AN ALTERNATIVE TO THE DESIGN SPEED CONCEPT FOR LOW SPEED ALINEMENT DESIGN

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While the design speed concept originated from considerations of driver speed behavior, it is now treated as an arbitrary means of designing and matching geometric elements. The implicit assumption of a maximum uniform driving speed is examined in terms of Australian research into the relationships between driver speed behavior and alinement design. For alinements based on design speeds of 110 km/h or more, driver behavior appears to be in accord with the design speed concept. However, for alinements with design speeds between 90 and 110 km/h, driver speeds tend to vary according to the standard of individual features, but the speeds adopted on horizontal curves are generally below the curve design speed. For alinements with design speeds of 90 km/h or less, driver speeds vary along the route and are consistently in excess of the design speed. The results of the speed studies have been used to formulate an alternative approach for the alinement design of two-lane rural roads where topographic or financial difficulties preclude the adoption of design speeds greater than 90 km/h. The method is based on the estimation of a desired speed of travel as related to terrain classification and overall alinement standard. This is used to predict the speed behavior of drivers on individual horizontal curves as a function of the curve standard. This method provides quantification, in terms of driver speed behavior, of what represents a sub-standard curve relative to the overall alinement standard.

As indicated by Table 1, extremes in several demographic characteristics place Australia in a unique position with regard to rural roads and rural road transport. Roads and road transport play an important role in Australian economic and social activity, yet much of the primary highway network is carrying traffic volumes typical of what are regarded as low volume roads in many other countries. While a number of the more significant routes have been designated as National Highways and are being progressively upgraded to a high geometric standard, economics demand that much of the primary network remain at a relatively low geometric standard (single carriageway with constrained alinement).

Table 1. Summary Australian population, vehicle and road statistics (1972).

Country	Population (millions)	Population per sq.km	Motor Vehicles per 100 Population	Road Length per 100 Population (km)
Australia	13.1	1.7	40.3	6.6
U.S.A.	208.8	22.3	56.7	2.9
Gt. Britain	54.2	235.6	26.7	0.6
Germany	62.0	248.0	28.4	0.7

Australian road authorities are confronted with the problem of designing roads for long distance, and often high speed, travel while only modest geometric standards can be afforded. The designers have been forced to look closely at the principles underlying geometric design practices, and this has led to a growing suspicion that the traditional design speed approach may not be appropriate for the design of the lower speed range alinements (1, 2). Accident studies suggested that horizontal curves had a considerable influence on the safety of traffic operations on such roads (3). Other studies revealed that, relative to other alinement properties, road curvature had the greatest influence on driver speed behavior (4).

These considerations caused the Australian Road Research Board (ARRB) to undertake a review of the design speed concept and its application to horizontal alinement design practice, and to carry out research into the relationship between horizontal alinement and driver speed behavior. The present paper summarizes the results of this research and the recommendations that have arisen from it. Full details of the work have been published in the project reports (5,6,7,8,9).

The Geometric Road Design Committee of the National Association of Australian State Road Authorities (NAASRA) played an active advisory and reviewing role during the course of this work and is currently examining the results and recommendations in conjunction with a revision of the NAASRA geometric design policy (10).

Evolution Of The Design Speed Concept

In the 1920s roads were located on long tangent sections as much as possible. The radii of the curves joining these tangents were determined solely by the topography and available funds. Little thought was given to the actual speeds at which vehicles might negotiate the curves, or to consistency in curve design. During the 1930s attention was given to the simple relationship between radius, superelevation, vehicle speed and centripetal force, resulting in a practice of superelevating curves to resist the total centripetal force for an assumed speed. While speed limits were low, the legal limit provided the assumed speed, but as limits were raised it became apparent that some alternative approach to design was required.

Barnett(11) provided the first formal definition of design speed and the design speed concept. Following field trials on road curves by volunteer subjects conducted by the Bureau of Public Roads, Barnett recommended that superelevation be designed to counteract the centripetal force for 0.75 of the assumed design speed, relying on side-friction to supply the remaining horizontal resistance. He defined the assumed design speed as:

> 'the maximum reasonably uniform speed which would be adopted by the faster driving group of vehicle operators, once clear of urban areas'.

While his design speed approach was developed specifically for determining design values for curve radius and superelevation, Barnett argued that all features of geometric design should be made consistent with the chosen design speed with a view to achieving balanced design.

The American Association of State Highway Officials (AASHO) gave official endorsement to the design speed concept in its 1938 'Policy on Highway Classification' (12). This policy defined design speed as:

> 'the maximum approximately uniform speed which probably would be adopted by the faster group of drivers but not, necessarily, by the small percentage of reckless ones'

The publication of AASHO's 'Policy on Geometric Design of Rural Highways' (13, 14) saw the design speed concept as it is known today. Here design speed is defined as:

> 'a speed used for the design and correlation of the physical features of a highway that influence vehicle operation'

and as

> 'the maximum safe speed that can be maintained over a specified section of highway when conditions are so favourable that the design features of the highway govern'

While these publications realized 'balanced design' as envisaged by Barnett, with minimum standards for all design elements being related to the chosen design speed, it shifted the design speed concept itself away from the behavioural measure proposed by him. Design speed is no longer the speed adopted by 'the faster driving group of vehicle operators', but has become a design procedural value used for the 'design and correlation' of design elements which is also a 'maximum safe speed'. This shift in interpretation has an important bearing on the subsequent development of this paper.

Australian road authorities have tended to follow American geometric road design practices. NAASRA (10) employs the design speed concept in much the same way as AASHO, with design speed being defined as the speed at which a vehicle can travel:

> 'without being exposed to hazards arising from curtailed sight distance, inappropriately superelevated curves, severe grades or pavements too narrow to accommodate the design volume'

Critique Of Current Alinement Design Practice

Design Speed Concept

While most Australian road authorities continue to use design speed as the basis for alinement design, there has been a growing suspicion that the concept may have deficiencies if applied in a literal sense. Three related criticisms of the design speed approach were raised by the author in a recent review of the design speed concept and its current application (5).

Type 1 Criticisms. Designing according to the design values permitted by a specified design speed does not necessarily ensure consistent alinement standards.

Design speed, as defined by both AASHO (14) and NAASRA (10) only really has meaning in the presence of physical roadway characteristics which limit the safe speed of travel. This is not the case for level, tangent sections. Even for physical features that limit safe speed of travel, the design speed only specifies minimum values; above minimum values are recommended wherever terrain and economy permit. Thus, a road can be designed with a constant design speed as conceived by the designer, yet have considerable variation in speed standard and, to a driver, appear to have a wide variation in design standard.

Type 2 Criticisms. Designing according to the design values permitted by a specified design speed does not necessarily ensure compatibility between the standards for combinations of design elements.

Minimum values for alinement are based on the safe operations, as defined by design criteria such as side friction factor, for a vehicle travelling at the design speed negotiating such features in isolation. In rolling and mountainous terrain, it is frequently necessary for vertical alinement elements to be combined with horizontal curves. Adequate minimum values for isolated elements do not provide the same level of safety when the elements occur in combination. Consequently design policies and manuals emphasise the importance of avoiding combinations of minimum values.

Statements on avoidance of combinations of minimum values are, in effect, an amendment to the design speed approach to alinement design. However, neither such statements, nor the design speed concept itself, guide the designer as to acceptable or appropriate combinations of values.

Type 3 Criticisms. Free vehicle operating speeds and design speed are not necessarily synonomous.

AASHO (14 p87) argues that, on rural highways, most drivers aim to travel at an 'approximately uniform speed'. (The original design speed concept is, to a large extent, based on such an assumption.) While this may be true for freeway standards, experience suggests that it does not accord with driver behavior on lower standard alinements. A driver adjusts his speed according to his desired speed of travel and the perceived hazard. As discussed above, the speed standard, and hence the perception of hazard presented by the alinement, may vary along a road designed with a constant design speed. The speed adopted by a driver tends to vary accordingly, and may often be in excess of the design speed. The situation is further complicated by differences in perceived hazard for different alinement elements. Entering a horizontal curve at an excessive speed will almost certainly result in a loss of control situation, so drivers adjust their speed accordingly. However, the possibility of curtailed sight distances concealing a hazard is perceived as remote, so drivers do not generally adjust their speed to a level commensurate with sight distance restrictions.

Curve Design Standards

Current minimum curve design standards are based on two criteria:

1. Ensuring that the side friction demand is not excessive for the design speed.
2. Ensuring that the sight distance is adequate for the design speed.

The first criterion has developed from railway engineering practice. It is based on the side force required for a vehicle to traverse a curve at the design speed and at a constant radius equal to the curve radius. The design standards are derived from the equation:

$$e + f = \frac{V^2}{127R} \qquad (1)$$

where: e = curve superelevation (m/m),
f = side friction factor (side force/force normal to the pavement),
V = vehicle speed (or design speed) (km/h),
and R = curve radius (m).

The design value for f is given as a decreasing function of design speed. The relationship between f and design speed is supposedly based on a 'driver comfort' interpretation of early empirical studies (11). However, it is often justified as being representative of the decline in pavement skid resistance with increasing speed.

The sight distance criterion is based on the minimum sight distance requirements for the design speed. The curve radius necessary to meet these requirements can be determined for the possible lateral clearance to line of sight obstructions. For high design speeds, the sight distance criterion tends to be the controlling factor.

The assumptions underlying the side friction criterion have not stood up to experimental investigation. Unlike the railway situation, road vehicles are not constrained to follow a path of fixed radius. Glennon and Weaver (15) examined vehicle trajectories on curves with radii ranging from 250 to 875 m, and found that the minimum radius on the trajectory tended to be tighter than the curve radius. Good and Joubert (16) found that, for substantial deviation angles (> 90 deg) and strong constraints on drivers' lateral positioning, this relationship also applied to curves of lower radius (18 to 116 m). However, for low radius curves with smaller deviation angles, or with room for lateral manoeuvreing, drivers tend to 'cut the corner' such that the vehicle path curvature remains less severe than the road curvature.

From a review of published speed-curve geometry data, the author (17) concluded that drivers do not respond to superelevation, and hence side friction factor, when selecting the speed at which they will traverse a curve. Road curvature appeared to be the dominant factor affecting speed. The strong relationship between speed and curvature is also at variance with the intent of the sight distance criterion. Increasing curve radius to improve sight distance may merely serve to increase operating speeds, so that the sight distance remains inadequate for the speeds that prevail.

ARRB Research Into Driver Speeds On Curves

Objectives And Data Collection

With a view to resolving differences between actual driver-vehicle behavior and the design assumptions, ARRB undertook an empirical study of driver speed behavior on horizontal curves. Speed data were collected at 120 curve sites on two-lane rural highways in three States, and on the approach tangents to the curve sites. The nominal speed standards of the curves ranged from 40 to 120 km/h. Free spot speeds were measured at 20 sites on level tangent sections, with lengths greater than 1.5 km, in the vicinity of curve sites.

Analysis And Results

Desired Speed and Overall Alinement Standard. The speed at which a driver might wish to travel a particular section of road should have a bearing on the speed at which he chooses to negotiate curves contained in that section. This speed was referred to as the 'desired speed' for the road section and was defined as the speed at which drivers choose to travel under free flow conditions when they are not constrained by alinement features.

A subjective assessment was made of each road on which curves were studied to divide it into sections of relatively uniform character, based on such factors as overall alinement standard, topography, cross-section, traffic volumes, adjacent land-use, and proximity to major urban development. The lengths of these sections ranged from 3 to 30 km. The higher value speed distributions measured on each section (measured on the better approach tangents or on long level sections) were regarded as a measure of the desired speed pertaining to the section. When directional differences occurred, separate desired speeds were estimated for each direction of travel.

Scrutiny of the data indicated that the desired speed on particular route lengths was influenced by road function, typical trip purpose and length for traffic on the road, proximity to major urban centres, and, most importantly for design purposes, by the overall standard of alinement as specified by the overall design speed and terrain type. Insufficient data were available to specify desired speeds for all circumstances. Table 2 gives the 85th percentile desired speeds that can be expected for the most common road conditions encountered during the research.

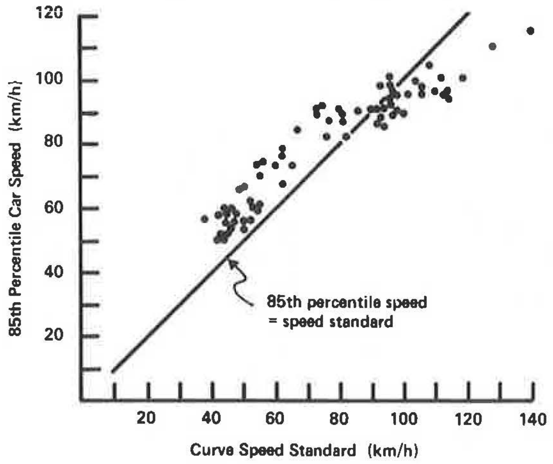
Observed Curve Speed and Speed Standard. The relationship between 85th percentile free speeds for cars on curves and the speed standard of curves is shown in Figure 1. The speed standard of a curve is regarded as the maximum speed at which a vehicle can negotiate the curve without exceeding the NAASRA (10) side friction factor criterion. This will often be in excess of the nominal design speed. For curves with speed standards of 100 km/h or more, 85th percentile free speeds tend to be less than the curve speed standard, while for curves of lower standard the reverse applies.

Table 2. 85th percentile desired speed of travel as a function of overall design speed and terrain type for single-carriageway rural roads with a State Highway classification.

Overall Design Speed (km/h)	Desired Speed (km/h)		
	Flat	Rolling	Mountainous
40 - 50			70*
50 - 70		90	
70 - 90		100	
90 - 120	115	110	
> 120	120		

* Under these conditions, tangent lengths are too short for a meaningful measure of 'desired speed'. The value given represents the typical maximum 85th percentile speeds measured on available tangents.

Figure 1. Relationship between observed 85th percentile car speeds and curve speed standard.



Speeds on Individual Curves. Regression analysis revealed that the observed 85th percentile curve speeds were dominantly influenced by the desired speed pertaining to the road section and the curve radius (expressed as curvature). While available sight distance had a statistically significant effect on curve speeds ($p < .05$), it represented less than one percent of the variability in observed 85th percentile speeds. The other traffic and road geometry parameters considered in the analysis failed to show a statistically significant effect on curve speeds ($p > .05$).

A regression based on desired speed and first and second order terms in curvature was found to provide a good description of the empirical data in terms of statistical significance and even spread of residuals. The resulting regression equation, with all terms significant at $p < .01$, was:

$$V_c(85) = 53.8 + .464\ V_F - 3.26\left(\frac{1}{R}\right) \times 10^3 + 8.5\left(\frac{1}{R}\right)^2 \times 10^4 \qquad (2)$$

$$r^2 = .92$$

where: $V_c(85)$ = 85th percentile curve speed (km/h);

V_F = desired speed of the 85th percentile car (km/h);

R = curve radius (m), and

r^2 = proportion of variance of the dependent variable explained by the regression.

Discussion of Results

The results indicate that the interpretation of design speed, as it relates to design standards and driver speed behavior, is very much a function of the overall alinement standard of the road. For roads with design speeds greater than 110 km/h in rolling terrain, or 120 km/h in flat terrain, 85th percentile desired speeds are less than the design speeds, and the original (11) concept of design speed applies.

In rolling terrain, for roads with design speeds of 100 or 110 km/h, speeds will vary according to the speed standards of individual features. However, the 85th percentile speeds on horizontal curves will not generally exceed the speed standard of those curves, though this may not hold for other design features such as crests. This situation is subject to the Type 3 criticisms of the design speed concept. Increases in alinement standards within this range would serve to reduce the basis for such criticisms.

When the design speed is 90 km/h or less, the 85th percentile driver will be traversing all sections of the road with a free speed in excess of the design speed. The Type 3 criticisms of the design speed concept apply over the length of the road, and attempts to overcome such criticisms by increasing curve radii will only serve to increase operating speeds by a commensurate amount.

The three general relationships (desired speed vs overall alinement standard, curve speed vs curve speed standard, and curve speed vs desired speed and curvature) have a circularity which suggests that it may not be feasible to produce a design procedure whereby the higher percentile speeds can be accommodated within the current criteria for safe operations. Increases in overall alinement standard will serve to increase the desired speed of travel which will, in turn, increase the operating speed on individual alinement features.

An Alternative Approach to Low Speed Alinement Design

Rationale

The remainder of this paper describes the development of an alternative approach to constrained alinement design based on predicted 85th percentile speeds. (The 85th percentile approximates a point of inflexion in the normal distribution curve, and, as speeds tend to be normally distributed, is likely to represent the point of diminishing returns when designing according to a percentile speed value.) This approach is most relevent to the design of horizontal alinements where terrain and/or financial constraints necessitate the use of standards corresponding to a design speed of 90 km/h or less. The variation in driven speed along the road is allowed for, and each alinement feature is designed according to the predicted speed of travel for the faster drivers. To this extent, it is a return to the original (11) concept of a design speed, but without the assumption of a uniform speed of travel. A suggested design procedure is outlined in Figure 2, and further details are given in reference (9).

It is suggested that current design standards and procedures be retained for alinements based on design speeds of 100 km/h or greater. On such alinements, driven curve speeds tend to be conservative relative to the design speed standards. This is in keeping with the view that the objective of high standard alinement is to provide a high level of comfort and convenience for the widest possible range of road users.

Curve Speed Prediction

The ARRB research showed that 85th percentile curve speed is determined largely by the desired speed of travel pertaining to the route section and the curve radius. While the regression equation (eqn 2) was appealing for its simplicity, and was very successful in terms of explaining the variability in observed curve speeds, it tends to produce anomalous results in the extremes of the data range.

The data were subsequently partitioned into four groups according to the desired speed value, and separate speed vs curvature regressions applied to each group. Higher order curvature terms failed to produce statistically significant improvements for the grouped data regressions, so four linear speed-curvature equations resulted. The regression coefficients were then iterated or extrapolated against desired speed value to produce the family of curve speed prediction relationships shown plotted against radius in Figure 3. The original data were used to check the validity of these relationships and, with observed desired speed rounded to the nearest 5 km/h, the family of relationships explained a greater proportion of curve speed variability than did eqn 2.

Each relationship shown in Figure 3 can be interpreted as the 85th percentile speed vs curve radius relationship pertaining to a length of road with a relatively uniform alinement standard giving rise to the desired speed shown. This gives the speed which should be used for the design of a curve of specified radius.

Side Friction Factor Design Criterion

A review of recent literature relating to driver behavior on curves (8) found that drivers do not adjust their speed on curves according to the f value utilized, and that the values actually utilized are often well in excess of the assumed design values, particularly on low standard curves. Furthermore, because of the variations in vehicle path radius, the actual tire/pavement friction force can vary appreciably from the f value given by the circular path formula (eqn 1). Despite these criticisms, designers still consider that f is both a necessary and valid design criterion. The difference between f and the actual friction available is the most important factor affecting safe vehicle operations on curves, and, as maintenance of pavement skid resistance is outside the realm of geometric design, the designer must concentrate on the friction demand contribution to the difference.

If f is to remain as a fundamental curve design criterion, the driver behavior literature suggests that it should be based on a different conceptual framework from that currently employed. In particular, f demand should be seen as an outcome of driver behavior, rather than as a representation of it (18). The objective of alinement design for the f criterion is, then, to ensure that the design driver does not exceed the design values of f. For such an approach, design values must be based on a realistic assessment of the behavior and comfort tolerance of modern drivers, and the pavement skid resistance that can be anticipated.

The design f values shown in Figure 4 are based on an assessment of the limits acceptable to the 85th percentile drivers observed during the ARRB research (8). As they have been derived from the circular path formula (eqn 1), they are appropriate for use in this formula. The values shown for speeds greater than 90 km/h are in excess of those likely to be required by the 85th percentile driver, in keeping with the concept that high speed alinements should provide a high degree of comfort and safety for all road users. The range of Side Force Coefficients measured on curves during routine pavement friction surveys by the Victorian Country Roads Board is shown for comparison.

Horizontal Alinement Standards

Minimum Curve Radii. NAASRA (10) specifies maximum superelevation rates of .06 in easy terrain and .10 in difficult terrain, with an absolute maximum value of .12 permitted in mountainous terrain. The curve speed prediction relationships in Figure 3 and the maximum design f values in Figure 4 can be used to compute the minimum curve radii corresponding to these superelevation rates for each desired speed. These are given in Table 3, together with the corresponding predicted curve speeds.

Above Minimum Radius Curves. In keeping with normal design practice, superelevation rates can be reduced on above minimum radius curves. The reduction in superelevation must be balanced against the desirability of reducing the expected side friction factor to a value below the design maximum. The superelevation rates suggested in Figure 5 are based on equalizing these two reductions when the required superelevation rate is less than .10.

Individual Curve Speed Standards. The speed standard of an individual curve is defined as the maximum speed at which it can be traversed without exceeding the design f criterion. For above minimum radius curves, this will generally be greater than the predicted speed. Figure 6 shows the relationship between curve speed standard, radius and superelevation.

Estimated Desired Speed (or Speed Environment). The speed at which a driver will travel a particular road section when unconstrained by traffic or alinement elements has an important bearing on curve speed selection. This speed is largely determined by the impression the driver gains of the overall alinement standard. This parameter has been referred to as a 'desired speed' when used in the context of driver behavior. However, the term 'speed environment' (after Armstrong, 1) has come into usage when the parameter is regarded as a property of the alinement design.

Table 2 gives typical desired speed values as a function of terrain type and the conventional design speed values. Table 4 presents this information, with some interpolation and extrapolation, in terms of the proposed alternative approach to alinement design. At the concept level, the 'speed environment value' would serve the same function as the current use of a 'ruling design speed'.

Figure 2. Suggested alinement design procedure.

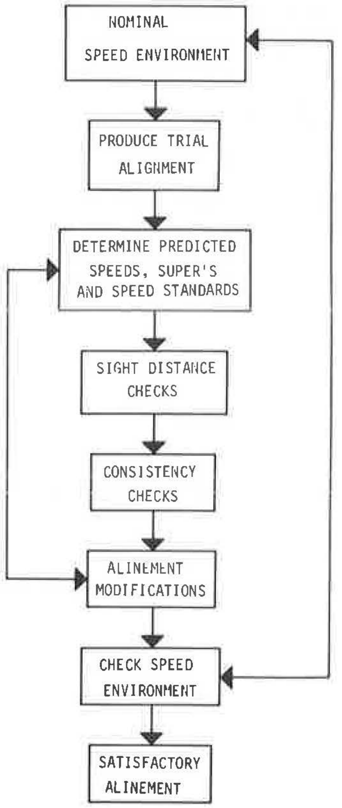


Figure 3. Curve speed prediction relationships.

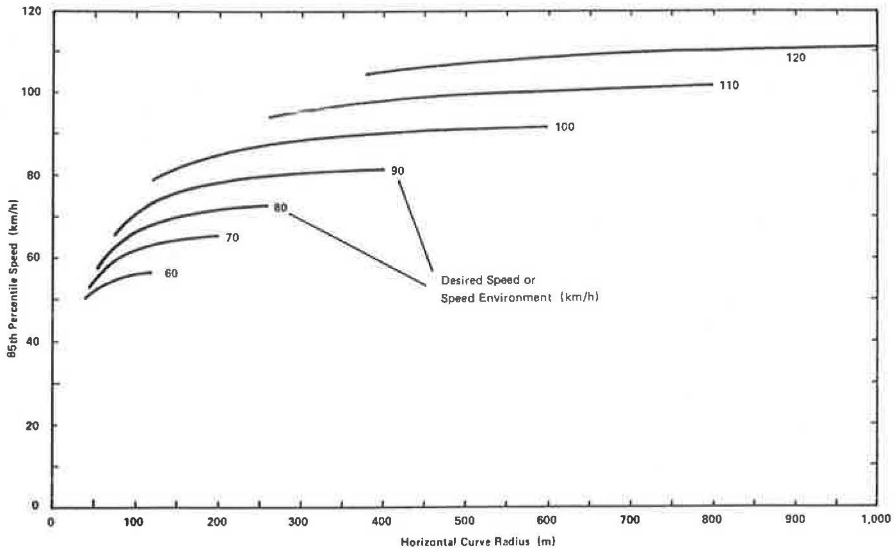


Table 3. Minimum curve radius and corresponding curve speed pertaining to desired speed or speed environment values.

Desired Speed or Speed Environment (km/h)	e = 0.12		e = 0.10		e = 0.10	
	Min. Radius (m)	Curve Speed (km/h)	Min. Radius (m)	Curve Speed (km/h)	Min. Radius (m)	Curve Speed (km/h)
60	45	50	50	50	55	55
70	50	55	60	55	70	60
80	65	60	70	60	85	65
90	85	70	95	70	120	75
100	140	80	160	85	210	85
110			300	95	400	100

Figure 4. Proposed maximum design f values for use with predicted curve speeds compared with the range of Side Force Coefficients measured on curves by the Victorian Country Roads Board.

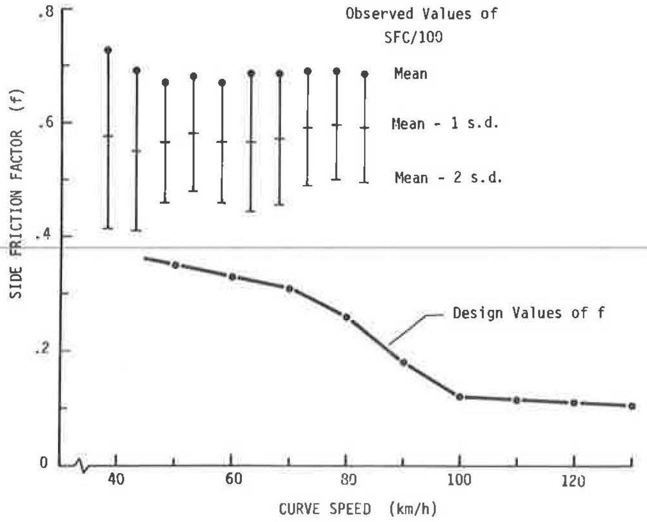


Figure 5. Recommended design superelevation rates.

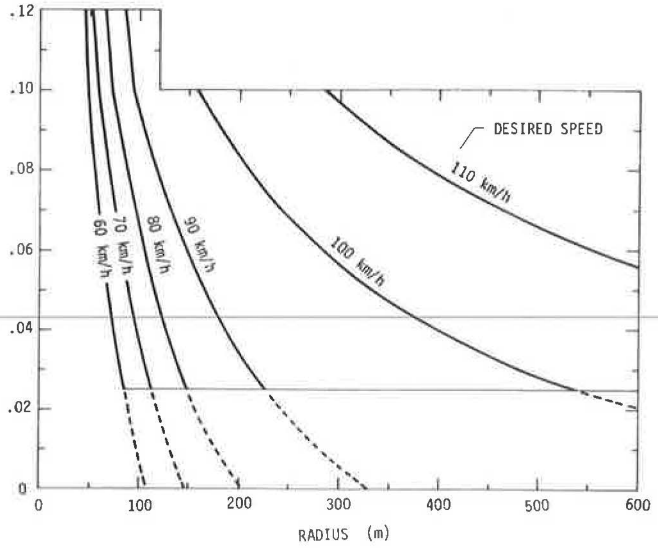


Figure 6. Curve speed standard related to radius and superelevation

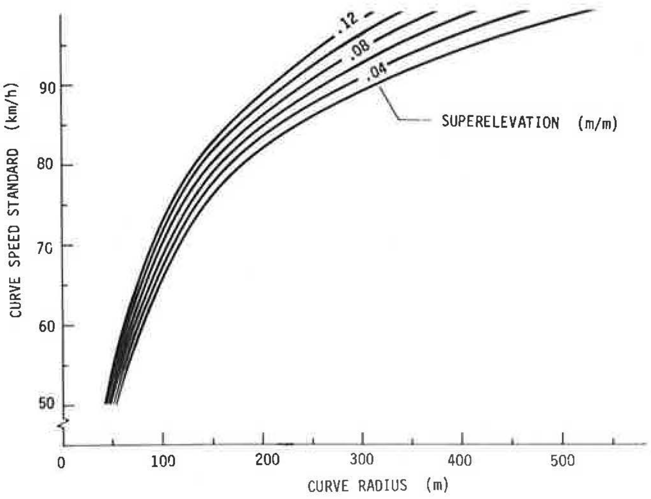


Table 4. The speed environment of two-lane rural highways as a function of horizontal alinement standard and terrain classification.

Typical Min. Curve Speed Standards (km/h)	Speed Environment (km/h)		
	Flat	Rolling	Mountainous
50			65
60		85	75
70		90	80
80		95	
90		100	
100		105	
110	115	110	
120	120	110	
>120	120		

Sight Distance Considerations

The ARRB speed studies revealed that, in terms of current NAASRA standards, the speeds at which drivers operate are often excessive for the sight distance available. While this applies to all forms of sight distance restriction, it is particularly true for sight distances restricted by crest vertical curves located on tangent sections.

Despite this anomoly, Australian designers consider that, in terms of operational experience, the current balance between horizontal and vertical alinement standards appear reasonable and should be retained. In Australian experience, serious accidents on crests are more often related to illegal overtaking manoeuvres than to stopping distance criteria, and this problem would not be alleviated by minor adjustments to minimum sight distance standards. As well as leading to additional construction costs, the lengthening of crests that would be associated with an increase in stopping distance standards would serve to reduce the total length of road with sight distance adequate for overtaking. It would also increase the difficulty of meeting the basic rule of good practice for combined alinement design that crest vertical curves should be contained within horizontal curves.

Other research at ARRB (19) suggests that modern vehicle/tire/pavement combinations are capable of achieving much higher deceleration rates than are assumed for the derivation of current stopping distance standards. With this research as justification, the design values for deceleration can be increased to maintain the current balance between horizontal and vertical alinement when a predicted speed is used as the basis for design.

Even with this amendment, it was evident that minimum horizontal sight distances appropriate to actual speeds were not being provided on many existing low radius curves which were studied, and that, when in cut, it would not be feasible to provide the necessary lateral clearance. However, as 'ran off road' is the main cause of accidents on such curves (3), the sight distance restrictions did not appear to be contributing directly. On tightly constrained alinements, drivers will be in an alerted condition, and a 2.5 sec reation time may not be required. An absolute minimum reaction time of 1.5 sec has been suggested when designing for predicted speed in constrained situations, which would accommodate most of the conditions encountered during the research. (The reduced reaction time value should not be used on isolated alinement features where the driver might well be in a relaxed state.)

Designing For Driver Expectancies

The importance of desired speed (or speed environment) for driver curve speed selection indicates that, above all else, the driver expects consistency in alinement standard. Based both on the research findings and the operational experience of major Australian road authorities, a number of rules of good practice can be formulated to ensure that the requisite degree of consistency is provided.

Section Speeds and Curve Standards. On a well designed section of road in an area with generally uniform topographical character, a driver develops a speed expectancy as quantified by the speed environment or desired speed concept. This expectancy should be reinforced by designing curves to an approximately uniform standard. Desirably, the speed standard of curves within the section should not differ by more than 10 km/h, and a 10 km/h variation in predicted curve speeds should be treated as the absolute maximum variation in curve standard. If this latter criterion cannot be met, the designer should seek to change the speed environment pertaining to the lower standard curves.

Isolated Curves. The predicted speed for curves occurring at the ends of long straights should desirably be not more than 10 km/h, and definitely not more than 15 km/h, below the speed environment pertaining to the road section. 'Long straights' is a relative term which relates to the overall alinement standard, and probably ranges from about .25 km for low standard alinements in difficult terrain to 3 km for high standard alinements in easier terrain.

Changing the Speed Environment. When a change in topographical character or some other constraint necessitates a change in alinement standard, this change should be made clear to the driver. This is best achieved by a sequence of horizontal curves, each having a predicted speed consistent with the design f criterion. When going from a high to a low standard, the predicted speed on sequential curves should not differ by more than 10 km/h, and the speed environment relevent to each curve can be taken as the predicted speed of the previous curve.

Discussion

Conservative Design Criteria

At a superficial level, it might appear that the proposed standards and procedures would result in alinements which are less safe than those based on current standards, due to the increse in design friction factor values and reduced sight distance standards. This is not the case, as the proposed values are derived from actual driver behavior on existing alinements designed according to current standards and procedures. The reality of driver behavior (for Australian drivers at least) is such that, on low standard alinements, many drivers operate with smaller safety margins than those traditionally assumed, and this fact should be recognized in design.

Traditional standards based on the design speed concept have attempted to build safety into design through the employment of very conservative design criteria. However, the ARRB research has demonstrated that for the lower range of speed standards, drivers compensate for the conservative criteria by travelling at speeds greater than the nominated design speed. The proposed alternative approach, in effect, matches the conservatism of the design criteria to the conservatism which drivers subjectively apply in actual situations.

Attempts at deriving standards from conservative criteria which are not consistent with driver behavior have led to some marked anomalies, particularly with regard to sight distance requirements. For example, AASHO (14)justifies the use of a conservative f criterion for low design speeds on the grounds that 'drivers tend to overdrive low design speed highways'. However, the minimum sight distance standards are derived from an assumed 'average running speed' which is less than the nominated design speed. A more recent amendment (20) bases desirable stopping sight distance on the nominated design speed, but this is still likely to be below the speed at which low standard alinements are 'overdriven'. The proposed alternative design standards are internally consistent, as well as being consistent with real world behavior.

Acceptance and Application

While application of the proposed procedure is recommended as a viable means of achieving effictive low speed alinement designs, it is recognized that it may not be acceptable in some authorities. Through several decades of usage, the design speed concept has become an integral part of the thinking, procedures and practices employed in most authorities for road planning, location and design. There are instances where the nomination of a ruling design speed and its associated standards has legislative significance. Removal of the design speed concept would, therefore, present problems in communication and the need for considerable retraining.

The main advantages of the proposed procedure are in its emphasis on producing alinements which are consistent with driver expectancies. Even if designs continue to be based on traditional standards, it is strongly urged that methods such as those outlined in this paper be used to check the consistency and acceptability, in terms of driver behavior, of low speed alinement designs.

Based on Australian experience, the inadequacies of the traditional design speed approach do not generally result in deficiencies in designs produced by central design offices in major road authorities. Here, the accumulated experience and expertise are applied at various parts of the design process to ensure that such deficiencies do not occur, and this probably has a greater bearing on the final product than either the design speed concept or the design standards. It is the designer of lesser experience working in isolation from centres of expertise who is most dependent on formalized design procedures. Low standard roads, for which current procedures appear deficient, are likely to be designed in this latter situation, and this is where the proposed alternative approach is likely to be of greatest use.

Continuing Research

With Australia's particular interest in low volume roads, ARRB is continuing to undertake research in this area which will lead to a more comprehensive consideration of the factors influencing the speed environment of a road. Attention is also being given to the relationship between traffic operations and alinement design standards. Indications are that, in undulating terrain and for design speed standards less than 90 km/h, improving the alinement speed standard produces only marginal improvements in traffic operations. Where traffic operations are a problem on a low speed alinement, the introduction of auxilliary lanes at various locations is probably the most cost-effective means of providing an improvement.

Conclusions

The original design speed concept was a driver behavioral approach to alinement design, with design speed being regarded as an upper estimate of a relatively uniform travel speed. While driver speed behavior no longer conforms to the assumptions implicit in the original concept, design speed is still used as a 'design procedure' directed at providing consistent and co-ordinated alinement.

For road alinements based on a design speed of 120 km/h or greater, drivers tend to adopt a relatively uniform speed which is less than the design speed. This is in keeping with the original concept, and for roads of this type, the traditional design speed approach provides a valid and rational method of alinement design.

On alinements with design speeds between 100 and 120 km/h, free operating speeds vary along the road according to the speed standard of the horizontal alinement, and, while seldom exceeding the speed standard on individual horizontal curves, they will often be in excess of the nominal design speed. While this speed variation does not appear to give rise to operational problems, it should be recognised by designers.

For the range of alinement standards below 100 km/h, driver behavior is completely at variance with the assumptions underlying the design speed approach. Free operating speeds not only vary along the road, but tend to be continually in excess of the design speed. Alinements can be designed according to a consistent design speed, yet, to a driver may appear to have markedly varying standards. Attempts to introduce additional safety through the application of additional conservatism in design criteria will only serve to increase the discrepancy between actual speeds and the assumed design speed.

An alternative method has been proposed for low speed alinement design which should overcome the deficiencies in the current design speed approach. As the method is based on observations of actual driver behavior, compatibility between the design criteria and assumptions and driver speed behavior and expectancies is ensured.

Even if the current design speed approach to alinement design is retained, it is strongly urged that quantified consistency checks, such as those presented in this paper, be included as part of the design procedure.

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