PB2000-106685

A Visualization Method for Teaching the Geometric Design of Highways

Norman W. Garrick
Christian F. Davis
Tomasz P. Janikula

UNITED STATES DEPARTMENT OF TRANSPORTATION

REGION I UNIVERSITY TRANSPORTATION CENTER

PROJECT UCNE 11-1

FINAL REPORT

April 11, 2000

Performed by

University of Connecticut
Connecticut Transportation Institute
Storrs CT 06269-2037

Exhibit C

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.

4. Title and Subtitle	5. Report Date
A Visualization Method for Teaching the Geometric Design of Highways	June 28, 2000
	6. Performing Organization Code
7. Author(s) Norman W. Garrick, Tomasz P. Janikula, Christian F. Davis	8. Performing Organization Report No. NEUTC UCNR 11-1
9. Performing Organization Name and Address University of Connecticut Connecticut Transportation Institute Civil and Environment Engineering, U-37 Storrs, CT 06269-2037	10. Work Unit No. (TRAIS)
	11. Contract or Grant No. DTRS95-G-0001
12. Sponsoring Agency Name and Address New England (Region One) UTC Massachusetts Institute of Technology 77 Massachusetts Avenue, Room 1-235 Cambridge, MA 02139	13. Type of Report and Period Covered Final September 1, 1998--December 31, 1999
	14. Sponsoring Agency Code

15. Supplementary Notes

Supported by a grant from the US Department of Transportation, University Transportation Centers Program

16. Abstract

In this project we employed state-of-the-art technology for developing visualization tools for teaching highway design. Specifically, we used photolog images as the basis for developing dynamic 3-D models of selected geometric elements. The resulting 3D-visualization toolbox links video clips of various road sections, with animated graphs representing their horizontal and vertical alignments. By the simultaneous display of the windscreen view of a roadway, along with the plan and profile graphs, the toolbox allows the user to study the effect on continuity and esthetics of combining specific plan and profile elements.

The visualization toolbox consists of 17 video clips, illustrating various design issues summarized in the literature. Some of the issues highlighted in the toolbox include broken back horizontal curves, diving, jumping, fluttering, coordination of vertical and horizontal alignment as well as consistency in alignment.

Currently the full visualization toolbox is only available on a CD ROM disc, however, a portion of the toolbox can be accessed through the following website: www.engr.uconn.edu/~garrick/VisToolBox/VidClipDescr.

17. Key Words	18. Distribution Statement
geometric design, highway design, alignment design, horizontal alignment, vertical alignment, continuous alignment, esthetics, visualization, computer graphics, animation	

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	**Unclassified**		

Form DOT F 1700.7 Reproduction of form and completed page is authorized

DISCLAIMER

Table of Contents

A Visualization Method for Teaching the Geometric Design of Highways.

INTRODUCTION

We are witnessing an evolution in an approach to the planning of transportation facilities: there is a renewed effort towards ensuring that the design of a project enhances the cultural, social, historical and, of course, the natural environment. This trend demands that engineers be trained to balance factors such as environmental fit and esthetics with the more traditional design objectives of efficiency, safety and cost. Changes are needed on many levels in the way we teach design to novice engineers. The issue of esthetics – which is fundamental for ensuring a good fit between the design and the existing manmade and natural environment – has traditionally been assigned a relatively low priority in the highway design process. We already have a broad general awareness of the design factors that affect the esthetics of transportation facilities. The challenge facing us is how to integrate these factors into the curriculum and how best to develop esthetic awareness in our students.

Given the nature and scale of highways, we need 3-D visualization techniques if we are to effectively study the visual implications of various design choices. From a practical viewpoint, design must be conducted in two separate stages: horizontal and vertical alignment. However, many of the worst esthetic problems result from poor coordination between these horizontal and vertical elements. Tools for visualizing the resulting design in three–dimensions would be valuable in training engineering students to think in 3-D and to better understand the visual implications of combining specific plan and profile elements. In this project we employed state-of-the-art technology for developing visualization tools for teaching highway design. Specifically, we used the photolog images as the basis for developing dynamic 3-D models of selected geometric elements. It is feasible to develop similar models using computer graphics; however, we believe our approach will prove superior in producing much more realistic models.

REVIEW OF HIGHWAY DESIGN GUIDELINES WITH RESPECT TO ESTHETICS AND CONTINUITY

Man Made America (6) defines an esthetically pleasing alignment as one in which the commencements and terminations of the individual curves and tangents cannot be noticed by the eye. An ideal alignment in the landscape would logically be a continuous curve, with constant and smooth changes of direction. In practice a highway is designed in three parts: horizontal (plan), vertical (profile) and cross section. To ensure continuity and esthetics of the driving space, the horizontal and vertical alignments must be carefully coordinated and planned. A number of guidelines and design policies have been developed to achieve a continuous, safe and esthetic alignment. Those guidelines are taken from: *Man Made America: Chaos or Control* (6), *A Policy on Geometric Design of Highways and Streets* 1990 (1), and an article by Bob Smith and Ruediger Lamm in TRR 1445, Coordination of Horizontal and Vertical Alignment with Regard to Highway Esthetics, (2). The following section is an outline of the design guidelines relating to form, scale and sequence of elements in both horizontal and vertical alignment, as well as the proper coordination of horizontal and vertical alignment.

Horizontal Alignment

The Horizontal Form

There are three elements that are commonly used for the horizontal alignment: tangent, circular curve and spiral curve. The detailed explanation of these elements can be found in Man Made America (6). A tangent section, or a straight line, is the most common form in the horizontal alignment. A tangent is easy to lay out and it provides the shortest path between two points. From a visual standpoint, a long tangent section is monotonous, esthetically uninteresting and can encourage excessive speeds. Circular arc is the second most commonly used element in the design of horizontal curves. It is also easy to lay out and provides clear and logical way of changing direction. From an operational standpoint, the circular arc is more desirable than the tangent, since it provides better optical guidance. The circular arc brings more roadside into view and encourages attention with a steady hold on the steering wheel.

The use of a tangent or the circular arc by themselves does not cause continuity problems. The problem appears when a tangent section is joined with a sharp circular curve. Such an alignment combination creates a visual break, which can be spotted some distance ahead. A spiral curve, a third element of the horizontal alignment, can be used to ease the transition between the tangent and a sharp circular arc. The radius of a spiral curve changes from infinity (tangent end), to the radius of a circular arc (circular curve end). The spiral is functionally used to achieve a gradual development of radial acceleration, and at the same time it softens the visual transition from a tangent to a circular arc.

The Horizontal Scale

The proper scale of elements in horizontal alignment is important in creating a continuous and safe road. The AASHTO Policy on Geometric Design of Highways and Streets (1) and Man Made America (6), outline the following important design guidelines relating to the horizontal scale:

- The use of maximum curvature at a given design speed should be avoided. The designer should use generally flat curves, saving the maximum curvature for the most critical conditions. The central angle of each curve should be as small as the physical conditions permit, to keep the highway as directional as possible. (1), (6)
- Curves should be sufficiently long to avoid the appearance of a kink. Curves should be at least 152.40 m long for a central angle of 5°, and the minimum length should be increased 30.48 m for each 1° decrease in the central angle. (1)
- The use of compound curves should be avoided especially when the curves are sharp. Compound curves with large differences in curvature introduce the same problems that arise at a tangent approach to a circular curve. (1)
- A design where majority of the alignment is composed of circular and spiral horizontal curves with limited use of straight tangent sections is desirable for continuity. (6)

Sequence of Design Elements

The proper sequence of design elements in horizontal alignment is another important factor in good design. The AASHTO Policy on Geometric Design of

Highways and Streets (1) discusses the importance of consistent alignment. Abrupt changes from areas of flat curvatures to areas of sharp curvatures should be avoided. Also the use of a "broken back" curve (which is an arrangement of a short tangent between two curves in the same direction) should be avoided due to its appearance and because it is a violation of driver expectancy. The issue of broken back horizontal curve has also been identified as problematic design in "Coordination of Horizontal and Vertical Alignment with Regard to Highway Esthetics", TRR 1445, (2).

Vertical Alignment

The Vertical Form

The Man Made America (6) describes the elements of vertical alignment as being made up of two major components: the grade and the vertical curve. The grade or a rate of incline is measured in percent. The downgrades are pleasing esthetically, with their high horizon lines permitting wide views of the roadside environment. The upgrades have a restricted field of vision and the roadbed dominates the view.

The changes in grade in the vertical alignment are accomplished through the use of parabolic vertical curves. The two distinct types of vertical curves are the crest (hill) and the sag (valley). The factors controlling for the minimum length of vertical curves are the stopping sight distance for crest, and the headlight sight distance for sag vertical curves.

The shape of vertical curves in road design is based on the parabola and is much flatter than the circular curve of horizontal alignment. Therefore, the parabola does not requires transition curves for continuity. As described in Man Made America (6), "Such a flat curvature poses neither functional nor visual problems of continuity at the point of change from tangent to a curve, and hence we do not have to worry about transitional spirals in the vertical plane".

The Vertical Scale

Similarly to the horizontal alignment, the implementation of short vertical curves, even though operationally safe will result in a design with numerous visual breaks. The AASHTO Policy on Geometric Design of Highways and Streets (1) suggests the use of a smooth gradeline with gradual changes as opposed to a line with numerous breaks and short lengths of grades. The Man Made America (6) suggests the selection of curve lengths two to three times greater than the minimum standards for safe operation, to assure continuity in profile.

Sequence of Design Elements

The issues to be avoided in the design of sequence of elements for the vertical alignment include diving, fluttering, and broken back vertical curves. The issues of diving and fluttering are explained in detail in Coordination of Horizontal and Vertical Alignment with Regard to Highway Esthetics (2). The diving is a of design where the roadway disappears from the driver's view, due to a crest vertical curve, with reappearance of the roadway section in a distance. Fluttering, or the "roller-coaster" type of profile is due to a multiple diving, and is a series of short sag and crest vertical curves that can be seen from by the drivers in a distance. The "roller-coaster" effect occurs on a relatively straight horizontal alignment where the roadway profile closely follows a rolling natural profile. The diving and fluttering should be avoided because it leads to discontinuities in the alignment and could pose safety problems. The Policy on

Geometric Design of Highways and Streets Green Book (1) further explains that this type of profile leads to passing maneuver problems, and is disconcerting because the driver can not be sure whether or not there is an oncoming vehicle hidden beyond the rise. A "broken back" gradeline is a design composed of two sag vertical curves connected by a short section of a tangent grade. This type of design should be avoided because it is not pleasing visually and discontinuous in appearance (1). Also a sag-sag broken back vertical curve permits ponding of water during inclement weather and should be avoided for safety reasons.

Coordination of Horizontal and Vertical Alignments

An important aspect of road design is ensuring a proper coordination between horizontal and vertical alignment. Specific coordination guidelines contained in the AASHTO Policy on Geometric Design of Highways and Streets (1) and the Man Made America: Chaos or Control (6) are summarized below:

- The scale of vertical and horizontal alignment should be similar. The lengths of vertical curves are naturally much shorter than horizontal curves (the minimum lengths required for continuity in plan and profile), but coordination of disproportional sizes of vertical and horizontal elements would result in a disassociated and discontinuous design (1), (6).
- Horizontal and vertical curves should not commence and terminate simultaneously. The horizontal curve should ideally lead the vertical curve and remain slightly longer. This type of coordination provides smooth and gradual changes between the individual elements in the alignment (1), (6).

- Elements of the horizontal alignment should coincide with the elements of the vertical alignment in terms of location. That is the vertex of the vertical curve should coincide with the vertex of the horizontal curve. The reason for this coordination guideline is to provide a continuous transition between the plan and profile curves. A shift by no more than a quarter of a phase will still result in a continuous alignment (1), (6).
- Sharp horizontal curvature should not be introduced at or near the top of pronounced crest vertical curve. This condition is undesirable because the driver cannot perceive the horizontal change in alignment past the vertical peak (1).
- A sharp horizontal curve should not commence near the low point of a pronounced sag vertical curve because of a distorted appearance of the roadway and potential operational problems for heavy vehicles (1).
- The alignment should be enhanced by attractive scenic views of the natural and man-made environment. The highway should head into rather than away from the outstanding landmarks (1).

VISUALIZATION TECHNIQUES

Various visualization techniques have been developed and used over the years to help in teaching and understanding the design issues important for continuous and safe roadway alignment. The first and simplest is the use of a graphical presentation in two dimensions of the plan and the profile of a road. An example of such presentation is taken from the AASHTO Policy on Geometric Design of Highways and Streets (1, pg.

301) and is shown in Figure 1. This figure illustrates the issue of diving in vertical alignment. According to "Coordination of Horizontal and Vertical Alignment with

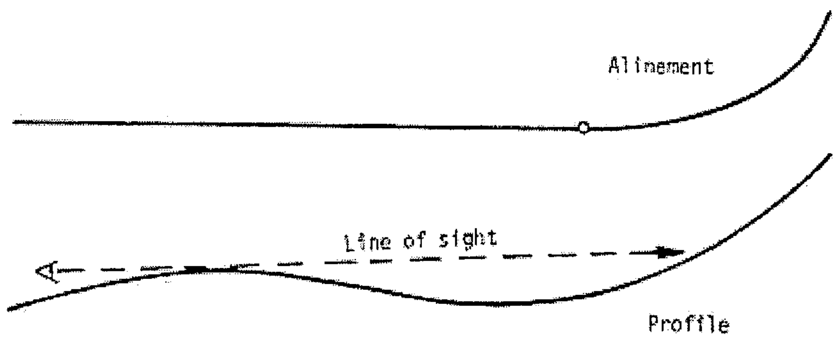


FIGURE 1 A 2-D graphical presentation of diving, with plan and profile (1).

Regard to Highway Esthetics" (2), diving occurs when the driver loses sight of part of the roadway and the remaining piece reappears in the distance. The disappearance is caused by a steep crest vertical curve, which limits the driver's sight distance, followed by a sag vertical curve and an upgrade section, which brings part of the roadway back into the driver's view. The use of plan and profile as a visualization tool helps in conveying the meaning of diving, but requires the observer to imagine the actual view of the road and how the alignment would change while traversing the driving space.

A second visualization technique used in publications is the perspective view of the road section, in conjunction with the plan and profile graphs. The use of a perspective view of a roadway as part of the visualization tool complements the message that the plan and profile graphs convey. The perspective view provides a better idea of what the road looks like, but this visualization tool cannot recreate the changing perspective as one drives along the alignment. Figure 2, from "Coordination of Horizontal and Vertical Alignment with Regard to Highway Esthetics" (2) shows an

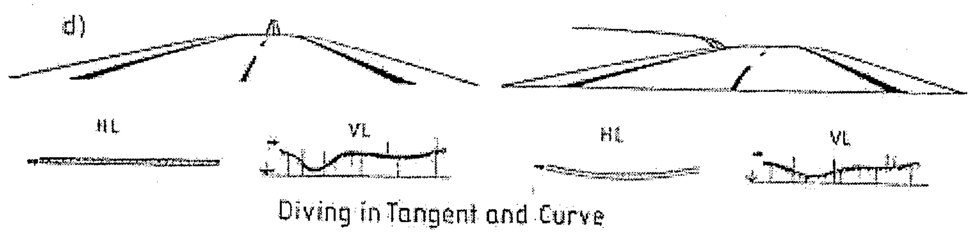


FIGURE 2 A 2-D display of diving with the plan, profile and graphical image (2).

example of plan, profile and a perspective view as a form of visualization, and illustrates the issue of diving in road design.

Recent advancements in personal computing have led to the creation of a new form of visualization to help in design and teaching, computer animation in 3-D. Computer animation, as described in "Applications of 3-D and 4-D Visualization Technology in Transportation" (3), consists of a series of images, which can create the illusion of motion when viewed at rates of 15 to 30 frames per second. The images are created from a computer model, which defines all displayed points in 3-D space. Animation gives the viewer a simulated experience of movement through roadways not yet built.

A possible difficulty with animation as a visualization tool is the realism of the visual message presented. The digitally created environment may not effectively display the real details of roadways, landscaping, roadside development, and the feel of driving. However, animation is indispensable for visualization of roadway segments not yet built. One existing software package with animation capabilities is the Computer Aided Drafting Design (CADD).

The visualization method proposed in this paper uses the video data of existing highway sections along with a simultaneous display of the horizontal and vertical alignment. We believe that use of video data will make this visualization method more realistic than the existing visualization methods and the inclusion of plan and profile graphs will further enhance the usefulness. This visualization tool can be used for teaching highway design and demonstrating highway design issues. We used the latest capabilities of the Connecticut Department of Transportation (ConnDOT) photolog system to develop this new 3-D presentation method. The next section describes in more detail the photolog system and the 3-D visualization method which we developed.

PHOTOLOG BASED 3-D VISUALIZATION METHODOLOGY

The following sections describe the development of the visualization method that is based on data from photologging. The capabilities of the photolog system are briefly introduced in the first section. Then a brief introduction of our 3-D visualization toolbox is given. The final section describes in more detail the development of visualization toolbox with the use of photolog.

Photolog

Photologing is a relatively mature technology being used by transportation departments nationwide to provide a visual inventory of various features of the highways. ConnDOT, for example, has had a photologing program since 1972. Recent enhancements in the technology have significantly increased the range of possible applications of the system. Currently the photolog system can be used to measure road slope, roughness and pavement characteristics, while simultaneously capturing video data of the roadway. The photolog can also be used to capture highway geometric information such as horizontal curvature, grade, and cross-slope. The following sections of this paper are based on a ConnDOT and University of Connecticut Report (4), as well as the photolog "Data Acquisition User's Guide" (5), and describe basic technical information on the video, and geometric data gathering subsystems for the 1997 photolog system.

Video Data

The video subsystem of the photolog is used to gather windshield images of the highway in real time (30 frames/second). Images of a given roadway are formatted in 10 meter increments and displayed by the photolog station. When these images are played in consecutive order, they convey the impression of a continuous video of the highway from the windscreen. The 1999 release of the photolog will be further improved to provide a continuous video of the roadway.

The Vertical and Horizontal Orientation

Station	Heading	Grade
71.62	20.2	-0.8
71.63	19	-0.8
71.64	17.7	-0.6
71.65	16	-0.9
71.66	15	-1.3
71.67	13.7	-1.5
71.68	12.4	-1.3
71.69	10.9	-1.4
71.7	10	-1.6
71.71	9	-1.4
71.72	8.5	-1.3
71.73	7.7	-1.7
71.74	7.5	-1.8
71.75	7.2	-1.6
71.76	7.1	-1.6
71.77	6.8	-1.7
71.78	6.7	-1.7
71.79	6.4	-1.6

TABLE 1 A sample Geometric Data output from Photolog

The grade of the roadway is obtained through the grade subsystem on the automated road analyzer (ARAN). The subsystem consists of a military-grade gyroscope and four ultrasonic sensors. The grade readings are in percent and the accuracy of the data is ± 0.05 %.

The horizontal orientation of the ARAN is measured with the use of a gyroscope. The gyroscope provides the vehicles headings in degrees measured clockwise from true north. The headings give an estimate of the roadway bearing and when analyzed in sequence, can be used to determine the horizontal alignment of the road. Table 1 is an example of a sample geometric output for a section of road. In this table, station indicates the relative distance in kilometers from the starting point of the road. The highway geometric data, such as heading or grade, is gathered by the photolog van in 10 meter increments. The method used to determine the horizontal and vertical alignment from this data is discussed later in this paper.

Description of the 3-D Visualization Toolbox

In this project we utilized the video and geometric data from photologing to develop the interactive visualization toolbox. The visualization toolbox displays an animated video image of a roadway, which is coordinated with the animated horizontal and vertical alignment graphs. The user of this toolbox is able to select previously identified highway section that is characterized by specific geometric design features and then simulate a drive over the selected section. Geometric features such as broken-back curves, diving and others, have been located with the use of photolog, and displayed in the toolbox. This form of visualization allows the user to study the various combinations of horizontal and vertical alignment and visually inspect the esthetics and continuity of each segment.

To enhance the viewing experience of the visualization toolbox we developed a separate set of video clips displaying only the road section, without including the road alignment graphs. The point of having separate video clips of the road sections was to improve the quality of the playback as well as alleviate any distraction caused by the presence of an animated alignment plots. The video clip of a road section may be displayed on the whole screen thus enhancing the viewing experience. Also, the playback speed is set to approximate the actual driving speed on a given roadway. Having the video clip separate from the animated graphs, allows the user to study the selected road at a real time speed and without distractions. The clip containing the video of the road, along with the animated alignment plot can be studied separately to evaluate the scale, sequence or coordination of the plan and profile elements.

An example of the toolbox display is shown in Figure 3. The selected section in

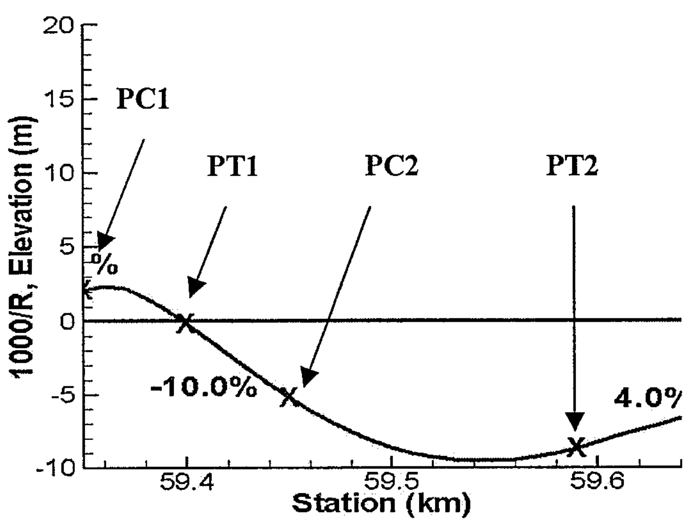


FIGURE 3 An Example of Visualization Toolbox Display

the example illustrates the issue of diving. The image from the video clip displays a section of roadway with the partial disappearance of the road from the driver's view. The disappearance is caused by a sharp, short vertical curve (PC1 to PT1), which is followed by a long sag curve (PC2 to PT2) and an upgrade section. The length and degree of curvature in the vertical alignment can be read from the profile graph. Also the characteristics of the horizontal alignment of this roadway section can be observed on the inverse of radius plot, 1/R (in this case the 1/R = 0 therefore, the road section is on a tangent). The current location of the vehicle on the plan and profile graphs is at the origin of the plot.

3-D Visualization Toolbox Development

The major aspects of the 3-D visualization toolbox development included i) identification of road sections of interest, ii) development of the presentation techniques, iii) development of plot animation and the coordination of those plots with the video data.

Locations of Interest

The literature review that we performed provided extensive background information on specific concepts influencing highway esthetics. The major literature sources that we used included: Man Made America: Chaos or Control (6), A Policy on Geometric Design of Highways and Streets 1990 (1), and "Coordination of Horizontal and Vertical Alignment with Regard to Highway Esthetics" (2). Some examples of highway design issues that we have identified include diving in vertical alignment, broken-back horizontal and vertical curves, issues of the scale of the design elements, and coordination of horizontal and vertical elements. The reference sources provide detailed descriptions of desirable and problematic highway design, caused by issues of coordination, scale or sequence of plan or profile elements. Based on this information, we did a visual search of Connecticut's state roads with the use of a photolog station, and identified road locations that illustrated specific highway design issues. A summary of the road sections that were selected is provided later in this paper.

Display of Horizontal and Vertical Alignments

Geometric data, as shown earlier in Table 1, was obtained for each of the selected road segments. The geometric data was in the form of heading (H) and grade (G) readings for every 10 meters of traveled distance. Each data point corresponds to a video image recorded by the photolog van.

Formula (1) below was used to develop the vertical alignment from the grade readings. The formula is used to calculate the roadway elevation (at 10 meter intervals) relative to the start point of the video clip. In the formula, the average change in

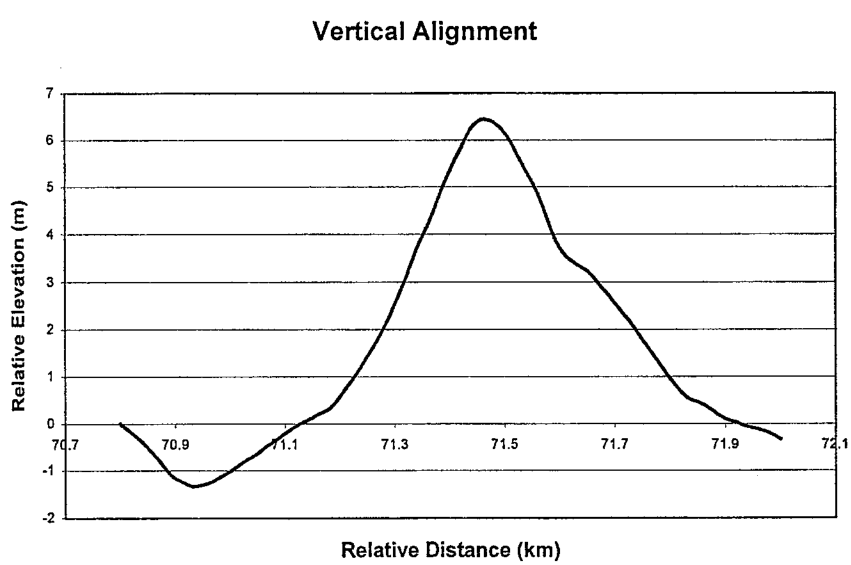


FIGURE 4 A sample plot of Vertical Alignment

elevation is determined by multiplying average grade by the horizontal distance (D = 10 m).

$$\text{Elevation}_K = \text{Elevation}_{K-1} + [D(G_K + G_{K-1})/2] \quad (1)$$

The relative elevations calculated with the use of Formula (1) were plotted against the relative horizontal distance to create plots of the road profile (see Figure 4).

The sequential grade readings were analyzed to identify the locations of vertical curves and tangents. The locations of points of curve (PC) and points of tangent (PT) were identified based on studying the pattern of the grade (G) data points. Constant grade indicated a tangent section, whereas the change in grade indicated the presence of a curve. For example, the sequential grade readings in Table 2 indicate a presence of a vertical curve. The average grade of - 1.7 % starts changing around the 56.16 km station. This indicates that a point of curve is located at that station.

Station	Grade
56.3	-1.6
56.29	-1.6
56.28	-1.7
56.27	-1.7
56.26	-1.6
56.25	-1.8
56.24	-1.7
56.23	-1.7
56.22	-1.8
56.21	-1.7
56.2	-1.5
56.19	-1.5
56.18	-1.5
56.17	-1.7
56.16	-1.3
56.15	-1.1
56.14	-0.9
56.13	-0.6
56.12	-0.5
56.11	-0.5
56.1	-0.3
56.09	-0.1
56.08	0.1
56.07	0.2
56.06	0.3

TABLE 2 Station and Grade Data

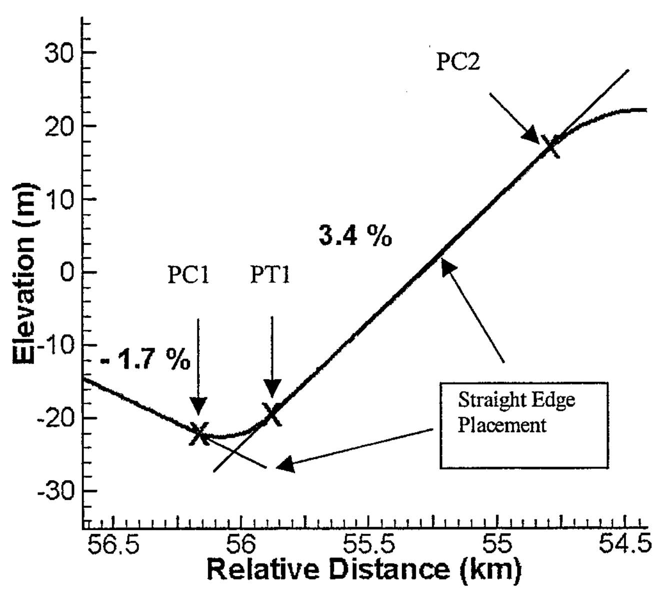


FIGURE 5 Identification of PT and PC locations with a Straight Edge

The profile plots can be used to double check the PC's and PT's identified by looking at the sequential grade readings. Using a straight edge we can estimate the PC and PT locations on the profile graphs. Figure 5 shows how a straight edge was applied to locate points of tangent and points of curves on a profile graph. The PC1 located with the use of a straight edge coincides with the PC identified in Table 2.

Heading versus horizontal distance graphs, such as in Figure 6, were used in determining the horizontal alignment. Locations where the heading was constant were identified as tangents. Those sections are identified on the heading versus distance graphs by a line with zero slopes. A consistent change in the value of consecutive heading points indicates the presence of a circular horizontal curve. The locations of horizontal curves can be identified on heading versus distance graphs by a sloped line (see Figure 6).

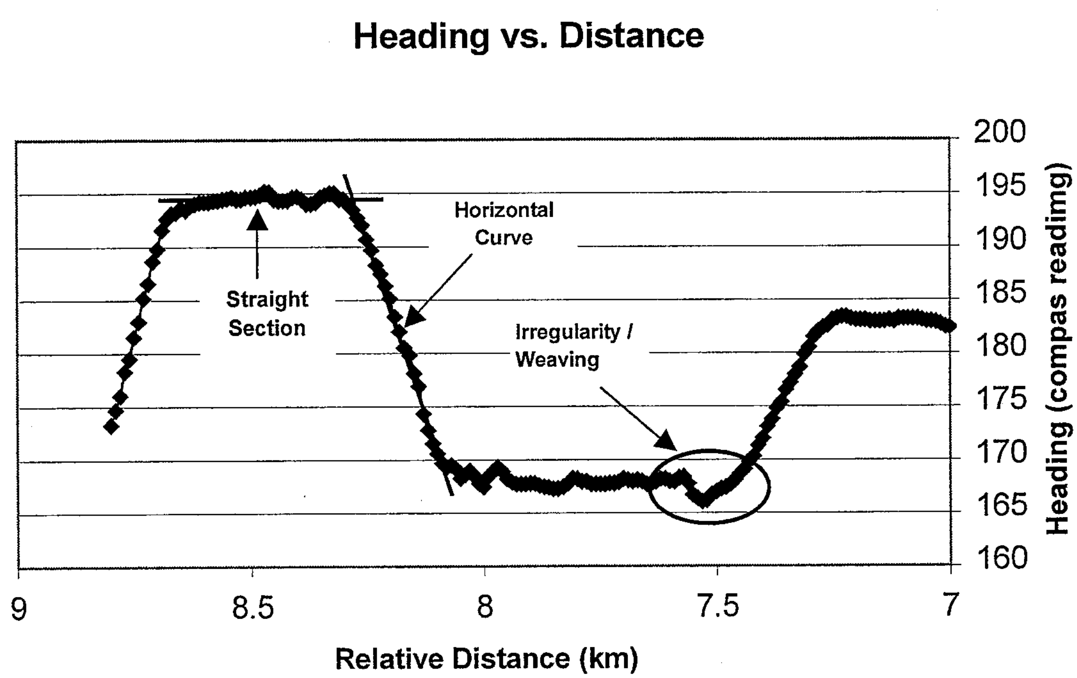


FIGURE 6 A sample Heading versus Distance Graph

One of the factors that affected the heading data was the driver's operation of the van, and in particular any weaving maneuvers. The weaving shows up as irregularity on the heading versus distance graph, such as between 7.4 km and 7.6 km station, in Figure 6. Analysis of the plan and profile graphs suggested the need for data smoothening. Examples of driver behavior influencing our data were situations in which the driver weaves due to roadside obstructions. This weaving would appear as a hump on the heading vs. distance graph, which is inconsistent with the actual road alignment at that spot.

The driver behavior while entering and exiting a circular curve also created a distortion in the heading vs. distance graph. In reality, the driver does not suddenly turn the steering wheel at the point of curvature on the road. Rather, the driver turns the steering wheel gradually and thus gradually changes the vehicular travel path from a straight line to the circular path of a horizontal curve. The driver in essence softens the transition from tangent to the circular arc and in fact the vehicular path approximates the characteristics of a spiral curve.

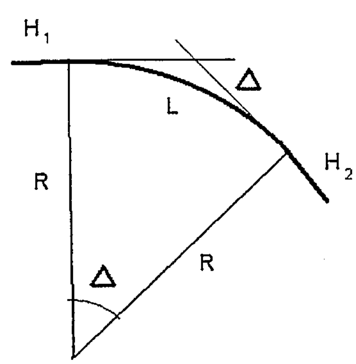


FIGURE 7 Layout of a Simple Circular Curve

To solve the problem of weaving caused by roadside obstructions, the video segments were visually inspected and the affected data points adjusted. To alleviate the problem brought on by the transition paths on entering or leaving horizontal curves, the video data was inspected to pinpoint the location of the points of tangent (PT) and points of curve (PC). The initial heading data at the entrance and exit of each curve were ignored in calculation of the radius of curvature.

Formula 2, which is based on the properties of a circular curve shown in Figure 7, was used to calculate the radii of the horizontal curves identified on the Heading versus Distance graphs. The difference in heading (the azimuth), H_1-H_2, was taken as an approximation of the central angle (Δ) of a horizontal curve with an arc length of L (m) (see Figure 7 and Figure 8).

$$R = 180L / \pi(H_1-H_2) \qquad (2)$$

The azimuth readings, H_1 and H_2, were obtained from the heading versus distance graphs, for the straight horizontal sections preceding and following each curve. The lengths of

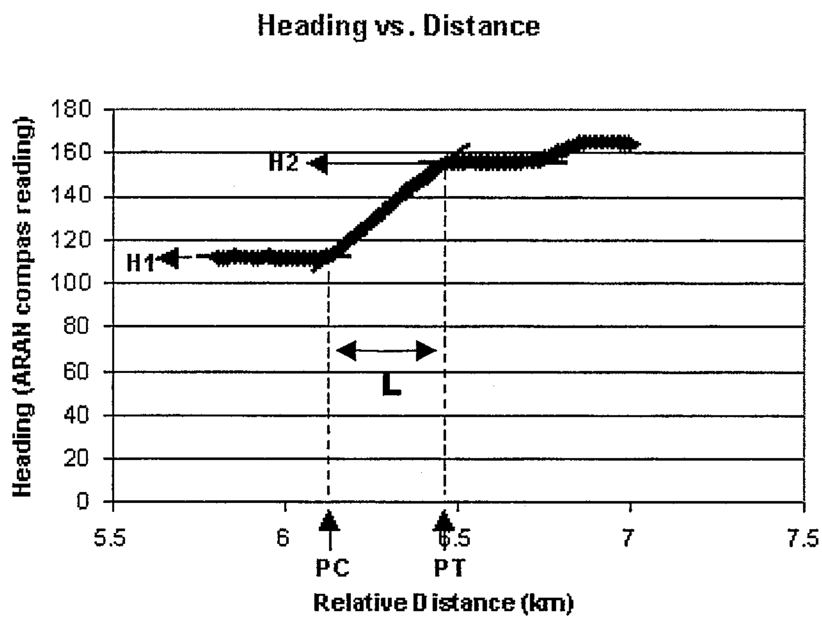


FIGURE 8 Horizontal Curve Calculations

the curves were also calculated from the heading versus distance graphs, by locating the PC and PT on the graph and subtracting their relative distance readings. Using Equation (2) we can estimate the radius of the circular curve for the alignment in Figure 8. The H_1

equals 111.5 degrees and the H_2 equals 156 degrees, which gives us the central angle of about 44.5 degrees. The length of curve can be read off Figure 8, and is about 340 meters (PT at 6.47km - PC at 6.13km). By inserting the above numbers into Equation (2) we can calculate the radius of the curve as 438 meters.

Selection of A Plotting Format

The selection of a proper plotting format is important for interpreting the features of the horizontal and vertical alignment. The plotting format representing the horizontal and vertical alignments must show the locations of PC and PT, and must also be suitable for evaluating the coordination between the vertical and horizontal elements. In development of the toolbox, we evaluated two plot types for horizontal, and two for the vertical alignment.

We considered the plan and the 1/R curvature diagram as candidates for representing the horizontal alignment. The plan of a road, as shown in Figure 9A, consists of circular arcs and tangents. The plan can be annotated to indicate the lengths of level sections and

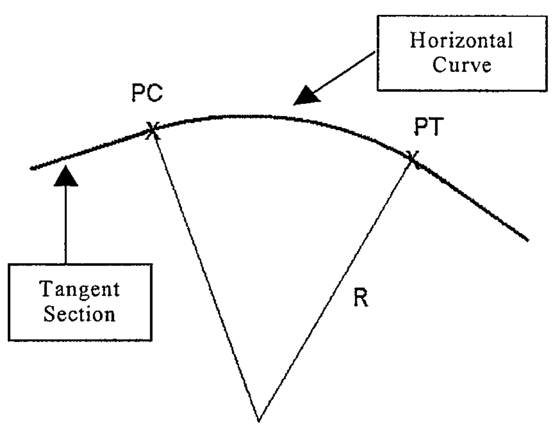


FIGURE 9A Plan – An Example of Horizontal Alignment Plot

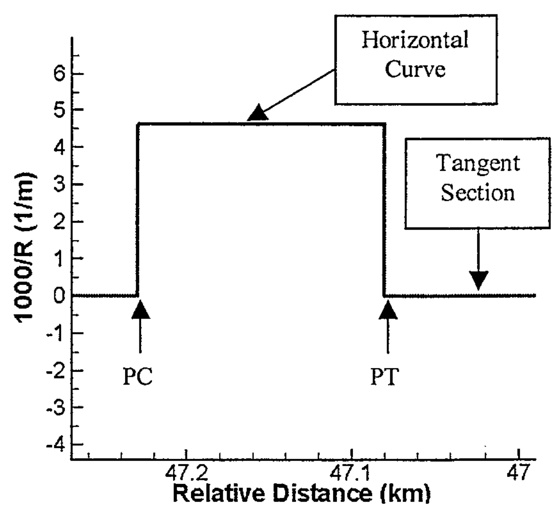


FIGURE 9B 1/R Curvature Diagram

horizontal curves. It also can be used to display the radii, the PC and the PT for the horizontal curves.

The 1/R curvature diagram, as shown in Figure 9B, is another display method of the horizontal alignment. The X-axis of the diagram represents the station (distance) along the road, and the Y-axis displays the inverse of radius. When the horizontal alignment is a straight line, the value for 1/R is zero. The presence of a horizontal curve is indicated by a non-zero value for 1/R. The radii of any of the horizontal curves can be calculated by taking the inverse of 1/R.

In selecting a plotting method for the vertical alignment we considered two methods: the profile and the 1/K diagram. The profile, as shown in Figure 10A, is a plot of the road elevation with respect to horizontal distance. We annotated the profile to indicate PC and PT as well as the grades of vertical tangents. The sharpness of vertical curves (K) can be calculated by dividing the average change in grade by the length of the

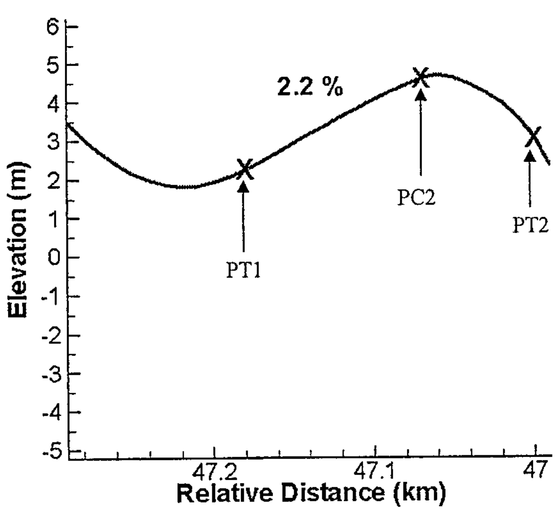


FIGURE 10A Profile – Representation of Vertical Alignment

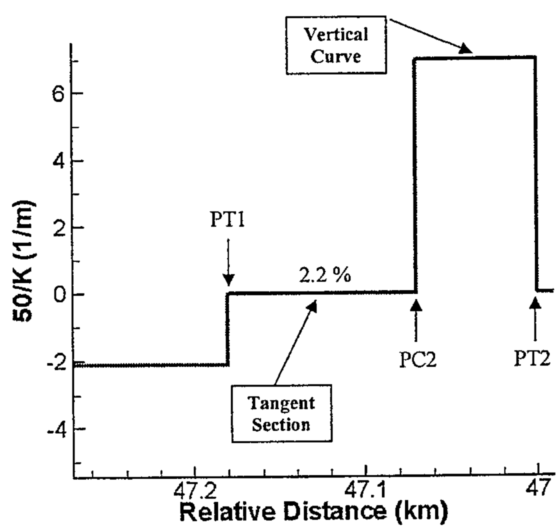


FIGURE 10B 1/K Vertical Curvature Plot

vertical curve. The 1/K vertical curvature plot, shown in Figure 10B, is another way of representing the vertical alignment. The X-axis indicates the horizontal distance, and the Y-axis gives the value for the inverse of the rate of vertical curvature (1/K). When the vertical alignment is a constant grade, the value for 1/K is zero. The presence of a vertical curve is indicated with a non-zero value for 1/K. This plot is annotated to indicate the grade of tangents.

As shown in Figure 11A, the plan is in a different dimension space (X-Y) than the profile or the 1/K diagram (X-Z), and it does not lend itself to be easily displayed in coordination with either the profile or 1/K diagram. Therefore, the plan was rejected as a viable method for representing the horizontal alignment for the purposes of this visualization tool. The profile graph was selected to represent the vertical alignment since it provides a much more complete representation of the features of the vertical alignment. The profile shows the incline and decline straight vertical sections, and displays the crest and sag vertical curves as they appear on the road. The 1/K curvature diagram displays the start and end points of vertical curves, as well as the degree of

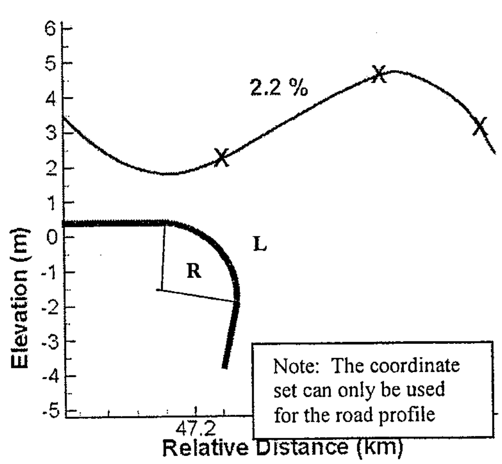


FIGURE 11A Plot of plan and Profile

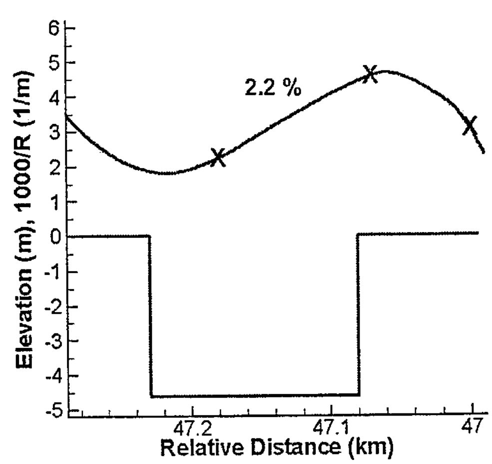


FIGURE 11B Plot of 1/R and Profile

vertical curvature, but it does not represent how the alignment looks.

The plotting method that we selected is illustrated in Figure 11B. The profile is annotated with grade readings to identify the level sections, and with X symbols to identify the vertical curves (the PC is identified with a blue X and the PT is identified by a black X). On the 1/R diagram the tangents are displayed with the value of zero. The presence of a horizontal curve is indicated by a non-zero value of 1/R. The coordination of the horizontal and vertical alignments can be easily evaluated, since the X-axis on both plots corresponds to the distance along the road.

Sight Distance Issue

The video from photologging does not represent the vantage point of a driver in a passenger vehicle. The camera height in a photolog van is at 1.78 meters. This is 0.71 meters higher than the height used for the driver's eyes in a passenger vehicle (in the AASHTO Guide). Since the camera is placed higher than the average location of driver's eyes, the perceived sight distance on the video images is longer than it would be in reality (from the point of view of a passenger car operator). Thus, the overestimated sight distance in the video data must be kept in mind when the visualization toolbox display is viewed.

Toolbox Animation and Display

The next step in the visualization toolbox development was the animation of the vertical and horizontal alignment graphs. The graphs were animated along the X-axis, in 10-meter increments, since the video images were recorded at that rate. Also the range of the horizontal axis, or the horizontal distance, was set to approximately represent available sight distance. The plot range (and hence sight distance) was set on the basis of road classification. It was decided to set the range of sight distance on an arterial state road at 300m and at 600m on a freeway section.

The creation of plot images was accomplished with the graphical software, Tecplot 7.5. Using this software we were able to export a series of images of the profile and 1/R graphs at 10-meter intervals. Each of the plot images corresponded to a photolog image of the road. Figure 12 gives an example of two plot images exported with Tecplot. The movement of the vehicle, and the changing position on the road alignment corresponds to that of the profile and 1/R plots.

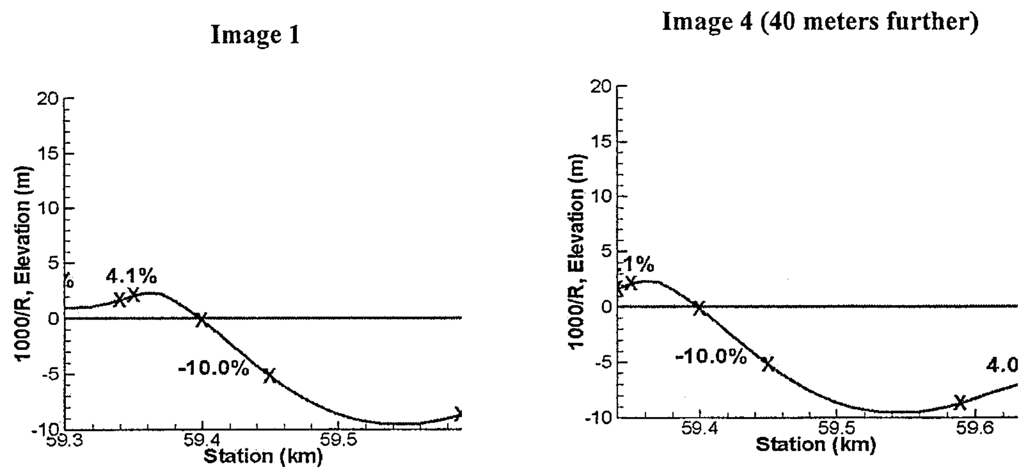


FIGURE 12 Exporting Alignment Plots

The next stage in the toolbox development was to create video clips from the separate sets of images, and link the road video clips with the animated plots. The sequential photos of the roadways and plot images were joined into separate video clips with the use of Media 100, a media editing software for the Macintosh. The Media 100 was also used to display and coordinate the plot and roadway video clips simultaneously on one screen. The Boris FX, a video transition tool within Media 100, was utilized to format the size, placement and background of the video clips. Once a desirable display format was established, the video clips of road segments coordinated with the plot of alignments were exported as a single video file.

The toolbox video clips developed in Media 100 are in Quicktime format, and can be displayed using the Quicktime Player. The advantages of using the Quicktime Player are that it provides the ability to run the program on both Macintosh and PC. Furthermore, the Quicktime Player can be downloaded as a free shareware from the internet.

SUMMARY OF TOOLBOX VIDEO CLIPS

The procedures described in the previous chapters were used to develop a number of toolbox video clips. The search of Connecticut roads, using the photolog system, resulted in the identification of 17 video clips illustrating many of the highway design issues summarized in the literature. The video clips selected have been grouped into three major categories: i) sequence and scale of plan and profile elements, ii) coordination of plan and profile alignments and iii) consistency issues. The section on sequence and scale of plan and profile elements, contains video clips displaying undesirable design such as broken back curves, diving, jumping and fluttering. The category on coordination and scale of horizontal and vertical alignment contains video clips visualizing examples of both problematic and desirable highway design relating to the coordination between vertical and horizontal alignments, and their effect on continuity and sight distance. The last section, consistency in alignment, contains a video clip illustrating the effect of a sudden change in sharpness of the horizontal curvature, and the safety problems that could result. The following subsections briefly introduce the developed toolbox video clips. The detailed descriptions of the video clips can be found in Appendix 1.

Scale and Sequence of Plan and Profile Elements

Several video clips have been identified and used to help visualize the issues of diving, jumping and fluttering in highway design. All of those are characterized by partial disappearance of the road from the driver's perspective due to steep crest vertical curves blocking part of the view. We identified and developed one example visualizing diving, one with fluttering and two with jumping. A solution to the issues of diving or fluttering could be a gentle continuous alignment with a long crest vertical curve, followed by sag vertical curve. A single video clip of such an alignment is presented to illustrate this point.

Broken back horizontal curve (BBHC) is caused by undesirable sequencing of the horizontal alignment elements. A BBHC consists of two horizontal curves bearing in the same direction, and joined by a short horizontal tangent section. This design is undesirable due to the discontinuity it presents from the driver's perspective, and the violation of drivers expectancy. Two road sections have been identified and developed into toolbox video clips to help illustrate the issue of BBHC.

The scale of the horizontal and vertical curves also has an effect on continuity of the alignment. The use of short horizontal or vertical curves in the design of highways can result in disjointed and discontinuous alignments. A video clip of a highway section, containing short horizontal and vertical curves, was developed to help in visualizing the effects of scale on alignment continuity.

Coordination of Vertical and Horizontal Alignments

The coordination and the relative scale of the elements in the horizontal and vertical alignments have a significant effect on the continuity of a road. Ideally we would like an alignment with horizontal and vertical curves of similar scale, and where the horizontal curves lead and remain slightly longer than the vertical curves. Four road sections have been identified, and video clips developed, to display the effect of problematic coordination and scale on continuity and sight distance of the alignment. Also, four video clips were developed to exemplify desirable coordination and scale of plan and profile elements.

Consistency in Alignment

An important factor in road design that affects driver safety is consistency of the alignment. A consistent alignment comprises of design elements with similar characteristics, for example an alignment with a series of horizontal curves with similar radii. An example of inconsistent alignment would be series of gentle horizontal curves linked with tangent sections, followed by a sharp horizontal curve. Such an alignment would violate the driver's expectancy and could lead to safety problems in vehicle operation. One road section has been identified and used in the toolbox to illustrate the issue of consistency in highway design.

Format of the Visualization Toolbox

The visualization toolbox, developed at the University of Connecticut, consists of video clips of road sections representing examples of important issues in highway design. Each of the toolbox examples consists of a quicktime video clip of the roadway, a quicktime video clip with an animated plan and profile graph and a description of the issues that the particular example is designed to illustrate. The visualization toolbox video clips are placed on a Recordable CD, which can be copied for further distribution. The toolbox CD also contains a copy of this paper for reference purposes, as well as a copy of Quicktime installation software. The Visualization Toolbox can be obtained from the University of Connecticut and used as a tool in teaching highway design. Currently a portion of the toolbox can be accessed through the following website: www.engr.uconn.edu/~garrick/VisToolBox/VidClipDescr. The website contains descriptions of the toolbox video clips, and will be expanded in the future to allow for full access to the visualization toolbox.

CONCLUSION AND FUTURE RESEARCH

The 3D visualization toolbox developed at the University of Connecticut incorporated capabilities of the photolog system to help visualize the highway design guidelines with respect to continuity and esthetics. The visualization toolbox links video clips of various road sections, with animated graphs representing their horizontal and vertical alignments. By the simultaneous display of the visual features of a roadway, with the plan and profile graphs, the toolbox allows the user to study the effect of combining plan and profile elements on the continuity and esthetics in design.

The visualization toolbox consists of 17 video clips, illustrating various design issues summarized in the literature. Some of the issues highlighted in the toolbox include broken back horizontal curves, diving, jumping, fluttering, coordination of vertical and horizontal alignment as well as consistency in alignment. The visualization toolbox is currently available on a CD ROM disc. The CD ROM contains the video clips along with the descriptions of issues that they illustrate, a copy of this paper for reference purpose, and a copy of a Quicktime installer software. The Quicktime Player is used to display the toolbox video clips and can be downloaded from the internet at no cost. Currently a portion of the toolbox can be accessed through the following website: www.engr.uconn.edu/~garrick/VisToolBox/VidClipDescr. The website contains descriptions of the toolbox video clips, and will be expanded in the future to allow full access to the visualization toolbox.

Future research will concentrate on improving the accessibility of the visualization toolbox, inclusion of information on the road cross section into the toolbox as well as development of additional video clips. The internet web-site should be expanded to serve as a distribution mean for the visualization tool. Inclusion of cross section information for the selected roadways would also be a valuable in representing the highway design. The cross section would provide information on road superelevation and its rate of change for the horizontal curves. Identification and creation of more toolbox video clips illustrating additional highway design guidelines could also be the subject of future research. Inclusion of more highway video clips, possibly from states other than Connecticut, would improve and enrich the existing visualization toolbox.

LITERATURE REVIEW

Introduction

The literary sources referenced in the development of the visualization toolbox include: AASHTO Policy on Geometric Design of Highways and Streets 1990 (1), an article by Bob Smith and Ruediger Lamm in TRR 1445, *Coordination of Horizontal and Vertical Alignment with Regard to Highway Esthetics* (2), Applications of 3-D and 4-D Visualization Technology in Transportation (3), ConnDOT and University of Connecticut report (4) , the photolog Data Acquisition User's Guide (5) and Man Made America: Chaos or Control (6). The publications were used to find information on the following subjects: i) identification of highway design issues with respect to continuity and esthetics, ii) examples of visualization techniques and iii) capabilities of ConnDot photolog system. The following sections of the literature review summarize the sources and findings of the above listed subjects.

Highway Design Issues

A number of design guidelines and policies have been developed to achieve continuous, safe and esthetic highway alignments. The initial step in the toolbox development was to identify roadway sections illustrating various design issues affecting continuity and esthetics. The road sections were selected based on design guidelines from the following sources: Man Made America: Chaos or Control (6), AASHTO Policy on Geometric Design of Highways and Streets 1990 (1), and an article by Bob Smith and Ruediger Lamm in TRR 1445, *Coordination of Horizontal and Vertical Alignment with Regard to Highway Esthetics* (2). Some of the design guidelines identified in those sources described coordination of horizontal and vertical alignments, scale and sequence of horizontal and vertical elements as well as consistency in alignment. The highway design issues are discussed detail in the report.

Examples of Visualization Techniques

Number of visualization techniques has been used to help illustrate highway design issues. Some of the existing visualization techniques include the use of plan and profile graphs, perspective drawings or photos of a roadway as well as 3D computer simulations. Four major sources were used in reviewing and presenting various visualization techniques: Man Made America: Chaos or Control (6), A Policy on Geometric Design of Highways and Streets 1990 (1), an article by Bob Smith and Ruediger Lamm in TRR 1445, *Coordination of Horizontal and Vertical Alignment with Regard to Highway Esthetics*, (2) and Applications of 3-D and 4-D Visualization Technology in Transportation (3).

The first three sources provide a number of examples of plan and profile graphs as visualization tools in displaying various highway design issues. Those sources also use 3-D drawings and photos of roadways to help visualize the various issues. The description of the visualization methods found in those sources can be found in the report.

Recent advancements in personal computing has made computer animation a viable option of visualization in highway design. Applications of 3-D and 4-D Visualization Technology in Transportation (3), by the National Cooperative Highway Research Program, describes the capabilities of 3-D animation in visualization of transportation issues. It describes various computer animation techniques in three and four dimensional space, that can be used to help visualize the look of highway corridors not yet built. The characteristics of the 3D computer animation techniques are discussed in the report.

Photolog System

Transportation departments throughout the nation have used photologgin for almost 30 years to obtain an inventory of various highway design features. Currently the photolog system is capable of providing measurment of the road slope, roughness, pavement characteristics, horizontal curvature and the roadway grade, while simultaneously capturing video data of the roadway. The 1997 ConnDot Photolog System, was used in development of the visualization toolbox.

The ConnDOT and University of Connecticut report (4) as well as the photolog Data Acquisition User's Guide (5) were our sources of technical information on the video, and geometric data gathering subsystems. Those sources were utilized to identify various uses of the photolog system and learn about the operation and output of the various data gathering subsystems. The photolog system capabilities are discussed in more detail in the report.

REFERENCES

1. *A Policy on Geometric Design of Highways and Streets* (Green Book). AASHTO, Washington, D.C., 1990.
2. Smith, B. L., and R. Lamm. Coordination of Horizontal and Vertical Alinement with Regard to Highway Esthetics. In *Transportation Research Record 1445*, TRB, National Research Council, Washington, D.C., 1994, pp. 73-85.
3. Landphair, H. C., and T. R. Larsen. *NCHRP Report 229: Applications of 3-D and 4-D Visualization Technology in Transportation.* TRB, National Research Council, Washington, D.C., 1996.
4. Davis, C. F., *Enhancement of Photolog Applications and Display Environment.* Draft Report, Project No. 97-3. Connecticut Department of Transportation, January 1999.
5. *Data Acquisition User's Guide.* Roadware Corporation, Version 4.4, July, 1997
6. Tunnard, C., and B. Pushkarev. *Man Made America: Chaos or Control.* Yale University Press, New Haven, Conn., 1963.

APPENDIX 1

Summary of Toolbox Video Clips

The visualization toolbox consists of 17 roadway video clips in quicktime format. The video clips illustrate many of highway design issues summarized in the literature. The video clips are grouped into three categories: I) sequence and scale of plan or profile elements, II) coordination of plan and profile elements, and III) consistency issues. The section on sequence or scale of plan and profile elements, contains video clips displaying design issues such as broken back curves, diving, jumping and fluttering. The category on coordination and scale of horizontal and vertical alignment contains video clips visualizing examples of both problematic and desirable coordination of highway elements. The last section, the consistency in alignment, contains a video clip visualizing the effect of a sudden change in sharpness of horizontal curvature, and the safety problems that it could create.

The following pages of the appendix contain a brief outline of the toolbox video clips, description of the plotting format and detailed descriptions for each of the video clips. The design issue or issues illustrated by each of the video clips are summarized on a separate page for each clip. The description pages are meant to provide a guide and a reference to the user of the toolbox. The video clip description pages can also be found on the Visualization Toolbox CD for easy and convenient reference.

Outline of the Video Clips

I. SCALE AND SEQUENCE OF PLAN OR PROFILE ELEMENTS

Examples of Diving, Jumping and Fluttering

Problematic:	Desirable:
1) Rt4E Fluttering	5) Rt8S Gentle Transition
2) Rt32N Diving	
3) Rt31E Jumping	
4) Rt84E Jumping	

Broken Back Horizontal Curve (BBHC)

6) Rt31E BBHC
7) Rt6W BBHC

Scale of Plan and Profile Elements

8) Rt395N Scale

II. COORDINATION AND SCALE OF PLAN AND PROFILE ELEMENTS

Problematic:	Desirable:
9) Rt4W Coordination	13) Rt8S#1 Coordination
10) Rt66E Coordination	14) Rt8S#2 Coordination
11) Rt32N#1 Coordination	15) Rt7N Coordination
12) Rt32N#2 Coordination	16) Rt66W Coordination

III. CONSISTENCY IN ALIGNMENT

17) Rt6W Inconsistency

DESCRIPTION OF PLOTTING FORMAT

The horizontal and vertical alignment for each of the selected roadway video clips is displayed with the use of profile and 1/R curvature diagrams. The road profile is plotted in red and annotated to indicate the locations of curves and tangents, as well as the grade of the tangents. The start points (PC) of vertical curves are indicated with a blue X symbol and the end points of vertical curves (PT) are indicated with black X symbols (see Figure A1). The 1/R curvature graphs represent the horizontal alignment of the road sections. The 1/R curvature diagram is plotted in blue. In the diagram a tangent is indicated by a value of zero for 1/R. The presence of a horizontal curve is indicated by a non-zero value of 1/R. The profiles and 1/R curvature diagrams are displayed simultaneously so that the coordination between the horizontal and vertical alignments can be easily evaluated.

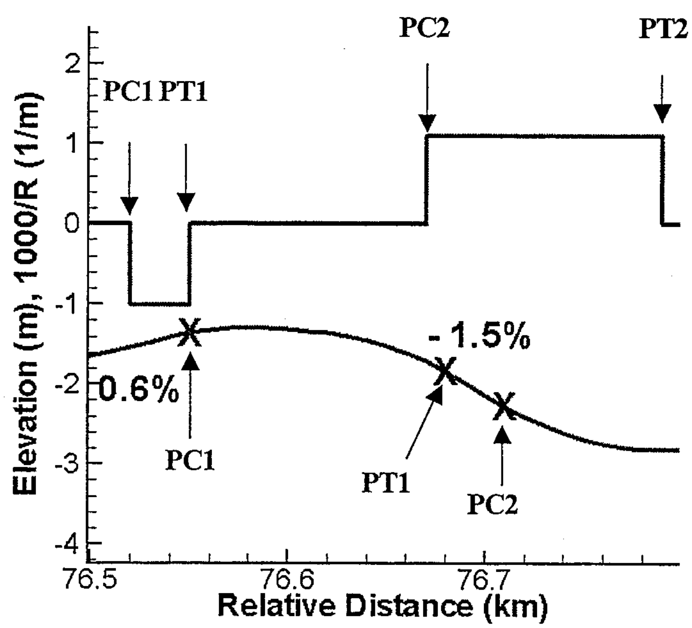


FIGURE A1 Sample Plan and 1/R Plot

I. SCALE AND SEQUENCE OF PLAN OR PROFILE ELEMENTS

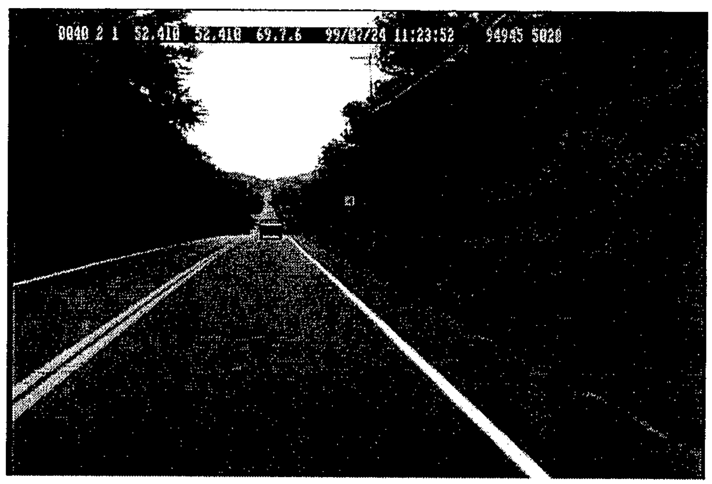
1) Rte 4 East - Fluttering

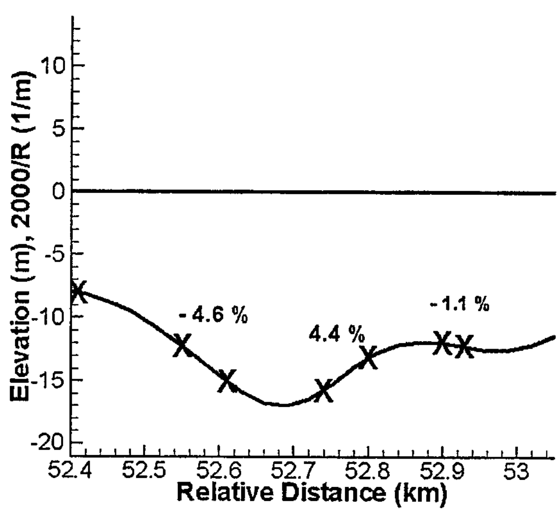
Location: Route 4 East in Burlington, CT Speed Limit: 45 mph

Video data: Photolog 1999.

Issue: Fluttering or the "Rollercoaster" alignment

The alignment consists of a long (1,050 m) tangent section in plan, with a series of three crest and two sag vertical curves in profile. This sequence of crest and sag vertical curves results in a disjointed alignment. From the drivers' point of view, the roadway disappears in the vicinity of the sag vertical curves, and reappears at the peaks of the crest vertical curves. An example of a design mitigating fluttering is an alignment in which horizontal curves are coincidental with vertical curves. This design limits the view of the driver to just a portion of the alignment.





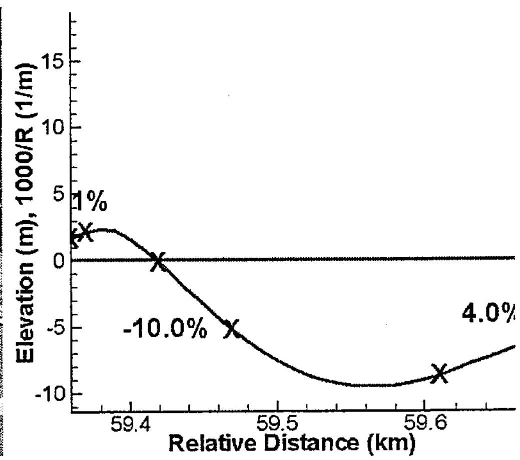
2) Rte 32 N – Diving

Location: Route 32 North in Mansfield, CT   Speed Limit: 40 mph

Video Data: Photolog 1999

Issue: Diving in Vertical Alignment.

The section of interest (53.5 km – 59.78 km) consists of a sharp crest vertical curve followed by a sag curve and a second crest vertical curve superimposed on a tangent section in plan. Since the crest vertical curve is too short (59.37 km – 59.42 km), the driver loses sight of part of the road, with a distorted piece of the road section reappearing in the distance. This type of alignment differs from fluttering by having a single distortion caused by the sharp crest curve, as opposed to multiple distortions in fluttering. Even if the minimum sight distance is provided at every point of the road, this type of alignment appears disjointed and may cause a safety problem. A possible solution to the issue of diving could be to increase the length of the crest vertical curve, such as in example # 5 of the toolbox. Another solution would be to add a horizontal curves in coordination with the crest vertical curve and so limit the driver's sight distance.



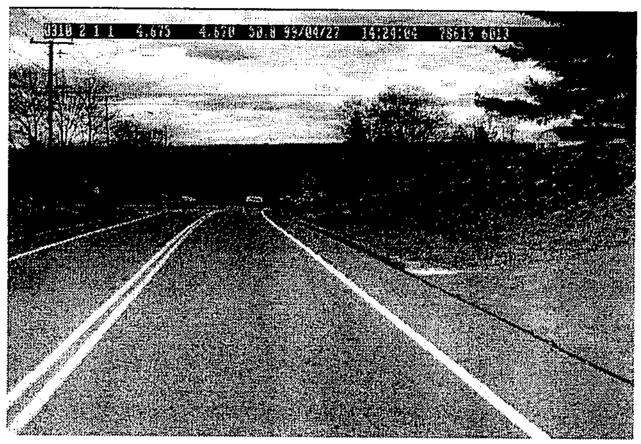
3) Rte 31 E – Jumping

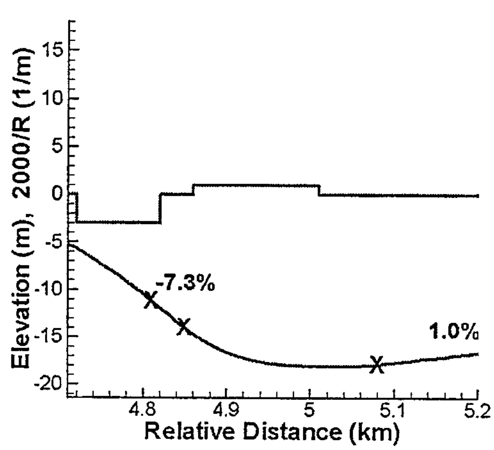
Location: Route 31 East in Tolland, CT Speed Limit: 35 mph

Video Data: Photolog 1999

Issue: Jumping in Horizontal and Vertical Alignment.

The sequence of curves in the section of interest (4.64km – 5.15 km) consists of a crest vertical curve followed by a sag vertical curve superimposed on two horizontal curves. Due to the crest vertical curve, the driver loses sight of part of the roadway (at about 4.7 km point) which reappears on the right side of the screen in the distance. This effect is caused by two horizontal curves placed past the crest vertical curve, and followed by an upgrade section. In this case the horizontal and vertical curves seem to be randomly placed and uncoordinated. Also the scale of the horizontal and vertical curves is reversed. We have vertical curves that are longer than the horizontal curves, which is undesirable. Jumping, the issue visualized by this example, differs from diving by the fact that the reappearing roadway is displaced to the side (the roadway 'jumps' to the side).





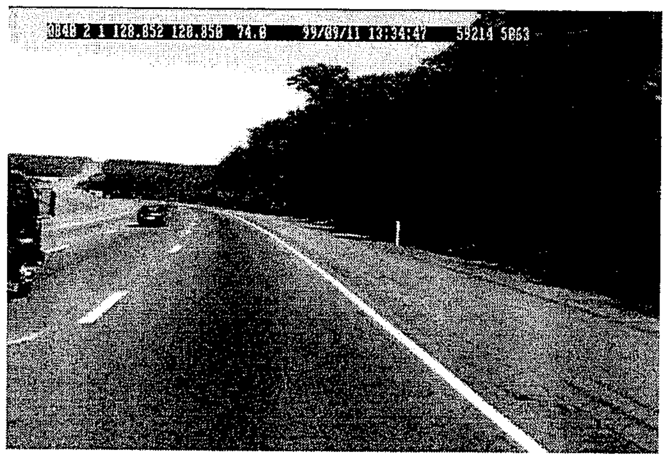
4) RTE 84 E – JUMPING

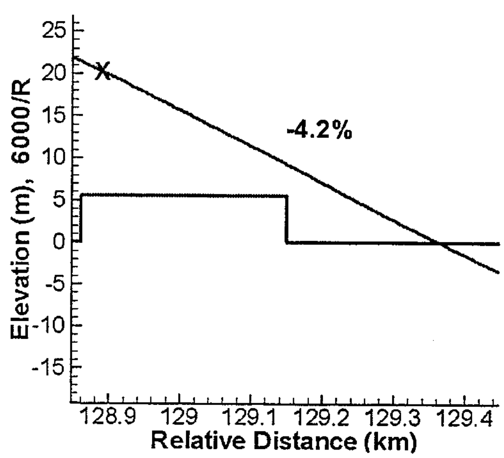
Location: Route 84 East in Tolland, CT Speed Limit: 65 mph

Video Data: Photolog 1999

Issue: Jumping in Horizontal and Vertical Alignment.

The alignment consists of a series of crest and sag vertical curves superimposed on two horizontal curves. The main elements of the alignment causing discontinuity are the downgrade (- 4.2 %) which is followed by a sag vertical curve (360 m long) and superimposed on two horizontal curves. The horizontal curves are not properly coordinated with the vertical curves, just randomly placed past the crest vertical curve on the downgrade section. Due to the two horizontal curves, the driver looses sight of part of the roadway, which reappears on the left side of the screen in the distance. The roadway can be seen in the distance due to the long sag vertical curve (240 m long), which is followed by a 5.5 % upgrade.





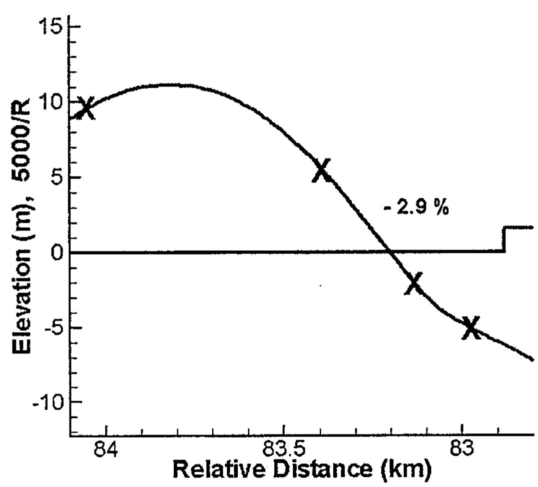
5) Rte 8 S – Gentle Transition between Vertical Curves

Location: Rte 8 S in Torrington, CT Speed Limit: 65 mph

Video Data: Photolog 1999

Issue: Gentle transition between crest and sag vertical curves

The vertical alignment consists of a long crest vertical curve (600 m long) followed by a short and gentle sag vertical curve. The horizontal alignment is a long tangent section followed by a gentle horizontal curve. The long and gentle crest vertical curve transitions smoothly into the short sag vertical curve. Due to the generous scale of both the vertical curves, there is no break in the driver's sight of the roadway. This type of alignment is an example how the issue of 'diving' in road design could be avoided or minimized.



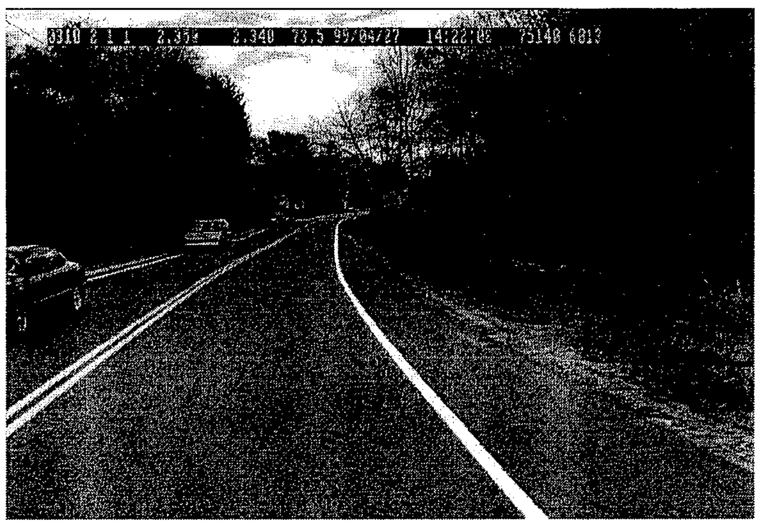
6) Rte 31 E – Broken Back Horizontal Curve

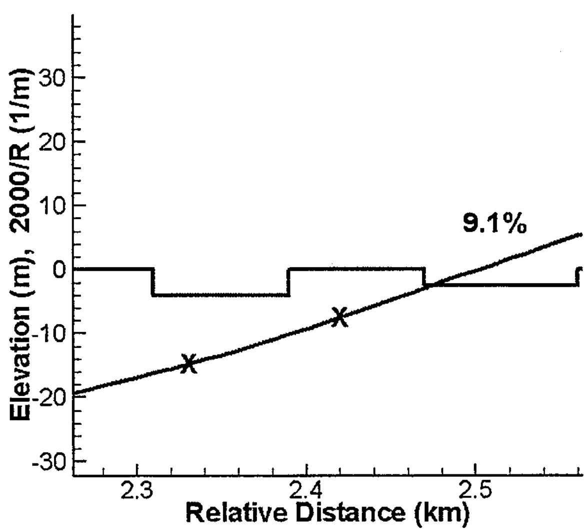
Location: Route 31 East in Tolland, CT Speed Limit: 35 mph

Video Data: Photolog 1999

Issue: Improper Sequence and Scale of Elements

The section of interest consists of two horizontal curves connected by a short tangent (80 m long). This type of alignment is commonly called a Broken Back Curve and it is undesirable due to the discontinuity it presents from the driver's perspective and the violation of drivers expectancy. An example of a more desirable alignment would be to use one long horizontal curve as opposed to two shorter ones connected by a tangent section.





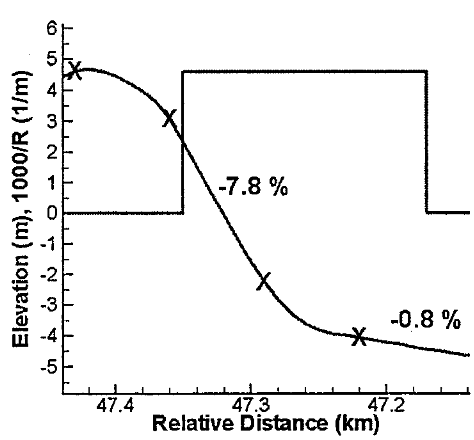
7) Rte 6 W – Broken Back Horizontal Curve

Location: Route 6 West in Woodbury, CT Speed Limit: 45 mph

Video Data: Photolog 1999

Issue: Undesirable Sequence of Plan and Profile Curves

The alignment of interest consists of a sharp crest vertical curve superimposed on a tangent section between two horizontal curves. A design with two horizontal curves bearing in the same direction and linked with a short straight section is undesirable due to violation of driver expectancy. This is referred to as a Broken Back Horizontal Curve. In this case the presence of crest vertical curve further violates the drivers' expectancy. The crest curve limits the sight distance and the driver is not able see the horizontal curve until about 25 meters from its start. The limitation in sight distance, shown in the picture below, may cause safety problems. A solution to this problem is a design with a single horizontal curve, which leads the crest vertical curve and remains slightly longer. An example of such an alignment is video clip # 16 in the visualization toolbox.



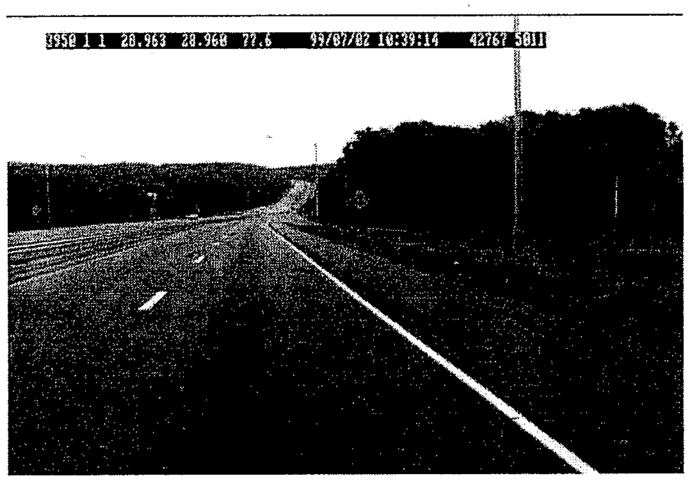
8) Rte 395 N – Discontinuity due to Short Curves – Long Tangent Alignment

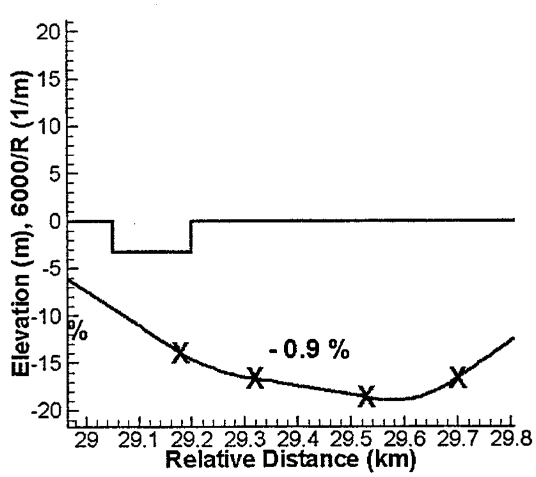
Location: Route 395 North in Norwich, CT Speed Limit: 65 mph

Video Data: Photolog 1999

Issue: Improper Scale in Plan and Profile.

The section of interest consists of two tangent sections and a short horizontal curve, superimposed on two short sag vertical curves connected by tangents. From the driver's perspective, around the 29.00 km point, the roadway looks discontinuous and disjointed. This is due to the short length of the two sag vertical curves (140 and 170 m) connected with a relatively short tangent section (210m). A design with a one long sag vertical curve would be preferable. Also continuity could be improved by increasing the length and radius of the horizontal curve.





II. COORDINATION AND SCALE OF PLAN AND PROFILE ELEMENTS

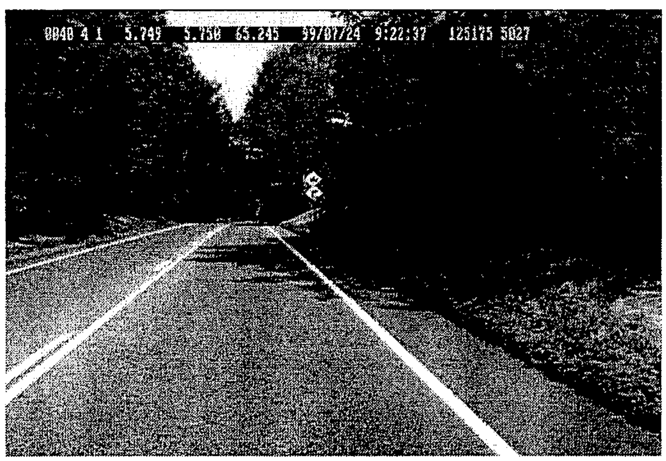
9) Rte 4 W – Poor Coordination of Horizontal and Vertical Curves

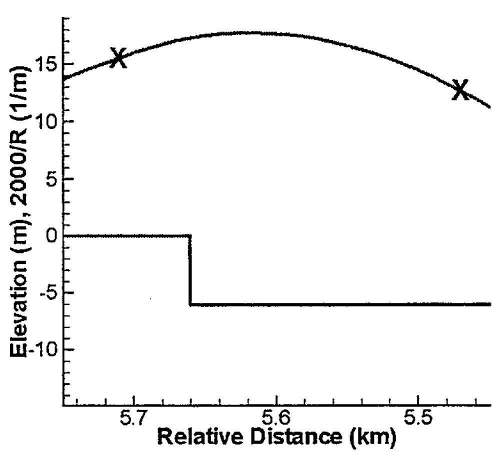
Location: Route 4 East in Sharon, CT Speed Limit: 45 mph

Video Data: Photolog 1999

Issue: Poor coordination of the horizontal and vertical curves.

The alignment consists of a horizontal and a vertical curve superimposed on each other. The crest vertical curve is short, and leads the horizontal curve by 50 meters. Placing the crest vertical curve before the horizontal curve limits the driver's sight distance. The horizontal curve is visible at 5.69 km station, giving the driver only about 30 meters to analyze the given situation and react by turning the steering wheel to negotiate the turn. A preferable design in this case would be to have the horizontal curve lead the vertical curve and remain slightly longer. An example of such a design is in the visualization toolbox example # 13.





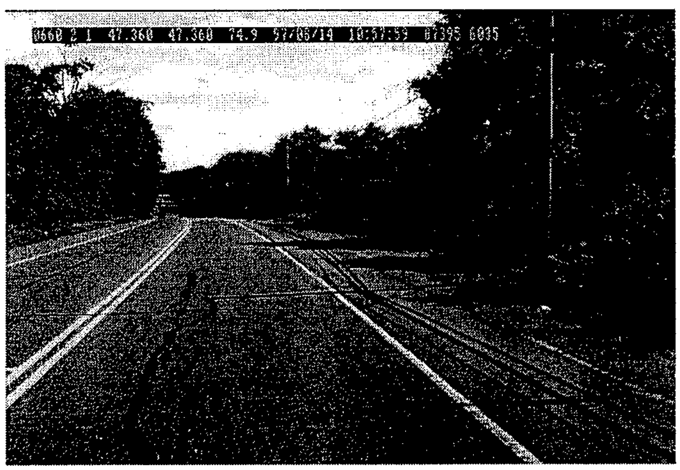
10) Rte 66 E – Poor Coordination of Horizontal and Vertical Curves

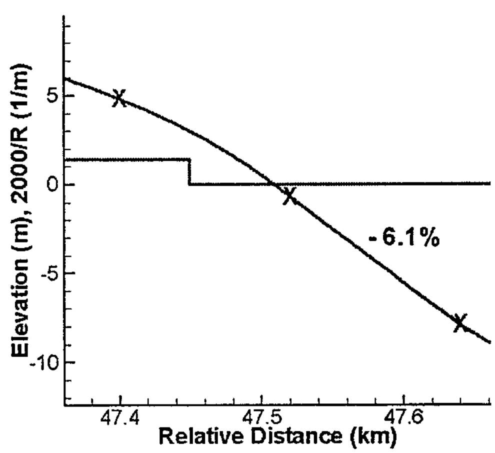
Location: Route 66 East in Columbia, CT Speed Limit: 45 mph

Video Data: Photolog 1999

Issue: Poor coordination of Horizontal and Vertical Curves

The curvilinear alignment of interest consists of a series of crest and sag vertical curves superimposed on two horizontal curves. The alignment in this example is discontinuous because the second crest vertical curve and the first horizontal curve are not properly coordinated. Ideally we would like to have an alignment with horizontal and vertical curves of similar scale, where the horizontal curves lead and remain slightly longer than the vertical curves. In this case the vertical curve extends past the end of the horizontal curve. Such an alignment leads to a distorted look of the road section, noticeable around the 47.36 km station, and makes the alignment discontinuous. An example of a desirable coordination is shown in example # 13 of the visualization toolbox.





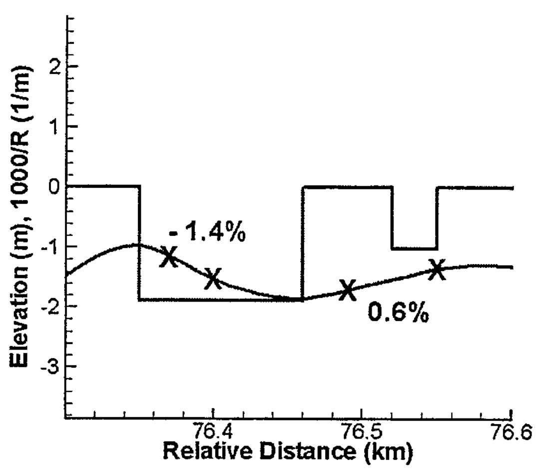
11) Rte 32 N #1 – Poor Coordination of Horizontal and Vertical Curves

Location: Route 32 North in Ellington-Stafford, CT　　Speed Limit: 45 mph

Video Data: Photolog 1999

Issue: Poor coordination of Horizontal and Vertical Curves

The section consists of a series of crest and sag vertical curves superimposed on a series of horizontal curves. The alignment in this example is discontinuous because the horizontal and vertical curves are improperly coordinated. Preferably we want an alignment with horizontal and vertical curves of similar scale, where the horizontal curves lead and remain slightly longer than the vertical curves. In this case the horizontal and vertical curves are very different in scale (short horizontal curves are combined with long vertical curves). Also the horizontal curves do not overlap the vertical curves properly. An example of a desirable coordination is shown in video clip # 14 of the visualization toolbox.



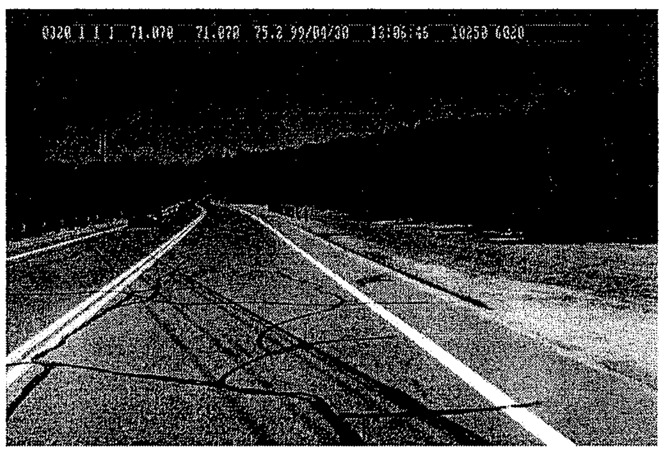
12) Rte 32 N #2 – Discontinuous Alignment due to Poor Sequence of Horizontal and Vertical Elements

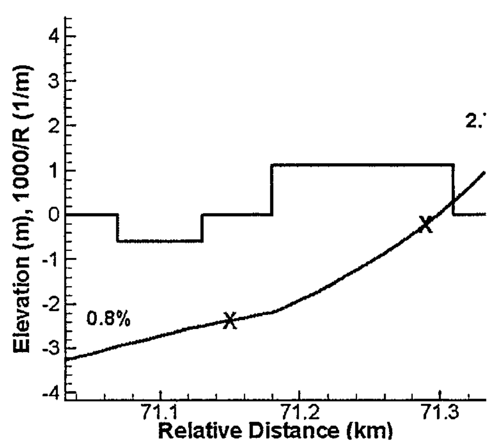
Location: Route 32 North in Willington, CT Speed Limit: 45 mph

Video Data: Photolog 1999

Issue: Improper Sequence and Scale of Elements

The section of interest (71.07 km – 71.58 km) consists of a series of four horizontal curves connected by short tangents and superimposed on a series of two sag and one crest vertical curves. The coordination of the first two short horizontal curves with the first sag vertical curve creates a disjointed effect visible at about 71.03 km. Furthermore, the crest vertical curve (71.43 km – 71.52 km) is poorly coordinated with the fourth horizontal curve. It leads the horizontal curve by about 40 meters, reducing the available decision sight distance for negotiation of the horizontal curve. An improvement to this design would be to use longer and gentler horizontal curves and make sure that they lead and are longer than the vertical curves.





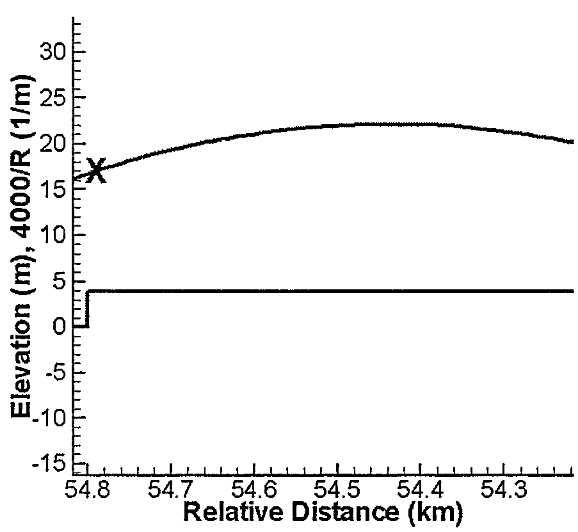
13) Rte 8 S#1 – Good Coordination of Plan and Profile

Location: Route 8 South in Watertown-Waterbury, CT Speed Limit: 65 mph

Video Data: Photolog 1999

Issue: Good Coordination and Scale of Plan and Profile

This video clip is a good example of proper coordination between horizontal and vertical alignment. The horizontal curves lead the vertical curves and remain slightly longer. Also the relative scale of the horizontal and vertical curve on this road section is similar (760 m long vertical curve superimposed onto a 940 m long horizontal curve). The desirable scale and the coordination of horizontal and vertical elements contribute to smooth transitions and continuity of this road section.



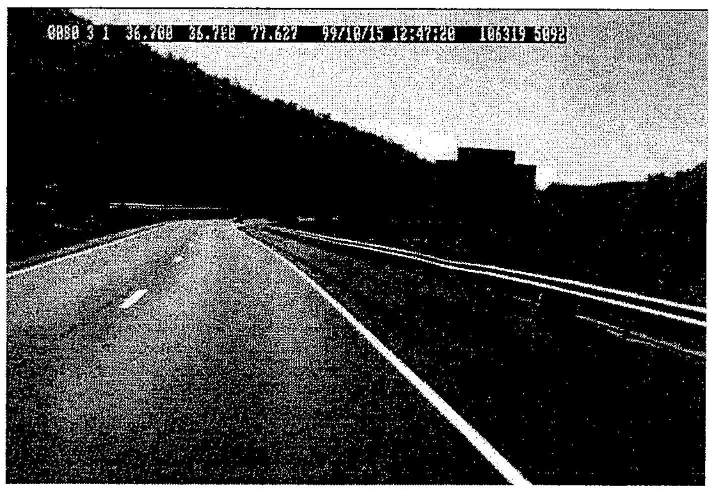
14) Rte 8 S#2 – Good Coordination of Plan and Profile

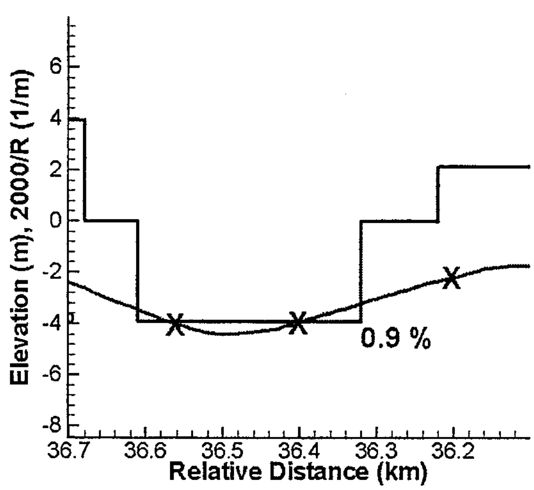
Location: Rte 8 S in Seymour, CT Speed Limit: 65 mph

Video Data: Photolog 1999

Issue: Good Coordination of Plan and Profile

This road section is a good example of proper coordination of horizontal and vertical alignment. The horizontal curves on this road section lead the respective vertical curves and remain slightly longer. The only exception is the coordination of the fourth horizontal and vertical curve. The vertical curve (35.12 km – 34.94) leads and overlaps part of the horizontal curve. This road section is also a good example of a curvilinear alignment, where a major part of the road section is on curves. In general this alignment is continuous, although, the use of spiral curves as a transition between the horizontal tangents and circular curves could lead to further improvement in continuity.





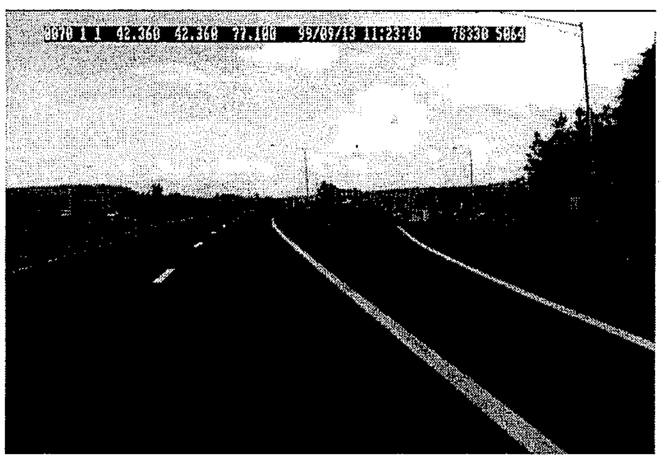
15) Rte 7 N - Good Coordination of Plan and Profile

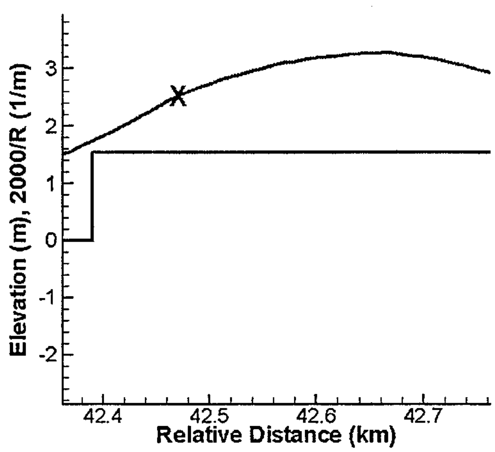
Location: Rte 7 N in Brookfield, CT Speed Limit 65 mph

Video Data: Photolog 1999

Issue: Good Coordination and Scale of Plan and Profile

The alignment consists of a crest vertical curve superimposed on a horizontal curve. The horizontal curve leads the vertical curve by 80 meters, but ends 30 meters before the termination of the vertical curve. Ideally we would like to have the horizontal curve lead the vertical curve and remain slightly longer than the vertical curve. The reason why the horizontal curve should lead the vertical curve is to provide guidance to drivers entering the curve. In this case the termination of the horizontal curve before the end of the vertical curve does not pose a problem since the alignment is a divided highway and as such the traffic does not enter the curve from the opposite direction.





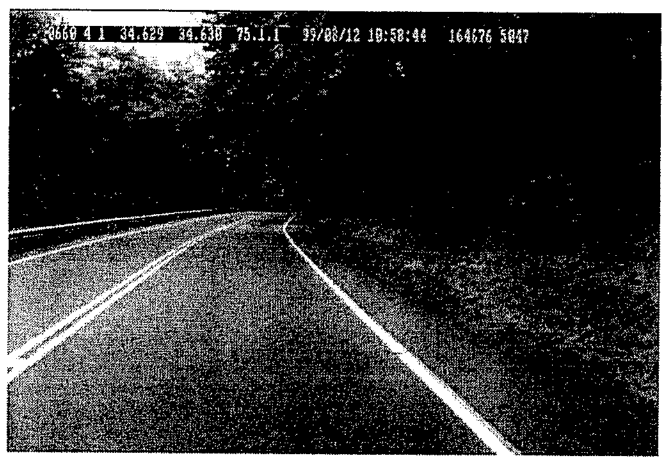
16) Rte 66 W – Good Coordination of Plan and Profile

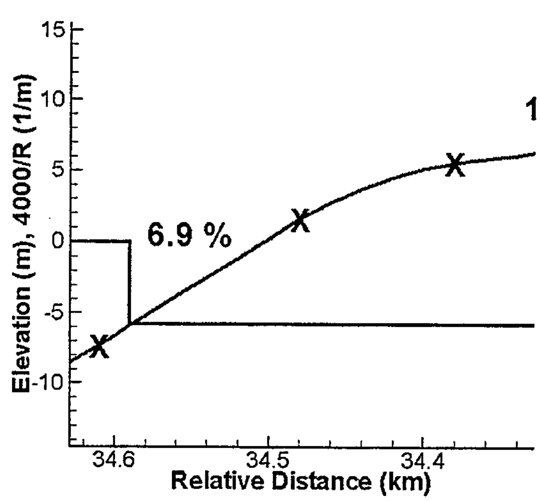
Location: Route 66 West in Marlborough, CT Speed Limit: 45 mph

Video Data: Photolog 1999

Issue: Good Coordination of Plan and Profile

This video clip is a good example of proper coordination between horizontal and vertical alignment. The horizontal curves lead the vertical curves and remain slightly longer. However, the relative scale of the horizontal and vertical curve on this road section is a little off (100 m long vertical curve superimposed onto a 340 m long horizontal curve). Ideally the horizontal and vertical curves should be close in length such as in the toolbox video clip # 14. Even though the scale of curves in this alignment is off, the alignment is still relatively smooth and continuous.





III. CONSISTENCY IN ALIGNMENT

17) Rte 6 W – Inconsistency in Radii of Horizontal Curves

Location: Route 6 West in Woodbury, CT   Speed Limit: 40 mph

Video Data: Photolog 1999

Issue: Inconsistent Alignment in Plan

The section consists of a series of gentle horizontal curves linked by tangents and then followed by two very sharp horizontal curves. This type of an alignment is undesirable due to violation of driver's expectancy. Safety problems may occur when a driver traversing an alignment with gentle curves is suddenly subjected to a change in the sharpness of curves. The radii of the gentle horizontal curves varies between 600 and 1200 meters and is much larger than the sharp curves with radii of about 160 m.