



# OHIO DEPARTMENT OF TRANSPORTATION



## **Rock Slope Design Guide**

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## SECTION 100 ROCK SLOPE DESIGN BACKGROUND

### 101 INTRODUCTION

This Manual is intended to provide guidance for the design of rock cut slopes, rockfall catchment, and rockfall controls. Recommendations presented in this manual are based on research presented in Shakoor and Admassu (2010) entitled “Rock Slope Design Criteria” (State Job Number 134325), previous FHWA co-sponsored research, and the experience of the Office of Geotechnical Engineering (OGE). These guidelines should be viewed as the presentation of the philosophy of the OGE regarding rock cut slope and catchment design. It is not possible to provide design guidance for all potential scenarios. If a scenario is encountered that falls outside those described in this manual, the design is recommended to be done in consultation with the OGE or District Geotechnical Engineer (DGE).

The Designer is responsible for preparing a design that is based on a site-specific geotechnical exploration and achieves the optimal balance of safety, construction costs, and future maintenance costs. The use of “template” designs shall be avoided. Instead, the designer shall use appropriate information regarding the site geology, slope of the natural hillside, and the condition of cut slopes in similar geology within proximity to the project to determine the appropriate slope configuration. The designed configuration will be influenced by lithology, rock properties, and bedrock structure. Research and experience has shown that a consistent design methodology can be formulated by using properties such as intact rock strength, rock durability, fracture frequency, regional joint characteristics, and other common rock properties.

The design approach first satisfies the overall global stability of the rock cut. It is recognized that in nearly all cases typical geologic and geometric conditions exist throughout Ohio., namely nearly horizontally bedded sedimentary rock strata with a range of lithologies that include limestone, dolomite, sandstone, siltstone, shale, claystone and coal. In this Bulletin, those strata defined as shale in the ODOT Construction and Material Specifications (C&MS) Item 203.02.P are considered a rock type and are included in this manual. Based on practice, OGE experience, and results of research (Woodard, 2004; Shakoor and Admassu, 2010), it is recognized that the primary cause of degradation and failure of rock cuts in Ohio are the differences in durability of rock units and intersecting discontinuities found throughout Ohio. The design approach presented in this manual accounts for these differences in durability of geologic units as well as anticipated geologic structure encountered in most rock cuts in Ohio.

Due to the geologic structure present in Ohio, the necessity for rigorous rock mechanics structural analyses (kinematic analysis) is typically rare for cut slope designs in Ohio. This manual addresses the basic methodologies used in most rock mechanics approaches for the investigation and design of cut slopes, but since these approaches are rarely needed, specifics on these methodologies are beyond the scope of this manual.

The Designer should note that the guidelines presented in this document may result in a designed slope with varying slope angles and benches where the excavation quantities and/or costs are similar to simply creating a continuous 1.5H: 1V cut slope, for example. The use of a continuous slope through varied geologic formations, while possibly simplifying construction, may not effectively address long-term

conditions with respect to weathering. Therefore, replacing the designed rock slope with a constant slope is generally not recommended.

OGE recognizes that rockfall poses a serious geologic hazard, and the selection of appropriate slope configurations as well as rockfall catchment controls will minimize this hazard. This manual presents guidelines to be used as a basis to provide adequate rockfall catchment and controls based on OGE experience and FHWA co-sponsored research.

This manual and other information may be obtained from the OGE's web site (<http://www.dot.state.oh.us/Divisions/ProdMgt/Geotechnical/Pages/default.aspx>). This web site contains other ODOT geotechnical documents and bulletins, including an online copy of the Geotechnical Engineering Design Checklists and Specifications for Geotechnical Explorations (SGE), which are referenced in this document.

## **102 SCOPE OF GUIDE**

This document presents guidelines for adequate geotechnical exploration to create an acceptable design. This guide is meant to supplement the requirements presented in the SGE. Recommended rock slope design criteria are discussed along with generalized guidelines for correlating various rock properties to appropriate slope configurations. Design criteria for rockfall catchment is included, with the recommendations based on a combination of FHWA co-sponsored research (Pierson, et al., 2001) and on-going ODOT sponsored research. Requirements for presentation of the rock cut slope design are also presented.

## **SECTION 200 GEOLOGIC EXPLORATIONS, DATA COLLECTION AND PRESENTATION**

### **201 INTRODUCTION**

Exploration for a rock cut slope, which includes geologic explorations, data collection, and presentation of information, are vital to the design and construction of rock cut slopes. This section describes the required steps for the design of a new rock cut slope or the rehabilitation of an existing slope. Each specific project involves unique situations and the explorations should be planned accordingly.

### **202 DEFINITION OF GEOLOGICAL TERMS**

Geologic terms used in Ohio need to be consistent to produce comparable results obtained by different personnel working at various sites. The types of information collected during a rock slope project depend on the site access, the extent of rock outcrops, the level of reliability required for the design, and the importance of each rock property to the long term performance of the slope. These factors will vary from site to site and, although exploration procedures need to remain flexible, the geologic terms used at each site need to be consistent while performing this work in the state of Ohio. The remainder of this discussion is summarized from the SGE and the FHWA Rock Slopes Reference Manual; Report Number FHWA-HI-99-007 (1998) which discusses geologic terms related to rock slope stability.

#### **202.1 Rock Type**

The rock type is defined by the origin of the rock, which in Ohio is predominantly sedimentary. The primary rock types in Ohio include claystone, coal, dolomite, limestone, sandstone, shale, siltstone, and underclay. A complete list of rock types found in Ohio with brief descriptions may be found in SGE Appendix A.3 ODOT Rock Type.

##### **202.1.1 Claystone**

A fine-grained rock formed of at least 75% clay sized particles. Claystone is comprised of lithified clay having the texture and composition of shale, but lacking the laminations and fissility of a shale. It generally has a blocky, thick to massive appearance. Claystone may range in color from red, gray, olive, yellow, or brown with multiple colors typical. Slickensides are commonly found within claystone.

##### **202.1.2 Shale**

A fine-grained sedimentary rock formed by the lithification of clay, silt or mud (predominant particle size is less than 0.002 mm). Shale has a laminated structure, which gives it fissility along which the rock splits readily. Shale is commonly interbedded with sandstone or limestone. Carbonaceous shale often grades into coal. Typical colors may be red, brown, black, green, or gray.

##### **202.1.3 Siltstone**

A fine-grained sedimentary rock formed from particles finer than sand, but coarser than clay. Siltstone is comprised of lithified silt and lacks lamination or fissility. Typical colors may be gray, olive, or brown. Generally, siltstone has a fine grit feeling when rubbed against teeth.

#### **202.1.4 Mudstone**

Mudstones are sedimentary rocks with particles that are less than 0.004 millimeter which consist mainly of clay and mica. Mudstone is a general term which may encompass siltstone, claystone, and shale. Mudstones are more thickly bedded than shale and typically have a lower durability than claystone. Although this term was widely used on past projects, the descriptions for siltstone, claystone, and shale are preferred for current projects.

#### **202.1.5 Sandstone**

A sedimentary rock comprised of grains of angular or rounded sand potentially in a matrix of silt and/or clay cemented together by silica, iron oxides, or calcium carbonate. Sandstones may be composed of up to 25% of particles of gravel, cobble, and/or boulder sizes. Color depends on the cementing agent with white, gray, yellow, orange, brown, and red colors common.

Friable sandstone is sandstone in which the cementing agent is extremely weak. Friable sandstones can be reduced to sand with little effort and may degrade rapidly when pressure is applied or the sandstone is exposed to water.

#### **202.1.6 Limestone**

A sedimentary rock consisting of the mineral calcite (calcium carbonate). Impurities may include chert, clay and minor mineral crystals. It may be crystalline (hard, pure, fine to coarse texture) with very fine grains not visible to the naked eye and/or fossiliferous (contains remains of organisms). Limestone is typically white to dark gray in color and reacts vigorously with cold dilute Hydrochloric Acid (HCL).

#### **202.1.7 Dolomite**

A sedimentary rock of which more than 50% consists of the mineral dolomite (calcium magnesium carbonate) and less than 10% is comprised of the mineral calcite. It is commonly interbedded with limestone, and the magnesium can be replaced with ferrous iron. Colors range from white to light gray and dolomite will weakly react with cold dilute HCL on fresh surfaces.

#### **202.1.8 Coal**

A combustible substance containing more than 50%, by weight, and more than 70% by volume, carbonaceous material; formed from the compaction and lithification of plant remains. It is generally light weight with a shiny appearance on fresh surfaces.

#### **202.1.9 Underclay**

A layer primarily composed of clay lying immediately beneath a coal bed or carbonaceous shale. This layer may be bioturbated and indurated or lithified. It is chiefly comprised of siliceous or aluminous clay capable of withstanding high temperatures without deformation, and may have a high shrink/swell potential.

### **202.2 Rock Properties**

The engineering properties of intact rock coupled with the properties of the discontinuities within the rock mass dictate the overall rock mass strength of the rock slope or individual rock units of the rock slope. Table 202-1 provides expected ranges of rock properties for common lithologies found in Ohio. Laboratory testing should be conducted to verify rock properties for a specific project.

**Table 202-1. Rock properties of typical rocks found in Ohio.**

<b>Rock Type</b>	<b>Unit Weight (pcf)</b>	<b>Unconfined Compressive Strength (psi)</b>	<b>Slake Durability Index (%)</b>
Claystone	160-165	50-1400	0-60
Shale	160-165	1900-2500	20-90
Siltstone	160-170	3600-8100	65-90
Sandstone	155-160	2000-7800	85-100
Friable Sandstone	125-140	2400-3800	60-85
Limestone	155-165	3500-16400	95-100
Dolomite	165-175	4100-10300	95-100
Coal	80-85	1300-7000	N/A
Underclay	125-135	200-400	0-20

### **202.2.1 Intact Rock Strength**

The intact rock strength is the strength of the rock that does not contain any discontinuities (i.e. bedding or joints). This strength can be estimated in the field using simple field tests (SGE Appendix A.2), such as point load testing or rebound hammer testing (point load testing and Schmidt hammer rebound are index tests which can be correlated to UCS). Laboratory testing is discussed in Section 206.

### **202.2.2 Rock Weathering**

Rock weathering describes the disintegration and decomposition of rock. Disintegration is the result of environmental conditions such as wetting and drying, freezing and thawing which breaks down the exposed surface layer. This is a common type of weathering where sedimentary rocks contain swelling clays. Decomposition weathering refers to changes in rock produced by chemical agents such as oxidation, hydration, and carbonation. Weathering categories range from ‘unweathered’ to ‘severely weathered’, corresponding with the categories provided in Section 605.4 and Appendix A.2 of SGE.

### **202.3 Rock Discontinuities**

Discontinuities in rock are planes of weakness. In Ohio, discontinuities typically consist of bedding planes, joints, faults, shears, valley stress relief joints, and stress induced joints.

Much of the rock in Ohio is orthogonally jointed with bedding planes. The orthogonal joints generally consist of two sets of joints that are inclined at about 90 degrees to bedding. This is common in sedimentary units, and Wyllie and Mah (2004) provide a detailed account of the consolidation and jointing of sedimentary rock, which is useful for understanding the geologic conditions of much of Ohio. In summary, because clastic sedimentary units are deposited in horizontal layers, the initial major principal stress ( $\sigma_1$ ) felt by the rock is in the vertical direction while the minor principal stress ( $\sigma_3$ ) develops horizontally. During consolidation and induration of the rock mass, slip occurs along the depositional contacts (i.e. bedding) and because the principal stresses are perpendicular, two sets of orthogonal joints form perpendicular to bedding. Tensile stresses are not transmitted across bedding during the jointing process and, therefore, many sedimentary rocks have two orthogonal joint sets: bedding accompanied by two sets of joints truncated at bedding.

### 202.3.1 Bedding Planes

Bedding is the arrangement of sediment particles into distinct layers of different sediment compositions or grain sizes. A bedding plane is a clear break that separates adjacent beds. Because of the genesis of bedding planes, they are generally continuous (persistent) over long distances.

### 202.3.2 Joints

This discontinuity is a fracture that divides the rock into two sections that have not visibly moved relative to each other.

### 202.3.3 Valley Stress Relief Joints

Valley stress relief joints form nearly vertical and parallel to valley walls because of unloading of rock due to rock removal; the result of erosional processes (Ferguson, 1967; Ferguson 1974; Gray et al., 1979; Ferguson and Hamel, 1981). Spacing between valley stress relief joints tends to widen further into the hillsides away from the valleys.

### 202.3.4 Stress Induced Fractures

These discontinuities generally occur above mine workings or other voids within the rock mass. These discontinuities form at high angles, the result of subsidence. An example of stress induced fractures is shown in Figure 202-1.

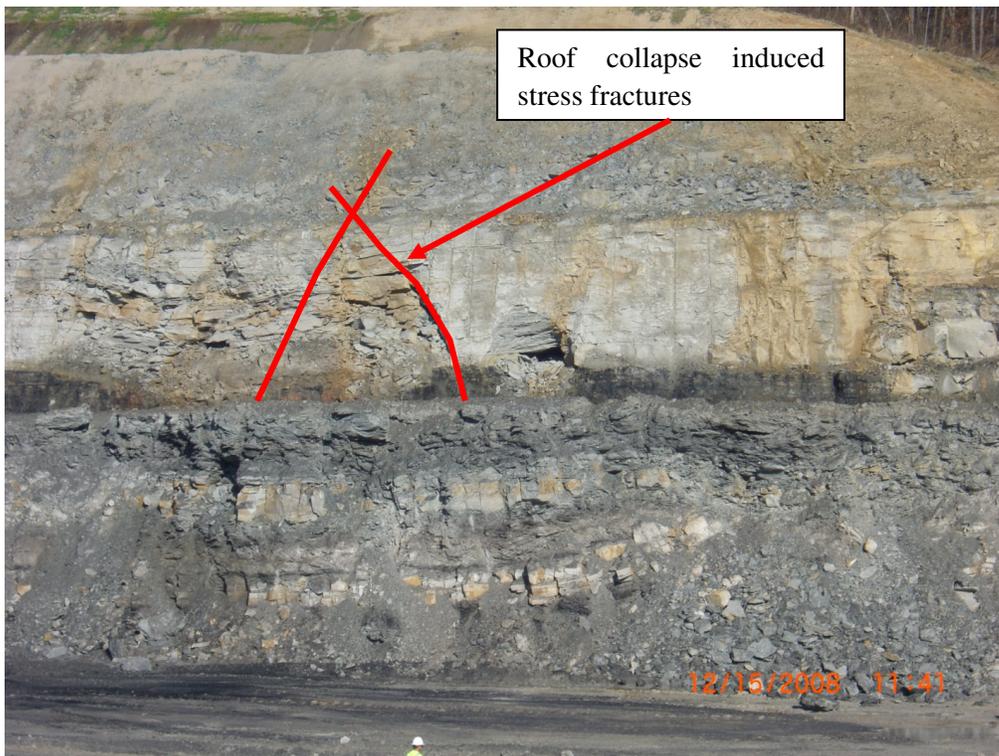


Figure 202-1. Examples of stress induced fractures occurring in a rock mass above mine workings.

### **202.3.5            Faults**

Faults are fractures in the rock that show visible movement. Faults, like bedding planes, can be very persistent. Refer to appropriate publications of the Ohio Department of Natural Resources.

### **202.3.6            Shears**

A shear is a fracture which expresses displacement parallel to the surface that results in polished surfaces or slickensides.

## **203    PLANNING OF AN EXPLORATION PROGRAM**

The exploration program for a rock cut slope design should be tailored to the specific project. A rock slope exploration and design will be for either a new rock cut or an existing cut that will be rehabilitated or reconfigured to meet the goals of an ODOT project.

### **203.1            New Rock Cut**

New rock cuts are excavated in areas where there typically are limited (if any) rock exposures, and therefore, a detailed subsurface exploration is required. Existing rock cuts that are located near a new cut area and that are located within a similar geology are helpful in assessing the performance of particular rock units.

Planning of the subsurface exploration should follow the guidelines presented in the SGE Section 303. The subsurface exploration program (e.g. borings) should be tailored to the site specific conditions determined after the site reconnaissance has been performed. It should be noted that variations can occur even in similar geology both vertically and horizontally. Occasionally these variations may occur rapidly over just a few feet.

### **203.2            Rehabilitation of Existing Rock Cut**

Existing rock cut slopes that are to be rehabilitated afford rock exposure that can be studied as part of the exploration efforts. Therefore, depending on the amount of information available and the scope of the remediation, subsurface explorations (e.g. borings) may be limited, or may not be required. The need for subsurface explorations should be assessed after a site reconnaissance is performed and should be tailored on a project specific basis.

As an example, a rehabilitation project that is being completed as part of widening of an existing cut that is performing well may not have the need for a detailed exploration. Evaluation of archival subsurface data, as well as geotechnical and geological characterization of the existing cut may be sufficient.

## **204    RECONNAISSANCE**

Field and office reconnaissance, generally performed near the start of a project, consists of studying the visible site conditions, site history, and the soil and geologic conditions for the design of the proposed work and establishing tentative types, locations and depths of exploratory methods for the subsurface exploration, with respect to project needs. Reconnaissance, both office and field, provides information to tailor field explorations and design considerations. Additional reconnaissance may be needed as unknown geologic and geotechnical conditions are encountered during the project development. In the absence of a Red Flag Summary, consider all of the resources from the Geotechnical Red Flag Summary in SGE Section 202 as part of the office reconnaissance. In particular for rock cut slope design purposes, perform the following:

- Provide a detailed description of the geology and hydrogeology as available in the literature search. Include existing or expected geologic formation names with descriptions of rock conditions based on nearby exposures or existing boring logs in the proximity of the project area.
- Identify the potential presence of any Special Care Formations as identified in Section 204.2 of this manual
- Identify any potentially significant geologic, hydrogeologic, or geomorphic features that should be considered relative to project interests.

### **204.1 Geology of Ohio**

The geology in Ohio is characterized by the presence of gently dipping, harder, more competent strata (siltstones, sandstones, limestones) alternating with softer, less competent strata (claystones and shales). This type of stratigraphy is highly susceptible to differential weathering which results in undercutting of the competent layers by erosion of the incompetent layers. Undercutting promotes a variety of slope movements such as rockfalls, plane and wedge failures, and toppling failures that may not occur otherwise (Shakoor and Weber, 1988; Shakoor, 1995). Many of the slope failures in Ohio initiate as plane, wedge or toppling failures in competent strata at higher elevations and descend as rockfalls. The frequency and size of these falls depend upon joint spacing within the competent unit and the extent by which it has been undercut. The undercutting-induced failures can be quite hazardous because of their instantaneous occurrence, high speed, and occasionally large volume of rock involved. There are also many road cuts in Ohio, however, where closely jointed rock units lead to rockfalls without the presence of undercutting (Shakoor, 1995).

Ohio can be divided into six geological regions (Figure 204.1), described as follows:

#### **204.1.1 Southwestern Ohio**

Southwestern Ohio is characterized by abundant outcrops of Upper-Ordovician shales and marine limestones in the hills of Cincinnati and surrounding areas. Therefore, rock slopes in this region are characterized by nearly horizontal, thinly bedded, alternating sequences of limestones and shales, which exhibit claystone characteristics. Special care formations elsewhere in this region are the Miami town, Fairview, and Kope formations (Section 204.2).

#### **204.1.2 Central Ohio**

Central Ohio contains fossiliferous carbonates interbedded with shales of Silurian-age rocks. Southward in the central area, other Mississippian formations and Lower Pennsylvanian rocks are exposed. Towards the eastern reach of this region, sandstones tend to replace limestones as dominant durable rocks in the rock slopes. Some friable sandstones such as the Blackhand and Sharon sandstones may be present in this region (Section 204.2).

#### **204.1.3 Northeastern Ohio**

Northeastern Ohio is comprised of siliciclastic rocks of the Late Devonian through Early Pennsylvanian age, which crop out in the deeper valleys and road cuts to the north. Friable sandstones may be present in this region (Section 204.2).

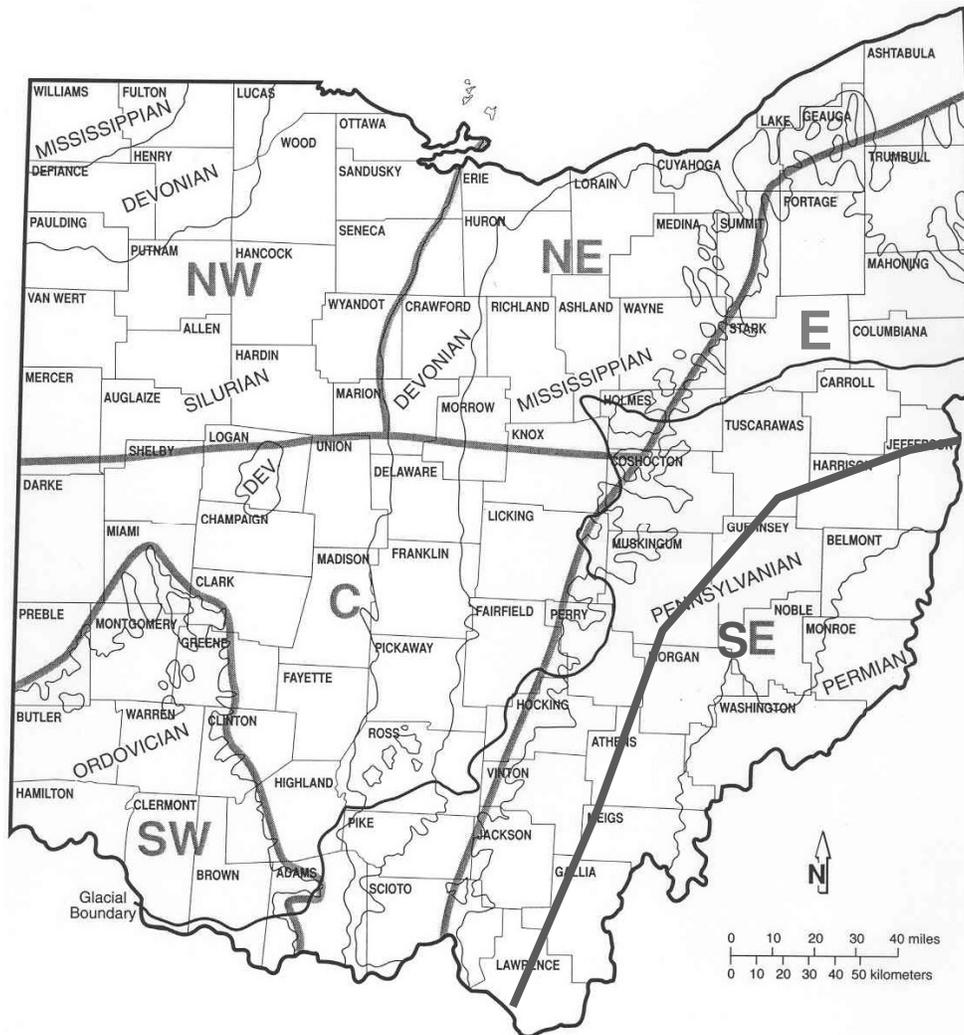


Figure 204-1. Six subdivisions of Ohio with respect to regional geology (modified from Feldman, 1996).

#### 204.1.4 Northwestern Ohio

Northwestern Ohio is dominated by carbonate rocks (limestones and dolomite), which are generally not exposed in this region except in quarries and deep river valleys. Along with the low frequency of rock cuts in this region, special care formations for rock cuts are generally not found in this region.

#### 204.1.5 Eastern Ohio

In Eastern Ohio, the surface rocks are primarily of the Pennsylvanian Age; Mississippian aged rocks are present in the western part of this area. Stream and road cuts expose Pennsylvanian-age interbedded sandstones, shales, coals, and thin limestones. Upper Pennsylvanian and Permian aged rocks contain several special care units including the Conemaugh and Monongahela formations and the Washington Formation (Section 204.2).

Abandoned underground coal mines are prevalent in Eastern Ohio. Abandoned underground mines may affect rock slope stability due to mine collapse failures, presence of stress joints extending upwards from roof collapse, and acid mine drainage. The design of mine seals is discussed in Section 602 of this manual.

#### **204.1.6 Southeastern Ohio**

Surface rocks in Southeastern Ohio primarily consist of Permian and Upper Pennsylvanian aged rocks. The Dunkard Group, which dominates this area, is characterized as an interbedded sequence of fine-grained rocks (claystone, shale, and siltstone), sandstones, limestones and coals. A special care formation, the Washington formation (Section 204.2) is also found within this region. The fine-grained rocks comprise 60 to 70 percent of the group with sandstones comprising 25 to 30 percent. The red bed claystones characteristically weather quickly upon exposure and are generally considered weak with shallow slope instability very common.

#### **204.2 Special Care Formations**

These geologic formations are prone to some or all of the following:

1. Rapid weathering because of low durability
2. Gradual change in shear strength because of weathering over time (change can be rapid in red bed units)
3. Landsliding where over steepened.

Therefore, where these formations are encountered within a new cut or during the remediation of an existing cut slope, the design should accommodate the expected weak residual strength, drainage, erosion controls, etc. The Special Care Formations identified in Ohio include:

1. Conemaugh formation: red beds–Round Knob Shale (below the Ames Limestone), Clarksburg Red Shale (below the Connellville Sandstone)
2. Monongahela formation: few red beds–Upper Uniontown Shale, Tyler Shale
3. Washington formation: red beds–Creston Red Shales
4. Fairview/Kope formation: highly weatherable shale in Cincinnati Area
5. Miamitown formation: weatherable shale in Cincinnati Area
6. Friable Sandstones: e.g. Sharon and Blackhand formations

#### **204.3 Presence of Mining in the Area**

Identify and document the limits and status of surface or underground mining, quarrying, reclaimed areas, or other excavation operations. Note any evidence of mining operations, spoil piles, mine water discharge, and possible mine subsidence features. Refer to the ODOT UVIRA – Underground Void Inventory and Risk Assessment Manual for additional guidance.

#### **204.4 Hydrogeology**

The hydrogeology of the rock cut area can be partially established during the field and office reconnaissance phase of the project by checking water levels from water well records, looking for surface water expressions such as seeps, identifying nearby bodies of water on topographic maps, and referencing the USDA soil reports and other pertinent information. Identify and document the general drainage capability of soils, the location of springs and seeps, and the extent of poorly drained areas, wetlands,

swamps, bogs, and ponds. Identify and document the condition and functionality of existing drainage features and systems relative to performance of geotechnical structures and earthwork.

#### **204.5 Landslides**

Identify and document evidence of dormant or active landslides, their locations and limits, and landslide topography in general. Note all surface cracks, scarps, toe bulges, and other indications of landslide activity. Useful tools for establishing the presence of landslides include the ODOT Landslide Inventory, USGS Open File Map Series #78-1057 “Landslides and Related Features”, USGS geologic hazard maps, review of aerial photographs, and ODNR – Ohio Geologic Survey reports. The presence of Special Care geologic units (described in Section 204.2) may also suggest the presence of landslides in the rock cut area.

### **205 EXPLORATION**

#### **205.1 Introduction**

Subsurface exploration includes characterizing exposed rock as well as boring explorations used to determine the lithology and characteristics of the rock mass to design a rock cut slope. Exposed rocks (e.g. existing rock cuts) provide access to tremendous information including performance of geologic units. Borings are completed where outcrops are sparse or not available to define subsurface conditions or where additional information besides outcrop mapping is needed to provide an adequate description of the rock stratigraphy and engineering properties for design.

#### **205.2 Surface Exploration**

Surface exploration includes all activities performed to investigate a rock cut slope that does not include significant ground disturbance (e.g. borings). The following is a description of some of the more common surface exploration activities.

##### **205.2.1 Geologic Mapping**

Geologic mapping refers to the process of describing the rock mass for engineering purposes. Geologic surface mapping of outcrops or existing cuts, in the similar geological formation in which the new cut will be performed, can furnish fundamental geological information required to design a cut. Where existing cuts are rehabilitated, geologic mapping will be the primary source of geological information for the rehabilitation, such as the identification of lithologic units and their historical performance which can be assessed. Furthermore, structural geology data provided by surface mapping is usually more reliable than that obtained from rock core drilling because outcrops show larger scale features and undisturbed or in-situ conditions compared to a very small volume of drill core. In cases where geologic structure is important to the design, the orientations of the geologic structure is more readily established at rock outcrops than within core unless specialized techniques such as oriented angle drilling or down hole televising is completed during the coring activities.

Geologic data collection should be carried out by the person or persons responsible for performing the cut slope design. The mapping objectives should be clearly identified and the data collected relevant to the design. For example, a large number of short impersistent joints that have little influence on the stability of the rock slope should be given much less attention than a highly persistent clay-filled valley stress relief joint that may cause the whole slope to fail. Two distinctive mapping methods include outcrop mapping and detailed line mapping and are discussed in more detail below.

### **205.2.2 Outcrop Mapping**

Where a new rock cut is planned, there are commonly pre-existing rock outcrops within the same or similar geology which provide adequate exposure for geologic mapping. Where rehabilitation of an existing rock slope is planned, the existing slope generally provides ample outcropping to perform detailed structural and geologic mapping.

The performance of geologic units provides important information for the design of new and rehabilitation of existing rock cuts. Performance should include assessments on the durability of units, propensity for undercutting more durable rock units, and rockfall generating units. OGE recognizes that past performance of rock cuts is more critical for the design of cuts in Ohio than examination of geologic structure for kinematic analysis. However, if a kinematic analysis is necessary it is essential that adequate data is collected both in terms of population (number of discontinuities) as well as the completeness of data collected for each discontinuity. Using either the Detailed Line Survey (Section 205.2.3) or Window Mapping, care should be taken to collect information on enough discontinuities within each discontinuity set to be able to statistically and visually identify each set on a stereographic (stereonet) projection.

Generally within most rock masses there are at least 3 to 5 discontinuity sets present. For example, in horizontally bedded sedimentary strata of the Allegheny Plateau region of the US, which encompasses Ohio, there is near horizontal bedding, two nearly vertical orthogonal tectonic joints, and commonly a near vertical valley stress relief joint for a total of at least 4 joint sets. Occasionally, there are individual discontinuities such as faults or shear zones that may be present. Care needs to be taken to ensure all discontinuity sets are identified in the field, on the data collection forms, and on the stereonets.

### **205.2.3 Detailed Line Mapping**

Detailed Line mapping comprises stretching a tape along a rock outcrop, horizontally (or) vertically creating a baseline, and mapping every discontinuity that crosses the tape. The length of the tape generally varies between 25 ft and 150 ft; the length of which depends upon site conditions and exploration goals. The information collected will include the following:

- Chainage (distance along baseline where discontinuities intersect)
- Discontinuity type
- Dip/Dip Direction
- Persistence
- Termination
- Aperture Width
- Nature of Infilling
- Strength of Filling
- Surface Roughness
- Surface Shape
- Joint Roughness Coefficient (JRC)
- Water Flow
- Spacing

An example detailed line survey mapping sheet can be found in FHWA (1998).

Vertical line mapping is aimed at collecting information regarding the rock stratigraphic section at the same time the discontinuity information is collected. In Ohio, the rock units are generally sub-horizontal and therefore, vertical line mapping provides a means to collect information for a number of rock units where horizontal line mapping will usually focus on a single or limited number of units.

Rock climbing techniques are sometimes required during the vertical line mapping. Personnel trained in proper climbing techniques should perform this mapping.

#### **205.2.4 Stratigraphic Profiles**

During the geologic mapping, stratigraphic sections should be recorded with specific reference to the engineering geologic properties of the rock units. Stratigraphic profiles should be presented in a format that conforms to SGE 702.6.3. Accurate measurement of the stratigraphic section may be made during the geologic mapping or vertical line mapping. The actual geologic thicknesses are established by correcting for the inclination of the tape during the vertical mapping. In addition to the stratigraphic profile requirements as listed in the SGE, it is recommended to denote the areas where undercutting is occurring for projects involving the rehabilitation of existing rock cuts.

#### **205.2.5 Remote Sensing**

In some cases, line, window, and outcrop mapping may not be practical for safety reasons. In those cases, other methods for collecting structural and stratigraphic data may be warranted. The two most common methods are LiDAR surveys and 3D-Photogrammetry.

LiDAR surveys are based on the travel time of a laser beam between the scanner and the outcrop. Multiple beams sweeping the outcrop enable the creation of a three-dimensional point cloud of the rock face at resolutions of 1 inch or better. These point clouds may then be manipulated so that digital photographs are overlain on the point cloud and/or so that structural information may be interpolated.

Three-dimensional photogrammetry is a method of overlapping high-resolution digital photographs and survey control data to produce 3-D outcrop models using principles of close range terrestrial photogrammetry. Two (or more) overlapping high-resolution digital photographs are taken of the outcrop and a prescribed distance to the outcrop and lateral distance between the photographs. The images are digitally rectified and overlain using specialized software. The 3-D photograph can then be manipulated using software to retrieve structural data from the rock outcrop.

No matter which remote sensing method is chosen for the geologic mapping, a limited number of structural data points needs to be collected by hand survey to ‘ground-truth’ the remotely-sensed data.

Surveying for existing rock cuts should include survey techniques where xyz coordinates are measured at an interval of 1 inch or less (Section 205.2.8). Surveying techniques that provide this level of information may be used to obtain geologic lithology and structural information as well as survey information.

#### **205.2.6 Interpretation of Structural Geologic Data**

Detailed explanation of the interpretation of structural geologic data is beyond the scope of this manual. Detailed information regarding this subject may be found in FHWA (1998) and Wyllie and Mah, 2004.

### **205.2.7 Sample Collection**

During the geologic mapping, samples may be collected for various laboratory tests in support of the rock slope design. Bulk rock sampling should be completed so that the in-situ moisture content of the rock specimen is maintained. Samples can be taken using a geologic hammer/pick or other similar means along with the use of rock face cores. The sample size and number of samples will be dependent on the laboratory testing to be completed. For details on sample collection procedures see SGE 405.5 Rock Cores and ASTM D5079 7.5.2.

### **205.2.8 Surveying**

Topographic surveys for new rock cuts require a maximum two foot contour interval. Surveying for existing rock cuts should include a Light Detection and Ranging survey (LiDAR survey), or other similar survey techniques, where xyz coordinates are measured at an interval of 1 inch or less. For most rehabilitation projects, scaling and/or reconfiguration of the slope will be required, and the LiDAR type survey is useful for estimating debris removal and haul quantities during construction.

### **205.2.9 Surface Geophysics**

Surface geophysical methods can be used to obtain information regarding the subsurface. Specifically in regard to rock cut slope design, geophysical techniques such as seismic refraction and electrical resistivity can be useful. Seismic velocities can be used to obtain an estimate of unconfined compressive strengths which may be useful in determining the rippability (need for blasting) of rock material. Electrical resistivity, as well as other techniques, can also be used to identify groundwater conditions and potential voids (e.g. mines and karst features) in the subsurface.

### **205.3 Subsurface Explorations (Borings)**

Subsurface explorations for new cuts should include borings that follow procedures outlined in the SGE (Section 303). In these procedures, borings are recommended at maximum intervals of 1000 feet (300 meters). These borings will typically be located at the back of the ditch line at the points of deepest cut. It is emphasized that where major changes in the geology or lithology occur, boring intervals should be reduced to establish the limits of these changes. Keep in mind that more severely weathered and deteriorated rock conditions are typically encountered on the sides and ends of a hill as compared to the middle. Supplement borings that core bedrock with soil borings that extend to the top of bedrock spaced a maximum of 400 feet (120 meters) apart in order to develop the elevation of the bedrock surface and the nature of the soil overburden throughout the cut.

### **205.4 Other Exploration Tools**

Other investigative tools can be used to supplement the rock core borings. Down-hole geophysics tests available include optical and acoustic televiewer soundings. In-situ tests that are common in Ohio include pressuremeter, borehole shear tests, and dilatometer. These other exploration tools are to be only used with DGE approval for rock slope design explorations when rock strength is critical and more traditional techniques cannot obtain samples.

#### **205.4.1 Down-hole Televiewer**

A down-hole televiewer is a camera or acoustical instrument that is placed within a boring after completion. The televiewer captures a continuous record of the borehole walls including all discontinuities, color changes, voids, and water conditions. The information can later be viewed as digital

images, and structural data can be retrieved by process of digitizing discontinuities on the digital images and processing the digitized discontinuities via computer programs.

#### **205.4.2 Pressuremeter**

A pressuremeter (PMT) consists of a long cylindrical probe that is expanded radially into the surrounding ground with a fluid such as water or gas (in soil) and hydraulic oil (in rock). The volume of fluid and fluid pressure is monitored to develop a stress strain curve for the ground. Standard probes range from 1.3 to 2.9 inches (35 to 73 mm) in diameter with a length to diameter ratio varying from 4 to 6. Some advantages of the PMT test are that it theoretically gives an accurate determination of the soil/rock parameters, the test influences a zone larger than other in-situ tests, and the PMT will develop a full stress-strain curve. Disadvantages include that the procedure required to run and interpret the data is complicated and requires a high level of expertise in the field, tests are time consuming, and the instrument is typically delicate and easily damaged.

#### **205.4.3 Borehole Shear Test**

A borehole shear test is an in-situ direct shear test that can be completed in soil or weak rock. The device is portable, and tests are conducted by expanding diametrically opposed contact shear plates into a borehole under a constant and known normal stress. The test is conducted by pulling the device vertically and measuring the shear stress required to “fail” the rock. A rock borehole shear tester can accommodate shear and normal stresses up to 6 and 12 kips per square inch, respectively (Yang et al., 2006). The information that is obtained includes an in situ Mohr-Coulomb ‘peak’ and ‘residual’ shear strength envelope for the rock.

#### **205.4.4 Flat Plate Dilatometer Test (DMT)**

The dilatometer test (DMT) uses pressure readings from a plate inserted into the ground to establish stratigraphy and estimates of in-situ water pressure, elastic modulus, and the shear strength of materials such as sand, silt, and clay. The DMT test also has applications in very weak and weak rock where the apparatus can be advanced to a depth of interest. Some advantages of the DMT are that the test is simple to complete, it is typically repeatable, and economical. Disadvantages include that it is difficult to advance in dense or hard materials, no samples are recovered and therefore, testing results are based on empirical relationships, and the instrument needs to be calibrated for the local geologic conditions.

### **206 LABORATORY TESTING**

Laboratory testing is completed to determine the engineering properties of small samples of the rock mass. These tests are later used to determine how the rock mass will perform in the rock slope. Of the many laboratory tests available, only those that are most common to rock slope engineering are presented below. In general, laboratory testing that is completed consists of strength testing, and index testing of the rock.

#### **206.1 Strength Tests**

These tests measure deformation and ultimate capacity of the rock to withstand axial loading. Empirical methods for establishing rock mass shear strength (i.e. Hoek et al., 2002) are based on the rock type and strength of intact rock and then ‘scaled’ to account for blockiness of the rock mass, and the conditions of the rock discontinuities.

### **206.1.1 Uniaxial Compressive Strength Tests**

Uniaxial compressive strength tests (UCS) are conducted according to ASTM D 7012, Method C. These tests are conducted by stressing a trimmed rock core specimen in the longitudinal direction (without lateral confinement) and taking the maximum measured force divided by the cross-sectional area. Following ASTM methodologies, the unit weight of the rock should be measured.

### **206.1.2 Direct Shear Tests on Discontinuities**

These tests are conducted according to ASTM D 5607 and may be completed on either saw cut samples (i.e. smooth) or natural (i.e. rough) discontinuities. The test is completed by placing two “matched” pieces of rock core with the discontinuity to be tested into a shear box and grouting into place. A normal force is applied perpendicular to the discontinuity surface. The lower sample is kept in place while a shear force is applied to the upper part sample keeping the normal force constant. The stress on the discontinuity surface and displacement of the upper specimen are recorded during the test. Direct shear testing should only be performed on cut slopes where kinematics control design and with consultation of the DGE.

### **206.1.3 Point Load Testing**

Point load testing (PLT) provides an indirect measurement of the rock uniaxial compressive strength. Point load testing is useful if site specific or lithology specific correlations between point load index and UCS are available. If correlations are not available, then UCS testing in tandem with the PLT is performed to establish a correlation.

The PLT is completed according to ASTM D 5731 by placing a piece of rock core or lump rock sample between two platens; a force is applied to the sample and the maximum load on the sample is recorded. The results are not acceptable if the failure plane lies partially along a pre-existing fracture in the rock, or is not coincident with the line between the platens. For weak rock, where the platens indent the rock, a correction factor is applied to the results.

In general, a minimum of three UCS tests should be conducted in tandem with three suites (10 PLT tests each) of PLT tests to determine a correlation between the PLT values and UCS for a specific site or lithology. As part of the PLT, it is recommended to record the unit weight of the rock sample (Section 206.2.2)

To obtain the unconfined compressive strength from PLT a conversion factor is commonly used. Generally in Ohio, competent rocks (sandstones and limestones) use a conversion factor of 24 and incompetent rocks (shales and claystones) use a conversion factor of 12 ( $UCS = \text{conversion factor} * I_s$ ). It should be noted that the weaker non-durable rocks obtain less accurate compressive strength values based on point load testing.

## **206.2 Index Tests**

Testing that gives an indirect measurement of the strength or deformation properties of rock are called index tests. Index test results are related empirically to engineering properties of interest for the rock slope design. Index tests commonly completed in evaluating rock slopes in Ohio are described as follows:

### **206.2.1 Slake Durability Index**

A rock's durability is its resistance to degradation or erosion when subjected to natural elements, seasonal weather, and repeated cycles of temperature. Rocks in Ohio range from high to very low durability. Durability is assessed by the ASTM D 4644 Slake Durability test (SGE Section 606). The basis for slake durability tests are empirical and the results are used to judge the performance of the rock when subjected to the elements over time. The durability of rocks in slopes or a difference in durability of rocks in slopes that promote undercutting within slopes are the main failure mechanisms causing block and rock fall in Ohio.

The test is completed according to ASTM D 4644 where dried fragments of a known weight are placed in a drum fabricated with 0.08 inch square mesh wire cloth. The drum is rotated and partially submerged in distilled water. The specimens remaining in the drum are dried at the end of the rotation cycle (10 minutes at 20 rpm). After two cycles, the dry weights of the specimens are recorded and the Slake Durability index (SDI) is calculated, (weight retained/initial weight) x 100.

### **206.2.2 Unit Weight**

Rock unit weight is the weight of the sample divided by the volume of the sample. Unit weight is used during slope stability calculations for rock slopes. It is recommended that the unit weight of rock be measured. It should be noted that the unit weight is not recorded as part of a point load test, however, it is recommended that unit weight be recorded for purposes of design in this manual.

## **207 ROCK MASS PROPERTIES**

The rock mass properties of geologic units are influenced by the intact rock properties and the conditions of the discontinuities within the rock. In addition to those intact rock and discontinuity properties described above, other properties such as fracture frequency, number of discontinuity sets, block size, seepage conditions and rock quality designation are required to describe the rock mass for the purpose of rock mass characterization and rock slope stability design.

### **207.1 Fracture Frequency**

This is the number of fractures or discontinuities encountered in a boring or measured along a linear segment of rock outcrop divided by the length of the core run or tape.

### **207.2 Block Size**

Block size is the size of individual blocks which may potentially dislodge from the rock slope. This can be measured directly at a rock outcrop or estimated based on the spacing of individual discontinuity sets measured in a boring or along a line mapping traverse (discussed in Section 205.2.3).

### **207.3 Seepage Conditions**

Water pressure within rock slopes is detrimental to the rock slope's stability because 1) an increase in water pressure decreases the effective stresses in the slope and thus the shear strength available to resist sliding along discontinuities and through the rock mass and 2) degradable materials such as claystones and friable sandstone lose strength over time when exposed to water.

### **207.4 Rock Quality Designation (RQD)**

Rock quality designation is a measure of the rock quality based on the fracture frequency. RQD is reported as a percent of the length sum of pieces greater than or equal to 4 inches within a given

stratigraphic unit (borings) divided by the total length of the core run(s) within that stratigraphic unit (SGE Section 605.10). For rock outcrops, RQD can be approximated using a relationship suggested by Palmström (2005) as:

$$RQD \approx 110 - 2.5J_v$$

$J_v$  is the volumetric joint count which is estimated by summing the number of discontinuities within a cubic yard (cubic meter according to reference) of the rock mass. Given the directional dependence of RQD in rock core,  $J_v$  is the preferred method to establish RQD when outcrops are available.

## **208 DISCONTINUITY ENGINEERING PROPERTIES**

Discontinuities within the rock are planes of weakness upon which sliding can occur. Therefore, in most rock slope evaluations, the engineering properties of discontinuities are important. However, due to the geologic structure present in Ohio the rigors of kinematic analysis are generally not necessary. This section is provided to give guidance for the cases where kinematic analysis may be necessary. FHWA (1998) provides a detailed discussion regarding the engineering properties of discontinuities. The main points of FHWA (1998) are summarized below.

### **208.1 Orientation**

Discontinuity orientation provides an indication in which direction sliding of rock blocks may occur and expressed as dip and dip direction (or strike) of the surface. Dip is the maximum angle of the plane measured from the horizontal. The dip direction is the direction of dip measured from north and reported azimuthally. A dip and dip direction reported as (56/180) would suggest that the plane in question dips at 56 degrees from horizontal in a direction of 180 degrees (due south).

Discontinuities in the State of Ohio are dominated by generally horizontal bedding planes and sub-vertical joints (valley stress relief joints and other joints formed by tectonic forces in the geologic past). Due to the dominance of these discontinuity orientations kinematic analysis of discontinuities is generally not performed.

### **208.2 Spacing**

The spacing of discontinuities provides an indication of the block size within the rock slope. The spacing is measured normal to the strike of a discontinuity plane. The spacing is also related to the rock mass strength, for example in very closely spaced rock, individual discontinuities may join together to form continuous zones of weakness. These types of weakness zones are sometimes encountered in special care units such as red beds.

### **208.3 Persistence**

Persistence is a measure of the continuous length of a discontinuity (e.g. vertically in the case of valley stress relief joints) and gives an indication of the size of blocks that may slide out of or topple from the rock slope. Rock slope mapping should concentrate on measuring the persistence of the set of discontinuities that has the greatest potential to facilitate failure. Although one of the most important parameters of discontinuities for rock slope stability, this is the most difficult attribute to measure in outcrops because often only a small part of the discontinuity is visible. Within rock core, persistence cannot be measured because of the limited sample size.

#### **208.4 Roughness, Wall Strength, & Weathering**

Roughness, wall strength, and surface weathering dictate the shear strength of ‘clean’ discontinuities; those that are not infilled with material. Measurements of joint roughness are typically calibrated against empirical Joint Roughness Coefficient (JRC) charts published by Barton (i.e. Barton and Choubey, 1977). Alternatively, qualitative descriptors such as those contained in SGE Appendix A.2 can be used to describe the discontinuity wall roughness.

Wall strength measurements can be conducted using field tests (ISRM, 1981), or if lump or core samples are available, by carrying out point load testing. Additionally the Schmidt hammer test (rebound hammer) is a method that estimates the strength of the discontinuity surfaces and is a common test for measuring the uniaxial compressive strength of concrete. These apparatuses are common in materials testing laboratories. An understanding of the discontinuity roughness and wall strength can be used with empirical methods published by Barton (1973) to establish the shear strength of clean discontinuities.

Weathering, an alteration of the discontinuity surfaces, decreases the wall strength, and therefore decreases the shear strength of a previously clean discontinuity. Weathering is an important parameter that should be measured in the field.

#### **208.5 Infilling**

Discontinuities can be infilled with material that changes the shear resistance along the discontinuity. Infilling materials may include clay and detritus material that are weaker than the host rock. Infilling of this type can reduce the shear resistance along a discontinuity. In some cases infilling can take the form of recrystallization along the discontinuity with minerals such as calcite, siderite, and limonite, which may increase shear resistance along the discontinuity. In cases where the shear resistance along a discontinuity is important the infilling material should be tested. For guidance in the testing refer to FHWA (1998).

### **209 GROUNDWATER EXPLORATIONS**

Groundwater conditions and the potential for groundwater seepage are factors in the design of rock slopes. However, the need for extensive groundwater explorations is generally not necessary for most rock cut designs in Ohio and should only be conducted with DGE approval.

Determination of groundwater levels and pressures includes measurements of the elevation of the groundwater surface and variations of this elevation based on seasonal fluctuation. Also important is the location of perched water tables, the location of aquifers, and the presence of artesian pressures. Water pressure in rock slopes reduces the stability of the slope by reducing the available shear strength of potential failure surfaces. Changes in moisture content of the rock, particularly those with low slake durability, causes materials to lose strength over time. Freezing of groundwater causes ice wedging and may effectively block drainage of discontinuities in the rock mass increasing pore pressures resulting in an increased rockfall potential and the potential for more large scale failures of the rock slopes.

Determination of the permeability of the rock strata is important because discharge of water from slopes along a highway can necessitate the requirement for increased maintenance as the result of pavement deterioration and the need for higher capacity drainage systems. During construction, there may be difficulties operating heavy equipment on wet ground, and water in blast holes may require special blasting ‘gels’ which are more expensive than blasting materials used for dry holes. Erosion of both

surficial soil and degradable rock units may occur because of groundwater flow. This increases the occurrence of rock fall.

#### **209.1 Determination of Groundwater Levels and Pressures**

A detailed discussion regarding methods of estimating groundwater levels and pressure can be found in FHWA, 1998 and SGE Section 500. The determination of groundwater level and pressure can be made from the following:

1. Information from existing wells in the area of the rock slope
2. Measurements of groundwater entry during drilling
3. Measurements of groundwater within bore holes after drilling (ASTM D 4750)
4. Installation of groundwater monitoring wells; piezometers, vibrating wire piezometers.

#### **209.2 Permeability and Seepage Pressures**

A detailed discussion of permeability and seepage pressures can be found in FHWA, 1998 and SGE Section 500. To summarize permeability and seepage pressure can be determined by:

1. Variable head permeability tests
2. Down hole packer tests
3. Groundwater pumping tests
4. Theoretical calculations of rock mass permeability based on discontinuity aperture and spacing

## SECTION 300 ROCK SLOPE DESIGN PROCEDURE

### 301 INTRODUCTION

The design of rock cut slopes is a step-wise process. After the exploration, segments, or the entire slope, are grouped into design units which are provided recommended cut slope angles according to their material properties. Guidelines for the interaction between the design units are provided and further discussed in Section 400 of this manual. Catchment areas and drainage are discussed in later sections (Sections 500 and 600) of this manual.

### 302 TERMS

**A. Lithologic Unit:** A body of rock comprised of a similar mineral composition, grain size, and engineering characteristics.

**B. Competent Unit:** A lithologic unit described as a limestone, sandstone, or siltstone and based on the following guidelines: (1) any limestone or sandstone visually described as moderately strong or stronger based on SGE 605.5, (2) any limestone or sandstone visually described as very weak, weak, or slightly strong based on SGE 605.5; have a unit weight of 140 pcf or greater; or a unit weight less than 140 pcf but with a second cycle ( $Id_2$ ) SDI value of 85 percent or greater as based on ASTM D 4644, and (3) any siltstone with a second cycle ( $Id_2$ ) SDI greater than 85 percent as based on ASTM D 4644.

**C. Incompetent Unit:** A lithologic unit described as shale or claystone, or a competent lithologic unit described as slightly strong, weak, or very weak based on SGE 605.5, with a unit weight less than 140 pcf and an  $Id_2$  value less than 85 percent as based on ASTM D 4644.

**D. Design Unit:** A portion of a slope, or the entire slope, that can be cut at a consistent angle. A design unit may be comprised of single or multiple lithologic unit(s). A design unit can be selected on the basis of characteristic lithology and the anticipated slope failure(s). The thickness of a design unit can range from a relatively short thickness (minimum 10 feet) to the height of the entire cut slope. Three (3) design units are considered in this manual, defined as follows:

- 1. Competent Design Unit:** Consists of greater than 90 percent competent rock units. The failures anticipated to occur in this design unit are those controlled by unfavorable orientation of discontinuities (plane, wedge, or toppling failures).
- 2. Incompetent Design Unit:** Consists of greater than 90 percent incompetent units. The failures anticipated in this design unit include raveling, mudflows and rotational slides.
- 3. Interlayered Design Unit:** Consists of interlayered competent and incompetent units, each ranging in proportion from more than 10 percent to 90 percent. Undercutting-induced failures (rockfalls) and mudflows are the anticipated primary failures in this design unit. However, raveling and rotational slides are possible.

### 303 DETERMINATION OF DESIGN UNIT SLOPE ANGLES

This section considers the appropriate cut slope angles for design units based on the rock units that comprise each design unit. Commentary is provided as to the most likely modes of failure, locations of benches, as well as the potential need for localized stabilization that may be employed. Discussion on the design of benches, catchment area, drainage, and other aspects of the design of rock cuts are found in later sections of this manual.

#### 303.1 Competent Design Units

Rock Quality or fracture frequency should be used to assess the overall stability of a competent design unit. Design units with closer spacing of discontinuities are prone to higher frequencies of rockfalls and potential global stability issues. An example of a slope comprised of a competent design unit is shown in Figure 303-1. Once it is established that the rock slope will consist of competent design units, the cut slope inclination may be determined based on Rock Quality Designation (RQD) as follows:

**Table 303-1. Cut Slope Angle: Competent Design Units**

RQD (%)	Recommendations
0-50	Cut slope to 1H:1V or consult with the DGE
51-75	Review global stability and design based on engineering judgment or consult with the DGE
76-100	Slope grade of 0.5H:1V, or 0.25:1V for thickly bedded sandstones

Zones of close joint spacing, especially near the cut slope edges should be flattened to transition to natural ground. These areas may also be stabilized using wire mesh nets or rock bolts with DGE approval.

For slopes comprised only of thickly bedded sandstone or other lithologic units with high RQD and rock mass strength, cut slope angles of 0.25H:1V may be used if adequate catchment area is provided. To utilize slope angles steeper than 0.5H:1V, contact the DGE. To steepen cut slope angles in competent design units, isolated areas may require additional support or stabilization. For guidance on these stabilization methods refer to Section 704.2. Problems associated with soil-rock contact should be addressed to avoid soil failure. This can be addressed using an overburden bench as described in section 502.



Figure 303-1. Slope comprised of competent design units located at TUS-77-3.106.

### 303.2 Incompetent Design Units

The design of the slope angle for incompetent design units is based on the average second-cycle SDI ( $Id_2$ ). An example of a slope comprised of an incompetent design unit is shown in Figure 303-2. The following design guidelines (Table 303-2) should be used:

**Table 303-2. Cut Slope Angle: Incompetent Design Units**

SDI ( $Id_2$ ) (%)	Slope Angle
< 20	2H: 1V or flatter -Special design; contact the DGE
20-60	2H: 1V
60-85	1.5H: 1V
85-95	1H: 1V
95-100	1H: 1V or steeper – contact the DGE

For incompetent design units that have SDI less than 20 percent the design should be based on engineering judgment and consultation with the DGE. For slopes steeper than 1H:1V use engineering judgment and consult with the DGE.



Figure 303-2. Slope comprised of incompetent rock located at WAS-821-1.9.

### 303.3 Interlayered Design Units

Interlayered units exhibit significant stratigraphic variations. Cut slope design recommendations for these units need to take into account these variations. Four stratigraphic configurations, designated as Type A through Type D, are recognized and defined in Table 303-3 below:

**Table 303-3. Definitions of Interlayered design unit types.**

Type	Description
Type A	Very thick (>3 ft) competent units underlain by incompetent units
Type B	Medium to thick bedded (10 inches to 3 ft) <i>sandstone and siltstone</i> units interbedded or interlayered with incompetent units in variable proportions
Type C	Medium to thick bedded (10 inches to 3 ft) <i>limestone</i> units interbedded or interlayered with incompetent units in variable proportions
Type D	Thin bedded (2 to 10 inches) limestone units interbedded with incompetent units in variable proportions

### 303.3.1 Recommended Cut Slope Design for Type A Stratigraphy

Type A stratigraphy, consisting of competent units underlain by incompetent units. Slope instability typically results in topples of flat or cubical rockfalls due to undercutting (Figure 303-3A). Type A stratigraphy may also be interpreted as an incompetent design unit overlain by a competent design unit. For either scenario, design should focus on reducing toppling failures within the competent unit and minimizing excessive weathering of the incompetent unit which causes undercutting of the overlying unit. The cut slope should follow the contour of the contact. Provide adequate catchment area (Section 500) and drainage. The following slope design options are recommended for Type A stratigraphy:

1. Cut the competent rock at 0.5H:1V to avoid toppling failures. If the incompetent unit is of significant thickness (10 feet thick or greater), cut the incompetent unit at an angle as specified in GB3 Table 2. If the incompetent unit is 3 feet to 10 feet thick, cut at 1H:1V. If the incompetent unit is less than 3 feet thick, cut at the same angle as the competent rock. If the incompetent unit is 3 feet or greater, provide a geotechnical bench following guidelines in Section D at the contact between units.
2. When the competent unit consists only of very thickly to massive bedded sandstone, slopes may be cut at 0.25H:1V. Use of this steeper cut slope angle may result in the need for localized or patterned stabilization using rock bolts. The decision to use the steeper cut angle should be based on engineering judgment in consultation with the DGE.



Figure 303-3A. Slope comprised of Interlayered Type A stratigraphy rock located at WAS-77-17.1.

### 303.3.2 Recommended Slope Design for Type B Stratigraphy

Type B stratigraphy consists of medium to thickly bedded sandstone and siltstone units interbedded or interlayered with incompetent units, which typically results in flat or cubical rockfall debris. The design approach for this type of stratigraphy should be to either cut the slope at a uniform gentle angle to reduce undercutting or cut at a steep slope (0.25H:1V) angle and provide an effective catchment ditch. Due to the thickness of the sandstone units, treating each sandstone unit as a separate design unit and using multiple benches will be impractical in this situation. Two cases are considered below.

#### 303.3.2.1 Case 1: Competent lithology comprises 50 percent or greater of unit

- Cut the slope at a uniform angle of 1.5H:1V. Provide adequate catchment area (Section 500) and drainage.
- Cut the slope at 0.25H:1V and evaluate if stabilization of the sandstone/siltstone units in the top half of the cut slope is needed. A higher frequency of maintenance should be anticipated.

An example of Type B Stratigraphy-Case 1 is shown in Figure 303-3-B1.

If a slope is comprised of multiple design units or a different design unit is present below the Type B stratigraphic sequence, a bench should be placed between the two design units. The bench should be designed in accordance with Section 403.



Figure 303-3-B1. Slope comprised of Interlayered Type B stratigraphy Case 1 design unit located at TUS-36-0.

### 303.3.2.2 Case 2: Incompetent lithology comprises greater than 50 percent of unit

An example of Type B Stratigraphy-Case 2 is shown in Figure 303-3-B2. Cut the slope at 1.5H:1V in order to contain the flat rockfalls on the slope face. Provide adequate catchment area (Section 500) and drainage (Section 605).



Figure 303-3-B2. Interlayered Type B stratigraphy Case 2 rock located at TUS-36-3.8.

### 303.3.3 Recommended Slope Design for Type C Stratigraphy

Type C stratigraphy, consisting of medium to thick bedded limestone units interbedded or interlayered with incompetent units. These slopes typically produce cubical rockfall debris. Two cases are considered below.

#### 303.3.3.1 Case 1: Competent lithology comprises 50 percent or greater of unit

An example of Type C Stratigraphy-Case 1 is shown in Figure 303-3-C1. Cut the design unit at 0.25H:1V for heights of design units not exceeding 25 ft. For design units in excess of 25 feet in height cut at 0.5H:1V.

In this case, the incompetent units are too thin to be independently designed. The appropriate design approach should be cutting slopes at steep angles and providing adequate catchment areas. Stabilizing limestone units in the upper portions of the slope, which have a greater potential to release rockfalls, may

be justified using engineering judgment with consultation of the DGE. Coal seams are common within this stratigraphy and should be protected from weathering. Placing benches on top of coal seams might not necessarily prevent undercutting.



Figure 303-3-C1. Interlayered Type C stratigraphy Case 1 rock located BEL-70-23.



Figure 303-3-C2. Interlayered Type C stratigraphy Case 2 rock located at WAS-77-15.3.

Undercutting of the limestone units may be prevented by shotcreting the undercutting units. If a different design unit underlies this case a bench should be placed along the contact following procedures outlined in Section 402. Reinforced shotcrete option may be considered to prevent undercutting by coal seams and underclay layers. Mine seals should be provided to support cavities of mined out coal layers as described in Section 602. Provide adequate catchment area (Section 500) and drainage (Section 605).

#### 303.3.3.2 Case 2: Incompetent lithology comprises greater than 50 percent of unit

An example of Type C Stratigraphy-Case 2 is shown in Figure 303-3-C2. In this case, the incompetent units are usually in red bed claystone units. The design approach should focus on reducing the degradation of the thick incompetent units and retaining the weathered material on the slope face by constructing a serrated slope (a series of small, 3-4' wide benches), especially in zones containing limestone units. The design should be based on the incompetent rock unit and follow procedures in Section 303.2. If the slope contains significant thicknesses of red beds, refer to Section 304 of this document. Provide adequate catchment area (Section 500) and drainage.

#### **303.3.4 Recommended Slope Design for Type D Stratigraphy**

Type D stratigraphy consists of thinly bedded limestone units inter-layered with incompetent units in variable proportions. This type of stratigraphy is especially prone to releasing flat-shaped rockfalls that can have long trajectories in the presence of steep slopes. Thinly bedded limestone units are most commonly associated with marine limestones that can be identified as fossiliferous (Figure 303.3-D). Field observations show that where limestone proportion is high (competent/incompetent ratio greater than 0.5) toppling and other types of undercutting-induced failures can occur.

Cut slope at 1H:1V or flatter based on engineering judgment. Provide adequate catchment (Section 500) and drainage.

### **304 SPECIAL CARE FORMATIONS**

These geologic formations identified in Section 204.2 are potentially prone to:

1. Rapid weathering because of low durability
2. Gradual change in shear strength caused by weathering
3. Landsliding where over steepened

Special care should be taken when these units are encountered. Design for these units should be based on engineering judgment and consultation with the DGE.



Figure 303-3-D. Interlayered Type D stratigraphy rock located in Hamilton County.

## SECTION 400 BENCHES

### 401 INTRODUCTION

A bench is a nearly horizontal surface constructed mid-slope. The purposes of a bench include 1) providing erosion provisions of a less durable rock underlying a more durable rock where weathering may result in undercutting, 2) allow for overall steeper angles of a slope where weaker lithologies are present, 3) provide stages of construction, and 4) provide transition areas. Even though rock slope benches provide some degree of protection against rockfall this is considered a secondary attribute of benches. Benches should be located to account for construction access and global or localized slope failures and not as a means of rockfall protection.

Benches constructed with the specific intent of catchment should be avoided. FHWA discourages mid-slope benches because they are rarely cleaned and could become launching features for rocks (FHWA, 1998). In general, mid-slope benches are not effective for rockfall control unless they are directly beneath a near vertical slope (0.25:1 or steeper). Design of slopes that include a maintained bench will require the inclusion of access points to all maintained benches as well as a sufficient width (accounting for weathering) for equipment access.

Types of benches include overburden benches, geotechnical (lithologic) benches, and construction benches.

### 402 OVERBURDEN BENCHES

The purpose of the soil overburden bench is to create an area where adjustments can be made during construction (due to unexpected variations in the soil-rock interface elevation) without requiring a change to cut slope design angles and limits. At the interface between soil overburden and bedrock, a minimum 10-foot wide bench should be provided.

Slopes in the soil overburden zone (where the soil is over 10 feet thick) should typically have a slope of 2H:1V. Stability analysis for an overburden zone thicker than 10 feet may be necessary in certain situations to confirm the appropriateness of a 2H:1V slope. If a 2H:1V slope does not daylight over a reasonable distance, steeper slopes may be required to minimize right-of-way and excavation. On occasion, the overburden zone may include or be comprised entirely of severely weathered rock. For the use of overburden zone slopes steeper than 2H:1V, contact the DGE. If the overburden zone is less than 10 feet thick or the natural slope is 1H:1V or steeper, rounding of the top of the cut to blend into the natural slope is permissible.

Design of these benches should include an evaluation of drainage, especially in the vicinity of large recharge areas..



Figure 402-1. Example of an overburden bench during construction.

### **403 GEOTECHNICAL (LITHOLOGIC) BENCHES**

A geotechnical (lithologic) bench is a bench placed at the top of a less durable design unit (e.g. shale or claystone) that underlies a more durable design unit (e.g. sandstone or limestone). The purpose of a geotechnical bench is to provide protection against undercutting of the more durable design unit as the less durable design unit weathers and erodes. Benches should be placed at locations where warranted. Guidance on design of geotechnical benches is provided below.

1. For incompetent design units 10 feet thick or less, the benches should be 10 feet wide.
2. For incompetent design units thicker than 10 feet, the benches should be made wider as necessary based on specific conditions. The designer should use engineering judgment to determine the site-specific minimum thickness of a weatherable bed that will require benching. Conditions to consider are the rate of weathering and the ultimate angle of repose of the weathered incompetent material. For instance, if a material weathers back to 2H: 1V, this should be considered in design to prevent undercutting.
3. For interlayered design units, provide a minimum 10-foot bench at the contact between different design units. The designer should use engineering judgment to determine the site-specific bench size required.

4. Where permeable formations overlie impermeable ones (including areas of fractured flow), which may indicate potential aquifer zones, the configuration of benches must consider drainage issues.
5. For coal, clay, or mineral seams of mineable thickness, or in the case of known or suspected underground mines that will be located within the cut slopes, a 20-foot wide bench should be inserted. Bench locations should be below suspected mine voids and above un-mined seams.
6. The slope of benches longitudinally should follow the base of the competent rock with the outslope having positive drainage typically at a grade of 10%, with a minimum grade of 3%. Special consideration should be given to drainage in vicinity of coal seams. Bench grades are extremely hard to control when rock is blasted.
7. Where there are competent/incompetent unit interfaces near the termination of the slope at the catchment ditch, a 10-foot wide bench should be inserted below road grade to prevent undercutting of the cut slope during maintenance procedures.
8. Where the above guidelines would result in different types of benches in the vicinity of each other (e.g. a construction bench and a geotechnical bench within a few feet vertically), the designer must use engineering judgment to produce a practical design, and combine benches.
9. Access roads to benches will most likely require additional right of way. Sufficient width for equipment access on maintained benches will also be necessary.
10. Bench widths may need to be modified in order to maintain a temporary working bench during construction. These geometric benches should accommodate relief in the existing slope face. The cut line needs to consider all relief as well as the burden thickness.
11. Geotechnical benching must be field adjusted during construction to follow any changes in the bedding surface.
12. Install a bench drain along the contact between competent-incompetent rock units where groundwater is encountered or anticipated to collect seeping water, and a backslope drain behind the slope crest to reduce runoff on slope face.
13. On occasion, geotechnical benches may be warranted in heavily fractured zones in competent units (i.e. collapse zone above a mine). Contact the DGE for additional guidance.



Figure 403-1. Example of a geotechnical (lithologic) benches during construction.

#### **404 CONSTRUCTION BENCHES**

A construction bench is a five (5)-foot bench that is used to accommodate construction practices (Figure 404-1). As discussed in Section 703, the maximum vertical depth of blasting for ODOT slopes is 30 feet. For design purposes where design unit thicknesses or sections of slope designs are greater than 30 feet blasting must proceed in stages. These benches are provided to account for the required 2-foot offset between lifts during pre-splitting due to constructability issues as well as for the tool variances that occur in drilling (such as tool wander). Without accounting for necessary construction offsets with construction benches, the as-built cut line will either be moved back at the top, impacting project right-of-way, or be made steeper, to maintain the plan offset at the toe of cut.

For slopes steeper than 1:1, or where pre-splitting is specified for a 1:1 slope, 5-foot wide horizontal construction benches should be placed at a maximum of 30-foot vertical intervals of a rock cut slope where no geotechnical benches are required. Variations of plan and actual construction bench width are expected and in fact these benches may, and should if possible, be eliminated during construction.



Figure 404-1. Example of a construction bench after construction. Note the weathered rounded appearance after a period of exposure.



## SECTION 500 ROCKFALL CATCHMENT DESIGN

### 501 INTRODUCTION

A rockfall is defined as a rock mass that has detached from a steep slope or cliff, along a surface on which little or no shear displacement occurs, and descends most of its distance through air (Hoek and Bray, 1981). Rockfalls constitute a hazard along Ohio roadways. Rockfalls are predominate in Ohio where rock discontinuities form blocks in competent units, which are underlain by easily erodible incompetent units. Erosion of underlying incompetent units allows blocks from the upper competent units to fall under the influence of gravity. The frequency and size of a rockfall depends on joint spacing within the competent unit and the extent by which it has been undercut. However, undercutting is not always required for rockfall to occur. Closely jointed rocks can lead to rockfalls even if there is no undercutting involved (Shakoor, 1995).

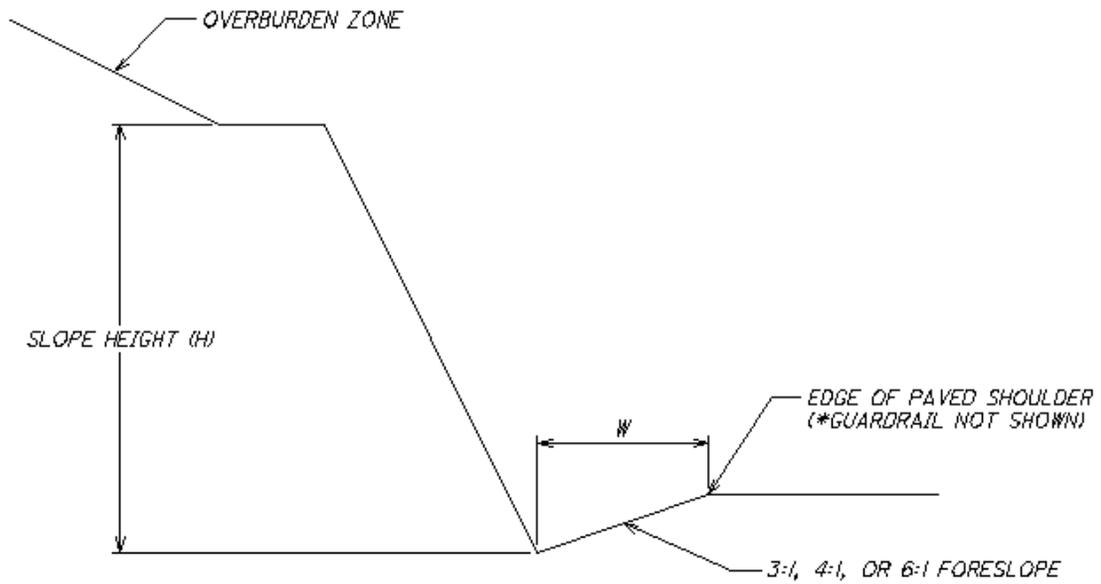
OGE has established a rockfall catchment design criteria of 95% rockfall catchment at the edge of pavement (typically edge of paved shoulder). An effective method of minimizing the hazard of rockfalls is to control the distance and direction in which they travel. The recommended and most frequently used method to control rockfall in Ohio is the appropriate sizing of a catchment area. Other rockfall control and protection methods beyond catchment ditches include barriers, wire mesh fences, and mesh slope drapes (Section 504). A common feature of all these protection methods is their energy-absorbing characteristics in which the rockfall is either stopped over some distance, or is deflected away from the roadway.

The use of design charts and rockfall computer simulation programs are necessary to select and design effective protection measures against rockfall. If design charts are used as the basis for design of catchment areas, representative critical sections along the rock cut slope should also be analyzed using a rockfall simulation program (Colorado Rockfall Simulation Program [CRSP] or equivalent software) to confirm the catchment ditch configuration is acceptable. The catchment area design should be the larger of the two designs; one based on Table 502-1 and the other being the computer simulation models. Figures 501-1 and 501-2 should be referenced for rock slope terminology.

It should be noted that the mid-slope geotechnical (lithologic) bench is not to be designed as a rockfall mitigation measure. However, its ability to attenuate rockfall hazards should not be ignored. The effectiveness or contribution of benches at limiting rockfall hazards should be evaluated using rockfall simulation computer programs. This is accomplished by evaluating both end-of-construction as well as long term conditions. Guidance on this is presented in Section 503.1 of this manual.

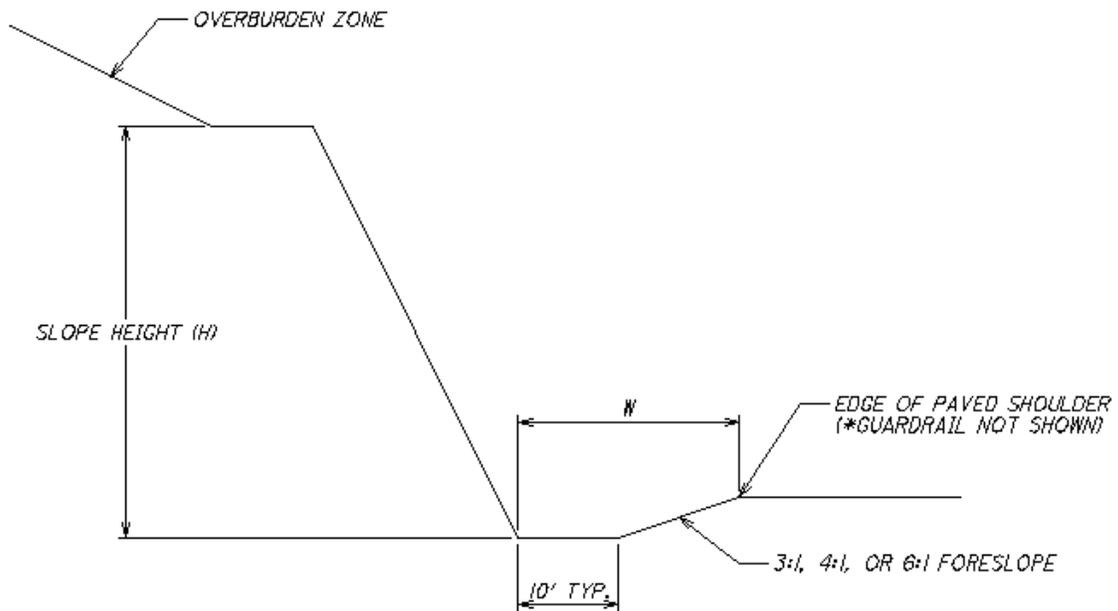
### 502 USE OF DESIGN CHARTS

Utilizing a combination of sources, including other state DOT standards, FHWA cosponsored research, and ODOT research, Table 502, Recommended catchment widths for varying slope and catchment foreslope angles, has been formulated for the various recommended cut slope angles (1.5H:1V or steeper). Table 502 is based on the OGE established 95% rockfall containment within the catchment area. In this table there are two general ditch configuration options presented, and these configurations are shown in Figures 501-1 and 501-2.



*\*Guardrail Required For All 3:1 Slopes and 4:1 Slopes With Safety Grading*

Figure 501-1. Typical ditch configuration for a catchment area with a single angle foreslope.



*\*Guardrail Required For All 3:1 Slopes and 4:1 Slopes With Safety Grading*

Figure 501-2. Typical ditch configuration for a catchment area with flat catchment area and angled foreslope.

In the case of rock cut slopes with multiple slope angles (e.g. presence of benches), the governing cut slope angle that will be used to determine adequate catchment should be the angle of the portion of slope that intersects the ditch. Catchment width for an individual rock cut slope section should not vary in width throughout the section and should be based on the critical section of the slope design. The critical section is typically the maximum rock cut slope height. However, instances where larger block sizes are anticipated for section of shorter heights may be the critical section. The height of cut slope (H) should be defined as the vertical distance from overburden bench (or lowest 2H:1V or flatter slope of more than 10 feet in height) to the base of the slope. Modifications to the examples in Figures 501-1 and 501-2 may be made for site-specific hydraulic concerns. The catchment ditch width (W) may include the 10-foot wide maintenance bench discussed in Section 402 Item 7, provided it is below the edge of pavement elevation.

**Table 502-1. Recommended catchment widths for varying slope and catchment foreslope angles.\***

	Cut Slope Height, H (ft)					
	0-40	50	60	70	80	>90***
<b>Overall Cut Slope Angle</b>	<b>Catchment Ditch Width, W (ft)</b>					
<b>3H:1V Catchment Foreslope Angle</b>						
0.25:1	10	15	15	15	20	25 min.
0.5:1	10	15	20	20	20	25 min.
1.0:1	15	20	20	20/25**	25	30 min.
1.5:1	15	20	20	20/25**	25	30 max.
<b>4H:1V Catchment Foreslope Angle</b>						
0.25:1	10/15**	15	20	20	25	30 min.
0.5:1	15	15	20	20	25	30 min.
1.0:1	15/20**	20	20/25**	25/30**	30	35 min.
1.5:1	15/20**	20	20/25**	25/30**	30	35 max.
<b>6H:1V Catchment Foreslope Angle</b>						
0.25:1	15	20	25	30	35	40 min.
0.5:1	20	20	25	30	35	40 min.
1.0:1	25/30**	25/30**	30	35	40	40 min.
1.5:1	25/30**	25/30**	30	35	40	40 max.

\* For new slopes only, consult ODOT Location and Design Manual, Volume 1, Section 307.2.1 for guidance on catchment foreslope angles

\*\* Option 1 Catchment Ditch Width / Option 2 Catchment Ditch Width

\*\*\* Slopes with a height (H) greater than 90 feet and at an angle of 1H:1V or steeper should be designed with Table 502-1 width as minimum and adjusted according to specific site conditions

Table 502-1 provides a basis to evaluate potential catchment area designs. Discussion on the use of a computer rockfall simulation program is provided in Section 503 of this manual. The designer should use engineering judgment and CRSP or equivalent software analysis to determine the appropriate catchment ditch width for a rock cut slope where the portion of the slope intersecting the ditch is flatter than 1.5H:1V.

### **503 COMPUTER ROCKFALL SIMULATION PROGRAMS**

Selection and design of effective protection measures require the ability to predict rockfall behavior. Rockfall simulation programs have been widely used in the field of geotechnical engineering since the early 1990s. The design of rock slopes greater than 90 feet in height or special cases for slopes less than 90 feet in height are to include a rockfall simulation analysis. For guidance on the operation of specific rockfall simulation computer programs the designer is referred to the program user's manual.

Computer rockfall simulation programs such as CRSP provide a 2-dimensional or cross-sectional analysis of the trajectories and energies of potential rockfall in its model. CRSP divides a rock cut into cells or segments. Each segment is provided characteristics as to its geometry, ability to attenuate energy, and its undulations or roughness. The size and shape of potential rockfalls are also required. Results of the simulation models provide rockfall trajectories, energies, and bounce heights along the length of the slope and catchment area.

Rockfall simulations should be performed for critical sections of a rock slope. The number of critical sections for a rock cut is project specific. At minimum a simulation must be done at the location of the highest vertical relief. The height of cut slope (H) should be defined as the vertical distance from overburden bench (or lowest 2H:1 V or flatter slope of more than 10 feet in height) to the base of the slope. Additional sections may be required due to changing slope conditions (e.g. change in elevation of roadway) or where geometries change that warrant additional simulations. Engineering judgment and/or consultation with the DGE should be used to determine the number of simulations.

#### **503.1 Guidance on the Colorado Rockfall Simulation Program**

With regard to CRSP, the OGE has established a number of guidelines to assist the designer.

1. Analysis should be run for both end of construction conditions and for long-term conditions. The long-term conditions should account for the weathering of the slope.
2. Analysis Points are locations on the horizontal axis of a model where resultant output variables such as energies, bounce heights, velocities, and percent passing are summarized. A simulation model may have multiple analysis points. OGE recommends the following analysis points:
  - a. Analysis Point 1, or AP1, is defined as the top of the catchment ditch.
  - b. Analysis Point 2, or AP2, is defined as the outside edge of the pavement (typically paved shoulder). OGE requires 95 percent of rockfalls not passing AP 2.
3. Surface Roughness accounts for the surface irregularities along segments of a slope. This value should also vary with the size of rock being analyzed. Surface roughness is considered to be the most sensitive variable.

For end-of-construction versus long-term conditions the following is recommended:

- a. For the analysis of end-of-construction conditions, the surface roughness should be a low value (0.15-0.50 for freshly cut portions of slopes).

- b. For long-term analysis, the surface roughness should be higher than end-of-construction analysis. Surface roughness should be increased based on engineering judgment using, for example, the performance of slopes in similar geology.
4. Rock dimensions for analysis should be site-specific. Consideration should be given to the size of fallen rocks in the existing slope ditch or in ditches in the vicinity of the site. Analysis should be performed for both the anticipated average and maximum size of potential rockfall.
5. A unit weight of the design unit should be input based upon laboratory testing of the collected rock core samples.
6. For the Normal and Tangential Coefficients, the CRSP User's Manual provides broad ranges of values to be used for different slope conditions. These ranges are shown in Table 503-1. This manual also provides Table 503-2 as a guide for a more refined selection of initial coefficient values. It should be noted that these coefficients, which are energy dissipation coefficients, are less sensitive to the rockfall simulation than surface roughness, but are still important for an appropriate computer simulation.
7. For mudstone/claystone slopes when modeled, use winter conditions (worst case), during which the ground is frozen resembling a "stronger" surface versus the softer conditions of spring.

**Table 503-1. CRSP Coefficient Guide for Normal and Tangential Coefficient (from Jones, et al., 2000)**

Description of Slope	Normal Coefficient (Rn)	Remarks
Smooth hard surfaces and paving	0.60-1.0	-For short slopes try lower values in applicable range  -If max. velocity/KE* are design criteria, use lower values in range; if avg. velocity/KE* are design criteria, use higher values in range
Most bedrock and boulder fields	0.15-0.30	
Talus and firm soil slopes	0.12-0.20	
Soft soil slopes**	0.10-0.20	

\*KE = kinetic energy

\*\*Soft soil slope coefficients were extrapolated from other slope types due to lack of data

Description of Slope	Tangential Coefficient (Rt)	Remarks
Smooth hard surfaces and paving	0.90-1.0	-Rt is not very sensitive compared to Rn, but may be important for hard or significantly vegetated slopes
Most bedrock and boulder fields	0.75-0.95	
Talus and firm soil slopes	0.65-0.95	
Soft soil slopes*	0.50-0.80	-Use lower Rt as the density of vegetation on the slope increases

**Table 503-2. Hardness reference guide with CRSP coefficient values (Modified from Woodard, 2004)**

<b>Hardness Input Code</b>	<b>Consistency</b>	<b>Field Identification</b>	<b>Normal Coefficient Values (Rn)</b>	<b>Tangential Coefficient Values (Rt)</b>
1	Very soft	Easily penetrated several inches by fist	0.10	0.50
2	Soft	Easily penetrated several inches by thumb	0.10	0.55
3	Firm	Can be penetrated several inches by thumb with moderate effort	0.15	0.65
4	Stiff	Readily indented by thumb but penetrated only with great effort	0.15	0.70
5	Very stiff	Readily indented by thumbnail	0.20	0.75
6	Hard	Indented with difficulty by thumbnail	0.20	0.80-0.85
7	Very weak rock	Can be carved with a knife. Can be excavated readily with a point of a pick. Pieces 1 inch (25 mm) or more in thickness can be broken by finger pressure. Can be scratched by fingernail.	0.15	0.75
8	Weak rock	Can be grooved or gouged readily by a knife or pick. Can be excavated in small fragments by moderate blows of a pick point. Small, thin pieces can be broken by finger pressure.	0.15	0.75
9	Slightly strong rock	Can be grooved or gouged 0.05 inch (2 mm) deep by firm pressure of a knife or pick point. Can be excavated in small chips to pieces about 1-inch (25 mm) maximum size by hard blows of the point of a geologist's pick.	0.20	0.80
10	Moderately strong rock	Can be scratched with a knife or pick. Grooves or gouges to ¼" (6mm) deep can be excavated by hand blows of a geologist's pick. Requires moderate hammer blows to detach hand specimen.	0.25	0.85
11	Strong rock	Can be scratched with a knife or pick only with difficulty. Requires hard hammer blows to detach hand specimen. Sharp and resistant edges are present on hand specimen.	0.25-0.30	0.9
12	Very strong rock	Cannot be scratched by a knife or sharp pick. Breaking of hand specimens requires hard repeated blows of the geologist hammer.	0.25-0.30	0.95-1.0
13	Extremely strong rock	Cannot be scratched by a knife or sharp pick. Chipping of hand specimens requires hard repeated blows of the geologist hammer.	0.25-0.30	0.95-1.0

OGE has concluded that in a number of cases, CRSP tends to underestimate required ditch width. Care should be taken to ensure the rockfall simulation is an accurate representation of the potential rockfalls for new construction or historical rockfalls for an existing slope.

**503.2 Rockfall Simulation Output**

As stated in Section 503.1 Item 2, an adequate catchment area requires at least 95 percent of rockfalls retained in the catchment area (AP2). Beyond the final rollout trajectory of potential rockfalls modeled, a simulation provides the trajectories, bounce heights, velocities, and energies of potential rockfalls both along a slope as well as in the catchment area. This information is important when a catchment area or a rock cut is constrained by issues such as right-of-way. This topic is discussed below.

**504. MODIFIED CATCHMENT AREAS**

The design of rock slopes, especially rehabilitation of existing slopes, may have constraints that prevent the full use of catchment areas as defined in Table 502-1. This is especially the case for slopes constrained by issues such as right-of-way, economic, or other constraints including the presence of structures such as bridges at the toe of slopes. In these cases, the use of other mitigation options placed either on the slope or within the catchment area may be considered. For these constrained slopes the most commonly used protection measures are Jersey barrier, Modified D-50 wall, and flexible barrier or rock fence. On-slope mitigation options such as draped mesh net systems have also been used in the rehabilitation of existing slopes. Examples of rockfall mitigation measures are provided in Table 504-1.

**Table 504-1. Examples of Rockfall Mitigation Measures (updated from McCauley et al., 1985)**

<b>Protection Measures</b>	<b>Stabilization Measures</b>	<b>Warning Measures</b>
Relocate Roadway	Flatten Slope	Signs
Bench	Scale or Trim	Signal Fence and Wire
Catchment Ditch	Design to Geology	Monitoring
Widening at Grade	Controlled Blasting	Patrols
Wire Mesh Fence	Surface and Subsurface Drainage	
Timber Lagging Walls	Rockbolts and Dowels	
Metal Guardrail	Shotcrete and Gunite	
Jersey Barrier	Anchored Wire Mesh	
Earth Berm	Retaining Walls	
Draped Mesh Net		
Modified D-50 Wall		
Flexible Containment Systems (Rock Fence)		

#### **504.1 Catchment Area Barriers**

The use of a barrier in the catchment area is often a cost effective mitigation measure. Care should be taken to design the chosen catchment area mitigation measures to contain rockfall based on the expected bounce heights and energies. Common mitigation measures include Jersey barriers, Modified D-50 wall, flexible containment systems, and berms.

Barriers can be divided into two groups; rigid barriers and flexible barriers. Rigid barriers include the Jersey barrier and Modified D-50 wall. Rigid barriers may be used for anticipated rockfall blocks of 5 feet in diameter or smaller. Anticipated rock blocks greater than 5 feet should use a flexible barrier system or other containment means. These barriers absorb the impact of rockfalls based on the strength of its materials. Flexible barriers are manufactured to bend and absorb the energy of rockfalls, dissipating the energy over a distance. Flexible barrier systems have energy absorbing potential generally from 100 to 5,000 kJ and can be sized in height according to the site specific needs.

The use of CRSP or other similar rockfall simulation programs is required in the selection and design of barriers. The appropriate selection of a barrier is based, in part, on the predicted rockfall bounce heights and energies of potential rockfalls at the placement location of a barrier. The barrier selection should of sufficient height to prevent rockfalls from bouncing over and should be able to absorb energy to limit the hazard to the traveling public. In general, rigid barriers are considered to have a lower energy absorbing capacity, shorter heights, and lower costs than flexible barriers. Flexible containment systems are designed based on the potential bounce heights and energies of rockfalls. These should be appropriately designed based on specific manufacturer's requirements.

#### **504.2 On-slope Mitigation Options**

Due to long term changes to mid-slope geotechnical (lithologic) benches, such as filling up with talus and weathering away, these benches should not be relied upon as a rockfall mitigation measure. Applicable on-slope rockfall attenuators include options such as barriers and mesh drape systems. A barrier may be useful on a slope where a specific location is identified on the slope, based on rockfall simulation analysis, where bounce heights and energies are such that the barrier would be more effective than being placed in the catchment area. Access for maintenance of the barrier should be provided. The selection of an on-slope or mid-slope barrier may be predicated on its cost effectiveness and should be done in consultation with the DGE.

Mesh drape systems are effective rockfall mitigation where there is a high volume of historic or predicted rockfalls. Drapes help attenuate energy and bounce height as well as directing where the rockfall lands. If rockfalls are greater than 5 feet in diameter, the use of wire mesh drape systems are not recommended. Drape systems are generally not recommended for new cut designs. For guidance on the design of wire mesh drape systems refer to the FHWA manual Design Guidelines for Wire Mesh/Cable Net Slope Protection (WA-RD-612.2, 2005) and the ODOT Supplemental Specification 862 Rockfall Protection.

## SECTION 600 OTHER GEOTECHNICAL CONSIDERATIONS

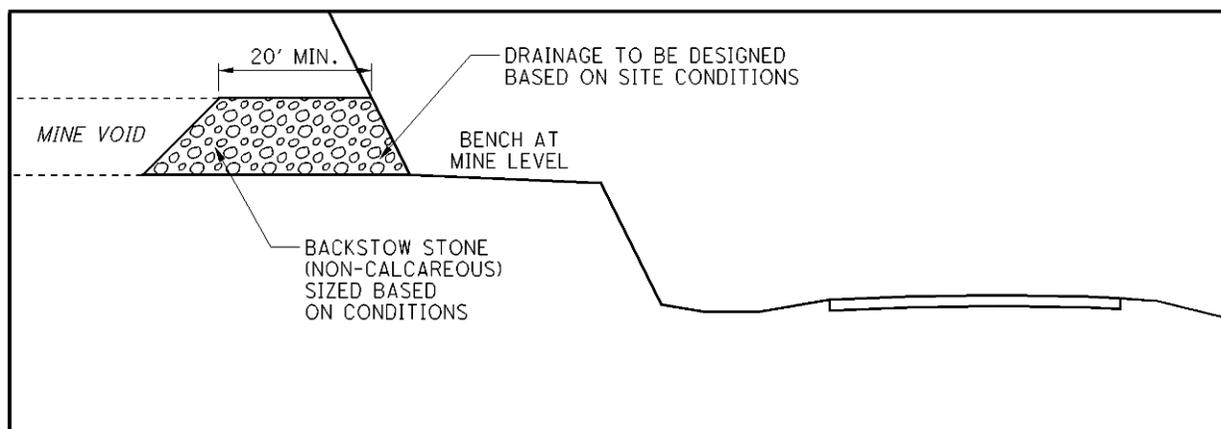
### 601 INTRODUCTION

In the design of rock cuts, situations may arise where modification to a design template are necessary. This section discusses several of the more common geotechnical situations that are encountered in Ohio. Design of these or other unique cases should be done with engineering judgment and coordination with the DGE.

### 602 MINES AND MINE SEALS

Horizontal mine openings encountered in rock slopes have the potential to destabilize portions of the slope and cause rockfall or deep seated failure. Therefore, efforts should be made to establish the presence of underground mining activities during the rock slope field exploration and design. Refer to ODOT, 1998 Abandoned Underground Mine Inventory and Risk Assessment Manual for the identification of mine related features.

Mine voids encountered in rock slopes should be cleared of debris by excavation equipment and then backfilled to a limited horizontal distance with 601 dumped rock backfill, followed by materials grading to #1 and #2 aggregate. Filter fabric should be placed over the backfilled drift entry to help prevent soil piping downward through the dumped rock backfill. A mine drain should be installed to prevent impounding water behind the backfilled material. A mine vent should be considered if there is a potential for buildup of gas because of the placement of the backfill materials. Pneumatic stowing is recommended where rock slope stability evaluations show that backfill is required at a greater horizontal distance than practical for excavation equipment. An example of a typical detail for backstowing an exposed mine void is shown in Figure 602-1.



## **603 WATER**

### **603.1 Groundwater**

Groundwater is often a cause of rock slope instabilities. The usual method for providing groundwater drainage is the use of horizontal drains to create an outlet for the water. There is no formula to predict the optimal inclination, spacing, and length of horizontal drains in a slope. Drains are typically installed on 10 to 30-foot spacing and penetrate to at least one-third the slope height. Because groundwater is concentrated within the discontinuities in the rock, it is advantageous to intersect as many of the discontinuities as possible or to locate the horizontal drains within the geologic formation that is carrying the water. Within horizontally bedded sedimentary rock slopes, the most prominent discontinuities within the slope are typically bedding and therefore, horizontal drains should target the water bearing unit, intersecting the bedding and steeply-inclined joints.

Drains consist of a perforated pipe with the perforations sized to minimize the infiltration of fines washed from the fracture infillings. Depending on the amount of water and durability of the rock where the water is discharged, it may be necessary to collect all seepage in a manifold and dispose of it some distance from the slope.

### **603.2 Surface Water**

Drainage along the top of a cut slope must be addressed to minimize the amount of water flow across the cut slope face. Drainage control measures should be designed to address site specific flows and velocity.

Surface water may enter fractures in the rock increasing the water pressure within the rock slope or run over the slope causing more rapid degradation of less durable materials. Therefore, where surface water is expected, it is often worthwhile to install a diversion ditch behind the crest of the slope and on individual benches. Ditches (except toe drain) should be lined with riprap.

## **604 TRANSITION ZONES**

A transition zone is the intersection of a natural slope with a constructed rock slope. This usually occurs at the end of the rock cut slope. Typically, because the natural slope has weathered over a period of time, the material (rock or soil) within the natural slope will be less durable than the newly exposed rock and therefore, the inclination of the slope from the rock cut to the natural slope should be decreased so that the new rock slope is 'blended' into the existing natural slope.

## **605 KARST**

Refer to the most recent version of "Ohio Karst Areas" published by the Ohio State Department of Natural Resources for known locations of karst features. During the rock slope exploration, identify and document ground surface features that may be related to karst formations.

Karst features exposed within rock slopes are similar to underground mine voids in that they are voids in the rock slope that can contribute to rock fall, subsidence, and global instability problems. Water within karst features may flow freely out of the feature and cause less durable rock materials to rapidly weather. Therefore karst within rock slopes is typically treated in the same manner as underground mine voids.

## SECTION 700 CONSTRUCTION CONSIDERATIONS

### 701 INTRODUCTION

Development of designs for a new cut slope or rehabilitation of an existing cut slope must consider the safety of the traveling public and contractors during construction, as well as the long term performance of the rock slopes. This section addresses items about construction and constructability which the designer should take into consideration.

### 702 BLASTING AND EXCAVATION

Specific blasting requirements are beyond the scope of this document. For details on blasting requirements refer to C&MS 208 ROCK BLASTING. However, the following are common issues observed by contractors in Ohio. These issues should be considered in the overall design of a rock slope.

#### 702.1 Pre-Splitting

Pre-splitting helps minimize blast damage to the final face of the excavation due to production blasting. CMS 208.01 requires pre-splitting of cuts steeper than 1H:1V and deeper than 5 feet, regardless of the method of excavation (i.e. ripping, hoe-ram, excavation with or without production blasting). However, the specification states that pre-splitting of 1H:1V slopes may be specified. It is preferred that competent design units with RQD of 0 to 50 percent, cut at a slope angle of 1H:1V per Table 303.1, be presplit. Likewise, it is preferred that incompetent design units with SDI greater than 85 percent, cut at a slope angle of 1H:1V or steeper per Table 303.2, be presplit. The Designer should specify by Plan Note pre-splitting of these design units whenever possible.

Design of rock cuts 1H:1V or steeper in design units of lower rock quality than those listed above should be rare, but may need to be specified on occasion due to right-of-way or other constraints. In this case, the Designer need not specify pre-splitting of 1H:1V slopes for the lower quality rock, and CMS 208.01 would require only slopes steeper than 1H:1V be presplit. As a general rule-of-thumb, the Designer need not specify pre-splitting of 1H:1V cuts when the rock is anticipated to be rippable.

Typically, to determine the effectiveness of blasting (including pre-splitting) versus ripping and mechanical excavation Contractors utilize values of

- Discontinuity Spacing (typified by RQD values)
- Strength Values (Qu or PLT)
- Seismic P-wave velocity

Pre-splitting effectiveness is relative to the weakest layer in the shot. Design units comprised of mixed lithologic units in which a single pre-split is placed is less effective than a pre-split in a single lithologic unit. In weak incompetent design units which can be easily excavated, mechanically scaling of the final face may be more beneficial than pre-splitting. In areas where multiple lithologic units of varying intact properties are present, or where the final face is highly fractured and jointed, the final face may have loose materials remaining after the excavation.

## **702.2 Production Blasting**

During the development of their Blasting Program a blaster will evaluate two primary items:

1. Spacing and depth of the pattern
2. Diameter of the blast holes

Generally, the smaller the area, the more expensive (the unit rate will be to excavate the slope. A two-lane side hill cut and fill will be more difficult and costly to construct than a large four-lane through cut. When the area of excavation becomes narrower, the spacing and diameter of the blast holes will both typically decrease. These measures help prevent breakage beyond the pre-split plane and limit the amount of fly rock, if there is an exposed outside face, and will increase excavation unit rates.

## **702.3 Scaling**

For areas where loose material remains on the final face after excavation, the face should be mechanically scaled prior to blasting the next lift. Mechanical scaling can be accomplished with either a large track hoe bucket scraping the final face, a hoe ram on isolated areas, or a heavy gauge chain or dragger. A dragger is a large heavy counter weight, such as a steel beam or steel plate (e.g. an old plow blade), which can be attached to a chain or cable. The chain or dragger is then attached to a dozer or crane and pulled along the face, both horizontally and vertically, multiple times to dislodge loose materials.

## **703 NEW CONSTRUCTION**

### **703.1 Weathered Areas**

Commonly, at the outer edges and top of a cut (referred to as the weathered mantle), or near natural drainages, the rock conditions become more weathered and broken (lower RQD). This presents both construction issues and potential rockfall concerns. To address these issues, several steps may be taken:

- a. The cut slope edges and top portions should be tapered (flattened) into the existing topography within the weathered mantle.
- b. The design catchment area (full width) should be extended along the full length including the tapered portions of the cut slope, since these areas may produce debris.
- c. Field adjustments should be made, based on actual conditions, as necessary.

### **703.2 Work Staging**

The Designer should evaluate the anticipated work area to consider how the project will be completed. For small projects the cut may be the primary or only work being completed. For larger projects comprised of multiple cuts and fills the Designer should anticipate how the work will progress and make sure the cut designs allow for flow during construction. Make sure the cut sections allow for haul roads to move the excavated materials out of the cuts and into the fills.

## **704 REMEDIATION OF EXISTING SLOPES**

Remediation of existing cut slopes are completed based on a wide variety of issues ranging from widening of existing roadway into the existing cut slope to slope failure resulting in rockfall debris that

may pose a hazard to the traveling public. Regardless of the reason for the remediation, work on an existing slope poses significant challenges during construction, which the design should attempt to minimize. The following is a brief discussion to the items which should be considered for cutting and stabilizing an existing slope face.

#### **704.1 Cutting an Existing Slope Face**

##### **704.1.1 Working Platform**

The working platform is a bench, from which work is initiated. The working platform will vary depending on the project and excavation limits necessary to complete the designed cut. For example, a site requiring hoe-ramming or trim blasting with loading of the excavated materials into road trucks at the road elevation for off-site disposal will require a narrower working platform compared to loading the excavated material into haul trucks on the slope for adjacent disposal.

General recommendations are:

**Table 704-1. Typical Minimum Widths of Working Platforms**

Equipment Type (On Working Platform)	Working Platform Width (Minimum in Feet)	Comments
Track-hoe only	25	Not beneficial for tall slopes because work will require casting (possibly multiple times) down slope for loading.
Track-hoe/loader & Dump Truck/Articulated Truck	30	May require trucks to back in and out one at a time limiting efficiency.
Track-hoe/loader & Heavy Rock Truck (Multiple entry/exit points)	35	Works well if trucks can move across the bench in one direction from an entry point to an exit point.
Track-hoe/loader & Heavy Rock Truck (Single entry/exit points)	45	Need sufficient room for trucks to maneuver on the bench.

The working platform should be comprised entirely of rock and is measured from the existing rock face to the cut line.

In general, the narrower the working platform, the higher the unit cost for excavation. Larger the equipment that can be utilized as the working platform becomes larger, and therefore, the lower the unit costs of excavation. As such, the wider working platform may be less expensive to construct over the narrower working platform even though a larger volume is being excavated. Additionally, a wider working platform may be beneficial to allow for adjustments during construction of the slope.

##### **704.1.2 Remediation Blasting and Excavation**

In addition to those items discussed in 702 Blasting and Excavation, the following items should be considered for remediation jobs due to narrow cuts typically being performed:

- During the production blasts the rock will swell due to the breakage. If there is a narrow working area, this swelled material could cast down the existing slope face.
- The unshot material located in the outer wedge of the slope may require the use of a hoe ram to be broken down into disposable pieces.

- A temporary berm or barrier may be needed to protect traffic if there is insufficient catchment at the base of the existing cut.
- Eliminate “pinch points”, where the working platform narrows, limiting the access of the equipment. These typically occur in natural drainage swales.
- Anticipate where the waste area is going to be located. Based on the anticipated haulage out of the cut, benches may need to be altered to efficiently tie the benches into the haul roads.

## **704.2 Stabilization of Existing Cuts**

Existing cuts may be stabilized instead of re-cut. Stabilization is typically used when right-of-way constraints or costs prohibit re-cutting. The following are discussions about the typical stabilization methods:

### **704.2.1 Mechanical Scaling**

When the slope face contains large amounts of loose, broken or unstable material with minimal or no overhangs, mechanical scaling as outlined 702.3 Scaling can be considered. Typically, slopes 40 feet high or less may be considered for mechanical scaling.

### **704.2.2 Hand (Manual) Scaling**

For higher slopes, or slopes where isolated areas of loose unstable rock is present, hand scaling may be considered. Hand scaling operations should conform to Supplemental Specification 862 Rockfall Protection.

### **704.2.3 Slope Drape**

Slope drapes may be considered where the entire slope contains loose or unstable materials. They may also be considered for isolated areas of loose unstable rock which is located above the effective height of mechanical scaling or where hand scaling will not be fully effective. A slope drape is a wire or cable net laid on the slope to direct rockfall into a catchment area by reducing the potential energy for the debris, thereby requiring a smaller catchment area. Slope Drapes should conform to Supplemental Specification 862 Rockfall Protection.

### **704.2.4 Trim Blasting**

For larger intact blocks that need to be removed, trim blasting should be considered. Trim blasting operations should conform to C&MS 208 Rock Blasting.

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