect the deck panels to the superstructure. Many current systems are detailed in timber design publications and manuals. The designer should carefully select and analyze these connection systems for strength, ability to resist shrink or swell of timber members, and for resistance to loosening due to vibration or deflection.

Few deck connection systems provide true lateral support to the compression flanges of supporting girders. This lateral support must be considered partial lateral support at diaphragms or cross-frames in most cases.

Most timber deck designs should include wearing planks (sometimes called running planks) to protect the primary decking from tire wear. These wearing planks are nailed to the lower deck and are replaced as required.

All timber decking should be pressure treated to extend decking life.

Timber decks may also be protected by an asphaltic concrete overlay. Detailed mix designs for these overlays are available from the American Institute of Timber Construction.

For some designs, this overlay can be used to provide a crown section for roadway drainage. It is not practical to crown decks constructed entirely of timber.

4. Rails and Posts. Timber rails and posts are commonly used for railings on pedestrian bridges due to the ability of timber to produce an aesthetically pleasing appearance. These railings normally use glue-laminated timber for the rails and either glue-laminated or sawn timber for the posts. Do not use creosote treated timber for pedestrian rail systems.

Timber rail systems, intended for vehicular traffic, almost always incorporate a heavy timber or concrete curbing and a steel backing plate for the timber rail elements. The rails are usually glue-laminated timber and posts may be either glue-laminated or sawn timber. As with all rail systems, timber railings must be carefully designed with particular attention paid to connection, joints, and splices.

I. Bearings. Bridge bearings serve several purposes, the first of which is to transmit vertical loads from the superstructure to the substructure. These bearings must also transmit lateral forces, longitudinal or transverse in direction, between the superstructure and the substructure. In addition, these bearings should take care of girder rotation.

Fixed (sometimes called pinned) bearings transmit both longitudinal and transverse forces. Expansion bearings generally transmit only friction or longitudinal shear forces from the movement of the bearing during longitudinal expansion or contraction. Expansion bearings also usually transmit transverse lateral forces from the superstructure to the substructure.

Numerous types of bearings are available. The following are the most common bearings in current use:

- *Elastomeric bearing pads* come in several configurations. Plain pads of 12-millimeter thickness are used for fixed bearings in conjunction with lateral-load transfer devices such as keys in construction joints, shear lugs, or anchor bolts. These 12-millimeter pads allow rotation of girders and provide distribution of loads between slightly uneven bearing surfaces.

- *Laminated pads* of thicknesses up to a maximum of about 100 millimeters are used for expansion bearings. These bearings may have either steel shims or fabric shims, usually spaced at 12-millimeter increments. Laminated pad bearings usually are used with transverse lateral load transfer devices. They are usually designed for horizontal movement in one direction only.

- *Steel-shim laminated bearings* with other than integrally molded edge protection have been found to be unsatisfactory in use. Laminated bearings not molded as a single unit under heat and pressure are susceptible to bond failure between the layers.

The durometer hardness of the elastomer should be specified on the plans. This hardness should be based on the lowest anticipated service temperatures.

Geometric proportions (shape factors) are given in the specifications to ensure stability of the bearings. Bearing design is controlled by compressive stress, shape factor, hardness, and compressive strain. Bearing thickness is controlled by movement requirements.

- *Sliding bearings* are a configuration normally consisting of a combination of a thin elastomeric pad (to allow rotation and to control the distribution of the bearing loads), steel bearing plates, and a TFE (teflon) surface moving against either another TFE surface or against a stainless steel surface. These bearings have very low friction valves. They are used for moderate-span steel structures. Lugs to transfer lateral forces are often incorporated into the design of bearing.

- *Pot bearings* are bearings used for longer span bridges in which the reactions could be 1.33 meganewtons or greater. They incorporate an elastomeric material-confined material. The fluid-type action distributes the load evenly on the base plate. These bearings may be designed with TFE sliding surfaces to allow movements.

- *Roller and rocker bearings* are bearings generally used for longer-span steel bridges. They are normally either painted or galvanized, even when used with weathering steel superstructures. Small diameter rollers do not perform satisfactorily due to corrosion and should not be used. These bearings can be designed for either fixed or expansion bearings.

All bearings should be accessible for inspection and maintenance. For bearings that are designed for longitudinal movement, the plans should include, in tabular form, the required settings throughout the probable temperature range at the time of erection or construction.

The designer should keep construction procedures in mind and carefully detail bearing seats. Difficult profile grade geometry and skew effects often will require the use of grout pads under bearings. These grout pads are cast after the abutment or pier seat is complete and allow exact bearing location to be achieved. Because it is unreinforced, the thickness of the grout pad should be limited, and the grout pad should be recessed into the bearing seat.

Together with deck joints, bridge bearings are a source of major structural problems and often are the cause of serious damage to other parts of the structure. Bearings must be engineered and designed to allow free movement and to transmit superstructure loads. Careful analysis should be made of all bridge bearings. A *Standardized* bridge bearing that fits all conditions does not exist.

J. Foundations and Substructures. The *substructure* is that part of the structure that serves to transmit the forces of the superstructure and the forces on the substructure itself onto the foundation.

The *foundation* is that part of a structure that serves to transmit the forces of the structure onto the natural ground.

If a stratum of soil suitable for sustaining a structure is located at a relatively shallow depth, the structure may be supported directly on it by a spread foundation. If the upper strata are too weak, the loads are transferred to more suitable material at greater depth by means of piles or piers.

The design of the structural elements for foundations, substructures and retaining walls shall be in accordance with AASHTO provisions.

Some of the items that are determined by evaluation of site investigations and/or by current practice are as follows:

- Bearing capacities of foundation soils.
- Settlement of foundation soils.
- Ability of piles to transfer load to the ground.
- Lateral earth pressures.
- Lateral earth resistances.

In stability analyses, the factors of safety for overturning and sliding are not specified by AASHTO. Determination of values to be used is based on accepted practice and evaluation of the risk involved.

1. Capacity of Shallow Foundations. A *shallow foundation* is a term applied to footings having a depth-to-base width ratio of 1 or less.

Two things control the capacity of a shallow foundation:

- The ability of the soil to support the loads imposed upon it, known as the bearing capacity of the soil.

- The amount of total or differential settlement that can be tolerated by the structure being considered.

2. Capacity of Deep Foundations. A *pier* is a structural member of steel, concrete or masonry that transfers a load through a poor stratum onto a better one. A *pile* is essentially a slender pier that transfers a load either through its tip onto a firm stratum (point bearing pile) and/or through side friction onto the surrounding soil over some portion of its length (friction pile).

In general, the bearing capacity of a single pile is controlled by the structural strength of the pile and the supporting strength of the soil. The smaller of the two values is used for design.

Piles driven through soft material to point-bearing may be dependent upon the structural strength of the pile for their bearing capacity.

The supporting strength of the soil is the sum of two factors (a and b):

a. The bearing capacity of the area beneath the base.

b. The frictional resistance on the contact surface area for the length of the pile.

For point-bearing piles, factor "a" is of primary significance while for friction piles, factor "b" is of primary significance.

Structural sections of piles are to be designed using the provisions for the material being used and satisfying the minimum requirements specified in AASHTO and this section in foundations.

A pile load test is probably the best method available for determining the bearing capacity of an individual pile. The tests are quite expensive, however, and on small jobs, the cost of their use cannot be justified.

3. Substructure Analysis and Design. In the design procedure, the allowable bearing determinations are performed by the geotechnical engineer prior to completion of the approved layout for final design such as the following:

- *Drilled Shafts* - allowable axial load versus depth for several different diameters is given for design flexibility.

- *Spread Footings* - allowable footing pressure and depth are given. When more refinement is called for, allowable pressures versus footing size are given.

- *Piles* - pile types, sizes, pile tip requirements, estimated tip elevation, and allowable load are given.

These foundation recommendations are presented in a report along with the foundation investigation information.

a. Reinforced Concrete Columns. Since these are the most common substructure elements for transferring superstructure loads to the foundations, discussion of other types will not be included. Reinforced concrete columns are designed by the load factor method for the factored load groups described under section 10.4.B.

Commonly used shapes are round, rectangular, rectangular with rounded ends, and rectangular with large chamfered corners. Flares and tapers are often required. The designer should obtain help from the FLHD bridge engineer and/or the senior structural engineers in determining the type and trial dimensions. The final design should provide adequate strength to cover all factored axial load plus axial or biaxial moment combinations magnified for slenderness as necessary. See section 10.4.E for additional information on reinforced concrete column design. Also, see the seismic specification for extra requirements that ensure connection strength, shear strength, and ductility.

b. Drilled Shafts. The designer usually receives allowable axial load information versus embedment for the foundation type from the geotechnical engineer. In addition to satisfying that the maximum unfactored axial loads do not exceed the allowable, the designer must also perform a lateral-load analysis. The designer must first consider the possible loss of the ground due to scour or erosion. Then shears and moments can be calculated at this level and applied to an embedded pole analysis to determine shears, moments, and deflections of the drilled shaft below the scoured ground level. See section 10.2 for a hand solution of this embedded pole analysis.

c. Spread Footings. The present state-of the-art procedure for these is based on an allowable pressure (working stress) from the geotechnical engineer. The current direction is to replace this with a procedure that will be consistent with load factor design. Until these new methods are developed, footing pressures are calculated from the unfactored loads and the footing is proportioned so that the allowable is not exceeded. The footing is then designed by the service load (working stress) procedure. See section 10.4.E for additional information.

Additional items to be considered in the design of spread footings are as follows:

- Pressure distribution for loads in kern and outside kern.

- Sliding factor of safety.

- Overturning factor of safety.

- Seismic over-strength requirements.

d. Pile Footings. Similar to spread footings pile footings are currently proportioned for a maximum allowable pile load determined by the geotechnical engineer. These pile loads are used for a service load (working stress) design for the footing. This procedure can be replaced with other approved procedures that are compatible with load-factor design.

Additional items to be considered in the design of pile footings are as follows:

- Uplift limitations
- Load distribution to piles
- Lateral-load analysis
- Local punching analysis
- Seismic over-strength requirements

e. Seals. Seals are required for cofferdam construction of foundation portions below water where the waterhead and soil permeability are too great to be controlled by pumping, diversion of water, etc. The need for seals is usually determined during preparation of the preliminary bridge layout. As rough guide is that seals are required for heads of water more than 3 meters depth. The designer calculates the depth of seals for spread footings at 0.43 times the water head at time of construction. A minimum depth of seal should be 600 millimeters. The factor 0.43 is the ratio of the unit weight of water (1000 kg/m^3) to the unit weight of plain concrete (2320 kg/m^3).

For pile footings where uplift resistance of the piles can be counted on, the seal depth may be reduced to 0.25 times the water head.

K. Retaining Wall Design. This section provides guidance in preparing design calculations, plans, and specifications for retaining walls.

Use the Service Load Design method for design of retaining walls. In general, concrete for retaining walls normally is Class A(AE) with a 28-day compressive strength of 20 to 30 megapascals.

Base earth pressures on soil weight are equal to 1920 kg/m^3, the surcharge slope, the coefficient of internal friction, and/or the cohesion of the backfill material. No structure should be designed for less than an equivalent fluid mass of 576 kg/m^3. At the junction of the abutment or abutment wing and retaining wall that is, an equivalent fluid mass of 864 kg/m^3 should be used. This increased loading can normally be reduced to 576 kg/m^3 at a distance from the junction of the abutment and retaining wall equal to the average height of the wall under design. The retaining wall can also be offset from the abutment to equalize deflection instead of designing a short section of wall with increased rigidity.

A minimum live-load surcharge of 600 millimeters of earth should be used.

The resultant of forces should be kept within the middle one-third of the footing for Group I loadings and within the middle one-half of the footing for all other service load conditions.

The designed safety factor and other wall criteria shall be in accordance with Table 10-3.

Table 10-3
Design[1] Safety Factors for Retaining Walls[5]

Components[2]	Safety Factor	
	Range	Typical
Bearing Capacity	2.5 - 3.0	2.5
Overturning	1.5 - 2.0	2.0
Sliding along base[4]	1.5 - 2.0	1.5
Reinforcement member pullout[3]	1.5 - 2.0	1.5
External Slope Stability	1.25 - 1.50	1.5

NOTE:
[1] Expected design life 50/100 years.
[2] Allowable stress not to exceed 0.55 f_y (yield of stress of steel).
[3] At 19 millimeters maximum deflection.
[4] The passive pressure of the earth in the front of the footing may be considered if the earth is more than 1 meter deep on the top of the footing and does not slope downward away from the wall. Do not consider passive pressure if the wall is subject to scour. Sometimes it may be necessary to slope the footing or to provide a key to resist horizontal thrust. The design soil pressure at the toe of the footing shall not exceed the allowable soil bearing capacity.
[5] Deviations from these safety factors shall be approved by the FLHD Structures Engineer.

1. Special Designs. Special wall designs may be required when surcharge conditions are unusual or exceed those values acceptable for standard wall designs. The surcharge conditions, heights, and types of wall in the standard plans cover most of the applications of retaining walls for highway design.

Railroad live load is an example of a severe surcharge. A building is another example of a severe surcharge. Additional load imposed by sign structures and site conditions that do not permit construction of a standard wall will require a special design.

Ordinarily, some decrease in cost may be realized by a special design for a long length of wall having surcharge conditions less severe than those shown in the standard plans. However, for most cases where the use of a standard wall is practical but conservative, the cost of preparing a special design would exceed the savings.

2. Aesthetic Considerations. The type of face treatment for retaining walls is decided on a job-to-job basis according to degree of visual impact. The wall should blend in with its surroundings and complement other structures in the vicinity. Top of walls are usually on smooth flowing curves as seen in elevation.

The profile of the top wall should be designed to be as pleasing as the site conditions permit. All slope changes at the top of the wall should be rounded with vertical curves at least 6 meters long. Small dips in the top of the wall should be eliminated. Sharp dips should be improved by using vertical curves, slopes and steps, or combinations thereof. Side slopes may be flattened or other adjustments made to provide a pleasing wall profile.

Where walls are adjacent to highways, frontage roads, or city streets, special surface texturing, recessed paneling, or provisions for landscaping shall be considered.

3. Footings. For economy and ease of construction of reinforced concrete retaining walls, consider the following criteria for layout of footing steps:

- Distance between steps should be in multiples of standard plywood sizes.

- A minimum number of steps should be used even if a slightly higher wall is necessary. Small steps less than 300 millimeters in height should be avoided unless the distance between steps is 29 meters or more. The maximum height of steps should be held to 1.2 meters. If the footing thickness changes between steps, the bottom of the footing elevation should be adjusted so that the top of the footing remains level.

4. Wall Joints. For cantilevered and gravity walls, Joint spacing should be a maximum 7 meters on centers. For counterfort wall, joint spacing should be a maximum of 10 meters on centers. For tieback walls, joint spacing should be 7 to 10 meters on centers for cast-in-place walls, but for precast units, the length of the unit would depend on the height and thereby the weight of the unit. Odd panels for all type of walls should normally be made up at the ends of the walls. For cast-in-place construction, a minimum of 12-millimeter premolded filler should be specified.

No joints other than construction joints should be used in footings except at bridge abutments and where the change from a pile footing to a spread footing occurs. In these cases, a 12-millimeter premolded expansion joint through the wall and a construction joint with shear keys through the footing should be used. In addition, dowel bars should be placed across the footing joints parallel to the wall elements to guard against differential settlement or deflection of the footings.

The maximum spacing of construction joints in the retaining wall footing should be 36 meters. The footing construction joints should not line up with the expansion joints in the wall.

5. Drainage. Gutters should be used behind walls in areas where there is a necessity to carry off surface water or to prevent scour. Low points in the vertical wall alignment or areas between return walls must be drained by downspouts passing through the walls.

The standard plans show typical drainage details. Special design of surface water drainage facilities may be necessary depending on the amount of surface water anticipated.

Where ground water is likely to occur in any quantity, special provisions must be made to intercept the flow to prevent buildup of hydro-static pressures and unsightly continuous flow through weep holes.

All concrete retaining walls should have 100-millimeter diameter weep holes located 200 millimeters above final ground line and spaced about 4 meters apart. In case the vertical distance between the top of the footing and final ground line in front of the wall is greater than 3 meters, additional weep holes should be provided 200 millimeters above the top of the footing.

Weep holes can get clogged and the water pressure behind the wall may start to increase. In order to keep the water pressure from increasing, it is of utmost importance to have free draining gravel backfill and underdrains.

6. Other. Make provisions to relocate or otherwise accommodate utilities conflicting with the retaining wall. Any modifications of a standard wall to accommodate utilities should be specially designed.

Show all special wall details such as sign bases, utility openings, drainage features, fences, and concrete barriers on the applicable sheet of the wall plans or on a separate plan sheet and include with the wall plans. Cross reference details between the various plan sheets on which they are shown.

10.5 APPROVALS

This section briefly discusses the steps taken by the division bridge staff to acquire client approval of proposed bridge structure type, size, and location for a given project. Steps taken to obtain such approvals must be both timely and contain adequate detail to maintain assigned program schedules.

A. Bridge TS&L. The first step in acquiring client approval of a proposed structure is to develop one or more drawings that depict the bridge type, size, and location for each site.

Data required to develop a bridge site plan is furnished by the highway design/location staff. A site plan shall include the following:

- A plan view showing the horizontal alignment of the roadway and the ground contours of the surrounding area.
- The vertical alignment of the roadway within the limits of the bridge site.
- The roadway typical section(s) to be used at the site.

After determining approximate span lengths and superstructure depths, the bridge opening shall be checked for adequacy.

For stream crossings, a hydraulic analysis shall be made for the site.

For roadway crossings, vertical clearance above the underpass roadway shall be checked. Once the appropriate clearance checks have been made, the profile grade can be adjusted for final TS&L development.

Once developed, the TS&L drawing is then distributed to the client agency for review and approval. Upon receipt of this approval, the structure design and contract plan development can begin.

B. Design Standards and Exceptions. There are many publications available to the design engineer to aid in the development of engineering design calculations for highway structures. Deviations from specific minimum values therein are permissible only after due consideration is given to all project conditions (such as maximum service and safety benefits, type and purpose of improvement, and compatibility with adjacent sections of unimproved roadway).

Exceptions to design standards are to be documented during the TS&L development stage. All responsible agencies should be made aware of each exception, agree to the need for the exception, and be fully aware of any safety and environmental impacts resulting from the deviation.

C. Plans, Specifications, and Estimate. Upon completion of the final plans, specifications, and estimate (PS&E) for a structure, all documents are to be forwarded to the highway design staff for inclusion with the roadway portion of the project.

The plans and specifications should address and adequately describe the design features incorporated into the structure, the construction requirements necessary to facilitate the building of the structure, and an estimate of construction costs of the project.

The estimate should reflect the anticipated cost of the project based on an analysis of previously bid items of work for structures of similar type and construction and geographic location.

Detailed plans for bridges should contain the following drawings and data:

- Site plan.
- Location and log of each foundation sounding or boring.
- Profile of the crossing.
- Typical cross section.
- Sectional drawings, as needed, to detail the structure completely.
- Quantities of materials required.
- Reinforcing bar list and bar bending diagram.
- Design loadings, working stresses, class(es) of concrete, and grade(s) of steel.
- Drainage area and applicable runoff of hydraulic properties.
- Design and construction details not otherwise covered in the specifications.
- References to applicable standard or industry specifications.

10.6 STANDARD FORMAT

A standard format is required in all plans and specifications. Standard formats have been established for drafting plan sheets, writing contract specifications, and establishing contract unit-bid items. Document storage and retrieval procedures for work developed on the Computer Aided Drafting and Design (CADD) System have been developed. See Chapter 9 for additional guidelines.

A. Plans. Standard formats for plan sheet border size, title block, and project identification data can be found detailed in Chapter 9. A majority of this information is also stored on the CADD system for ready use and reproduction. Standards for appropriate line weight, lettering fonts, and commonly used symbols and details can also be found in Chapter 9 or in the CADD user manual.

B. Specifications. There are 3 major types of specifications used in a contract and they are:

- Standard specifications.
- Supplemental specifications.
- Special contract requirements.

See the definition for contract document hierarchy in Chapter 1, Section 1.4.B.

Each Division office maintains a file of special contract requirements that have been developed for addressing unique or specialty work that may be required due to a project's geographical location or special design features that would not be covered in the standard or supplemental specifications.

When it becomes necessary to develop special contract requirements, they shall be written in the same format as the standard specifications.

C. Estimate. An engineer's estimate is developed in the preliminary PS&E stage of plan development based on an average cost per square meter of bridge deck. As the structural design proceeds toward the final PS&E stage, a revised cost estimate is developed based on a unit price analysis for all items of work to be accomplished under the project.

One source of data that can be used for estimating purposes is past contract unit-bid prices for similar type work within the same geographical area. Caution is urged when establishing unit prices from past records.

When estimating, the engineer must consider the current economic environment and be aware of regional cost trends and industry pricing data.

Estimates should be realistic and should be based on a reasonable cost analysis for the work to be accomplished. Unrealistic estimates (either too high or too low) have a detrimental impact on future project planning and programming.

10.7 DIVISION PROCEDURES

Reserved for Federal Lands Highway Division office use in supplementing the policy and guidelines set forth in this chapter with appropriate Division procedures and direction.

LIST OF EXHIBITS

Exhibit

Design Methods and Strength Requirements

By: Ashby T. Gibbons, Jr.

Introduction

Existing historical evidence indicates that there was serious, and probably, heated, debate in the first decade of this century between proponents of two concrete design methods similar (for beam design) to those in the revised AASHTO specifications. The committee established to write the first what is now known as the "ACI Building Code" recommended, in 1908, approval of the design provisions of the existing model code of the insurance industry "based on the assumption of a load four times as great as the total working load producing a stress in the steel equal to the elastic limit and a stress in the concrete equal to 1.4 MPa." The recommendation was overturned at the convention of the National Association of Cement Users (now ACI) in favor of working loads, working stresses and straightline theory. The first Joint Committee on Standard Specifications for Concrete and Reinforced Concrete also decided in favor of working stress design in 1909. It seems evident that the deciding factor was not the properties of reinforced concrete, which were surprisingly well known for flexural members, but the desire of engineers to use the familiar theories used for the design of cast iron, wood, and steel. As a result, conditions at working loads were emphasized in design, the real safety of concrete structures became obscured by the approximations and assumptions of design formulae, and designers made countless calculations of stresses which have little relationship to those existing in structures but which year by year became the object of devout belief.

The decision to use allowable stresses and elastic straightline theory would have served very well if concrete actually had a straightline stress-strain relationship and if concrete did not creep significantly more than steel under stress. It was not long before design procedures had to be modified to account for these properties. Column design for concentric loads and for small eccentricities has not followed elastic theory for years; the effect of compression reinforcement in beams was doubled from that indicated by straightline theory; and the re-evaluation of shear and development of reinforcement in recent years has been based on strength capacity with nominal stresses used only as a convenience. Thus, by the 1960's, the latest methods for proportioning concrete members and those of the 1973 AASHTO Specs used unmodified straightline theory only for flexural members without compression reinforcement.

It so happens that the strength of a beam without compression reinforcement is not influenced significantly by concrete strength, and the straightline theory gives reasonably good results for low percentages of reinforcement.

However, the straightline theory grossly underestimates the ability of concrete to resist moment in compression. Consequently, many designs in the past have required compression reinforcement where it was not actually needed to provide the desired strength.

The straightline theory has been notably unsuccessful in predicting column strength because the stress-strain relationship of concrete has a very significant effect when the member is subjected to axial compressive loads. For many years, the strength addition formula has been used for concentrically loaded columns, a modified strength approach has been used for small eccentricities, and elastic-straightline theory used only for large eccentricities. However, the resulting column designs has a widely varying "factor of safety" which ranged from over 4 to nearly one, depending on material strengths, eccentricity and the amount and distribution of the reinforcement. Therefore, concrete column design throughout the AASHTO specifications has been completely revised and is based on strength relationship for both Service Load Design and Load Factor Design.

Analysis

The methods to be used in determining the load effects on concrete bridge members, and some dimensional limitations for specified members, are given in AASHTO Specifications and are to be used for both the Service load Design and the Strength Design methods. Design rules are included for Expansion and Contraction, Stiffness, Modulus of Elasticity, Thermal and Shrinkage Coefficient, Span Length, Computation of Deflection, Composite Concrete Flexural Members. Shoring. T-Girder Construction, Box Girder Construction and Concrete Arch Construction.

The theory of elastic analysis is to be used to determine the moments and forces resulting from loads on statistically indeterminate structures.. This is true for both Service Load and Load Factor Design The principal difference between the two design methods resulting from analysis is that the live load effects are amplified in the load factor method, since the ratio of the live load to dead load is multiplied by 5/3. For example, the points of contraflexure for negative moments will be farther from the supports, and those for positive moments closer to the supports in Strength Design than in Service Load Design.

Design

The specifications not only assure adequate strength. but include provisions to provide acceptable performance at service load levels. There is not always a clear separation between provisions for strength and those for serviceability. For actions other than flexure, the strength and detailing provisions will assure satisfactory performance at service loads. For flexure, special serviceability provisions have been introduced for Strength Design. These serviceability requirements are not necessary when Service Load Design is used since that method is based upon providing acceptable behavior at service loads.

When the Strength Design method is used, members of reinforced concrete structures shall be proportioned for adequate strength using the capacity reduction factors and the factored loads.

Strength. The usable strength for the design of a member, is that calculated in accordance with the specifications—including a capacity reduction factor, ∅. The specifications are based generally on conservatively chosen limiting states of stress, strain, cracking or crushing, and fits to research data for each type of structural action. An understanding of the physical significance of the strengths computed for various actions can only be obtained by review of the background of the provisions.

The concept of the capacity reduction factor, ∅, is (1) to define a level of strength for design which is less than that what could be expected if all dimensions and material properties were those used in computations, (2) to reflect the degree of ductility, toughness, and reliability of the member under the load effects being considered, and (3) to reflect the importance of the member. For example, a lower ∅ is used for columns than for beams because columns generally have less ductility, are more sensitive to variations in concrete strength, and carry larger loaded areas than beams. Furthermore, spiral columns are assigned a higher ∅ than tied columns since they have greater ductility or toughness.

A sliding ∅ factor is permitted for members subjected to bending and small axial loads. The ∅ may be increased from that for compression members to the 0.90 for flexure as the design axial load decreases from a specified value to zero. The upper value of design load below which an increase in ∅ can be made is 0.10 f'_cA_g or P_b, whichever is less.

Note: P_b will be greater than 0.10 f_cA_g and need not be calculated if f_y does not exceed 400 MPa, the reinforcement is symmetrical and $(h-d'-d_s)/h$ is not less than 0. 70. The distance, d_s, is from the centroid of the tension steel to the tension face of the member.

Required Strength. The basic criterion for load factor design may be expressed as follows:

Required strength $\leq$ Calculated usable design strength

All members and all sections of members must be proportioned to meet this criterion.

This required strength is expressed in terms of design loads or their related internal moments and forces. Design loads are defined as load groups multiplied by the appropriate load factors. The loads to be used are described in the specifications.

Design loads are multiplied by appropriate "load factors" to account for increased load effects possibly resulting from such causes as overloads and inaccuracies in analysis. The designer has the choice of multiplying the loads by the load factors before computing the design load effects, or computing the effects from the unfactored loads and multiplying the effects by the load factors. Under the principle of superposition, both procedures yield the same answer.

The factor assigned to each load was influenced by the degree of accuracy to which the load usually can be calculated and the variation which might be expected in the load during the lifetime of the structure. Hence, dead loads, because they are more accurately determined and less variable, are assigned a lower load factor than live loads.

In assigning factors to combinations of loading, some consideration was given to the likelihood of simultaneous occurrence.

Due regard is to be given to sign in determining the effects from combinations of loadings, as one type of loading may produce effects of opposite sense to that produced by another type.

Consideration must be given to various combinations of loading to determine the most critical design condition. This is particularly true when strength is dependent on more than one load effect, such as strength for combined moment and axial load, or shear strength in members with axial load.

CHAPTER 11 - DESIGN FOLLOW UP

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CHAPTER 11 - DESIGN FOLLOW UP

11.1 GENERAL

The purpose of design followup is to determine if the design is accomplishing its intended objectives and to provide an input process for improving project development and design procedures. This chapter discusses the methods, guidance, and general procedures for design followup. The process can be described as a means of obtaining feedback for the purpose of evaluating the effectiveness of the project development and design processes through

- PS&E reviews,
- analysis of construction changes,
- post construction reviews,
- PS&E improvement meetings, and
- periodic program reviews.

Although an effective and efficient design is sought for each project, the proposed design may not always be the ideal solution. Conducting reviews and analyzing feedback data are methods that will be useful in substantiating that current processes are adequate and assist in determining if changes are necessary. The feedback systems may range from informal communications to formal review and reporting procedures.

11.2 GUIDANCE AND REFERENCES

Most of the available guidance is concerned with reviews to be undertaken and the types of reporting formats. The following manuals are available in each Division Office and are to be reviewed for specific guidance.

A. Federal-Aid Policy Guide (FAPG). Although developed mainly for the Federal-Aid program, the manual contains many regulatory and not-regulatory applications to the FLH Program.

- FAPG G6011.9, Value Engineering. This section discusses policy relating to value engineering in design and construction and the review of designs and standards.
- FAPG G6021.2, *Monitoring of Federal-Aid Highway Design Projects*. This section discusses different types of reviews which aid in evaluating the effectiveness of current design policy and detecting design features that can be improved.
- FAPG 23 CFR 630B, *Plans, Specifications, and Estimates*. Paragraph 5C in the non-regulatory attachment, NS 23 CFR 630B, discusses the transformation of developmental specifications to standard specifications after gaining adequate and satisfactory experience from active contracts.
- FAPG G6042.4, *Construction Projects Incorporating Experimental Features*. This section provides guidelines relating to inspection, reporting, and evaluating experimental features included in construction projects.

B. Federal Lands Highway Manual (FLHM). This manual, issued by FLHO, contains the policies and procedures applicable to the FLH Program.

- FLHM 1-C-1, *Management Reviews*. This section sets forth general guidance for carrying out a management review program that includes internal reviews of Division Office operations and procedures.
- FLHM 1-C-2, *Work Method Improvements-Alternate Work Methods*. This section establishes policy for the divisions to continuously search for methods to improve the effectiveness of performing the work by analyzing and scrutinizing existing methods, policies, and procedures.
- FLHM 3-C-2, *Exceptions to Minimum Engineering Standards - Risk Factors*. This section sets forth policy for adequate review, evaluation, and documentation of engineering standards and exceptions to standards.
- FLHM 4-A-3, *Construction Claims and Disputes.* This section sets forth policy aimed at reducing claims by requiring a routine analysis of claims as they are settled. It also provides emphasis and direction toward improving operational procedures that deal with construction claims.

C. FHWA Construction Manual. This manual, prepared by FLHO includes procedures for processing plan and specification changes and the requirements for final construction reports and as-constructed plans. These reports and plans are important sources of design feedback information.

11.3 FEEDBACK PROCEDURES

This section provides general guidance and suggested methods for conducting design follow up. In addition to some of the more formalized written procedures, a great deal of information is gained through informal contacts and communications. This is true both within FHWA and with client and cooperating agencies. Principal sources for this information are PS&E reviews and data obtained from tracking construction projects.

A. PS&E Review and Improvement Processes. Policy established in FLHM 1-C-2 requires that methods be established to provide improvements to existing methods, policies, and procedures.

(1) PS&E improvement meetings. These may be held to evaluate design features, policies, specifications, or other items relating to PS&E development.

(2) Project PS&E reviews. These may involve both written comments and meetings held to resolve comments received in the review process. Items pertinent to other projects should also be distributed to others.

B. Active Construction Projects. There are a number of methods used to provide feedback information during construction. These involve a great deal of informal communications as well as specific reviews and reports. The following list identifies some of the more common sources of this information.

- Partnering meetings.
- Contract modifications.
- Value engineering proposals.
- Trip reports from construction staff reviews.
- Field reviews of proposed design changes for problems such as slides, drainage, materials sources, etc.
- Environmental compliance reviews (see Chapter 3).
- Formal program management reviews. These may be general in nature or cover specific emphasis areas such as hydraulics and safety.
- Informal contacts or field reviews with project personnel. Designers should be encouraged to visit the site of active construction projects when they are in the vicinity.
- Construction feedback report. (See Exhibit 11.1 for sample report format).
- Videotapes, photographs, etc.
- Contacts with owner/maintaining agencies.
- Final inspections.
- Contractor interviews.
- Work-zone traffic-control reviews.

C. Post Construction. The following are some of the sources of information available after completion of construction projects that will be of value in evaluating the effectiveness and adequacy of design features.

- Evaluation of contractor claims.
- Feedback from owner/maintaining agency. Information may be gained from informal contacts or specific reviews of problems or deficiencies.
- Formal post-construction reviews. These reviews provide an excellent means for evaluating the effectiveness of various design features. Reviews should encompass maintenance, traffic operations, safety, drainage, erosion control, and roadway performance.
- Skid testing.
- As-constructed plans.
- Final construction reports.
- Closeout meetings with the construction project engineer(s). These meetings can be an excellent means for obtaining suggestions and recommendations for improvement of future designs.
- Bridge Inspection Reports and Roadway Inventory Reports

11.4 MONITORING

Each division office shall have procedures to monitor their project development processes, including integrated feedback systems. The purposes of this monitoring are as follows:

- To assure management that the processes being used are in compliance with applicable regulations.
- To identify areas for needed improvements (technical and procedural).
- To sustain efficient, safe, and cost effective designs.

Monitoring will provide appropriate and timely input for revisions and/or modifications to the following:

(1) Federal Lands Highway Manual.
(2) Project Development and Design Manual.
(3) Standard specifications.
(4) Standard plans.
(5) Division operating procedures.

FLHO is responsible for modifying or revising items (1),(2),(3), and (4). Although accountable to FLHO, each Division Office is responsible for its own standard operating procedures (5). Significant items identified through design followup will be considered for nationwide use. Copies of such items shall be furnished to FLHO and the other FLH Divisions. After appropriate reviews, ideas found to have merit will be adopted. FLHO will coordinate these reviews and issue the appropriate revisions. However, in the interim prior to national adoption and distribution, divisions should implement the changes on an as-needed basis.

11.5 (Reserved)

11.6 (Reserved)

11.7 DIVISION PROCEDURES

Reserved for Federal Lands Highway Division office use in supplementing the policy and guidelines set forth in this chapter with appropriate Division procedures and direction.

LIST OF EXHIBITS

Exhibit

FEEDBACK REPORT

To: ____________

From: ____________

Date: ____________

Instructions:

1. One problem per report.
2. May be completed in pencil or ink.
3. Forward original and 1 copy to Division office.
4. Retain a copy for your records.

Project Name: ____________

Type of Contract: ____________
(Grading, Base, Paving, Bridge, etc.)

List any problems encountered in the plans, specifications, or administration of your contract, any problem associated with Division support services, or any deficiencies where correction action or improvements can be incorporated into upcoming projects. Timely submission is essential for implementation of corrective actions

Problem: ____________

(attach additional pages if more space is needed)

Corrective Action Taken and Improvements Recommended for Future Projects: ____________

Division Staff Comments ____________

Action Recommended and by Whom: ____________

EXHIBIT 11.1 Sample Feedback Report

☆ U.S. GOVERNMENT PRINTING OFFICE : 1989 O - 220-051 : QL 3