Vertical and Horizontal Alignment

Design Considerations for Combined Highway Alignment

The writers of this paper see the current highway design standards as a two-dimensional projection which the horizontal and vertical alignments are treated separately. A model developed in this paper considers and study the sight distance as a three-dimensional alignment on the design requirements. The paper examines the required minimum radius of a horizontal curve combined with a crest or sag vertical curve in a cut section. Also, the required minimum length of a crest vertical curve combined with a horizontal curve in a fill section is studied. According to the result, the 3D design requirement differs significantly from the current 2D projections. Generic 2D design is highly dependent on the cut side-slope and vertical alignment, and it may under/overestimate the required radius. Also, the 2D alignment overestimates the required length of the crest vertical curve in fill section when combined with long horizontal curves. The 2D alignment can compromise both safety and economics of highway. Therefore, 3D-based design standards should be developed and used in highway geometric design.

Gis Platform For Multicriteria Evaluation Of Route Alignments

The selection of an appropriate alignment for a proposed highway is determined largely by relating topographic, urban, and environmental features to geometric design controls. Typically, aerial photographs and topographic, geologic, and soil maps are reviewed. In this paper, a geographic information system (GIS) platform that incorporates the main coverages needed for evaluating route alignments is described. Using the GIS and a geographically referenced database, a decision-aid tool for multicriteria evaluation of route alignments is developed. Possible alignments are evaluated based on community disruption and environmental, geotechnical, and geometric design criteria. The developed decision-aid tool integrates slope stability and roadway design packages and specifically written codes with GIS packages ARC/INFO and ArcView, the latter acting as the system engine and interface. A case study is presented that applies the developed platform to the testing of potential alignments for a proposed 12 km highway to the south of the city of Beirut, Lebanon. Results of the case study demonstrated the advantages of the decision-aid tool and highlighted its potential in providing a quick, multicriteria screening evaluation of possible route alignments.
The three common requirements in the vertical alignment design of roads are critical length of grade, fixed-elevation points, and non-overlapping of horizontal and vertical curves. However, in the conventional road alignment optimization analysis, these three are not addressed properly because of the complexity in the mathematical formulation and solution of the problem. This paper shows that the artificial intelligence algorithms can be used to handle these constraints more effectively. The formulation of the genetic-algorithm computer program and the method of solution are explained in the paper. The validity of the optimization algorithm is verified against a dynamic programming solution. In summary, these constraints had significant effects on the computed optimal alignments and the construction costs.

Effect of Vertical Alignment on Driver Perception of Horizontal Curves
Y. Hassan, M.ASCE, and S. M. Easa, M.ASCE

The perception of the driver of the road features ahead is an important human factor that can considerably affect traffic safety and design consistency, and should be addressed in road design. An erroneous perception of the road can lead to actions that may compromise traffic safety. Previous studies have shown that combined horizontal and vertical alignments can cause a wrong perception of the horizontal curvature. In this paper, the hypothesis that the perception of the driver of the horizontal curvature is affected by the overlapping vertical alignment is examined analytically. Computer animation was selected as a three-dimensional presentation method of the road perspective, and was found to produce a realistic view of the road. A sample of drivers was interviewed to determine the radius of a horizontal curve on a level grade that would look equal to a radius of a horizontal curve overlapping with a vertical curve. The statistical analysis showed that the horizontal curvature looked consistently sharper when it overlapped with a crest curve and consistently flatter when it overlaps with a sag curve. Field measurements of operating speed profiles on a selected sample of combined alignments confirmed that, for the selected sample of alignments, driver behavior on horizontal curves depended on the overlapping vertical curve rather than the vertical grade of the approach tangent.

Analytical model to determine the influence of horizontal alignment of two axle heavy vehicles on upgrades.
Author: Mavromatis, S; Psarianos, B

Existing design policies determine the speed variation of vehicles on upgrades solely as a function of specific values: initial speed, grade, and weight-to-power ratio. This paper establishes a dynamic model that considers in addition the influence of the roadway's horizontal alignment. The model was validated on both tangents and curves. The model output was examined on a roadway alignment. It was found that sharp horizontal curves influence the speed of heavy vehicles significantly on mild upgrades. Therefore, the conventional speed profile determination has to be supplemented by incorporating the
horizontal alignment as well. The proposed model can be used to provide solutions in a more efficient and realistic way than does the current practice.

**Side Friction And Speed As Controls For Horizontal Curve Design**  
ASCE Journal of Transportation Engineering, Vol.125, No.6, November/December, 1999

This paper describes an examination of the relationship between vehicular speed and side friction demand on horizontal curves. Models of speed and friction demand are described. The curve speed model explains the effect of approach speed, radius, and super elevation rate on curve speed. The side friction model explains the effect of approach speed and curve speed reduction on side friction demand. The terms in the side friction model reflect a general desire by motorists for a lower side friction demand at higher speeds. Model terms also reflect a willingness by motorists to tolerate slightly higher side friction demand in an effort to minimize the amount of speed reduction required by relatively sharp curvature. This model is recommended as a rational basis for defining the maximum side friction factors for use in curve design.

**Required Stopping Sight Distance On Crest Vertical Curves**  

Required stopping sight distance (SSD), used to calculate the minimum rate of vertical curvature or the minimum length of a crest vertical curve (CVC), is usually calculated on the assumption that the grade of the braking section is zero (G = 0). This assumption is not the worst case and may lead to the selection of a CVC on which there is a segment with SSD restriction. On each CVC there are braking sections on one or both directions of travel, on which average grade is negative (G < 0). In the present paper a method for calculating required SSD, partly or wholly on a CVC, is developed, using the average grade over the braking distance. In addition, a computer program is compiled for calculating the value of the required SSD for all driver positions before or on a CVC. An SSD profile is drawn and it is proven that, for a significant length of the CVC, the required SSD is greater than the value used for calculating the minimum value of the rate of vertical curvature.

**Optimizing Highway Grades To Minimize Cost And Maintain Traffic Speed**  
Yusin Lee and Juey-Fu Cheng, ASCE Journal Volume 127, Jul/Aug 2001 Issue

In practice, the task of designing the vertical alignment of a highway is done manually by an experienced engineer. As a result, the work is both time and resource consuming and relies heavily on human expertise. This work presents a mathematical model that solves for a set of optimal highway vertical grades for a given horizontal alignment. In addition to construction costs, facts considered by this model include earthwork balance and traffic speed in both directions. Code requirements and design practice are also considered. A three-layered heuristic is developed to solve the model. In the first layer, a neighborhood search heuristic is used to determine the locations where grade can change. The second layer sets penalty terms for sections where speed is undesirable, and the third
layer solves a mixed integer program that has very few or no 0-1 integer variables. Computational testing on a 2-km road segment shows that the model yields good solutions.

**Design Of Sag Vertical Curves In Three-Dimensional Alignments**

Headlight sight distance has been an important element in designing sag vertical curves because nighttime drivers need sufficient sight distance for stopping, and also because they depend on the road marking to maintain uniform speed and proper lane positioning. Considering an isolated sag vertical curve in a two-dimensional projection based on the sight distance needs for stopping, the current design standards recommend a minimum length of the sag curve. However, little research work has been directed toward determining the available headlight sight distance in three-dimensional highway alignments. A new analytical model developed by the writers for 3D analysis of headlight sight distance has shown that the 2D analysis may overestimate the available headlight sight distance on sag vertical curves combined with horizontal curves. In this paper, a computer program based on the 3D analytical model is used to evaluate the current 2D standards for sag vertical curves on fill sections. The results show that the current 2D design standards overestimate the available headlight sight distance and therefore underestimate the required length of sag vertical curves combined with horizontal curves. In this paper more accurate values for the required length of sag vertical curves combined with horizontal circular curves are developed. A more economical design is also suggested through the use of asymmetrical (compound) sag vertical curves.

**Predicting Operating Speeds On Tangent Sections Of Two-Lane Rural Highways**

The prediction and estimation of speeds on two-lane rural highways are of enormous significance to planners and designers. The estimation of speeds on curves may be easier than the prediction of speeds on tangent sections because of the strong correlation of speeds on a few defined and limiting variables, such as curvature, super elevation, and the side-friction coefficients between road surface and tires. On tangent sections, however, the speed of vehicles is dependent on a wide-array of roadway characteristics, such as the length of the tangent section, the radius of the curve prior to and after the section, cross-section elements, vertical alignment, general terrain, and available sight distance. This research analyzed the variability of the operating speeds on 162 tangent sections of two-lane rural highways and developed models for its prediction based on the geometric characteristics available. After considerable examination of the sites, the data were assembled into four groups of similar characteristics: Group 1 (small radii and short tangent length); Group 2 (short radii and intermediate tangent length); Group 3 (intermediate radii and intermediate tangent length); and Group 4 (any radius and long tangent length). Separate prediction models for the 85th percentile speed were developed for each of the four groups separately. The models for Groups 1 and 2 sections provided a good fit to the data and could be adapted for prediction purposes during the planning process for new two-lane highways. The models for Groups 3 and 4 sections were preliminary, and clearly need additional data.
Visual Perception Of Horizontal Curves In Three- Dimensional Combined Alignments
Yasser Hassan and Said Easa, Lake head University, Thunder Bay, Ontario, Canada, TRB Publications 2000

Traffic safety is an important element in roadway design, that is considerably affected by human factors. Among these factors is the drivers’ perception of the road ahead, which affects their decisions and actions. Thus, an erroneous perception of the road can lead to erroneous actions, and hence can compromise the traffic safety. Experimental evidences have shown that combined horizontal and vertical alignments can cause a wrong perception of the horizontal curvature and can affect the drivers’ choice of operating speed on horizontal curves. This paper examines the hypothesis that the driver’s perception of the horizontal curvature depends on the overlapping vertical alignment. Computer animation was selected as a three-dimensional presentation method of the road perspective, and was found to produce a realistic view of the road. A sample of drivers was interviewed, where they were asked to determine the horizontal curvature (overlapping with a level vertical grade) that matched a specific horizontal curvature (overlapping with a vertical curve). The results showed that the horizontal curvature looked consistently sharper when overlapping with a crest vertical curve and consistently flatter when overlapping with a sag vertical curve. The data, though preliminary and limited in size, showed that the perception of the horizontal curvature did not depend on the turning direction or the algebraic difference of the vertical curve grades. Further investigation is required to examine the effect of these factors and other alignment parameters on the perceived radius of horizontal curves more accurately and conclusively. It was established in the paper that crest vertical curves cause overlapping horizontal curves to look sharper while sag vertical curves cause overlapping horizontal curves to look flatter than what they actually are. Within the limited size of data points collected, the perceived radius of the horizontal curve did not depend on the turning direction or the algebraic difference of grades of the vertical curve. However, this latter finding may have been affected by the large standard deviation caused by using a large step in the radius of reference curves. Therefore, more research is required by extending the work described in this paper to include larger sample size, more curve parameters, and finer step in the radius of reference curves.

Evaluating Horizontal Alignment Design Consistency of Two lane rural Highways: Development of New Procedure
Wooldridge, MD; Fitzpatrick, K; Harwood, DW; Potts, IB; Elefteriadou, L; Torbic, DJ

This report discusses the design consistency particularly of rural roads. Design consistency refers to the condition wherein the roadway geometry does not violate driver expectations. Operating-speed profile models are used to evaluate the consistency of a design by identifying locations with large speed variability between successive design elements. There is a direct correlation between safety and variability in speeds. Recent operating-speed models predict the 85th percentile speeds on horizontal curves and compare this value with the expected 85th percentile speeds on the approach tangent.
There is a direct correlation between speed variability between successive design elements and crash rates. Eighty-fifth percentile speeds, however, do not necessarily represent the speed reductions experienced by drivers. The primary objective of the research was to assess the efficacy of the use of 85th percentile speed by operating-speed profile models to evaluate the consistency of a design. Speed data were collected at 21 horizontal curve sites. These data were used to evaluate the implication of using 85th percentile speed for evaluating design consistency. A new parameter was investigated for analyzing design consistency: the 85th percentile maximum reduction in speed (85MSR). This parameter is calculated by using each driver's speed profile from an approach tangent through a horizontal curve and determining the maximum speed reduction each driver experiences. These maximum speed reductions are sorted, and the 85th percentile value becomes the statistic of interest. 85MSR was compared with the difference in 85th percentile speeds (85S), and it was found that 85MSR is significantly larger than 85S. The data showed that, on average, 85MSR is approximately two times larger than 85S. Models were developed that predict 85MSR as a function of geometric design elements, and these models could be used to complement existing operating-speed models.

**Improved Design Of Vertical Curves With Sight Distance Profiles**
(Transportation Research Board).

Design of vertical alignment is one of the main tasks in highway geometric design. This task requires, among other things, that the designer ensure drivers always have a clear view of the road so they can stop before hitting an unexpected object in the road. Therefore, the ability to determine the required and available stopping sight distance (SSD) at any point of the vertical alignment is essential for the design process. Current design guides in the United States and Canada provide simple analytical models for determining the minimum length of a vertical curve that would satisfy the sight distance requirement. However, these models ignore the effect of grade on the required SSD. Alternative approaches and models have also been suggested but cover only special cases of vertical curves. Two specific models were expanded to determine the required SSD on crest and sag vertical curves. By comparing profiles of available SSD and required SSD on examples of vertical curves, it was shown that current North American design practices might yield segments of the vertical curve where the driver's view is constrained to a distance shorter than the required SSD. An alternative design procedure based on the models was developed and used to determine the minimum lengths of crest and sag vertical curves. Depending on the approach grade, these new values of minimum curve length might be greater than or less than values obtained through conventional design procedures. Design aids were therefore provided in tabular form for designers' easy and quick use.

**Graphical Solution For Vertical Curve Computation**
(American Society of Civil Engineers)

Traditionally, highway vertical curve data has been calculated and tabulated for construction staking. The design drawing showed the parabola drawn using the calculated station-offset information. With the procedure described herein, a draftsperson can draw...
the parabola, given the station-elevation data on the beginning of vertical curve, the point of vertical intersection, and the end of vertical curve, using any drafting software. The construction staking data can then be obtained directly from the drawing by means of an appropriate command to get the information. There is no need to compute the grade elevation for staking purposes. While the graphical methods are not new, the use of computer-aided drafting (CAD) facilitates obtaining precise solutions from the CAD-computed database, which was not possible with the paper drawings of the past.

**Optimal Vertical Alignment Analysis For Highway Design**

American Society of Civil Engineers

Critical length of grade control, fixed-elevation points, and non overlapping of horizontal and vertical curves are 3 common requirements in the vertical alignment design of roads. These 3 forms of constraints are, however, usually not addressed in the conventional road alignment optimization analysis because of the complexity in considering them in the mathematical formulation and solution of the problem. This paper shows that the artificial intelligence technique of genetic algorithm (GA) can be adopted to handle these 3 forms of constraints effectively. Formulation of the GA computer program and the method of solution are explained. The validity of the optimization algorithm is verified against a dynamic programming solution. Examples are presented to illustrate the application of the GA program to problems involving critical length of grade requirements, fixed-elevation control, and non overlapping of horizontal and vertical curves. These 3 constraints were found to have significant effects on the computed optimal alignments and associated construction costs.

**Determining Critical Length of Grade for Geometric Design of Vertical Alignments**

Transportation Research Board 2004

The 2001 Green Book defines the critical length of grade as the length of grade that would produce a speed reduction of 10 mph for a 200 lb/hp truck while climbing a hill at a certain grade. In some locations, trucks with weight/power ratios other than 200 lb/hp are appropriate, but the green book hasn’t provided a way for traffic engineers to calculate critical grade length for these applications. This paper presents the results of a study performed to determine the distribution of truck weight/power ratios in various regions of the country. A climbing lane is necessary on an upgrade if the grade length exceeds this critical length so as to not lower the level of service.