# WORLDWIDE REVIEW OF ALIGNMENT DESIGN POLICIES

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## INTRODUCTION

This paper reviews highway alignment design policies and practices in a sample of countries throughout the world. The goal is to broaden our understanding and perspective of alignment design by highlighting similarities and differences between design philosophies and quantitative guidelines. It is hoped that accomplishing this goal will stimulate the continued improvement of highway geometric design.

The information presented in this paper combines and builds upon recent studies in the United Kingdom, United States, and Germany that included reviews of alignment design policies and practices in a sample of countries (*1,2,3*). It was generally observed that there are many similarities in fundamental alignment design principles and philosophies and in quantitative guidelines on basic design parameters. These similarities may reinforce the reasonableness of countries' guidelines that fall within the norm of worldwide practice. What may be most interesting and important, however, are differences in policy emphasis and concern that have led to more advanced guidelines on certain geometric elements, and differences in local conditions and experience that have led to deviations from apparent worldwide norms for certain quantitative guidelines. It is the intent of this paper to gain insight by understanding the reasons for differences rather than to make judgments about deviations from the norm.

Some countries combine their policies for rural and urban streets, whereas other countries have separate policies. This review focuses on alignment design for rural roadways.

The review is divided into two major sections: first, a qualitative comparison of alignment design philosophies; and second, a quantitative comparison of design guidelines. The paper concludes with general observations about worldwide alignment design policy and practice.

## COMPARISON OF ALIGNMENT DESIGN PHILOSOPHIES

Many countries' alignment design policies were based initially upon the design-speed concept described by the American Association of State Highway and Transportation Officials in 1940 (AASHTO) (*4*). This classical approach involves the selection and application of a design speed to assure uniformity of operating speed along an alignment. Design speed is selected based upon road type, terrain, and development environment (rural versus urban). The selected design speed is used to determine minimum curve radii, actual superelevation rates, and required sight distances. It is presumed that drivers operate at the design speed and, therefore, that no checks on actual operating speeds are required.

During the past 55 years, many countries have adapted, refined, and updated their policies to reflect national conditions and safety and operating experience. Design speed continues to be a cornerstone of alignment design, but interesting differences now exist in how design speed is selected and applied. Several countries have recognized a need to base design speeds more directly upon actual driver speed behavior and to include checks on estimated operating speeds along designed alignments.

To illustrate the similarities and differences in alignment design philosophy throughout the world, a sample of 11 countries' alignment design policies were reviewed in some detail:

- Australia,
- Belgium,
- Canada,
- France,
- Germany,
- Italy,
- South Africa,
- Sweden,
- Switzerland,
- United Kingdom, and
- United States.

### Australia

National geometric design policy, which individual states may modify, is published by AUSTROADS, the national association of State, Territory, and Federal road and traffic authorities in Australia (*5*). Early alignment design policy in Australia was based upon the design-speed concept and patterned after AASHTO. In 1980 a change in basic design philosophy was documented in an interim guide, and in 1989 the current guidelines were published. The current philosophy is that "what actually happens on the road network (85th percentile value of observed vehicle speeds) is adopted as the basis for geometric form, rather than the earlier approach of adopting a predetermined *speed standard.*"

Procedures differ for high-speed (≥ 100 km/h) and intermediate- and low-speed (< 100 km/h) environments. Speed environment is defined as "the 85th percentile of the observed free speed distribution on the longer straights (or large radius curves) on the section, at low traffic volumes" (*5*). For high-speed environments, in which drivers expect to operate at uniform speeds, the design-speed concept is applied classically.

For intermediate- and low-speed environments, an iteractive procedure is used to check for and resolve speed consistency problems. The interative procedure involves: (1) selecting a nominal speed environment based upon the terrain type and approximate range of horizontal curve radii, (2) developing a trial alignment, (3) determining its speed environment, (4) estimating 85th percentile speed on curves as a function of the speed environment and radius of the curvature, which becomes the design speed for curves, (5) checking for speed consistency and sight distance, and, if necessary, (6) modifying the alignment, and (7) repeating steps 3 through 6. The consistency check is that the design speeds of successive elements should differ by no more than 10 km/h. Sight distance should be adequate for the design speed as defined by the estimated 85th percentile speed.

The maximum superelevation rate varies among regions of Australia. In mountainous terrain 10 percent is most common, but 12 percent is used in some regions. In flat terrain, 6 to 7 percent is used. In selecting superelevation rates for curves with radii larger than the minimum, the frictional demand with the proposed rate at the design speed (85th percentile speed) should not exceed specified maximum values.

Australian policy encourages the use of clothoid transition curves except where the lateral shift between the extended tangent line and extended circular arc is small (i.e., less than 250 mm). The length of transition curves is based upon the superelevation development length, which is based upon the rate of rotation of the pavement surface and the relative grade of the edge of the roadway and the axis of rotation (typically the centerline of two-lane roadways).

Compound curves are discouraged. Where possible, a single curve is preferable. Where necessary, the guideline on the relationship between the two radii is that the design speed of the flatter curve should be no more than 10 km/h greater than the design speed of the sharper curve. Furthermore, it is recommended that the superelevation of the sharper curve be adjusted such that the frictional demand on the sharper curve at the design speed is not significantly greater (i.e., 20 to 25 percent) than on the flatter curve.

With respect to vertical alignment, guidelines are given on maximum grades (as a function of terrain and design speed) and minimum lengths of crest (convex) and sag (concave) curves. The minimum length of crest vertical curves is based upon sight distance requirements. The minimum length of sag vertical curves is generally based upon a comfort criterion, although on high standard, unlit roadways the guidelines encourage consideration of providing headlight sight distance equal to that available on crest curves, up to 150 m. Guidelines on maximum grades are a function of design speed and terrain; grades steeper than 10 percent are discouraged.

**Belgium**

Standards for roads and motorways in the Walloon part of Belgium are set out in Circular No A/WA/205/91/02685 "Characteristics of Roads and Motorways" published under Belgium Law of March 1985, by the "Director Generale des Autoroutes et des Routes," of the Ministere Walloon de L'Equipment et des Transports (*6*).

The designer uses the mean daily two-way traffic volume, estimated to occur after 10 years of operation, to determine carriageway provision and type of road. From these factors, the appropriate design speed is selected which sets the geometric characteristics for the road. Design speed options are 120 km/h or 90 km/h for motorways, and 120 km/h, 90 km/h, or 60 km/h for other roads. Local circumstances are taken into account in considering the options. The design speed is the "safe speed" for vehicles on horizontal and vertical curves.

Horizontal layout and vertical profile must ensure minimum sight distances for the design speed. Unobstructed vision must be available over the range. Specific distances for each design speed are given, but how they are derived is not stated.

Minimum horizontal radii are stated for the design speeds with maximum superelevation. Maximum superelevation rates are: 5 percent for 120 km/h, 6 percent for 90 km/h and 7 percent for 60 km/h. Superelevation is designed to absorb 1/3 of the centrifugal force, and is applied over the spiral length. Minimum radii are given for curves not requiring superelevation and for those which require no modification of superelevation, i.e., normal crossfall is maintained although it may be adverse.

Clothoid spiral transitions are required at all locations where curve radii change. Criteria for the selection of the clothoid parameters are based on aesthetics, comfort and superelevation application. Minimum values are recommended for the clothoid parameters according to the design speed. Clothoid parameters less than the minimum values are not permitted.

Vertical alignment consists of sections of uniform gradient joined together by parabolic curves. Maximum longitudinal gradients range from 4 percent at a design speed of 120 km/h to 8 percent at 60 km/h. The parameter values for vertical curves are dependent on design speed. Minimum values of radii (equivalent to rate of vertical curvature or K-value, which is used in some countries) for crest curves are given for one-way and two-way carriageways. The latter are based upon the distance needed for safe overtaking. For sag curves a desirable value from an aesthetic view and an absolute minimum are given.

Departures from standards are permitted in exceptional circumstances arising from local conditions, subject to the approval of the Director Generale.

## Canada

Although individual Canadian provinces have their own design policies, the 1986 "Manual of Geometric Design Standards for Canadian Roads," published by the Transportation Association of Canada, is the general guide and basis for current design policy in Canada (*7*).

Much of Canadian policy is patterned after U.S. (AASHTO) policy. Canadian alignment design policy applies the design-speed concept classically. Roads are classified by type (local, collector, arterial, and freeway), by adjacent land use (rural or urban), and as either undivided or divided (i.e., single or dual carriageway). Design speeds are recommended for each class. For example, rural undivided collectors may have design speeds of 60, 70, 80, 90, or 100 km/h, based upon consideration of topography and local conditions. There are no formal checks of operating speed consistency.

Maximum superelevation rates may vary among Provinces. In rural areas, either 6 or 8 percent is used. Lower maximum rates (typically 4 to 6 percent) are specified for urban areas. The Manual provides tables that specify the appropriate superelevation rate for a given radius, design speed, and maximum superelevation rate. The rates follow a parabolic relationship with radius (referred to as Method 5 for distributing superelevation by AASHTO).

Transition curves (clothoids) are encouraged. Compound curves should be connected by transition curves unless the ratio of the longer to shorter radius is less than 1.5.

Guidelines are provided for maximum grade (as a function of roadway classification, terrain, and design speed), minimum grades (considering drainage requirements), and vertical curve lengths. Vertical curves are parabolic in shape. Both crest (concave) and sag (convex) vertical curve lengths are generally controlled by stopping sight distance requirements. Guidelines are also given for crest (convex) vertical curve lengths for minimum passing (overtaking) sight distance, but they are considered generally impractical.

## France

Service d'Etudes Techniques des Routes et Autoroutes (SETRA), a service agency of the French Ministère de L'Èquipment des Transports et du Tourisme, develops design standards for national roads and motorways in France. The existing design policy "Instruction sur les Conditions Techniques D'Aménagement des Routes Nationales" was last revised in 1975 (*8*). In 1994, the Ministry adopted guidelines developed by SETRA for national two-lane highways, entitled "Amenagement des Routes Principales: Recommandations techniques pour la conception générale et la géométrie de la route" (*9*). The new guidelines are the product of a comprehensive review of the safety and operational effects of roadway geometry and a reassessment of basic design assumptions.

The new French guidelines are considerably different in concept from the "Instruction," which was classical in approach and reliance on the design-speed concept. The new guidelines depart from the design-speed concept and emphasize that the driver-roadway interaction influences speed behavior and must be taken into account.

The "Instruction" had five road categories, and each had a design-speed range from 40 km/h to 120 km/h. All alignment features were related to the design speed. SETRA observed that this approach does not consider the effect of alignment on the actual speed behavior of drivers; it disregards the fact that the design may permit higher speeds. Furthermore, it may encourage the designer to use larger radii, which is not desirable if a sharper curve that requires slower speeds exists downstream. In the new guidelines, therefore, the correlation between roadway type and design speed is stronger, i.e., the new guidelines specify only a 20-km/h range of design speeds for each of the three new road categories.

For new roads, the new French guidelines on horizontal alignment consider lateral acceleration and consistency. Because French research suggests that the safety effects of lateral acceleration are not very significant, the guidelines suggest levels of comfort for lateral acceleration. These values result in minimum radii based upon actual speeds. The values are considered desirable but not mandatory. Similarly, since French research has not identified an effect of superelevation on operating speeds, the new guidelines do not place much emphasis on superelevation rate. They determine superelevation as a function of the inverse of radius.

Consistency is important in the new French guidelines. French research found safety problems involving a sharp horizontal curve when preceded by a long tangent and compound curves. The new guidelines reflect these findings by specifying a minimum radius following a long tangent (i.e., a minimum radius of 200 m if the preceding tangent is longer than 0.5 km, and a minimum radius of 300 m if the preceding tangent is longer than 1 km). With respect to compound curves, they specify that the ratio of the radii of compound curves should be between 0.67 and 1.5.

French design policy calls for clothoid transition curves on all horizontal curves, except those that do not require superelevation. The new guidelines, however, depart from the traditional approach for estimating transition curve length, in which the length increases with decreasing final curve radius. The French have experienced problems on short, sharp curves when the transition curve is long and the remaining circular curve is too short. The concern is that if the transition is too gradual, drivers may underestimate the risk associated with the curve. Therefore, the new guidelines use a higher variation rate for sharp curves than for mild curves. In the resulting guidelines, transition curve length increases with increasing final radius.

The new French guidelines include some interesting concepts related to sight distance that influence vertical alignment design. One unique guideline specifies that the minimum sight distance to the beginning of horizontal curves should be 3 seconds driving time at the 85th percentile speed or, for sharp curves, 1.5 s reaction time and deceleration at a rate of 0.3 g from the 85th percentile speed of the tangent to the 85th percentile speed of the curve. With respect to passing sight distance, French experience is that their previous policy led to many sections with minimally/questionably adequate and few sections with clearly adequate passing (overtaking) sight distance. In the new guidelines, the French have adopted a philosophy similar to the United Kingdom of avoiding sections with marginally adequate passing (overtaking) sight distance.

**Germany**

German geometric design guidelines are prepared by committees of the German Road and Transportation Research Association (Forschungsgesellschaft für Strassen- und Verkehrswesen) consisting of both researchers and practicing engineers. German alignment design policy emphasizes operating speed consistency and promotes flowing, curvilinear alignments. A design consistency evaluation procedure was first included in the 1973 edition of German alignment design guidelines. The 1984 edition of the alignment design guidelines is the most current published version (*10*). An English translation of the 1984 guidelines is quoted herein (*11*). During June 1995, the committee responsible for alignment policy approved revisions to the 1984 guidelines, but the new guidelines have not yet been published.

The German guidelines use both design and 85th percentile operating speeds for alignment design of rural roadways. The design speed is used, as in most countries, to determine minimum radii of horizontal curves, maximum grades, and minimum radii for crest vertical curves. The estimated 85th percentile speed, however, is used to evaluate and design superelevation rates and sight distances.

The 85th percentile speed on rural two-lane highways is estimated using empirical relationships based upon curvature change rate and pavement width. The curvature change rate is computed for roadway sections as the sum of the angular change in direction divided by the length of the segment. For a simple circular curve without spiral transitions, the curvature change rate is equivalent to degree of curvature, except for different units.

German guidelines indicate that the design speed and expected 85th percentile speed on two-lane highways should be well-balanced. The expected 85th percentile speed should not exceed the design speed by more than 20 km/h. If it does, then the guidelines require that either the design speed be increased or the design be modified to reduce the expected 85th percentile speed.

The German guidelines provide several instructions for achieving consistency in alignment design. First, the design speed "shall remain constant for longer road sections so that the road characteristic is well-balanced for a road operator over the course of the road section. If, in the course of a longer road section—for example, by definite changes in topography—a change in the road characteristic and a corresponding change of the design speed is necessary, then in the transition section the design elements must be carefully tuned to each other so that they change only gradually" (*11*).

Second, the German guidelines specify that, "The 85th percentile speed shall be consistent for the duration of the road section" (*11*). Acceptable ranges are specified for the radii of successive curves. Minimum radii following a tangent are also specified. For example, for rural principal arterials, if the length of tangent is greater than 600 m, then the radius of the subsequent curve should be at least 600 m; if the length of tangent is less than 600 m, then the radius should be greater than the length of tangent.

Third, the German guidelines specify, "If the determined values for the 85th percentile speed between successive road sections differ by more than 10 km/h, the speed values between the two sections should be adjusted to allow for a gradual transition of the speed" (*11*). If the speed differential between sections exceeds 10 km/h, a transition section should be designed with an intermediate value for curvature change rate and, therefore, expected 85th percentile speed.

The maximum superelevation rate for main rural roads is 7 percent. For suburban and urban roads, lower maximum rates (6 and 5 percent, respectively) are used. Superelevation rates for curves with above-minimum radii are based upon a linear relationship between superelevation rate and radius.

Transition curves (clothoids) are required on rural roads and major arterials in suburban and urban roads, and they are considered desirable on other urban roads. The transition curve length generally increases with decreasing radius.

With respect to vertical alignment, guidelines are provided for maximum grade (as a function of roadway class and design speed), minimum grade (for drainage purposes where longitudinal slope is important), and minimum rate of crest (convex) and sag (concave) vertical curves. The guidelines for crest (convex) curves are based upon stopping sight distance requirements. The guidelines for sag (concave) curves are based upon general appearance and yield minimum radii approximately one half the radii of minimum crest (convex) curves.

**Italy**

Italian standards are set by Consiglio Nazionale Delle Ricerche (*12*). The current version is dated 1980.

The design speed is determined from the type of road and its cross section. However, rather than set a specified design speed, a speed range, within which the design speed of the various sections (or elements) must fall, is given. The upper limit is the safe speed for a single vehicle within acceptable margins of safety. It is therefore possible for different sections of the same road to have different design speeds. This is to allow the designer a certain freedom in adapting the alignment to the terrain which is being traversed. The range is limited to ensure that the design speed does not vary by much along a road, thus giving a consistent message to the driver, which should lead him/her to behave in a manner forecast by the designer.

Although two successive elements can have different design speeds, the difference must not be so great as to create a safety risk. For example, it is not permissible to have an element designed to the maximum permissible design speed followed immediately by one designed to the minimum design speed.

A maximum length of straights, which is based upon design speed, is suggested. This is to maintain the drivers' attention and to ensure that he drives at a speed within the design speed range and to enable the designer to adapt the alignment in hilly and mountainous terrain to meet environmental requirements. When the alignment is predominantly composed of circular and transition curves, it may be necessary to introduce straights of a stated minimum length to ensure full overtaking sight distance is achieved.

The minimum radius of horizontal curves is a function of an inverse square of the angle of deviation ($R > 12/w^2$ where the angle of deviation $w < 1/8$). Additionally, the radius must exceed certain minimum values which are determined by the length of the adjoining straight. The minimum horizontal radius is also a function of design speed and superelevation and primarily derived from safety considerations.

Superelevation is applied below certain stated radii and is determined from the horizontal radius and design speed. The amount of superelevation is derived from limiting values of sideways friction which in turn vary with design speed. The maximum superelevation is 7 percent.

Transition (clothoid) curves must be used between curves of a constant radius and between straights and constant radius curves.

Requirements for sight distance for both stopping and overtaking (passing) are stated. The stopping sight distance is a function of design speed, longitudinal gradient and skidding resistance (which is in itself a function of speed). It includes a perception and reaction time of 1 sec. Two different object heights are used, one for moving objects and a lower one for fixed objects. The overtaking sight distance is notionally derived from design speed, the difference between design speed and the speed of overtaken vehicle and the average length of the two vehicles, but a relationship is given which is solely a function of design speed. A "reduced" distance which is half the full overtaking distance may also be used. On dual carriageways, the requirement for forward visibility is either the stopping sight distance or the reduced overtaking sight distance, whichever is greatest. On single carriageways (two-lane roadways) forward visibility is twice the stopping sight distance where overtaking is not allowed and the full overtaking sight distance where it is. Signing is required where overtaking is not allowed.

Crest curve radii are designed to ensure that the relevant requirement for forward visibility is met along the vertical curve. For sag vertical curves, the designer is advised to use radii close to those required for crest curves although in exceptional cases, the use of a lower minimum radius which will guarantee night time visibility using headlamps is permissible.

Maximum longitudinal gradients depend upon the type of road and range from 5 to 12 percent.

**South Africa**

South African geometric design policy for rural roads is published by the Committee of State Road Authorities (*13*). Early policy was based largely on U.S. practice, but over the years it has been modified to better reflect local conditions. The policy is based upon a classical implementation of the design-speed concept. No formal checks are specified on operating speeds or speed consistency.

With respect to horizontal alignment, South African policy maximum superelevation rates as a function of the road type: 0.06 for urban freeways, 0.08 for rural freeways, 0.10 for rural dual carriageways. These rates, combined with maximum side friction factors, yield a minimum radius of curvature for various design speeds. Superelevation rates are also specified for curves with above-minimum radius, using a similar method for distributing superelevation as specified by AASHTO in the United States.

Transition curves (clothoid) are recommended for circular curves requiring a superelevation rate at least 60 percent of the maximum. Compound curves are considered acceptable as long as the ratio of the larger to smaller radius is less than 1.5. With respect to vertical alignment, guidelines are provided for maximum grade as a function of design speed and topography. Minimum rates of vertical curvature (from which are derived minimum curve lengths) are specified for crest curves (based upon stopping sight distance requirements) and for sag curves (based upon headlight illumination distances).

**Sweden**

Geometric design policy in Sweden is developed and maintained by the Swedish National Road Administration (Vägverket) with research support from the Swedish Road and Traffic Research Institute (Väg-och Trafik-Institutet, or VTI). The Administration prepared an English translation of the current edition of their geometric design guidelines, entitled "Standard Specifications for Geometric Design of Rural Roads" (Trafikleder på Landsbygd), which is dated 1986 (*14*). Bergh and Carlsson (*15*) report on new guidelines published in 1994 which elaborate on the combined choice alignment and cross section for rural highways.

The appropriate design speed is based upon land-use intensity (urban or rural) and the roadway classification (national roads, principal, secondary, or tertiary country roads). However, "In determining geometrical minimum elements, it has been taken into consideration that speeds higher than the actual design speed often occur. Therefore the speed selected for the respective design speeds is that which survey results indicate 85 percent of drivers can be expected to be under" (*14*). This consideration is reflected in the design guidelines through two sets of standards: regular minimum and exceptional minimum. The regular minimum is based upon the 85th percentile speed associated with the design speed, whereas the exceptional minimum is based upon driving at the speed limit.

For horizontal curve radius, minimum and exceptional minimum values are specified for design speeds of 50, 70, 90, and 110 km/h. Superelevation rates are selected among three values (5.5, 4.0, and 2.5 percent). Radii sufficiently long that normal cross slope can be maintained are also specified.

Swedish policy encourages the use of transition curves (clothoids), except for curves exceeding specified radii. Transition curve length increases as radius decreases.

With respect to vertical alignment, guidelines are provided for maximum longitudinal grade (6 percent, typically, and 8 percent under exceptional cases), and maximum oblique grade for superelevated horizontal curves on grade, which reflects special concern with slow-moving or stationary vehicles on icy pavement. Vertical curves are parabolic, and minimum radii are specified for crest curves (based upon stopping sight distance requirements) and sag curves (based upon nighttime headlight sight distance requirements).

The new guidelines (*15*) consider tradeoffs between roadway alignment and cross section. For roadways with 90 and 110 km/h speed limits, either normal (9 m) or wide (13 m) cross sections may be considered. The normal cross section is recommended for lower volumes (less than 2,500 vehicles per day) and the wide cross section for higher volumes (greater than 8,000 vehicles per day). For intermediate volumes, economic comparisons must be made between normal cross sections with upgraded sight distance designs and the wide cross section.

**Switzerland**

Alignment design policy in Switzerland is embodied in a series of norms (*16*). The policies are developed by committees of the Swiss Association of Road Specialists (Vereinigung Schweizerisher Straßenfachleute) consisting of both researchers and practitioners.

Swiss alignment design policy incorporates consideration of two speeds: design speed and project speed. The design speed is based upon the road type and urban versus rural location and is used to establish minimum radius of horizontal curvature and maximum grades. The project speed is the maximum speed at which individual elements can be safely traversed; it is used in evaluating speed consistency along alignments and to establish superelevation and sight distance requirements.

The Swiss speed consistency procedure originated more than 30 years ago and is detailed in Swiss Norm 640 080b (*16*). The procedure estimates the speed profile along an alignment and identifies excessive speed differentials between successive elements. The procedure is applied to rural highways only. The original procedure considered the effects of both horizontal curve radius and vertical grade. Research in the late 1970's indicated, however, that grade up to 6 to 7 percent had no influence on passenger-car operating speeds. Therefore, in the current version of the procedure, speeds are estimated based upon only the horizontal alignment.

The speed profile is estimated based upon three pieces of information: speed on horizontal curves, maximum speed on tangents, and deceleration and acceleration rates entering and exiting horizontal curves.

Originally, the speed profile represented observed 85th percentile speeds. The most recent data, however, indicate that speeds have increased on sharper curves (i.e., radii less than 400 m), and there has been a corresponding increase in accident experience. Instead of modifying the speed-radius relationship to reflect these new data, the Swiss decided to retain the old relationship and use it as a standardized speed that they consider safe rather than as the 85th percentile speed. The speeds used for long tangents in the speed profile are the national speed limits for different classes of roadways. The national speed limits were recently reduced. This change was incorporated into the current version of the procedure, which made it necessary to change the definition of an excessive speed differential.

Prescribed acceleration and deceleration rates (0.8 m/s$^2$) are used to estimate the speed profile on the tangents between curves. It is assumed that acceleration occurs immediately upon departing a curve and that deceleration commences a sufficient distance in advance of a curve so that vehicles can decelerate at the prescribed rate to the prescribed speed on curves.

The speed profile for a roadway should satisfy three conditions (*16*):

1. If the preceding element is a tangent or a large-radius curve ($\geq$ 420 m), then the speed differential to the succeeding curve should not exceed 5 km/h. This condition is new to the latest version of the procedure. It was introduced because more problems have been observed at curves following a long tangent than at curves following a sequence of curves.
2. In a sequence of curves, the speed differential should be $\leq$ 10 km/h. Differentials $\geq$ 20 km/h must be avoided.
3. The existing sight distance should equal or exceed the length of transition required to change speed at a rate of 0.8 m/s$^2$ between successive curves.

There is little new roadway construction in Switzerland; therefore, the procedure is applied primarily to existing roadways. If any of the three conditions is violated, accident experience on the roadway is checked. If there is an accident problem, action is taken to correct the violation.

The maximum superelevation rate for rural roadways is seven percent. For above-minimum radius curves, the superelevation rate decreases approximately linearly with increasing radius, up to a radius where normal cross slope may be maintained.

Swiss guidelines call for the use of transition curves (clothoids), except for curves whose radii are longer than specified values. Transition curve length increases with decreasing radius. Guidelines are provided on the use of transition curves between tangents and circular curves as well as in compound and reverse curve combinations.

With respect to vertical alignment, guidelines are provided on maximum grade (as a function of design speed) as well as minimum radius of crest and sag vertical curves (based upon sight distance requirements).

**United Kingdom**

UK geometric design standards for national roads are set out in the Design Manual for Roads and Bridges for which the lead organization is the Highways Agency, an executive agency of the English Department of Transport. The current UK standard for alignment is TD9/93, which is based upon principles first established in 1981 (*1*).

For rural roads, the design speed is based upon the actual 85th percentile speed for light vehicles in the wet and is determined from the "bendiness," forward visibility (single carriageways only), carriageway and verge widths, and the number of access points and junctions of a particular road taken over a minimum distance of 2 km. (Bendiness is a measure of the angle through which the road turns over a distance of 1 km.) It should be noted that the UK uses values for various design parameters (horizontal radius, stopping sight distance, etc.) which give a consistent speed along the road.

For urban roads, the design speed is determined by the appropriate speed limit.

The design speed is used to calculate "desirable minimum" values for the various design parameters such as horizontal radius and stopping sight distance. These are the values which produce a high standard of safety and the designer's initial objective should be to meet desirable minimum values.

In the UK there is a fixed relationship of $\sqrt[4]{2}$ between the 50th percentile, 85th percentile, and the 99th percentile speeds. The design speeds are structured such that the 85th percentile parameter values for a particular design speed would be appropriate for the 99th percentile speed for the next lower design speed and the 50th percentile speed for the next higher design speed. For example, the horizontal radius for a 100 km/h design speed would accommodate 99 percent of the traffic if the actual design speed were 85 km/h and 50 percent of the traffic if the actual design speed were 120 km/h.

This structured system of design speeds enables the UK to adopt a flexible approach to design and affords the opportunity to use values below desirable minimum when to do so would result in significant cost savings and/or environmental benefits and there is no significant effect on safety and operation. The design process is therefore an iterative one.

The UK has two different requirements for forward visibility (sight distance). On both single and dual carriageways, adequate forward visibility is required to enable a driver to see an object on the carriageway and stop safely in the wet. On single carriageways it is necessary to provide lengths of carriageway where a driver can safely overtake (overtaking sections). At the start of these sections, forward visibility will be such that the driver can see vehicles sufficiently far ahead to be able to complete the overtaking maneuver (full overtaking [passing] sight distance). Certain horizontal radii can produce situations where forward visibility is such that it is unclear to the driver whether it is safe to overtake. The use of such radii is not recommended. Thus on horizontal curves on single carriageways, the driver should either be able to see sufficiently far ahead that it is clear it is safe to overtake or, alternatively, visibility should be so restricted that he/she will not overtake.

Values of superelevation are determined by the lateral acceleration which is comfortable to the driver. At desirable minimum values the driver traveling at design speed experiences a lateral acceleration which is half the maximum level of comfort. At radii below desirable minimum, the superelevation is increased to an arbitrary maximum and the maximum comfortable acceleration for a driver traveling at design speed is attained when the radius is equivalent to the desirable minimum value for a design speed two steps below the actual design speed. Superelevation at desirable minimum radius is 5 percent; at smaller radii the superelevation is increased to a maximum of 7 percent.

Transition curves (clothoids) are required to limit the rate of increase of centripetal acceleration when approaching a horizontal curve. Superelevation is applied on or within the transition.

For crest vertical curves, desirable minimum values are determined by the need to provide adequate forward visibility (stopping sight distance) although if values below desirable minimum are to be used, comfort may be a consideration, particularly at lower design speeds.

For sag vertical curves, the values are determined by comfort criteria for design speeds of 85 km/h and above and by headlight visibility (i.e., the distance illuminated by headlamps) for speeds of 70 km/h and below.

Desirable minimum gradients are 3 percent for motorways, 4 percent for other dual carriageways, and 6 percent for single carriageways. Steeper gradients of up to 8 percent may be used where consideration has been given to the savings in construction costs compared to the increase in journey times.

### United States

AASHTO publishes *A Policy on Geometric Design of Highways and Streets* which is the basis for geometric design policy in the United States (*4*). Many states develop their own geometric design manual, but all states closely conform with AASHTO policy. The most recent update is the 1994 metric version.

Alignment design policy is based upon a classical implementation of the design-speed concept. Minimum design speeds are recommended based upon roadway functional class (local, collector, arterial), land use (urban or rural), and terrain. Policy presumes that drivers will maintain and not exceed the selected design speed. As a result, there are no formal checks to ensure compatibility between the design speed and estimated operating speeds.

With respect to horizontal alignment, the policy specifies minimum radii for various design speeds and for maximum superelevation rates ranging from 4 to 6 percent for urban areas to 8 to 12 percent for rural areas. Superelevation rates for curves with radii larger than minimum are specified based upon a parabolic relationship (referred to as Method 5 by AASHTO); it is presumed that this method for distributing superelevation rates (and corresponding side friction factors) over the range of curve radii ensures speed consistency along an alignment. Growing recognition in the United States of disparities between design speed and operating speeds is leading to consideration of operating speed and speed consistency evaluations such as have been implemented in Australia, France, Germany, and Switzerland (*2*).

U.S. policy encourages but does not require the use of transition curves (clothoids). Transition curve lengths increase with increasing design speed and with decreasing radius. An assumed rate of change of centripetal acceleration also influences the length calculation.

With respect to vertical alignment, guidelines are provided for maximum grades (as a function of roadway functional classification, terrain, and design speed) and minimum grade (based upon drainage requirements). Vertical curves are parabolic, and guidelines are provided for minimum rate of vertical curvature (i.e., the minimum length of curve per percent change in grade), which is equivalent to the radius used in many countries. Minimum crest (convex) vertical curve lengths are generally governed by stopping sight distance; lengths required to provide passing (overtaking) sight distance are reported but considered impractical. Minimum sag (concave) vertical curve lengths are governed by headlight sight distance to provide adequate stopping sight distance at night.

## QUANTITATIVE COMPARISON OF DESIGN PARAMETERS

This section provides a quantitative comparison of selected horizontal and vertical alignment design parameters. Horizontal alignment parameters include maximum superelevation rate, maximum coefficient of side friction, and the resulting minimum radius of horizontal curves. Vertical alignment parameters include maximum grade and minimum radius of crest (convex) and sag (concave) vertical curves. The data come either directly from countries' design guidelines or indirectly from reviews of design guidelines (*2,3*).

### Horizontal Alignment

*Maximum Superelevation Rate*

Table 1 summarizes and Figure 1 illustrates the maximum superelevation rate(s) for rural roadways in 19 countries. Most countries have a single nationwide maximum rate, some of which are supplemented by a higher rate for exceptional cases. Maximum rates are limited by the risk of stationary vehicles sliding on icy or frozen pavement surfaces. In the largest countries (e.g., Australia, Canada, and United States), which have wide ranges of climate, individual States or Provinces may select their own maximum rates, and therefore a range of rates is indicated.

Most countries' normal maximum rate falls within the range of 6 to 8 percent. Sweden uses a maximum rate of 5.5 percent. A maximum rate of 10 percent is used in Japan, on certain road types in South Africa, in mountainous terrain in Australia, and in rural areas not subject to ice and snow in the United States. A maximum rate of 12 percent is used for

**TABLE 1 Maximum Superelevation Rates in Various Countries**

| Country | Maximum Superelevation Rates (Percent) | Comments |
|---|---|---|
| Australia | 6 - 12 | Varies among State road authorities and by terrain. Most authorities use 10 %, some 12% in mountainous terrain. In flat terrain, 6 to 7 % is common. |
| Austria | 6 - 7 | |
| Belgium | 6 | |
| Canada | 6 - 8 | |
| France | 7 | |
| Germany | 7, 8 | 8 % is used only in exceptional cases |
| Greece | 6 - 9 | 6 % for suburban roads, 7 % in hilly and mountainous terrain, 8 % in level terrain, 9 % is used only in exceptional cases |
| Italy | 7 | |
| Japan | 10 | |
| Luxembourg | 5 - 6.5 | |
| Norway | 8 | |
| Portugal | 6 - 8 | |
| South Africa | 6 - 10 | 6 % for urban freeways and dual carriageway roads, 8 % for rural freeways, 10 % for rural dual carriageway and single lane roads |
| Spain | 7, 10 | 10 % is used only in exceptional cases |
| Sweden | 5.5 | |
| Switzerland | 7 | |
| The Netherlands | 5, 7 | 7 % is used only in exceptional cases |
| United Kingdom | 5, 7 | 5 % is the desirable maximum<br>7 % is the absolute maximum |
| United States | 8 - 12 | 8 % is general maximum in areas with ice and snow<br>10 % applies in areas with no ice or snow<br>12 % applies only in exceptional cases |

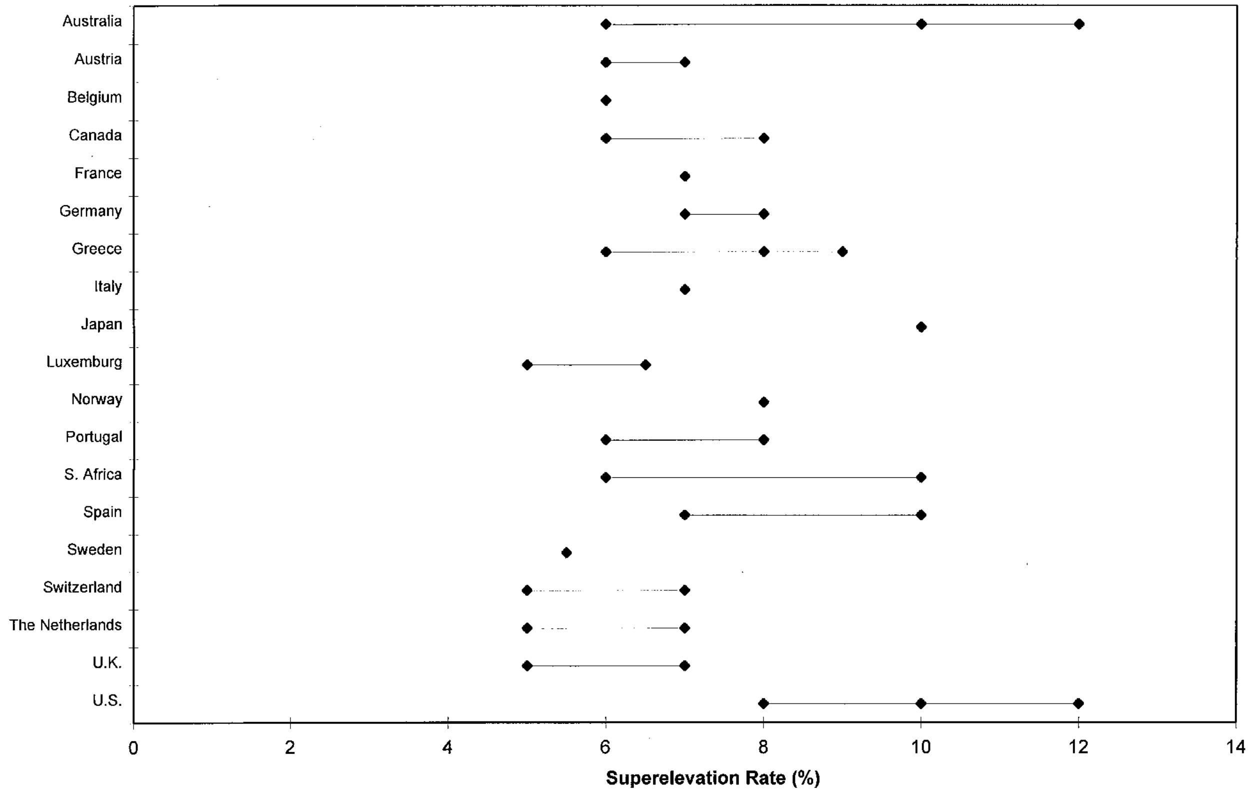


**FIGURE 1 Maximum Superelevation Rates in Various Countries**

**TABLE 2 Maximum Coefficients of Side Friction in Various Countries**

| Design Speed (km/h) | Coefficients of Side Friction | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Australia | Aust. | Bel. | Can. | Den. | Fr. | Ger. | Gr.[1] | Italy | Japan | Lux. | Neth. | Nor. | Port. | S. Afr. | Spain | Swed. | Swit. | U.K. | U.S. |
| 50 | 0.35 | | | 0.16 | | | | 0.16 | | 0.10 | | | 0.20 | | 0.16 | | 0.18 | 0.19 | 0.10 | 0.16 |
| 60 | 0.33 | 0.16 | 0.14 | 0.15 | | 0.17 | 0.14 | 0.15 | 0.17 | 0.09 | 0.17 | 0.15 | 0.18 | 0.16 | 0.15 | | | 0.17 | 0.10 | 0.15 |
| 70 | 0.31 | 0.14 | | 0.15 | | | 0.12 | 0.14 | 0.08 | | 0.16 | 0.08 | 0.16 | 0.13 | 0.15 | 0.08 | 0.15 | 0.15 | 0.10 | 0.14 |
| 80 | 0.26 | 0.14 | | 0.14 | | 0.14 | 0.11 | 0.13 | | 0.08 | 0.17 | | 0.14 | 0.12 | 0.14 | | | 0.14 | | 0.14 |
| 85 | | | | | | | | | | | | | | | | | | | 0.10 | |
| 90 | 0.18 | 0.13 | 0.10 | 0.13 | | | 0.10 | 0.12 | | | 0.13 | | 0.12 | | 0.13 | | 0.12 | 0.13 | | 0.13 |
| 100 | 0.12 | 0.12 | | 0.12 | | 0.12 | 0.09 | 0.11 | 0.13 | 0.07 | 0.15 | 0.10 | 0.10 | 0.09 | 0.13 | 0.10 | | 0.12 | 0.10 | 0.12 |
| 110 | 0.12 | 0.11 | | 0.10 | | | | 0.10 | | | 0.12 | | 0.08 | | 0.12 | | 0.10 | 0.11 | | 0.11 |
| 120 | 0.11 | 0.10 | 0.07 | 0.09 | | | 0.07 | 0.09 | 0.10 | 0.06 | 0.12 | 0.08 | 0.07 | 0.08 | 0.11 | 0.10 | | 0.10 | 0.10 | 0.09 |

(1) For Level Terrain. Different values apply for hilly and mountainous terrain.

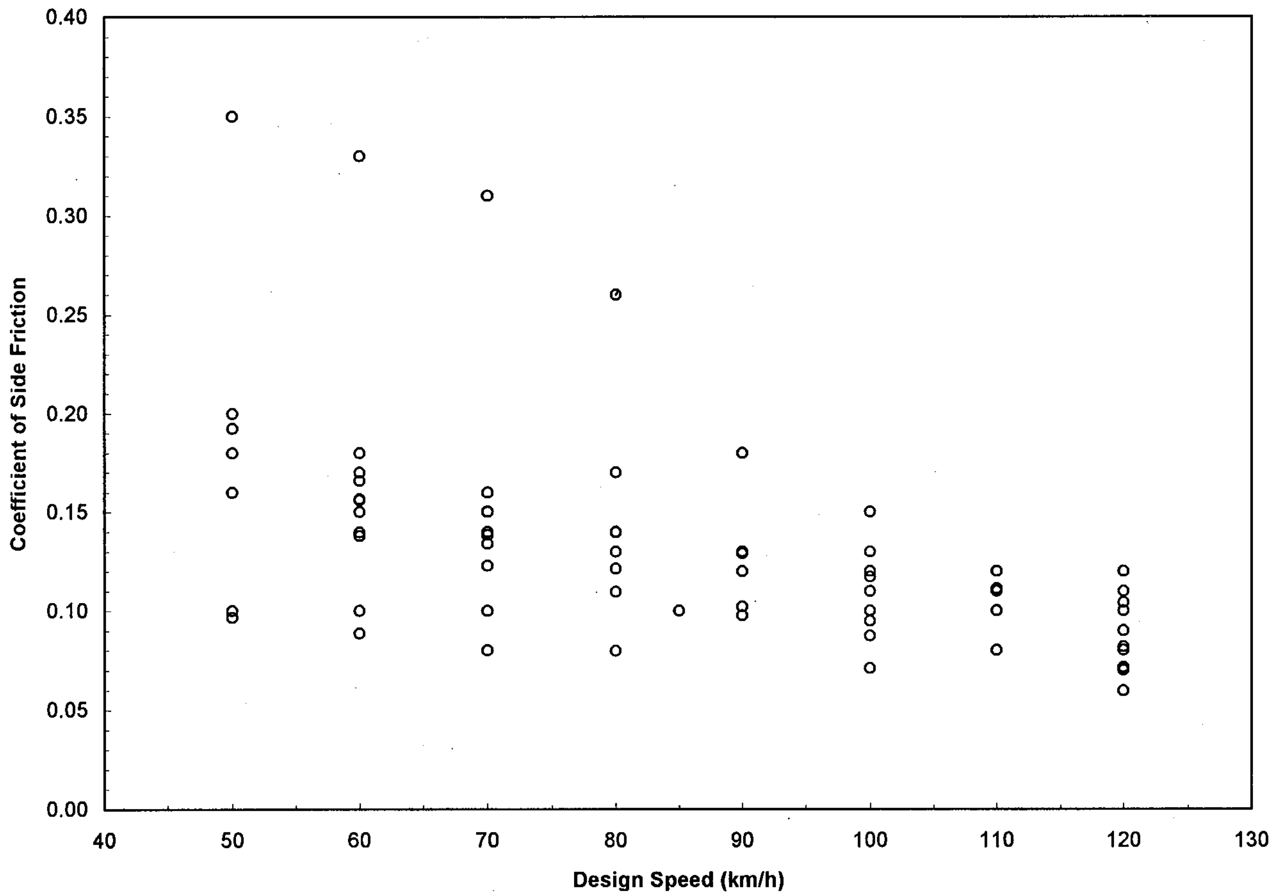


**FIGURE 2 Maximum Coefficients of Side Friction in Various Countries**

**TABLE 3 Minimum Radius of Horizontal Curvature as a Fraction of Design Speed in Various Countries**

| Design Speed (km/h) | Minimum Radius (m) | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Australia | Aust. | Bel. | Can. | Den. | Fr. | Ger. | Gr.(1) | Italy | Japan | Lux. | Neth. | Nor. | Port. | S. Afr. | Spain | Swed. | Swit. | U.K. | U.S. |
| 50 | 45 | | | 80 | | | | 80 | | 100 | | | | | 80 | | 160 | 75 | 127 | 80 |
| 60 | 70 | 125 | 130 | 120 | 120 | 120 | 135 | 125 | 120 | 150 | 120 | 130 | 110 | 120 | 110 | | | 120 | 180 | 125 |
| 70 | 95 | 185 | | 170 | 200 | | 200 | 180 | 250 | | 175 | 260 | 160 | 180 | 160 | 250 | 350 | 175 | 255 | 175 |
| 80 | 140 | 240 | | 230 | 280 | 240 | 280 | 250 | | 280 | 215 | | 230 | 250 | 210 | | | 240 | | 230 |
| 85 | | | | | | | | | | | | | | | | | | | 360 | |
| 90 | 230 | 320 | 350 | 300 | 380 | | 380 | 330 | | | 320 | | 320 | | 270 | | 500 | 320 | | 305 |
| 100 | 360 | 420 | | 390 | 500 | 425 | 500 | 420 | 400 | 460 | 370 | 450 | 430 | 450 | 350 | 450 | | 420 | 510 | 395 |
| 110 | 435 | 525 | | 530 | | | | 530 | | | 525 | | | | 430 | | 625 | 525 | | 500 |
| 120 | | 650 | 750 | 670 | 800 | | 800 | 650 | 650 | 710 | 600 | 750 | | 700 | 530 | 650 | | 650 | 720 | 665 |

(1) For level terrain. Different values apply for hilly and mountainous terrain.

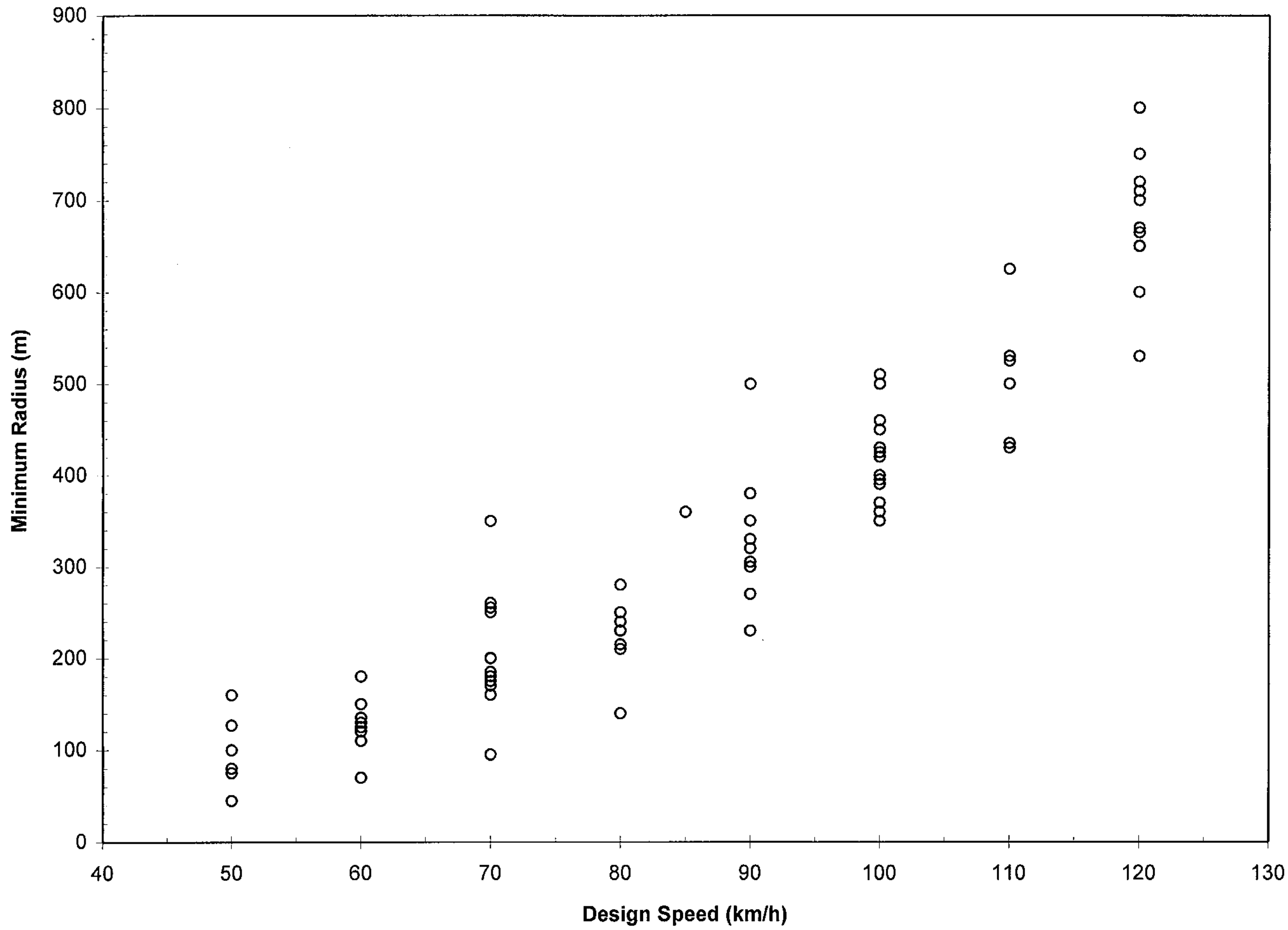


**FIGURE 3 Minimum Radius of Horizontal Curvature as a Function of Design Speed in Various Countries**

mountainous terrain in some States in Australia and may be used under special circumstances in the United States.

*Maximum Coefficient of Side Friction*

Maximum coefficients of side friction (sideways friction) or lateral acceleration rates are specified for driver safety and/or comfort. Table 2 summarizes and Figure 2 illustrates the maximum coefficients of side friction in various countries. Many countries do not report the values used. Where possible, values were calculated from their minimum radius for a given design speed and their maximum superelevation rate. Two groups of values can be observed. Many countries values range from 0.16-0.18 for a 50 km/h design speed to 0.09-0.11 for a 120 km/h design speed. Some countries use higher values for low design speeds. For example, Australia uses values between 0.35 and 0.26 for 50 to 80 km/h roadways; these are the values drivers were observed to be accepting based upon their 85th percentile speeds on curves. Germany specifies side friction as a percentage of tangential friction used for stopping sight distance; for a given design speed on main rural roadways, their maximum side friction is 50 percent of their maximum tangential friction.

*Minimum Radius of Horizontal Curvature*

Table 3 and Figure 3 summarize minimum radius of horizontal curvature as a function of design speed in various countries. These values are a product of maximum superelevation rates and maximum coefficients of side friction. For a 60 km/h design speed, for example, most countries' minimum radius is between 120 and 130 m. Exceptions include Australia, whose value is 70 m, based

**TABLE 4 Minimum Radius (K-Value) of Crest (Convex) Vertical Curvature as a Function of Design Speed in Various Countries**

| Design Speed (km/h) | Austral. | Bel. | Can. | Fr. | Ger. | Gr. | Italy | Japan | Neth. | Nor. | S. Afr. | Spain | Swed. | Swit. | U.K. | U.S. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 40 | | | 4 | | | | 5 | | | | 6 | | | 15 | | 5 |
| 50 | 5.4 | | 7 | | | 15 | | 8 | | | 11 | | 11 | 21 | 11 | 10 |
| 60 | 9.2 | 16 | 15 | 15 | 27 | 20 | 10 | 14 | | 8.2 | 16 | | | 30 | 19 | 18 |
| 70 | 15.7 | | 22 | | 35 | 27 | | | | 15 | 23 | | 35 | 42 | 33 | 31 |
| 80 | 24 | | 35 | 30 | 50 | 38 | 30 | 30 | 18 | 29 | 33 | 35 | | 60 | | 49 |
| 85 | | | | | | | | | | | | | | | 59 | |
| 90 | 42 | 75 | 55 | | 70 | 54 | | | | 44 | 46 | | 70 | 85 | | 71 |
| 100 | 63 | | 70 | 60 | 100 | 75 | 70 | 65 | 41 | 66 | 60 | 60 | | 125 | 105 | 105 |
| 110 | 95 | | 85 | | | 110 | | | | 98 | 81 | | 100 | 200 | | 151 |
| 120 | 135 | | 105 | 100 | 200 | 150 | 140 | 110 | 124 | 140 | 110 | 120 | | | 185 | 202 |

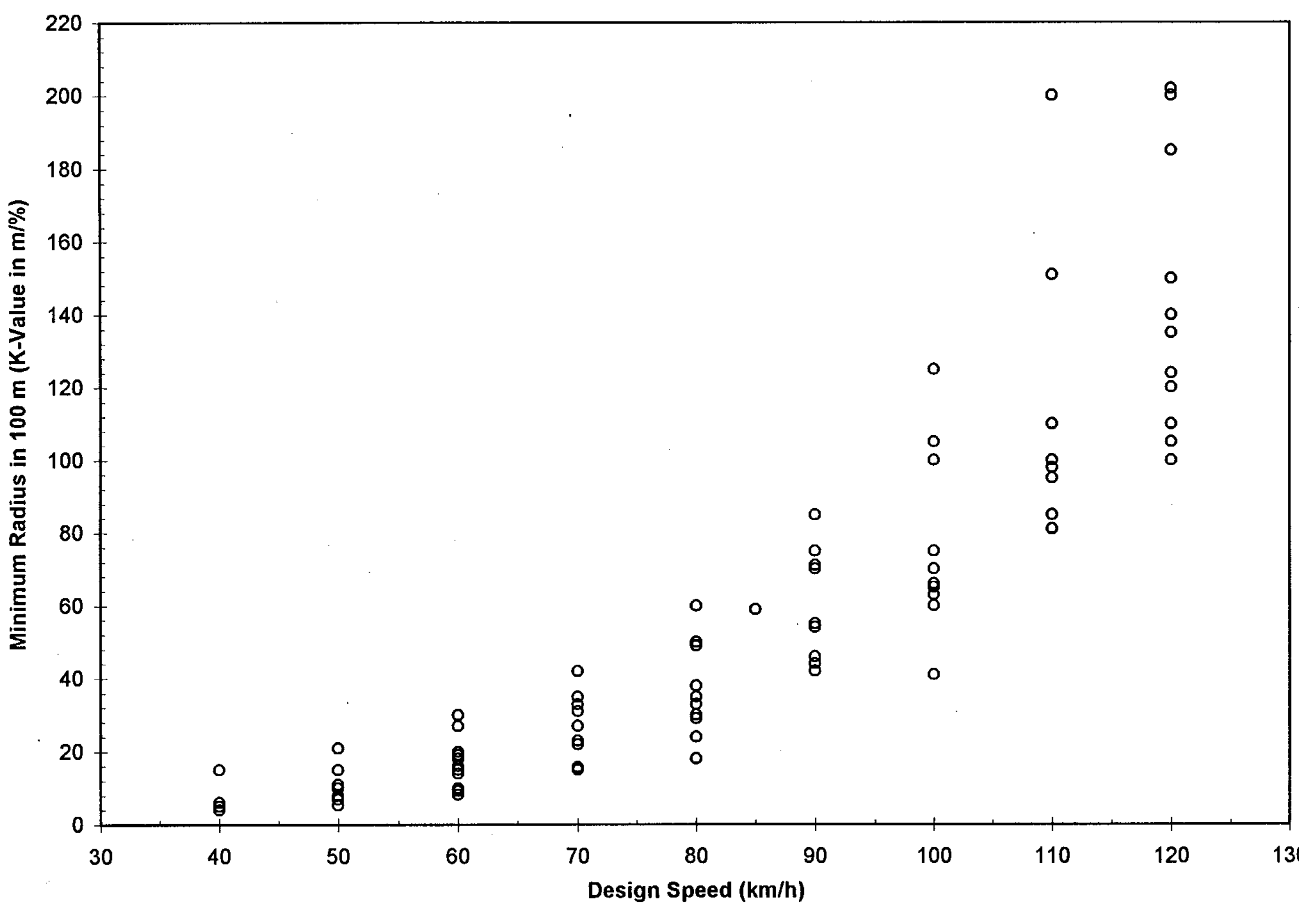


**FIGURE 4 Minimum Radius (K-Value) of Crest (Convex) Vertical Curvature as a Function of Design Speed in Various Countries**

upon higher observed side friction values, and several countries (Austria, Greece, Luxembourg, Portugal, and Spain) whose minimum radius is larger (160-185 m). For a 100 km/h design speed, minimum radius ranges between 350 and 510 m.

**Vertical Alignment**

*Maximum Gradient*

Maximum gradient guidelines range in complexity, with various countries considering some or all of the following factors: road type (or functional classification), design speed, and terrain. For example, in the United Kingdom, desirable-absolute maximum gradient values are specified for road types: motorway (3-6 percent), dual carriageway (4-8 percent), and single carriageway (6-8 percent). In Switzerland, maximum gradient is a function of design speed (from 10 percent for a 60 km/h design speed to 4 percent for a 120 km/h design speed). In Germany, maximum gradient is a function of road type and design speed; for main rural roads, values range from 8 percent for 60 km/h to 4 percent for 120 km/h. In South Africa, maximum gradients are based upon design speed and topography; in flat terrain maximums range from 6 to 3 percent for 60 to 120 km/h design speeds, in rolling terrain 7 to 4 percent and in mountainous terrain 8 to 5 percent for the same design speed range. In the United States, maximum gradients are based upon road type, topography, and design speed.

*Minimum Radius of Crest (Convex) Vertical Curves*

Most countries specify the use of parabolic vertical curves. They report a minimum radius for crest vertical curves to satisfy stopping sight distance requirements. This radius corresponds to the K-value, or rate of vertical curvature, which is used in several countries. Table 4 and Figure 4 summarize the minimum radii for various design speeds. For a 60 km/h design speed, the values range from 1000 to 3000 m; for a 100 km/h design speed, the range is 4100 to 12500 m; and for a 120 km/h design speed, the range is 10000 to 20200 m.

*Minimum Radius of Sag (Concave) Vertical Curves*

Table 5 and Figure 5 summarize the minimum radii of sag (concave) vertical curves for various design speeds. Sag vertical curves are generally considered less critical from a safety standpoint than crest vertical curves. Several different principles are applied as a basis for the design standards. Several countries base their values on headlight illumination distances to satisfy stopping sight distance requirements on unlit roadways at night. Other countries base their design values on driver comfort. In Germany, the minimum radius of sag vertical curves is one half the minimum radius of crest vertical curves at a given design speed. For a 60 km/h design speed, for example, the lower values (500-600 m) correspond to a comfort criterion, and the higher values (1500-2000 m) are based upon headlight illumination.

## GENERAL OBSERVATIONS ABOUT ALIGNMENT DESIGN POLICY AND PRACTICE WORLDWIDE

This review and comparison of alignment design policies throughout the world yielded some valuable insights. There are far more similarities than differences among the alignment design policies for the sample of countries reviewed. As expected, several interesting differences and unique approaches are likely to generate additional thought and discussion in many countries.

All countries use design speed as a basis for establishing limits for basic parameters (e.g., minimum radius of horizontal curvature and maximum vertical grade). A fundamental difference among countries is the speed used to establish other alignment parameters, including superelevation rates, sight distance, and rate (or radius) of vertical curvature. Some countries (e.g., Canada, South Africa, and the United States) follow the approach described by AASHTO, wherein the design speed is selected (based upon road type, land use, and terrain) and used as the basis for all other alignment parameters. This approach presumes that drivers will not exceed the design speed and, therefore, no formal checks of actual speed behavior are required. Other countries (e.g., Australia, France, Germany, Switzerland, and the United Kingdom) give more formal and explicit consideration of operating speeds and speed consistency among successive alignment features. Although the details vary, these countries estimate operating speeds (typically 85th percentile speeds) or a surrogate for operating speed (project speed in Switzerland) along the alignment, check for excessive differences between successive features, and iterate to reduce these differences to acceptable levels. They also typically use this operating speed measure (when it is greater than the design speed) for establishing superelevation rates and sight distance requirements (and corresponding vertical curvature parameters). The United Kingdom has a structured system of design speeds that are explicitly related to 99th, 85th, and 50th percentile speeds and uses an interactive approach to ensure operating speeds and design speeds are in harmony.

Minimum radius of horizontal curvature for a given design speed varies among countries. This range results from differences in maximum superelevation rates and maximum side friction coefficients (lateral acceleration). Most countries' maximum superelevation rates for rural roadways fall between 6 and 8 percent, but some are as high

**TABLE 5 Minimum Radius (K-Value) of Sag (Concave) Vertical Curvature as a Function of Design Speed in Various Countries**

| Design Speed (km/h) | Australia 1 | Australia 2 | Bel. | Can. | Fr. | Ger. | Gr. | Italy | Japan | Neth. | Nor. | S. Afr. | Spain | Swed. | Swit. | U.K. | U.S. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 40 | 3 | | | 7 | | | | 5.5 | | | | 8 | | | 8 | | 8 |
| 50 | | 17 | | 11 | | | 13.5 | | 7 | | 6.5 | 12 | | 14 | 12 | 13 | 12 |
| 60 | 6 | 28 | 5.5 | 20 | 15 | 15 | 19 | 12 | 10 | 5.5 | 9.3 | 16 | | | 16 | 20 | 18 |
| 70 | | 48 | | 25 | | 20 | 25 | | | | 12.7 | 20 | | 28 | 25 | 20 | 25 |
| 80 | 10 | 74 | | 30 | 22 | 25 | 33 | 22 | 20 | 10 | 16.5 | 25 | 25 | | 35 | | 32 |
| 85 | | | | | | | | | | | | | | | | 20 | |
| 90 | | 131 | 12.5 | 40 | | 35 | 42 | | | | 20.9 | 31 | 35 | 45 | 45 | | 40 |
| 100 | 16 | 150 | | 50 | 30 | 50 | 52 | 39 | 30 | 15 | 25.8 | 36 | | | 60 | 26 | 51 |
| 110 | | | | 55 | | | 63 | | | | 31.2 | 43 | | 55 | 80 | | 62 |
| 120 | 23 | | 22 | 60 | 42 | 100 | 75 | 58 | 40 | | 37.1 | 52 | 50 | | | 37 | 73 |

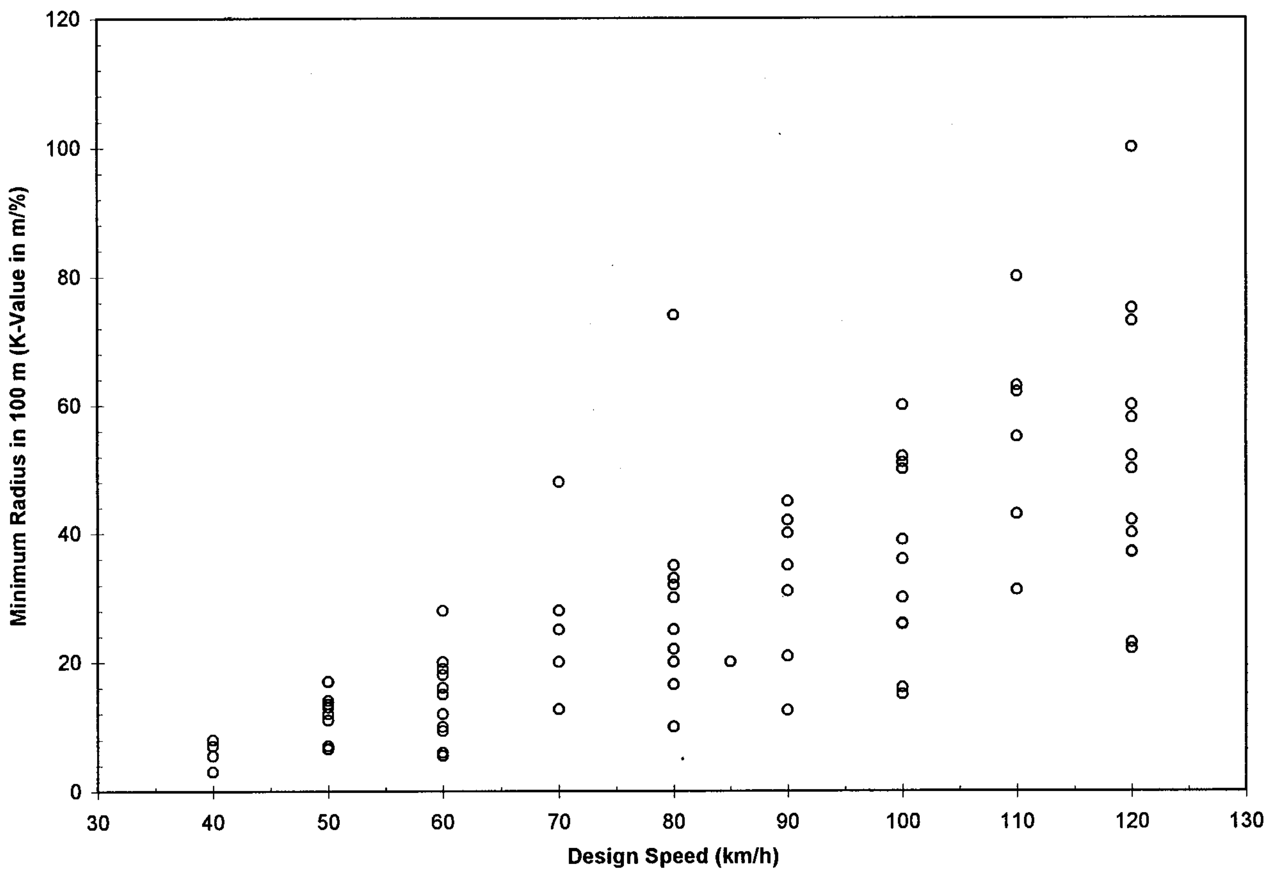


**FIGURE 5 Minimum Radius (K-Value) of Sag (Concave) Vertical Curvature as a Function of Design Speed in Various Countries**

as 10 percent (or 12 percent for exceptional cases). Countries apply margins of safety to different aspects of their design guidelines. For example, Japan has a relatively high maximum superelevation rate (10 percent) but relatively low side friction coefficients. Australia's minimum radii for design speeds ≤ 90 km/h are lower than for most countries, but these radii are based upon relatively precise estimates of 85th percentile speeds and observed side friction coefficients. Values for individual parameters must be evaluated within the context of a country's overall design policy, which demands considerable care in making comparisons.

Most, but not all, countries specify superelevation rates for curves with above-minimum radii. Several countries use a linear relationship between superelevation and radius. Canada, South Africa, and the United States use a more complex parabolic relationship. Sweden uses only three superelevation rates.

A common concern is the relative dimensions of successive horizontal alignment elements. Several countries (Australia, Germany, and Switzerland) estimate speed profiles along alignments and have guidelines based upon acceptable speed reductions between successive features. Several countries provide quantitative guidelines on the relationship between the radii of successive horizontal alignment elements. Most countries have guidelines on the radii of compound curves, a ratio of 1.5 to 1 is common. Other guidelines for the radii of compound curves are related to speed. France, Germany, and Italy have guidelines on the minimum radii following long tangents. Germany has a comprehensive guideline indicating acceptable and unacceptable ranges of radii for successive features.

Most countries require the use of transition curves (clothoids) from tangents to most curves and between successive curves. Exceptions are made for certain curves following tangents. These exceptions are stated in various ways: for example, curves not requiring superelevation (France), curves requiring superelevation less than 60 percent of the maximum rate (South Africa), or curves with radii longer than specified values (various countries). Some countries, such as the United States, encourage but do not require the use of transition curves. In most countries, transition curve lengths decrease with increasing radius of the subsequent circular curve. France uses a different philosophy, wherein the length decreases with decreasing radius, such that a higher rate of change of centripetal acceleration alerts the driver of a sharper curve.

With respect to vertical alignment, maximum gradient guidelines vary in structure but result in similar maximum values. For higher type roadways (motorways or freeways) with higher design speeds (100-120 km/h), maximum gradients of 3 to 4 percent are typical. For lower type roadways (two-lane or single carriageway) with lower design speeds (60 to 80 km/h), maximum rates of 6 to 8 percent are typical. In several countries, gradients in more rolling and mountainous terrain may be 1 to 2 percent steeper. Vertical curves are typically parabolic in shape. Crest (convex) vertical curve radii (K-values in some countries) are based upon stopping sight distance requirements. Two different criteria for minimum sag (concave) vertical curve radii are prevalent; some countries use stopping sight distance, whereas other countries use less stringent comfort criteria.

For freeways (motorways) and other multilane divided highways (dual carriageways), curvilinear alignments are preferred to conform with the terrain for cost and environmental reasons. For rural two-lane roadways (single carriageways), some countries (e.g., Germany) call for curvilinear alignments to assure operating speed consistency; whereas other countries place greater emphasis on passing (overtaking), which generally leads to segments with longer tangents (straights). Several countries (including France and the United Kingdom) have observed safety problems associated with marginally adequate passing (overtaking) sight distance and have adapted their alignment guidelines to avoid this condition. The United Kingdom avoids certain ranges of horizontal and vertical curve radii, so that passing sight distance is either adequate or clearly inadequate.

Various provisions are made for dealing with exceptional cases. For example, several countries permit higher maximum superelevation rates. Several countries integrate consideration of climbing lanes as an alternative in vertical alignment design to permit go-with-the-ground designs that avoid costly earthwork but maintain desirable traffic operations. The United Kingdom has perhaps the most systematic approach for dealing with departures from standards (design exceptions), wherein a given design speed corresponds to the 85th percentile speed on a roadway with that design speed, the 99th percentile speed on a roadway with the next lower design speed, and the 50th percentile speed on a roadway with the next higher design speed. As considerations involving impacts on natural and manmade environments become more important, so too will policies for dealing with exceptions. In closing, several issues seem particularly fertile for fruitful discussions among a worldwide audience:

- Considering the move toward more detailed checking of design for both individual elements and for consistency between adjacent elements: What are the most effective methods to predict and accommodate actual operating speeds along proposed alignments? What factors influence which methods work best in a particular country?
- Considering the interrelationships among horizontal and vertical alignment and roadway cross section: What are the tradeoffs between flowing alignments

for operating speed consistency and requirements for overtaking (passing) sight distance? What are effective methods for considering tradeoffs between alignment (e.g., maximum longitudinal grade) and cross section with respect to the cost and operational efficiency of designing to satisfy overtaking demands and to minimize the operational effects of heavy vehicles on grade?

- Considering the variability among maximum superelevation rates and maximum side friction coefficients: What are the safety and operational impacts of alternative maximum superelevation rates and maximum side friction coefficients?
- Considering differences in transition curve length design among countries: What insight does worldwide safety and operational experience provide concerning when transition curves should be used and the extent to which transition curve length increases with decreasing radius?
- Considering the increasing constraints within which roadway geometry is designed: What are appropriate and effective elements of policies for considering exceptions to design policy?

Unique combinations of topography, climate, driving behavior and culture, motor vehicle rules and regulations, vehicle characteristics, and traffic volumes preclude a single set of parameter values or policies working equally well in all countries. In dealing with these issues, however, individual countries can benefit from an understanding and appreciation of the practices and experiences in other countries. An ongoing interchange of ideas, policy evaluations, and research results among countries is recommended.

## REFERENCES


1. *Road Layout and Geometry: Highway Link Design.* Departmental Standard TD 9/93, and Advice Note TA 43/84, Department of Transport, London, England, 1993 and 1984.
2. Krammes, R.A., R.Q. Brackett, M.A. Shafer, J.L. Ottesen, I.B. Anderson, K.L. Fink, K.M. Collins, O.J. Pendleton, and C.J. Messer. *Horizontal Alignment Design Consistency for Rural Two-Lane Highways.* Report FHWA-RD-94-034. FHWA, U.S. Department of Transportation, 1995.
3. Durth, W. and C. Lippold. *Adjustment of the German Design Guidelines for the Alignment (RAS-L-1, 1984) to Newer Design Guidelines.* English Translation by R. Lamm. Technical University of Darmstadt, Darmstadt, Germany, 1993.
4. *A Policy on Geometric Design of Highways and Streets.* AASHTO, Washington, D.C., 1994.
5. *Rural Road Design: Guide to the Geometric Design of Rural Roads.* AUSTROADS, Haymarket, New South Wales, Australia, 1989.
6. *Characteristiques Routieres et Autouroutieres.* Ministere Waloon de L'Equipment et des Transports, Bruxelles, Belgium, 1991.
7. *Manual of Geometric Design Standards for Canadian Roads.* Transportation Association of Canada, Ottawa, Ontario, Canada, 1986.
8. *Instruction sur les Conditions Techniques D'Aménagement des Routes Nationales.* Ministère de L'Èquipement et du Logement, Paris, France, 1975.
9. *Amenagement des Routes Principales: Recommandations Techniques pour la Conception Génèrale et la Géomètrie de la Route.* Service d'Etudes Techniques des Route et Autoroutes, Paris, France, 1994.
10. *Richtlinien für die Anlage von Straßen (RAS); Teil: Linienführung (RAS-L); Aufschnitt 1: Element der Linienfürung (RAS-L-1).* Forschungsgesellschaft für Strassen- und Verkehrswesen, Cologne, Germany, 1984.
11. Lamm, R. and J.G. Cargin. Translation of the "Guidelines for the Design of Roads (RAS-L-1)," Edition 1984, Federal Republic of Germany. Clarkson University, Clarkson, NY, May 1985.
12. *Norme sulle Caratteristiche Geometriche delle Strade Extaurbane.* Consiglio Nazionale Delle Ricerche, Rome, Italy, 1980.
13. *Geometric Design of Rural Roads.* Draft TRH 17, Committee of State Road Authorities, Pretoria, South Africa, 1984.
14. *Standard Specifications for Geometric Design of Rural Roads.* English Translation of *Trafikleder på landsbygd.* Swedish National Road Administration, Borlänge, Sweden, 1986.
15. Bergh, T., and A. Carlsson. "Design Criteria and Traffic Performance Research in New Swedish Guidelines on Rural Highways." International Symposium on Highway Geometric Design Practices, Boston, Massachusetts, USA, August 1995.
16. Swiss Norm 640 080b, 100, 105, 110, 123a, 138a, 140, 141, 145, and 198. Vereingung Schweizerischer Strassenfachleute, Zurich, Switzerland, various dates.