# 4 Horizontal Alignment

## 4.1 General

A horizontal road alignment is a usually series of straights (tangents) and circular curves. Transition curves are often used to join straight sections smoothly into circular curve sections.

A curve should normally be used whenever there is a change of direction in a road alignment and must be of sufficient length to avoid the appearance of a kink in the road alignment.

Small changes in alignment are not usually noticed by drivers and in some cases it might not be necessary to provide a curve between adjacent straight tangent sections of road, provided they do not produce a kinked road alignment.

Horizontal road alignments without significant straight sections are described as curvilinear. A curvilinear alignment normally has:

- long, large radius circular curves, with or without spiral transitions, and
- occasionally, other types of curves which conform to polynomial mathematical relationships.

Curvilinear alignment is most suited to dual carriageway roads but can also be successfully used on two-lane roads in flat and undulating terrain, providing overtaking provisions are not impaired. The horizontal curves of a curvilinear alignment are generally of large radius and:

- do not normally restrict overtaking opportunities,
- help reduce headlight glare, and
- give drivers a better perception of the speed of approach of opposing vehicles.

## 4.2 Vehicle Stability

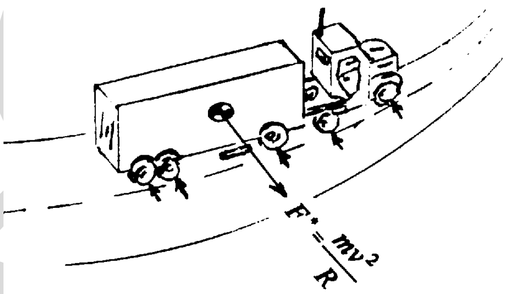
### 4.2.1 General

Vehicles become unstable by either sliding or overturning, or both. Cars rarely overturn without sliding first.

When a vehicle slides sideways it is susceptible to tripping by an uneven road surface, potholes or kerbs. Under these conditions both cars and trucks can overturn at low speeds, ie. sliding sideways at approximately 10 km/h.

Trucks, particularly those with high or moving loads, are susceptible to overturning at all speeds. This problem is however greatest on small radii curves, eg. the radii typically encountered at intersections.

Figure 4.1 shows the lateral forces which act on a vehicle as it travels around a curve.

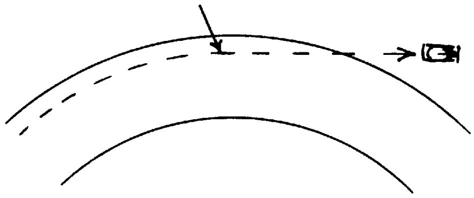



Source: Vicroads

**Figure 4.1: Lateral Forces Acting on a Heavy Vehicle**

### 4.2.2 Sliding

The lateral friction developed at the tyre/road interface as a vehicle travels around a curve is directly related to the square of its speed. As speed is increased the force required to maintain a circular path eventually exceeds the force which can be developed by friction and superelevation. At this point the vehicle will start to slide in a straight line tangential to the road alignment. This is illustrated in Figure 4.2.



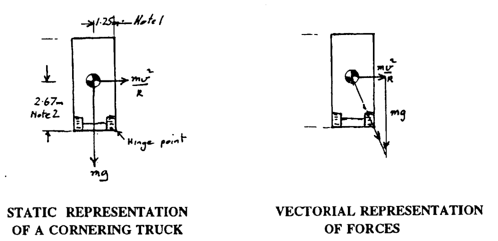

Source: Vicroads

**Figure 4.2: Lateral Sliding Illustration**

### 4.2.3 Overturning

Overturning is not normally a problem for cars and other light vehicles. It can however be a significant problem for trucks, particularly those with a high centre of gravity.

When a vehicle travels around a curve an overturning moment is formed by the forces acting on it. Figure 4.3 shows the forces which act on a cornering truck.




*Source: Vicroads*

**Figure 4.3: Forces acting on a Cornering Truck**

Overturning will occur when the vectorial sum of the two forces extends beyond the limits of the wheels.

Other features which also contribute to reduce the stability of trucks on curves are:

- Adverse superelevation which reduces the horizontal distance between the centre of gravity and the hinge point.
- The dynamic affects associated with wheel bounce on curves.
- The rigidity of the fifth wheel linkage between the prime mover and the trailer on articulated vehicles.
- The changes in geometry which occur on low radius curves.

The truck side friction factors shown in Figure 2.7 should provide safe operating conditions for the majority of trucks. However, trucks can roll over at friction factor levels below those listed because at low speeds overturning can also be initiated by:

- **Tripping:** A vehicle sliding sideways can overturn at speeds below 10 km/h when tripped by a kerb or pothole. Road surfaces must be kept in good condition where critical turning movements occur to help avoid this problem.

- **Loading:** Small lateral offsets of the centre of gravity of a truck’s load can significantly reduce its lateral stability. Uneven longitudinal loading can also reduce the vehicle’s stability.

- **Load Shift:** A moving load such as liquid in tankers or animals on the top deck of stock transporter.

- **Dynamic Forces:** These are associated with tyre and suspension bounce and are related to the speed of the vehicle and the condition of the pavement.

- **Aquaplaning:** This can lead to loss of control and rollover.

- **Braking:** As the brakes are applied the friction available in the radial direction decreases. If the wheels lock, lateral stability and steering is lost.

- **Rearward Amplification:** This is a "whiplash" effect and is defined as the ratio of the maximum lateral acceleration at the rear axle over the lateral acceleration on the prime mover.

- **Speed:** Critical lateral accelerations (or friction forces) are speed dependent.

## 4.3 Sight Distance Requirements

### 4.3.1 Stopping Sight Distance

Where a lateral obstruction off the pavement such as a bridge pier, building, cut slope, or natural growth restricts driver sight distance, the minimum radius for an adjacent horizontal curve is determined by the design speed stopping sight distance. Table 2.12 shows stopping sight distances on a level grade.

Figure 4.4 shows the relationship between sight distance, horizontal curve radius and lateral clearance to the obstruction This relationship is valid when the sight distance is not greater than the length of the curve and assumes that the driver's eye and the sighted object are above the centre of the inside lane, ie. there is no or very little vertical curvature.

When the sight distance is greater than the horizontal curve length a graphical solution is appropriate.

***NOTE:***

> ***All technical reductions in design speed caused by partial or momentary horizontal sight distance restrictions must be approved - refer to Section 2.7.1: Design Speed - General for details of the approval process.***

### 4.3.2 Truck Stopping Distances

Road curvature adversely affects the stopping distances of all vehicles, trucks more so than other vehicles. Until reliable research figures are available, the following guidelines are suggested for use on curves of less than 400 m radius:

- If the design vehicle is a rigid truck, stopping distances should be increased by 10%.
- If the design vehicle is an articulated truck stopping sight distances should be increased by 20%.

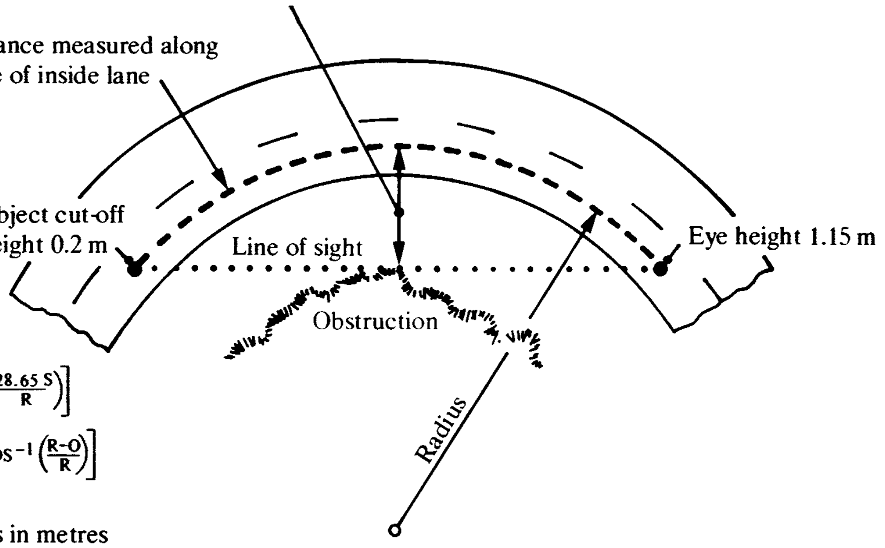
This allows for the tendency of these vehicles to jack-knife under heavy braking while travelling on a horizontal curve.

### 4.3.2 Benching for Visibility on Horizontal Curves

Benching is the widening of a cutting on the inside of a curve to obtain the specified sight distance and usually takes the form of a flat table or bench over which a driver can see an approaching vehicle or an object on the road.

In plan view, the benching is fixed by the envelope formed by the lines of sight. The driver and the object are assumed to be in the centre of the inner lane and the sight distance is measured around the centre line of the lane, ie. the path the vehicle would follow while braking. Benching adequate for inner lane traffic more than meets requirements for the outer lane.

The horizontal and vertical limits of sight benching in cuttings on horizontal curves, or a combination of horizontal and vertical curves, should be determined graphically.



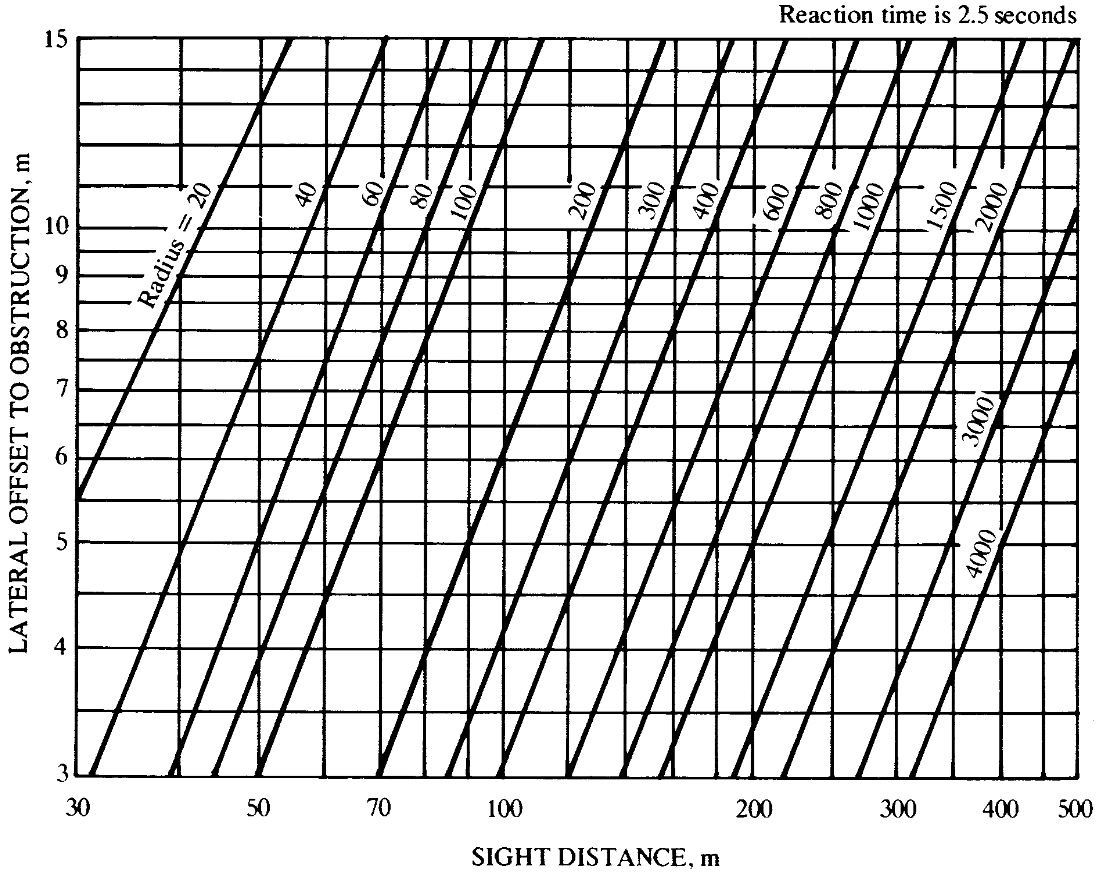

$$O = R\left[\text{VERS}\left(\frac{28.65\,S}{R}\right)\right]$$

$$S = \frac{R}{28.65}\left[\cos^{-1}\left(\frac{R-O}{R}\right)\right]$$

Where :
R = radius in metres
S = sight distance in metres
O = offset in metres

Note : Use this formula only when S $\overline{\overline{<}}$ the length of circular curve.

Note : This graph is used for horizontal sight restrictions only.
Reaction time is 2.5 seconds




*Source: Austroads Rural Road Design Guide*

**Figure 4.4: Horizontal Stopping Sight Distance on a Horizontal Curve**

## 4.4 Curve Widening

### 4.4.1 General

Traffic lanes may need to be widened on horizontal curves to maintain lateral clearances between vehicles equal to those available on straight sections of road. This is commonly known as *'curve widening'* and it is required for one or more of the following reasons:

- Vehicles travelling on a curve occupy a greater width of pavement than they do on a straight - at low speeds the rear wheels track inside the front wheels and at high speeds the rear wheels track outside the front wheels.
- Vehicles tend to deviate more from the centreline of the traffic lane on a curve than on a straight.
- To maintain clearances between vehicles to those on straight sections of road.

Other factors, such as overhang of the front of the vehicle, wheelbase and track width, also contribute to the need for curve widening.

### 4.4.2 Traffic Lane Widening Requirements

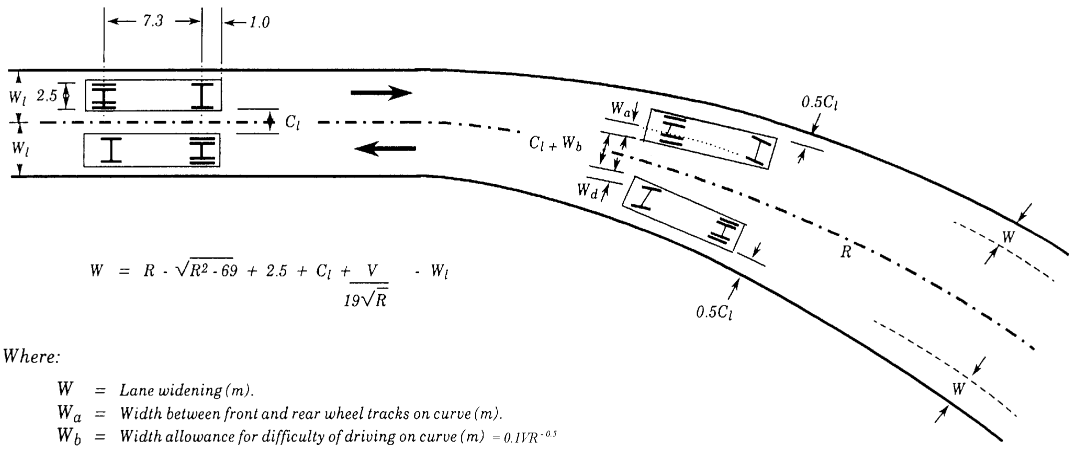
Approximate values for the total amount of curve widening required by a single unit design truck on a circular arc section of a two-lane two-way road are shown in Table 4.1.

The amount of widening required, on a per lane basis, can be calculated using the method detailed in Figure 4.5.

| Curve Radius (m) | Total amount of traffic lane widening required (in metres) on horizontal curves where the normal width of two traffic lanes is: | | | |
|---|---|---|---|---|
| | 6.0 m | 6.5 m | 7.0 m | 7.5 m |
| 30 - 50 | 2.0 | 1.5 | 1.5 | 1.0 |
| 50 - 100 | 1.5 | 1.0 | 1.0 | 0.5 |
| 100 - 250 | 1.0 | 1.0 | 0.5 | – |
| 250 - 750 | 1.0 | 0.5 | – | – |
| Over 750 | 0.5 | – | – | – |

*Source: Austroads*

**Table 4.1: Recommended Values for the Widening of Two-lane Pavements on Horizontal Curves**




$$W = R - \sqrt{R^2 - 69} + 2.5 + C_l + \frac{V}{19\sqrt{R}} - W_l$$

*Where:*

$W$ = *Lane widening (m).*
$W_a$ = *Width between front and rear wheel tracks on curve (m).*
$W_b$ = *Width allowance for difficulty of driving on curve (m)* $= 0.1VR^{-0.5}$
$W_d$ = *Width between tracks of front wheel and front overhang of vehicle on curve (m).*
$W_l$ = *Lane width (m).*
$R$ = *Radius of centreline of two-lane (m).*
$V$ = *Design speed for curve radius (km/h).*
$C_l$ = *lateral clearance between vehicles in adjacent lanes (m)*

*Source: R.T.A.*

**Figure 4.5: Lane Widening on Horizontal Curves**

### 4.2.3 Application

Curve widening should not be applied until 200 mm, or more, per lane is necessary.

Traffic lane widths for curves of 30 m, or less, radii should be determined by the tracking requirements of the appropriate design vehicle(s), using turning path templates or computerised vehicle path plotting programs.

On transitioned curves traffic lane widening is normally applied in a uniform manner along the plan transition. Half the total widening required should be applied on each side of the curve centreline.

On circular curves traffic lane widening should be applied in a uniform manner over the length of road used to develop superelevation. The total widening required should be normally be applied on the inside of the curve, to give the effect of a plan transition.

## 4.5 Horizontal Curves

### 4.5.1 General

The design standards for horizontal curves on state highways are derived from the basic design criteria described in Section 2.8: Horizontal Alignment and are shown in Tables 4.2 and 4.3. They show the minimum radius horizontal curve that can be used for a given design speed when the maximum values of superelevation and side friction allowable at that design speed are applied. The unit chord, which relate superelevation development at the appropriate pavement rotation rate to curve radii, is also shown.

Although any radii greater than the minimum shown for the design speed selected can be used, the range of curve radii suitable for a given design speed is normally a function of speed environment. Good design practice avoids the use of minimum radii and pavement rotation rates in excess of 2.5% per second, except in extreme cases. Superelevation and side friction requirements are also reduced at radii greater than the minimum, by Transit's convention, to less than their maximum values. This practice results in road designs which have some additional margin of safety built in to them.

When minimum radii are avoided, ie. the values towards the left hand end of the speed environment graph segments of Figure 2.5 (also 4.14), it will be found that the design speeds of all curves are within 10 km/h, or thereabouts, of adjoining curves.

The curve notation used in this Manual, and formulae which can be used for manual calculation of critical curve details while developing horizontal alignment schemes are shown in Figures 4.6, 4.7 and 4.8.

### 4.5.2 Maximum Tangent Deflection Angle before a Horizontal Curve must be used

A horizontal curve must be used when the deflection angle between intersecting straight tangent sections of road exceed those shown in Table 4.2.

| Road Type | Two-lane road | Multi-lane road |
|---|---|---|
| Dual Carriageway: | | |
| Motorway | 0 | 0 |
| Expressway | 0° 15´ | 0° 15´ |
| 2 Lane Arterial | 1° 00´ | 0° 30´ |
| 2 Lane Collector | 1° 00´ | 0° 30´ |
| Minor road | 1° 30´ | N/A |

**Table 4.2: Maximum Tangent Deflection Angle before a Horizontal Curve must be used**

***NOTE: A succession of short tangents and small deflection angles cannot be used to avoid the need for a horizontal curve.***

### 4.5.3 Minimum Length of a Horizontal Curve

The minimum length of a horizontal curve is determined mainly by aesthetic considerations and is therefore very subjective. The radii to needed to give a curve of sufficient length to avoid an unsightly kink in the horizontal alignment in flat terrain is given in Table 3.1 while Table 4.3 indicates the minimum length of curve requires for some typical design situations.

| Road Type | Minimum Length of Curve (m) |
|---|---|
| Dual Carriageways: | |
| Motorway | 250 |
| Expressway | 200 |
| Arterials | 150 |
| Others | No limitations |

**Table 4.3: Minimum Length of Horizontal Curve needed to avoid an Unsightly Kink**

Two convenient methods for determining the length of horizontal curves, which satisfy most aesthetic requirements, are:

**(i)** The circular arc portion of a transition curve should be approximately 1.5 to 3 three times the transition spiral length.

**(ii)** The length of a plain circular curve should be about the distance travelled by a vehicle during one second for each 10 km/h of curve design speed.

The latter can be calculated by the following formula:

$$L = \frac{V^2}{36}$$

Where:

$L$ = length of curve (m)
$V$ = design speed (km/h).

### 4.5.4 Circular Curves

Plain circular arc horizontal curves may be used in horizontal alignments if the plan transition shift distance $P$, as calculated by the following formula, is less than 250 mm.

$$P = \frac{SL^2}{(0.024 \times R)}$$

Where:

$P$ = plan transition shift (mm)
$SL$ = plan transition length (m)
= $\frac{(UC^2 \times 35.81)}{R}$
$R$ = circular arc radius (m)
$UC$ = unit chord (m), from Tables 2.9 and 2.10.

| | | |
|---|---|---|
| *PI* | = | tangent intersection point |
| *TC* | = | tangent point on back tangent |
| *CT* | = | tangent point on ahead tangent |
| *CC* | = | curve centre point |
| *I* | = | tangent deflection angle |
| *R* | = | circular arc radius |
| *TL* | = | tangent length |
| | = | $R \times Tan \frac{I}{2}$ |
| *L* | = | circular arc length |
| | = | $R \times I_{(radians)}$ |
| *ET* | = | external distance |
| | = | $R\left(Sec \frac{I}{2} - 1\right)$ |
| *MO* | = | mid ordinate distance |
| | = | $R\left(1 - Cos \frac{I}{2}\right)$ |
| *LC* | = | long chord length |
| | = | $2R * Sin \frac{I}{2}$ |

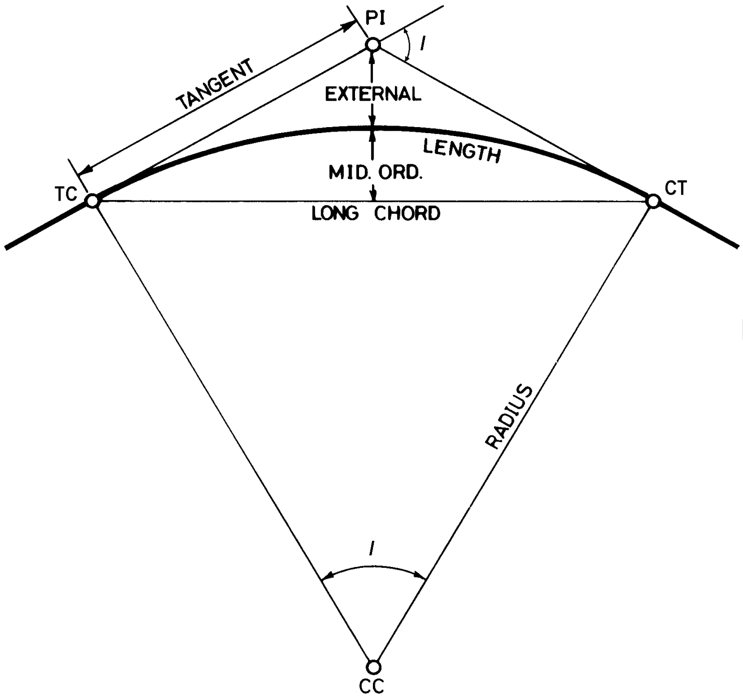



**Figure 4.6: Circular Curve Details**

| | | |
|---|---|---|
| *TS* | = | tangent point on back tangent |
| *XC* | = | X coordinate, refer unit chord spiral table |
| | = | $LC \times Cos\ \phi$ |
| *LT* | = | long tangent length |
| | = | $XC - YC\ Cot\ \theta$ |
| *YC* | = | Y coordinate, refer unit chord spiral table |
| | = | $LC \times Sin\ \phi$ |
| *ST* | = | short tangent length |
| | = | $YC\ cosec\ \theta$ |
| *SC* | = | common tangent point of central circular arc and back spiral |
| $\phi$ | = | long chord deflection angle |
| $\theta$ | = | spiral angle |
| *SL* | = | plan transition length |
| *LC* | = | long chord |
| *R* | = | central circular arc radius |
| *P* | = | shift distance |
| | = | $\frac{SL^2}{24R}$ (approx.) |
| *K* | = | shift point distance |
| | = | $\frac{SL}{2}$ (approx.) |

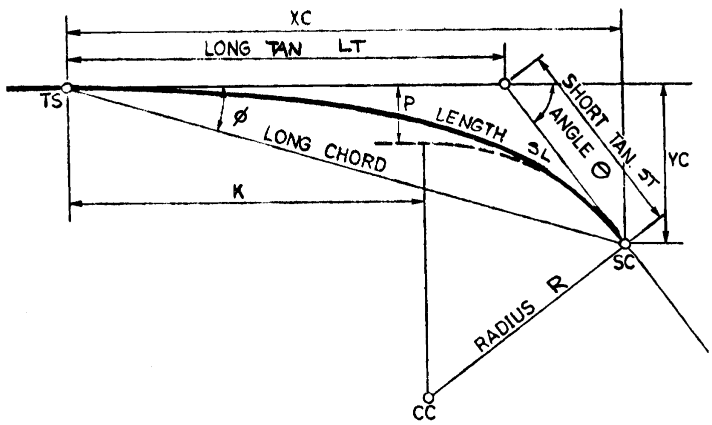



**Figure 4.7: Plan Transition Curve Details**

| | | |
|---|---|---|
| *PI* | = | tangent intersection point |
| *I* | = | tangent deflection angle |
| *TS (ST)* | = | tangent point back (ahead) |
| $TT_A$ ($TT_B$) | = | tangent length ahead (back) |
| $SL_A$, ($SL_B$) | = | plan transition length ahead (back) |
| $\theta_A$ ($\theta_B$) | = | plan transition ahead (back) deflection angle |
| $P_A$ ($P_B$) | = | shift distance ahead (back) |
| | = | $\frac{SL^2}{24R}$ (approx.) |
| $K_A$ ($K_B$) | = | tangent shift point distance ahead (back) |
| | = | $\frac{SL}{2}$ (approx.) |
| *SC (CS)* | = | common tangent point of central circular arc and back (ahead) spiral |
| *CI* | = | tangent intersection point of central circular arc |
| *R* | = | central circular arc radius |

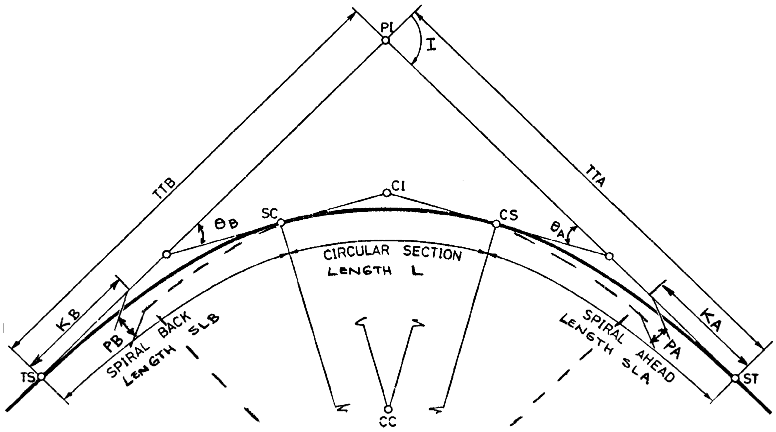



**Figure 4.8: Transition Curve Details**

For curves with equal transitions:

$$TT_A = TT_B = (R + P)\,Tan\,\frac{I}{2} + K$$

$$L = (R \times I_{(radians)}) - SL$$

$$ET = (R + P)\,Sec\,\frac{I}{2} - R$$

For curves with unequal transitions:

$$TT_A = (R + P_A)\,Tan\,\frac{I}{2} + K_B - ((P_A - P_B) \times Cosec\,I)$$

$$TT_B = (R + P_B)\,Tan\,\frac{I}{2} + K_B - ((P_B - P_A) \times Cosec\,I)$$

$$L = (R \times I_{(radians)}) - \left(\frac{SL_B - SL_A}{2}\right)$$

***NOTE:*** ***Should other curve formula be required eg. the exact formula for P, K, SL etc, consult survey and other recognised road design textbooks.***

### 4.5.5 Transition Curves

**(a) General**

A plan transition helps to produce a smooth, pleasing alignment when joining a straight or tangent section of a road to a circular curve, or when joining two adjacent curves. The resultant compound curve normally contains a plan transition section either side of the central circular arc section and is commonly known as a *'transition curve'*.

he plan transition shifts the extended circular curve arc away from the extended straight tangent line and:

- provides a convenient length of road over which superelevation and/or widening is applied,
- can improve the appearance of a road, particularly on a bridge where a rigid handrail follows the exact road alignment,
- can improve the appearance of the road where a curve is visible in plan at the end of a long straight,
- provides a length of road over which steering adjustment can be made, particularly in reverse curve situations, and
- provides a length of road over which speed adjustments may be made between curves of different radii.

A plan transition:

**(i)** ***is not necessary*** when the shift distance is less than 250 mm because the contribution by the plan transition to the positioning of vehicles on a curve and to curve appearance is negligible.

**(ii)** ***is not necessary*** where the shift distance is less than approximately half of the extra widening needed to accommodate the off-tracking requirements of heavy vehicles on the curve, ***provided that all the widening is applied on the inside of the curve and over the length that would normally be occupied by the plan transition.***

**(iii)** ***may be used*** for appearance purposes when it is of sufficient length to give a shift distance of 250 mm or more.

In predominantly flat terrain and in high speed environments where curves are visible from long distances the appearance of a road can sometimes be improved by increasing the length of the plan transition to give a shift of about 500 mm.

**(iv)** ***may not be appropriate*** in low speed environments where drivers regulate their travel speed from their judgement of the apparent curvature of the road ahead.

Some variation of curve approach speeds can occur in these situations. Plan transitions introduced merely for appearance reasons may affect a driver's perception of the road's curvature and are probably best avoided.

**(v)** ***should not be used*** on small radii curves in low speed environments where pavement widening to accommodate the tracking widths required by heavy vehicles is necessary.

In these cases all pavement widening should be applied on the inside of the curve and introduced over the length that would normally be occupied by the plan transition. A centreline marked on the centre of the widened pavement effectively forms a transition curve while a circular arc form is retained on the outside of the curve, to help drivers make a better judgement of the apparent curvature of the road ahead.

**(b) Transition Form**

A wide range of curve forms can be successfully used for a plan transition but the most common are the Clothoid, Lemniscate and Cubic spirals, because they provide a uniform rate of change of curve radius.

**(c) Transition : Circular Arc : Transition Ratio**

When all, or most, of a transitioned horizontal curve is visible in plan to an approaching driver its transition length : circular arc length : transition length ratio should be in the range 1 : 1.5 : 1 to 1 : 3 : 1, and desirably 1 : 2 : 1. Greater ratios are acceptable where the whole curve is not visible in plan to approaching drivers.

There is little difference between the various spirals and as an approximation the selection of transition curve proportions can be based on the fact that in the Lemniscate the angle equivalent to $\phi$ is equal to $\frac{\theta}{3}$ when $\theta$ is small and in the range of normal transition curve design. For larger tangent deflection angles this is not so and $\phi$ because is less than $\frac{\theta}{3}$.

It can be shown that the spiral angle $\theta = \frac{I}{2\ (x+1)}$ when the transition : circular arc : transition ratio is 1 : x : 1. This means that for ratios:

| | | | |
|---|---|---|---|
| 1 : 1.5 : 1 | $\phi = \frac{I}{15}$ | or | $\theta = \frac{I}{5}$ |
| 1 : 2 : 1 | $\phi = \frac{I}{18}$ | or | $\theta = \frac{I}{6}$ |
| 1 : 2½ : 1 | $\phi = \frac{I}{21}$ | or | $\theta = \frac{I}{7}$ |
| 1 : 3 : 1 | $\phi = \frac{I}{24}$ | or | $\theta = \frac{I}{8}$ |

**(d) Transition Length**

The plan transition length is normally the distance needed to develop the full superelevation required on the circular arc section of the curve at a reasonable pavement rotation rate, from the point where the pavement crossfall is level, ie. 0% superelevation.

Superelevation is normally applied at a rate of pavement rotation not exceeding 2.5% per second of travel time at design speed, for vehicle occupant comfort reasons. In more difficult situations, ie. in low speed environments of 70 km/h and less, this may not always be achievable and pavement rotation rates of up to 3.5% per second of travel time may be used without undue vehicle occupant discomfort.

On sections of two-way roads with wider than normal pavements, eg. passing lanes, the relative grade of the two pavement edges must be kept within reasonable limits, for appearance and comfort reasons. This becomes the control for transition length and the appropriate design standards should be used in these situations.

***The standard superelevation and side friction requirements for horizontal curves are always met when the unit chord design method is used.*** The unit chord *(UC)* can be calculated from the following formula:

$$UC = \sqrt{\frac{R \times L}{35.81}}$$

Where:

$R$ = circular arc radius (m)
$L$ = plan transition length (m)

***NOTE: The calculated unit chord must equal, or exceed, the minimum value given in Table 2.nn for the relevant design speed and road type.***

### 4.5.6 Unit Chord Spiral

Table 4.4 contains details of the unit chord spiral. These include unit dimensions for:

- Spiral length — $SL$
- Phi C — $\phi$ — (degrees, minutes, seconds)
- Long chord — $LC$
- X Curve coordinate — $XC$ — (distance from TS to SC along curve tangent)
- Y Curve coordinate — $YC$ — (offset from tangent to SC from curve tangent)
- Curve radius — $R$
- Spiral angle — $\theta$ — (degrees, minutes, seconds)
- Shift — $P$ — (offset from tangent to circular arc)
- Shift distance — $K$ — (distant from TS to circular arc)

A plan transition for any circular curve can be determined by multiplying the unit chord spiral values obtained from Table 4.4 by the appropriate design speed unit chord from Table 2.9 or 2.10.

The unit chord is in effect a scaling factor. A greater or lesser length of the scaled spiral is used depending on the circular arc radius it must match.

An example of how to use the unit chord spiral table to calculate horizontal curve details is:

Design speed: *80 km/h*
Tangent deflection angle: *30° 10′ 00″*
Transition : circular arc : transition ratio: *1 : 2 : 1*
Spiral Angle: $\frac{30°\ 10'}{6} = 5°01'40''$

From Table 2.9:
Min. unit chord for 80 km/h = *18.6 m*

From Table 4.4:

| | | |
|---|---|---|
| Spiral angle | = | *5° 00′ 00″ (nearest match)* |
| Radius | = | *14.3239* |
| Shift | = | *0.0182* |
| Shift distance | = | *1.2497* |
| Spiral length | = | *2.50* |

Therefore:

Curve radius $R = 14.3239 \times 18.6 = 266.4\ m$
Transition length $SL = 2.50 \times 18.6 = 46.5\ m$
Shift $P = 0.0182 \times 18.6 = 0.3385\ m$
Shift distance $K = 1.2497 \times 18.6 = 23.2\ m$

The tangent length, external distance and circular curve arc length are calculated from the formula shown in Figure 4.nn, ie:

$$TT = \left[\left((14.3239 + 0.0182) x \ Tan\ \frac{30°10'}{2}\right) + 1.2497\right] x \ 18.6$$

$$= 95.1\ m$$

$$ET = \left[\left((14.3239 + 0.0182) x \ Sec\ \frac{30°10'}{2}\right) - 14.3239\right] x \ 18.6$$

$$= 9.9\ m$$

$$L = \left(\left(14.3239 \ x \ 30°10_{\ (radians)}\right) - 2.5\right) x \ 18.6$$

$$= 93.8\ m$$

Alternatively, where an approximate radius, say 300 m, is known for the same deflection angle, then:

Unit chord $UC = \frac{300}{14.3239}$

$= 20.9\ m$, which equates to a design speed of approximately 83 km/h.

| SPIRAL LENGTH SL | PHI C ø D M S | LONG CHORD | CO-ORDS OF CURVE POINTS XC | YC | RADIUS R | SPIRAL ANGLE θ D M S | SHIFT P | SHIFT DIST K |
|---|---|---|---|---|---|---|---|---|
| 0.05 | 0 0 2 | 0.0500 | 0.0500 | 0.0000 | 716.1972 | 0 0 7 | 0.0000 | 0.0250 |
| 0.10 | 0 0 10 | 0.1000 | 0.1000 | 0.0000 | 358.0987 | 0 0 29 | 0.0000 | 0.0500 |
| 0.15 | 0 0 22 | 0.1500 | 0.1500 | 0.0000 | 238.7324 | 0 1 5 | 0.0000 | 0.0750 |
| 0.20 | 0 0 38 | 0.2000 | 0.2000 | 0.0000 | 179.0493 | 0 1 55 | 0.0000 | 0.1000 |
| 0.25 | 0 1 0 | 0.2500 | 0.2500 | 0.0001 | 143.2394 | 0 3 0 | 0.0000 | 0.1250 |
| 0.30 | 0 1 26 | 0.3000 | 0.3000 | 0.0001 | 119.3662 | 0 4 19 | 0.0000 | 0.1500 |
| 0.35 | 0 1 58 | 0.3500 | 0.3500 | 0.0002 | 102.3139 | 0 5 53 | 0.0000 | 0.1750 |
| 0.40 | 0 2 34 | 0.4000 | 0.4000 | 0.0003 | 89.5247 | 0 7 41 | 0.0001 | 0.2000 |
| 0.45 | 0 3 14 | 0.4500 | 0.4500 | 0.0004 | 79.5775 | 0 9 43 | 0.0001 | 0.2250 |
| 0.50 | 0 4 0 | 0.5000 | 0.5000 | 0.0006 | 71.6197 | 0 12 0 | 0.0001 | 0.2500 |
| 0.55 | 0 4 50 | 0.5500 | 0.5500 | 0.0008 | 65.1088 | 0 14 31 | 0.0002 | 0.2750 |
| 0.60 | 0 5 46 | 0.6000 | 0.6000 | 0.0010 | 59.6831 | 0 17 17 | 0.0003 | 0.3000 |
| 0.65 | 0 6 46 | 0.6500 | 0.6500 | 0.0013 | 55.0921 | 0 20 17 | 0.0003 | 0.3250 |
| 0.70 | 0 7 50 | 0.7000 | 0.7000 | 0.0016 | 51.1569 | 0 23 31 | 0.0004 | 0.3500 |
| 0.75 | 0 9 0 | 0.7500 | 0.7500 | 0.0020 | 47.7465 | 0 27 0 | 0.0005 | 0.3750 |
| 0.80 | 0 10 14 | 0.8000 | 0.8000 | 0.0024 | 44.7623 | 0 30 43 | 0.0006 | 0.4000 |
| 0.85 | 0 11 34 | 0.8500 | 0.8500 | 0.0029 | 42.1292 | 0 34 41 | 0.0007 | 0.4250 |
| 0.90 | 0 12 58 | 0.9000 | 0.9000 | 0.0034 | 39.7887 | 0 38 53 | 0.0008 | 0.4500 |
| 0.95 | 0 14 26 | 0.9500 | 0.9500 | 0.0040 | 37.6946 | 0 43 19 | 0.0010 | 0.4750 |
| 1.00 | 0 16 0 | 1.0000 | 1.0000 | 0.0047 | 35.8099 | 0 48 0 | 0.0012 | 0.5000 |
| 1.05 | 0 17 38 | 1.0500 | 1.0500 | 0.0054 | 34.1047 | 0 52 55 | 0.0013 | 0.5250 |
| 1.10 | 0 19 22 | 1.1000 | 1.1000 | 0.0062 | 32.5544 | 0 58 5 | 0.0015 | 0.5500 |
| 1.15 | 0 21 10 | 1.1500 | 1.1500 | 0.0071 | 31.1390 | 1 3 29 | 0.0018 | 0.5750 |
| 1.20 | 0 23 2 | 1.2000 | 1.2000 | 0.0080 | 29.8416 | 1 9 7 | 0.0020 | 0.6000 |
| 1.25 | 0 25 0 | 1.2500 | 1.2499 | 0.0091 | 28.6479 | 1 15 0 | 0.0023 | 0.6250 |
| 1.30 | 0 27 2 | 1.3000 | 1.2999 | 0.0102 | 27.5461 | 1 21 7 | 0.0026 | 0.6500 |
| 1.35 | 0 29 10 | 1.3500 | 1.3499 | 0.0115 | 26.5258 | 1 27 29 | 0.0029 | 0.6750 |
| 1.40 | 0 31 22 | 1.4000 | 1.3999 | 0.0128 | 25.5785 | 1 34 5 | 0.0032 | 0.7000 |
| 1.45 | 0 33 38 | 1.4499 | 1.4499 | 0.0142 | 24.6965 | 1 40 55 | 0.0035 | 0.7250 |
| 1.50 | 0 36 0 | 1.4999 | 1.4999 | 0.0157 | 23.8732 | 1 48 0 | 0.0039 | 0.7500 |
| 1.55 | 0 38 26 | 1.5499 | 1.5498 | 0.0173 | 23.1031 | 1 55 19 | 0.0043 | 0.7750 |
| 1.60 | 0 40 58 | 1.5999 | 1.5998 | 0.0191 | 22.3812 | 2 2 53 | 0.0048 | 0.8000 |
| 1.65 | 0 43 34 | 1.6499 | 1.6498 | 0.0209 | 21.7030 | 2 10 41 | 0.0052 | 0.8250 |
| 1.70 | 0 46 14 | 1.6999 | 1.6997 | 0.0229 | 21.0646 | 2 18 43 | 0.0057 | 0.8500 |
| 1.75 | 0 49 0 | 1.7499 | 1.7497 | 0.0249 | 20.4628 | 2 27 0 | 0.0062 | 0.8749 |
| 1.80 | 0 51 50 | 1.7998 | 1.7996 | 0.0271 | 19.8944 | 2 35 31 | 0.0068 | 0.8999 |
| 1.85 | 0 54 46 | 1.8498 | 1.8496 | 0.0295 | 19.3567 | 2 44 17 | 0.0074 | 0.9249 |
| 1.90 | 0 57 46 | 1.8998 | 1.8995 | 0.0319 | 18.8473 | 2 53 17 | 0.0080 | 0.9499 |
| 1.95 | 1 0 50 | 1.9498 | 1.9495 | 0.0345 | 18.3640 | 3 2 31 | 0.0086 | 0.9749 |
| 2.00 | 1 4 0 | 1.9997 | 1.9994 | 0.0372 | 17.9049 | 3 12 0 | 0.0093 | 0.9999 |
| 2.05 | 1 7 14 | 2.0497 | 2.0493 | 0.0401 | 17.4682 | 3 21 43 | 0.0100 | 1.0249 |
| 2.10 | 1 10 33 | 2.0996 | 2.0992 | 0.0431 | 17.0523 | 3 31 41 | 0.0108 | 1.0499 |
| 2.15 | 1 13 57 | 2.1496 | 2.1491 | 0.0462 | 16.6558 | 3 41 53 | 0.0116 | 1.0749 |
| 2.20 | 1 17 26 | 2.1996 | 2.1990 | 0.0495 | 16.2772 | 3 52 19 | 0.0124 | 1.0998 |
| 2.25 | 1 21 0 | 2.2495 | 2.2489 | 0.0530 | 15.9155 | 4 3 0 | 0.0133 | 1.1248 |
| 2.30 | 1 24 38 | 2.2994 | 2.2987 | 0.0566 | 15.5695 | 4 13 55 | 0.0142 | 1.1498 |
| 2.35 | 1 28 21 | 2.3494 | 2.3486 | 0.0604 | 15.2382 | 4 25 5 | 0.0151 | 1.1748 |
| 2.40 | 1 32 9 | 2.3993 | 2.3984 | 0.0643 | 14.9208 | 4 36 29 | 0.0161 | 1.1997 |
| 2.45 | 1 36 2 | 2.4492 | 2.4483 | 0.0684 | 14.6163 | 4 48 7 | 0.0171 | 1.2247 |
| 2.50 | 1 40 0 | 2.4992 | 2.4981 | 0.0727 | 14.3239 | 5 0 0 | 0.0182 | 1.2497 |
| 2.55 | 1 44 2 | 2.5491 | 2.5479 | 0.0771 | 14.0431 | 5 12 7 | 0.0193 | 1.2746 |
| 2.60 | 1 48 9 | 2.5990 | 2.5977 | 0.0818 | 13.7730 | 5 24 29 | 0.0204 | 1.2996 |

**Table 4.4: Dimensions of Unit Chord Spiral and Central Circular Arc**

| SPIRAL LENGTH SL | PHI C ∅ D M S | LONG CHORD | CO-ORDS OF CURVE POINTS XC | YC | RADIUS R | SPIRAL ANGLE θ D M S | SHIFT P | SHIFT DIST K |
|---|---|---|---|---|---|---|---|---|
| 2.65 | 1 52 21 | 2.6489 | 2.6475 | 0.0866 | 13.5132 | 5 37 5 | 0.0216 | 1.3246 |
| 2.70 | 1 56 38 | 2.6988 | 2.6972 | 0.0915 | 13.2629 | 5 49 55 | 0.0229 | 1.3495 |
| 2.75 | 2 0 59 | 2.7486 | 2.7469 | 0.0967 | 13.0218 | 6 3 0 | 0.0242 | 1.3745 |
| 2.80 | 2 5 26 | 2.7985 | 2.7966 | 0.1021 | 12.7892 | 6 16 19 | 0.0255 | 1.3994 |
| 2.85 | 2 9 57 | 2.8484 | 2.8463 | 0.1076 | 12.5649 | 6 29 53 | 0.0269 | 1.4244 |
| 2.90 | 2 14 33 | 2.8982 | 2.8960 | 0.1134 | 12.3482 | 6 43 41 | 0.0284 | 1.4493 |
| 2.95 | 2 19 13 | 2.9481 | 2.9456 | 0.1194 | 12.1389 | 6 57 43 | 0.0299 | 1.4743 |
| 3.00 | 2 23 59 | 2.9979 | 2.9953 | 0.1255 | 11.9366 | 7 12 0 | 0.0314 | 1.4992 |
| 3.05 | 2 28 49 | 3.0477 | 3.0449 | 0.1319 | 11.7409 | 7 26 31 | 0.0330 | 1.5241 |
| 3.10 | 2 33 44 | 3.0975 | 3.0944 | 0.1385 | 11.5516 | 7 41 17 | 0.0346 | 1.5491 |
| 3.15 | 2 38 44 | 3.1473 | 3.1440 | 0.1453 | 11.3682 | 7 56 17 | 0.0363 | 1.5740 |
| 3.20 | 2 43 49 | 3.1971 | 3.1935 | 0.1523 | 11.1906 | 8 11 31 | 0.0381 | 1.5989 |
| 3.25 | 2 48 58 | 3.2469 | 3.2429 | 0.1595 | 11.0184 | 8 27 0 | 0.0399 | 1.6238 |
| 3.30 | 2 54 12 | 3.2966 | 3.2924 | 0.1670 | 10.8515 | 8 42 43 | 0.0418 | 1.6487 |
| 3.35 | 2 59 31 | 3.3463 | 3.3418 | 0.1747 | 10.6895 | 8 58 41 | 0.0437 | 1.6736 |
| 3.40 | 3 4 55 | 3.3961 | 3.3912 | 0.1826 | 10.5323 | 9 14 53 | 0.0457 | 1.6985 |
| 3.45 | 3 10 24 | 3.4458 | 3.4405 | 0.1907 | 10.3797 | 9 31 19 | 0.0477 | 1.7234 |
| 3.50 | 3 15 57 | 3.4955 | 3.4898 | 0.1991 | 10.2314 | 9 48 0 | 0.0498 | 1.7483 |
| 3.55 | 3 21 35 | 3.5451 | 3.5390 | 0.2078 | 10.0873 | 10 4 55 | 0.0520 | 1.7732 |
| 3.60 | 3 27 18 | 3.5948 | 3.5882 | 0.2166 | 9.9472 | 10 22 5 | 0.0542 | 1.7980 |
| 3.65 | 3 33 6 | 3.6444 | 3.6374 | 0.2258 | 9.8109 | 10 39 29 | 0.0565 | 1.8229 |
| 3.70 | 3 38 58 | 3.6940 | 3.6865 | 0.2351 | 9.6783 | 10 57 7 | 0.0589 | 1.8477 |
| 3.75 | 3 44 56 | 3.7436 | 3.7356 | 0.2448 | 9.5493 | 11 15 0 | 0.0613 | 1.8726 |
| 3.80 | 3 50 58 | 3.7931 | 3.7846 | 0.2546 | 9.4236 | 11 33 7 | 0.0638 | 1.8974 |
| 3.85 | 3 57 4 | 3.8427 | 3.8335 | 0.2648 | 9.3013 | 11 51 29 | 0.0663 | 1.9223 |
| 3.90 | 4 3 16 | 3.8922 | 3.8824 | 0.2752 | 9.1820 | 12 10 5 | 0.0689 | 1.9471 |
| 3.95 | 4 9 32 | 3.9417 | 3.9313 | 0.2859 | 9.0658 | 12 28 55 | 0.0716 | 1.9719 |
| 4.00 | 4 15 54 | 3.9911 | 3.9801 | 0.2968 | 8.9525 | 12 48 0 | 0.0743 | 1.9967 |
| 4.05 | 4 22 19 | 4.0406 | 4.0288 | 0.3080 | 8.8419 | 13 7 19 | 0.0772 | 2.0215 |
| 4.10 | 4 28 50 | 4.0900 | 4.0775 | 0.3195 | 8.7341 | 13 26 53 | 0.0800 | 2.0462 |
| 4.15 | 4 35 25 | 4.1393 | 4.1261 | 0.3313 | 8.6289 | 13 46 41 | 0.0830 | 2.0710 |
| 4.20 | 4 42 6 | 4.1887 | 4.1746 | 0.3433 | 8.5262 | 14 6 43 | 0.0860 | 2.0958 |
| 4.25 | 4 48 51 | 4.2380 | 4.2230 | 0.3557 | 8.4258 | 14 27 0 | 0.0891 | 2.1205 |
| 4.30 | 4 55 40 | 4.2873 | 4.2714 | 0.3683 | 8.3279 | 14 47 31 | 0.0923 | 2.1452 |
| 4.35 | 5 2 35 | 4.3365 | 4.3197 | 0.3812 | 8.2322 | 15 8 17 | 0.0955 | 2.1699 |
| 4.40 | 5 9 34 | 4.3857 | 4.3680 | 0.3944 | 8.1386 | 15 29 17 | 0.0989 | 2.1947 |
| 4.45 | 5 16 38 | 4.4349 | 4.4161 | 0.4079 | 8.0472 | 15 50 31 | 0.1023 | 2.2193 |
| 4.50 | 5 23 47 | 4.4840 | 4.4642 | 0.4217 | 7.9577 | 16 12 0 | 0.1057 | 2.2440 |
| 4.55 | 5 31 0 | 4.5331 | 4.5121 | 0.4358 | 7.8703 | 16 33 43 | 0.1093 | 2.2687 |
| 4.60 | 5 38 19 | 4.5822 | 4.5600 | 0.4502 | 7.7848 | 16 55 41 | 0.1129 | 2.2933 |
| 4.65 | 5 45 42 | 4.6312 | 4.6078 | 0.4649 | 7.7010 | 17 17 53 | 0.1166 | 2.3180 |
| 4.70 | 5 53 9 | 4.6802 | 4.6555 | 0.4799 | 7.6191 | 17 40 19 | 0.1204 | 2.3426 |
| 4.75 | 6 0 42 | 4.7291 | 4.7031 | 0.4953 | 7.5389 | 18 3 0 | 0.1243 | 2.3672 |
| 4.80 | 6 8 19 | 4.7780 | 4.7506 | 0.5109 | 7.4604 | 18 25 55 | 0.1282 | 2.3917 |
| 4.85 | 6 16 1 | 4.8268 | 4.7979 | 0.5269 | 7.3835 | 18 49 5 | 0.1322 | 2.4163 |
| 4.90 | 6 23 48 | 4.8756 | 4.8452 | 0.5432 | 7.3081 | 19 12 29 | 0.1363 | 2.4409 |
| 4.95 | 6 31 39 | 4.9243 | 4.8924 | 0.5598 | 7.2343 | 19 36 7 | 0.1405 | 2.4654 |
| 5.00 | 6 39 35 | 4.9730 | 4.9394 | 0.5767 | 7.1620 | 20 0 0 | 0.1448 | 2.4899 |
| 5.05 | 6 47 36 | 5.0216 | 4.9863 | 0.5940 | 7.0911 | 20 24 7 | 0.1492 | 2.5144 |
| 5.10 | 6 55 42 | 5.0702 | 5.0331 | 0.6116 | 7.0215 | 20 48 29 | 0.1536 | 2.5388 |
| 5.15 | 7 3 52 | 5.1187 | 5.0798 | 0.6295 | 6.9534 | 21 13 5 | 0.1582 | 2.5633 |
| 5.20 | 7 12 7 | 5.1671 | 5.1264 | 0.6478 | 6.8865 | 21 37 55 | 0.1628 | 2.5877 |

**Table 4.4 (cont.): Dimensions of Unit Chord Spiral and Central Circular Arc**

| SPIRAL LENGTH SL | PHI C ø D M S | LONG CHORD | CO-ORDS OF CURVE POINTS XC | YC | RADIUS R | SPIRAL ANGLE θ D M S | SHIFT P | SHIFT DIST K |
|---|---|---|---|---|---|---|---|---|
| 5.25 | 7 20 27 | 5.2155 | 5.1728 | 0.6664 | 6.8209 | 22 3 0 | 0.1675 | 2.6121 |
| 5.30 | 7 28 51 | 5.2639 | 5.2190 | 0.6853 | 6.7566 | 22 28 19 | 0.1723 | 2.6365 |
| 5.35 | 7 37 20 | 5.3121 | 5.2652 | 0.7046 | 6.6934 | 22 53 53 | 0.1772 | 2.6608 |
| 5.40 | 7 45 54 | 5.3603 | 5.3112 | 0.7242 | 6.6315 | 23 19 41 | 0.1821 | 2.6851 |
| 5.45 | 7 54 33 | 5.4085 | 5.3570 | 0.7442 | 6.5706 | 23 45 43 | 0.1872 | 2.7095 |
| 5.50 | 8 3 16 | 5.4565 | 5.4027 | 0.7645 | 6.5109 | 24 12 0 | 0.1924 | 2.7337 |
| 5.55 | 8 12 4 | 5.5045 | 5.4482 | 0.7852 | 6.4522 | 24 38 31 | 0.1976 | 2.7580 |
| 5.60 | 8 20 56 | 5.5524 | 5.4936 | 0.8062 | 6.3946 | 25 5 17 | 0.2029 | 2.7822 |
| 5.65 | 8 29 54 | 5.6003 | 5.5388 | 0.8276 | 6.3380 | 25 32 17 | 0.2084 | 2.8064 |
| 5.70 | 8 38 56 | 5.6480 | 5.5838 | 0.8493 | 6.2824 | 25 59 31 | 0.2139 | 2.8306 |
| 5.75 | 8 48 2 | 5.6957 | 5.6287 | 0.8714 | 6.2278 | 26 27 0 | 0.2195 | 2.8547 |
| 5.80 | 8 57 14 | 5.7433 | 5.6733 | 0.8939 | 6.1741 | 26 54 43 | 0.2252 | 2.8788 |
| 5.85 | 9 6 30 | 5.7908 | 5.7178 | 0.9167 | 6.1213 | 27 22 41 | 0.2311 | 2.9029 |
| 5.90 | 9 15 50 | 5.8383 | 5.7621 | 0.9399 | 6.0695 | 27 50 53 | 0.2370 | 2.9269 |
| 5.95 | 9 25 16 | 5.8856 | 5.8063 | 0.9634 | 6.0185 | 28 19 19 | 0.2430 | 2.9509 |
| 6.00 | 9 34 46 | 5.9329 | 5.8502 | 0.9873 | 5.9683 | 28 48 0 | 0.2491 | 2.9749 |
| 6.05 | 9 44 20 | 5.9801 | 5.8939 | 1.0116 | 5.9190 | 29 16 55 | 0.2553 | 2.9989 |
| 6.10 | 9 53 59 | 6.0271 | 5.9374 | 1.0362 | 5.8705 | 29 46 5 | 0.2616 | 3.0228 |
| 6.15 | 10 3 43 | 6.0741 | 5.9807 | 1.0612 | 5.8227 | 30 15 29 | 0.2680 | 3.0466 |
| 6.20 | 10 13 32 | 6.1210 | 6.0238 | 1.0866 | 5.7758 | 30 45 7 | 0.2745 | 3.0705 |
| 6.25 | 10 23 25 | 6.1678 | 6.0666 | 1.1124 | 5.7296 | 31 15 0 | 0.2811 | 3.0943 |
| 6.30 | 10 33 23 | 6.2144 | 6.1093 | 1.1385 | 5.6841 | 31 45 7 | 0.2878 | 3.1180 |
| 6.35 | 10 43 25 | 6.2610 | 6.1517 | 1.1650 | 5.6393 | 32 15 29 | 0.2946 | 3.1417 |
| 6.40 | 10 53 32 | 6.3074 | 6.1938 | 1.1919 | 5.5953 | 32 46 5 | 0.3015 | 3.1654 |
| 6.45 | 11 3 43 | 6.3538 | 6.2357 | 1.2191 | 5.5519 | 33 16 55 | 0.3085 | 3.1891 |
| 6.50 | 11 13 59 | 6.4000 | 6.2774 | 1.2467 | 5.5092 | 33 48 0 | 0.3156 | 3.2127 |
| 6.55 | 11 24 20 | 6.4461 | 6.3188 | 1.2747 | 5.4672 | 34 19 19 | 0.3228 | 3.2362 |
| 6.60 | 11 34 45 | 6.4921 | 6.3600 | 1.3031 | 5.4257 | 34 50 53 | 0.3301 | 3.2597 |
| 6.65 | 11 45 15 | 6.5380 | 6.4009 | 1.3319 | 5.3849 | 35 22 41 | 0.3376 | 3.2832 |
| 6.70 | 11 55 50 | 6.5837 | 6.4415 | 1.3610 | 5.3448 | 35 54 43 | 0.3451 | 3.3066 |
| 6.75 | 12 6 29 | 6.6294 | 6.4819 | 1.3905 | 5.3052 | 36 27 0 | 0.3527 | 3.3300 |
| 6.80 | 12 17 12 | 6.6749 | 6.5220 | 1.4204 | 5.2662 | 36 59 31 | 0.3605 | 3.3533 |
| 6.85 | 12 28 0 | 6.7202 | 6.5618 | 1.4507 | 5.2277 | 37 32 17 | 0.3683 | 3.3766 |
| 6.90 | 12 38 53 | 6.7654 | 6.6013 | 1.4814 | 5.1898 | 38 5 17 | 0.3763 | 3.3998 |
| 6.95 | 12 49 50 | 6.8105 | 6.6405 | 1.5124 | 5.1525 | 38 38 31 | 0.3843 | 3.4230 |
| 7.00 | 13 0 51 | 6.8555 | 6.6794 | 1.5438 | 5.1157 | 39 12 0 | 0.3925 | 3.4461 |
| 7.05 | 13 11 58 | 6.9002 | 6.7180 | 1.5756 | 5.0794 | 39 45 43 | 0.4008 | 3.4692 |
| 7.10 | 13 23 8 | 6.9449 | 6.7562 | 1.6078 | 5.0436 | 40 19 41 | 0.4092 | 3.4922 |
| 7.15 | 13 34 23 | 6.9894 | 6.7942 | 1.6403 | 5.0084 | 40 53 53 | 0.4177 | 3.5151 |
| 7.20 | 13 45 43 | 7.0337 | 6.8318 | 1.6732 | 4.9736 | 41 28 19 | 0.4263 | 3.5380 |
| 7.25 | 13 57 7 | 7.0779 | 6.8691 | 1.7065 | 4.9393 | 42 3 0 | 0.4350 | 3.5609 |
| 7.30 | 14 8 35 | 7.1219 | 6.9061 | 1.7402 | 4.9055 | 42 37 55 | 0.4438 | 3.5837 |
| 7.35 | 14 20 8 | 7.1658 | 6.9427 | 1.7743 | 4.8721 | 43 13 5 | 0.4527 | 3.6064 |
| 7.40 | 14 31 46 | 7.2095 | 6.9789 | 1.8087 | 4.8392 | 43 48 29 | 0.4618 | 3.6291 |
| 7.45 | 14 43 27 | 7.2530 | 7.0148 | 1.8435 | 4.8067 | 44 24 7 | 0.4709 | 3.6517 |
| 7.50 | 14 55 14 | 7.2964 | 7.0504 | 1.8787 | 4.7746 | 45 0 0 | 0.4802 | 3.6742 |
| 7.55 | 15 7 4 | 7.3396 | 7.0856 | 1.9142 | 4.7430 | 45 36 7 | 0.4896 | 3.6967 |
| 7.60 | 15 18 59 | 7.3826 | 7.1203 | 1.9501 | 4.7118 | 46 12 29 | 0.4991 | 3.7191 |
| 7.65 | 15 30 59 | 7.4254 | 7.1548 | 1.9864 | 4.6810 | 46 49 5 | 0.5087 | 3.7414 |
| 7.70 | 15 43 3 | 7.4680 | 7.1888 | 2.0230 | 4.6506 | 47 25 55 | 0.5184 | 3.7637 |
| 7.75 | 15 55 11 | 7.5104 | 7.2224 | 2.0600 | 4.6206 | 48 3 0 | 0.5282 | 3.7859 |
| 7.80 | 16 7 23 | 7.5527 | 7.2556 | 2.0974 | 4.5910 | 48 40 19 | 0.5382 | 3.8080 |

**Table 4.4 (cont.): Dimensions of Unit Chord Spiral and Central Circular Arc**

| SPIRAL LENGTH SL | PHI C ∅ D M S | LONG CHORD | CO-ORDS OF CURVE POINTS XC | YC | RADIUS R | SPIRAL ANGLE θ D M S | SHIFT P | SHIFT DIST K |
|---|---|---|---|---|---|---|---|---|
| 7.85 | 16 19 40 | 7.5947 | 7.2884 | 2.1351 | 4.5618 | 49 17 53 | 0.5482 | 3.8301 |
| 7.90 | 16 32 1 | 7.6366 | 7.3208 | 2.1732 | 4.5329 | 49 55 41 | 0.5584 | 3.8521 |
| 7.95 | 16 44 27 | 7.6782 | 7.3528 | 2.2117 | 4.5044 | 50 33 43 | 0.5686 | 3.8740 |
| 8.00 | 16 56 56 | 7.7197 | 7.3844 | 2.2504 | 4.4762 | 51 12 0 | 0.5790 | 3.8959 |
| 8.05 | 17 9 30 | 7.7609 | 7.4155 | 2.2896 | 4.4484 | 51 50 31 | 0.5895 | 3.9176 |
| 8.10 | 17 22 9 | 7.8019 | 7.4461 | 2.3291 | 4.4210 | 52 29 17 | 0.6002 | 3.9393 |
| 8.15 | 17 34 51 | 7.8427 | 7.4764 | 2.3689 | 4.3938 | 53 8 17 | 0.6109 | 3.9609 |
| 8.20 | 17 47 38 | 7.8832 | 7.5061 | 2.4091 | 4.3671 | 53 47 31 | 0.6217 | 3.9824 |
| 8.25 | 18 0 29 | 7.9236 | 7.5354 | 2.4496 | 4.3406 | 54 27 0 | 0.6327 | 4.0039 |
| 8.30 | 18 13 24 | 7.9637 | 7.5643 | 2.4904 | 4.3144 | 55 6 43 | 0.6437 | 4.0252 |
| 8.35 | 18 26 24 | 8.0036 | 7.5926 | 2.5316 | 4.2886 | 55 46 41 | 0.6549 | 4.0465 |
| 8.40 | 18 39 28 | 8.0432 | 7.6205 | 2.5731 | 4.2631 | 56 26 53 | 0.6662 | 4.0677 |
| 8.45 | 18 52 35 | 8.0826 | 7.6479 | 2.6150 | 4.2379 | 57 7 19 | 0.6776 | 4.0888 |
| 8.50 | 19 5 47 | 8.1217 | 7.6748 | 2.6571 | 4.2129 | 57 48 0 | 0.6891 | 4.1098 |
| 8.55 | 19 19 3 | 8.1606 | 7.7012 | 2.6996 | 4.1883 | 58 28 55 | 0.7008 | 4.1308 |
| 8.60 | 19 32 24 | 8.1993 | 7.7271 | 2.7424 | 4.1639 | 59 10 5 | 0.7125 | 4.1516 |
| 8.65 | 19 45 48 | 8.2376 | 7.7524 | 2.7854 | 4.1399 | 59 51 29 | 0.7244 | 4.1723 |
| 8.70 | 19 59 16 | 8.2758 | 7.7773 | 2.8288 | 4.1161 | 60 33 7 | 0.7364 | 4.1930 |
| 8.75 | 20 12 49 | 8.3136 | 7.8016 | 2.8725 | 4.0926 | 61 15 0 | 0.7484 | 4.2135 |
| 8.80 | 20 26 25 | 8.3512 | 7.8254 | 2.9165 | 4.0693 | 61 57 7 | 0.7606 | 4.2340 |
| 8.85 | 20 40 6 | 8.3885 | 7.8486 | 2.9608 | 4.0463 | 62 39 29 | 0.7729 | 4.2543 |
| 8.90 | 20 53 50 | 8.4255 | 7.8713 | 3.0053 | 4.0236 | 63 22 5 | 0.7853 | 4.2746 |
| 8.95 | 21 7 39 | 8.4623 | 7.8934 | 3.0502 | 4.0011 | 64 4 55 | 0.7979 | 4.2948 |
| 9.00 | 21 21 31 | 8.4987 | 7.9150 | 3.0953 | 3.9789 | 64 48 0 | 0.8105 | 4.3148 |
| 9.05 | 21 35 27 | 8.5349 | 7.9360 | 3.1406 | 3.9569 | 65 31 19 | 0.8233 | 4.3348 |
| 9.10 | 21 49 28 | 8.5707 | 7.9564 | 3.1863 | 3.9351 | 66 14 53 | 0.8361 | 4.3546 |
| 9.15 | 22 3 32 | 8.6063 | 7.9763 | 3.2322 | 3.9136 | 66 58 41 | 0.8491 | 4.3743 |
| 9.20 | 22 17 40 | 8.6415 | 7.9955 | 3.2783 | 3.8924 | 67 42 43 | 0.8622 | 4.3940 |
| 9.25 | 22 31 52 | 8.6765 | 8.0142 | 3.3247 | 3.8713 | 68 27 0 | 0.8754 | 4.4135 |
| 9.30 | 22 46 8 | 8.7111 | 8.0323 | 3.3713 | 3.8505 | 69 11 31 | 0.8886 | 4.4329 |
| 9.35 | 23 0 27 | 8.7454 | 8.0497 | 3.4182 | 3.8299 | 69 56 17 | 0.9020 | 4.4522 |
| 9.40 | 23 14 51 | 8.7794 | 8.0666 | 3.4652 | 3.8096 | 70 41 17 | 0.9156 | 4.4714 |
| 9.45 | 23 29 18 | 8.8130 | 8.0828 | 3.5125 | 3.7894 | 71 26 31 | 0.9292 | 4.4904 |
| 9.50 | 23 43 49 | 8.8463 | 8.0984 | 3.5600 | 3.7695 | 72 12 0 | 0.9429 | 4.5094 |
| 9.55 | 23 58 23 | 8.8793 | 8.1134 | 3.6077 | 3.7497 | 72 57 43 | 0.9567 | 4.5282 |
| 9.60 | 24 13 1 | 8.9120 | 8.1277 | 3.6556 | 3.7302 | 73 43 41 | 0.9707 | 4.5469 |
| 9.65 | 24 27 43 | 8.9443 | 8.1414 | 3.7037 | 3.7109 | 74 29 53 | 0.9847 | 4.5655 |
| 9.70 | 24 42 29 | 8.9762 | 8.1544 | 3.7520 | 3.6917 | 75 16 19 | 0.9988 | 4.5840 |
| 9.75 | 24 57 18 | 9.0078 | 8.1668 | 3.8004 | 3.6728 | 76 3 0 | 1.0131 | 4.6023 |
| 9.80 | 25 12 11 | 9.0390 | 8.1785 | 3.8490 | 3.6541 | 76 49 55 | 1.0274 | 4.6205 |
| 9.85 | 25 27 7 | 9.0698 | 8.1896 | 3.8978 | 3.6355 | 77 37 5 | 1.0419 | 4.6386 |
| 9.90 | 25 42 7 | 9.1003 | 8.2000 | 3.9467 | 3.6172 | 78 24 29 | 1.0564 | 4.6566 |
| 9.95 | 25 57 10 | 9.1304 | 8.2097 | 3.9958 | 3.5990 | 79 12 7 | 1.0711 | 4.6744 |
| 10.00 | 26 12 17 | 9.1602 | 8.2187 | 4.0449 | 3.5810 | 80 0 0 | 1.0858 | 4.6921 |

**Table 4.4 (cont.): Dimensions of Unit Chord Spiral and Central Circular Arc**

# 4.6 Superelevation

## 4.6.1 Standards for Superelevation

The maximum superelevation rates for use on state highways are shown in Tables 2.9 and 2.10.

The use of normal crossfall , ie. -3% superelevation, may only be considered when curve radii exceed the values given in Table 2.7.

Figures 4.15, 4.16 and 4.17 must be used to determine the design superelevation required all state highway horizontal curves.

## 4.6.2 Axis of Rotation

### (a) General

Crossfall is used on straight sections of road to shed water. This crossfall, which is commonly known as *'normal crossfall'*, is usually away from the centreline on two-lane two-way roads and away from the median on dual carriageway roads. Normal crossfall generally changes to superelevation when the horizontal alignment becomes a curve, except where the curve radius is very large and adverse or normal crossfall can be used, ie. -3% superelevation.

The point about which the pavement is rotated to develop superelevation, ie. the *'axis of rotation'*, depends upon the type of road, the road cross section, terrain and the location of the road.

### (b) Two-lane Two-Way Roads

On two-lane, two-way roads the axis of rotation for superelevation development is usually the road centreline, as shown in Figure 4.9 below.

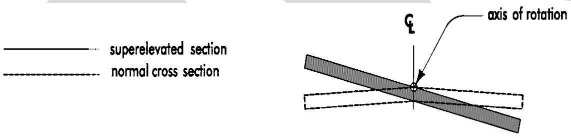



**Figure 4.9: Axis of Rotation for Superelevation Development on Two-lane Two-way Roads**

Each half of the pavement, including shoulders, is rotated about the road centreline and the resultant profiles of the edges of the carriageways are in opposite directions to each other. This can lead to the creation of flat sections of pavement and drainage problems particularly in flat terrain where curves are preceded by long relatively level tangents. In these situations the axis of rotation for superelevation development should be shifted to the edge of the traffic lane on the inside of the curve, to improve drainage as well as driver perception of the curve.

### (c) Interchange Ramps and Motorway / Expressway to Motorway / Expressway Connections

The axis of rotation may be about either edge of the travelled way or, the centreline, if multilane. However, the lower side of the travelled way is normally the best location. See Figure 4.10.

Appearance and drainage considerations should always be taken into account in the selection of the axis of rotation for superelevation development on ramps and motorway / expressway connectors.

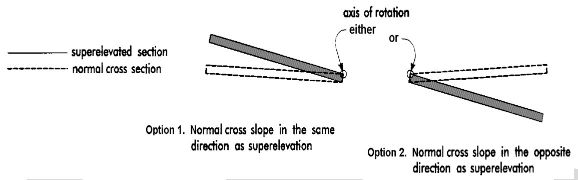



**Figure 4.10: Axis of Rotation for Superelevation Development on Ramps and Motorway / Expressway Connectors**

### (d) Dual Carriageway Roads

#### (i) General

Aesthetics, grade distortion, superelevation transitions, drainage and driver perception must all be considered when selecting the location of the axis of rotation for dual carriageway roads. In flat country it may be desirable to adopt the left (or outer) edge of the carriageway as the axis of rotation or to use independently graded carriageways

#### (ii) Motorways and Expressways

Where the median width is 4.0 m or less, the axis of rotation should be the centreline of the road.

For staged construction projects where the initial median width is greater than 4.0 m, and the ultimate median width is to be 4.0 m or less, the axis of rotation should be at the road centreline, except where the resulting initial median slope would be steeper than 1:10. In the latter case, the axis of rotation should be at the ultimate median edges of the travelled way.

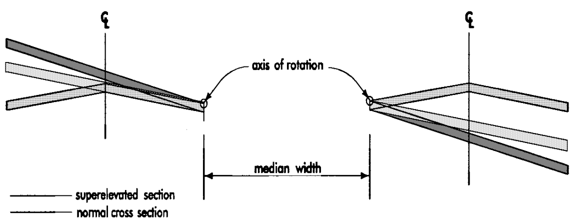



**Figure 4.11: Axis of Rotation for Superelevation Development on Dual Carriageway Roads where the median is wider than 4.0 m**

Where the ultimate median width is greater than 3.8 m, the axis of rotation should be at the ultimate median edges of the travelled way.

To avoid a *'sawtooth'* profile on bridges with decked medians, the axis of rotation, if not on the centreline, should be shifted to it.

#### (iii) Other State Highways

The location of the axis of rotation should be considered on an individual project basis and the most appropriate solution for the specific design conditions selected.

For roads with painted medians the axis of rotation will normally be the road centreline. In all other situations the location of the axis of rotation should be determined by using the selection criteria given in Section 4.6.2 (d) (i) above.

### 4.6.3 Application of Superelevation

#### (a) General

The transition from normal crossfall to the maximum superelevation for a horizontal curve on a two-lane two-way road generally consists of a crown runoff and a superelevation runoff, as shown on Figure 4.12 (a).

This type of superelevation transition is also applicable to wide one-way pavements on dual carriageway roads where a longitudinal crown is needed for drainage reasons.

The more normal situation on dual carriageway roads is a one-way pavement which has a constant crossfall from the median towards the shoulder. This pavement is rotated at a constant rate to the maximum superelevation required by the horizontal curve, as indicated on Figures 4.12 (a), (b) and (c).

#### (b) Superelevation Runoff

*'Superelevation runoff'* is the length of road required to rotate the road pavement from level, or 0% crossfall, to the maximum superelevation rate required.

On circular curves the superelevation runoff should occur 60 % on the tangent and 40% within the curve itself. This results in 60% of the full superelevation rate at the beginning of the curve.

On transition curves the superelevation runoff should normally occur over the plan transition length.

***NOTE:***

***The use of the unit chord in transition curve design will ensure the correct relationship between transition curve spiral length, circular arc radius and superelevation runoff.***

#### (c) Crown (Tangent) Runoff

*'Crown runoff'* is the length of road required to rotate one half of a crowned road pavement from normal camber to level, or 0% crossfall, at the same pavement rotation rate used to apply superelevation on the associated horizontal curve, see Figure 4.12 (a), (b) and (c).

*'Tangent runoff'* is the length of road required to rotate a constant crossfall road pavement from normal camber to level, or 0% crossfall, at the same pavement rotation rate used to apply superelevation on the associated horizontal curve, see Figure 4.13 (a), (b) and (c).

#### (d) Superelevation Development Length

**(i)** The criteria used to determine the length of road over which superelevation is developed are:

- design speed, and
- the rate of pavement rotation, ie. a vehicle occupant comfort control, or
- the relative grade between grade between the inner and outer edges of the travelled way, ie. an appearance control.

The superelevation development length must be long enough to ensure a satisfactory riding quality and also give a visually pleasing road alignment.

**(ii)** On two-lane two way roads superelevation development length is determined by rate of pavement rotation. This rate should not normally exceed 2.5% per second of travel time at the design speed.

**(iii)** However, on two-lane two-way roads in constrained design conditions, eg. low speed environments, mountainous terrain, etc, and where design speeds are ≤ 70 km/h, pavement rotation rates up to 3.5% per second at the design speed may be used. In some specially approved cases this rate may also sometimes be used at an 80 km/h design speed.

**(iv)** Divided roads ae usually designed to higher standards and have wider pavements than two-lane two-way roads. Superelevation on these roads is developed over the longer of the lengths determined by the following criteria:

- an enhanced vehicle occupant comfort criteria which limits the maximum pavement rotation rate to 2% per second at the design speed,
- an appearance criteria which limits the relative grade between edges of the travelled way to a value considered appropriate for the design speed.

**(v)** The minimum superelevation development length to satisfy the rate of rotation criteria for any road is determined by the following expression:

$$L_e = \frac{(e_1 - e_2) \times V_d}{k}$$

Where:

| | | |
|---|---|---|
| $L_e$ | = | superelevation development length (m) |
| $e_1, e_2$ | = | crossfall or superelevation at the ends of the superelevation development length (%) |
| $k$ | = | 7.2 for a rotation rate of 2.0% per second,<br>9.0 for a rotation rate of 2.5% per second, and<br>12.6 for a rotation rate of 3.5% per second |
| $V_d$ | = | design speed (km/h) |

**(vi)** The minimum superelevation development length to satisfy the road relative grade criteria for a divided road is determined by the following expression:

$$L_e = \frac{W \times (e_1 - e_2)}{G_d}$$

Where:

$L_e$ = superelevation development length (m)

$W$ = width of the travelled way

$e_1, e_2$ = crossfall or superelevation at the ends of the superelevation development length (%)

$G_d$ = relative grade from Table 4.5.

| Design Speed (km/h) | Relative Grade between the inner and outer edges of the traffic lane(s) (%) | | |
|---|---|---|---|
| | 1 lane [1] | 2 lanes [2] | More than 2 lanes [3] |
| 30 | 0.75 | 1.50 | 1.25 |
| 40 | 0.70 | 1.39 | 1.16 |
| 50 | 0.64 | 1.28 | 1.07 |
| 60 | 0.59 | 1.18 | 0.98 |
| 70 | 0.54 | 1.08 | 0.90 |
| 80 | 0.50 | 1.00 | 0.83 |
| 90 | 0.46 | 0.92 | 0.77 |
| 100 | 0.43 | 0.86 | 0.72 |
| 110 | 0.40 | 0.80 | 0.67 |
| 120 | 0.38 | 0.75 | 0.63 |
| 130 | 0.36 | 0.71 | 0.59 |
| 140 | 0.34 | 0.67 | 0.56 |

1 One lane one-way roads where the axis of rotation is one edge of the traffic lane.

2 4 lane divided roads where the axis of rotation is one edge of the one-way road travelled way, and passing lane sections of two- lane two-way roads where the axis of rotation is the road centreline.

3 6 or more lane divided roads where the axis of rotation is one edge of the one-way road travelled way.

**Table 4.5: Relative Grade between Edges of the Travelled Way**

### (e) Shoulder Transitions

Shoulders are normally part of the carriageway plane and rotate with it. Shoulder profiles should be made smooth and compatible with the adjacent pavement.

Shoulders on superelevated curves must have the same superelevation as the traffic lanes.

The pavement outside the shoulder should sloped away from the road and sealed, to minimise the likelihood of drivers losing control on the curve and infiltration into the pavement layers.

Unsealed shoulders on straight sections of two-lane two-way roads must have a crossfall away from the pavement, to minimise infiltration into the unsealed shoulder.

### (f) Superelevation Application Problem Areas

#### (i) General

Profiles for both edges of the travelled way and both shoulders should always be plotted and any irregularities resulting from interactions between the superelevation transition and vertical alignment of the roadway should be eliminated by introducing smooth curves. Flat areas of pavement, which are undesirable for stormwater drainage reasons, will also be revealed by this process and they can be remedied at the design stage.

In restrictive situations, such as two lane roads in mountainous terrain, interchange ramps, collector roads, frontage roads, etc., where curve radii are small, curve length and the tangents between curves are short, standard superelevation rates and/or development lengths may not be attainable. In such situations the highest permissible superelevation rates and the shortest development lengths should be used.

In situations where it is considered desirable to exceed the maximum permissible superelevation and pavement rotation rates specific approval to do so must be sought from the Strategy and Standards Manager on a case by case basis.

#### (ii) Bridges

A superelevation transition on a bridge has almost the same effect as a vertical curve in the same situation and almost always results in an unsightly appearance of the bridge and the bridge railing. If possible, horizontal curves should begin and end a sufficient distance from the bridge so that no part of the superelevation transition extends onto the bridge. Alignment and safety considerations are, however, of paramount importance and they must not be sacrificed to meet the above criteria. Refer to Section 3.8 for more details on the effect of combined horizontal and vertical curvature.

#### (iii) Adverse Crossfall

Adverse crossfall should normally be avoided except on curves with radii sufficiently large to be regarded as straight sections of road. Such curves need not be superelevated but superelevation at the normal crossfall rate used on straights should be applied.

In rural situations all curves less than 3000 m radius should be superelevated. However, to improve pavement drainage on very flat longitudinal grades, or in the design of temporary roadways and connections, consideration may be given to the use of up to 3% adverse crossfall.

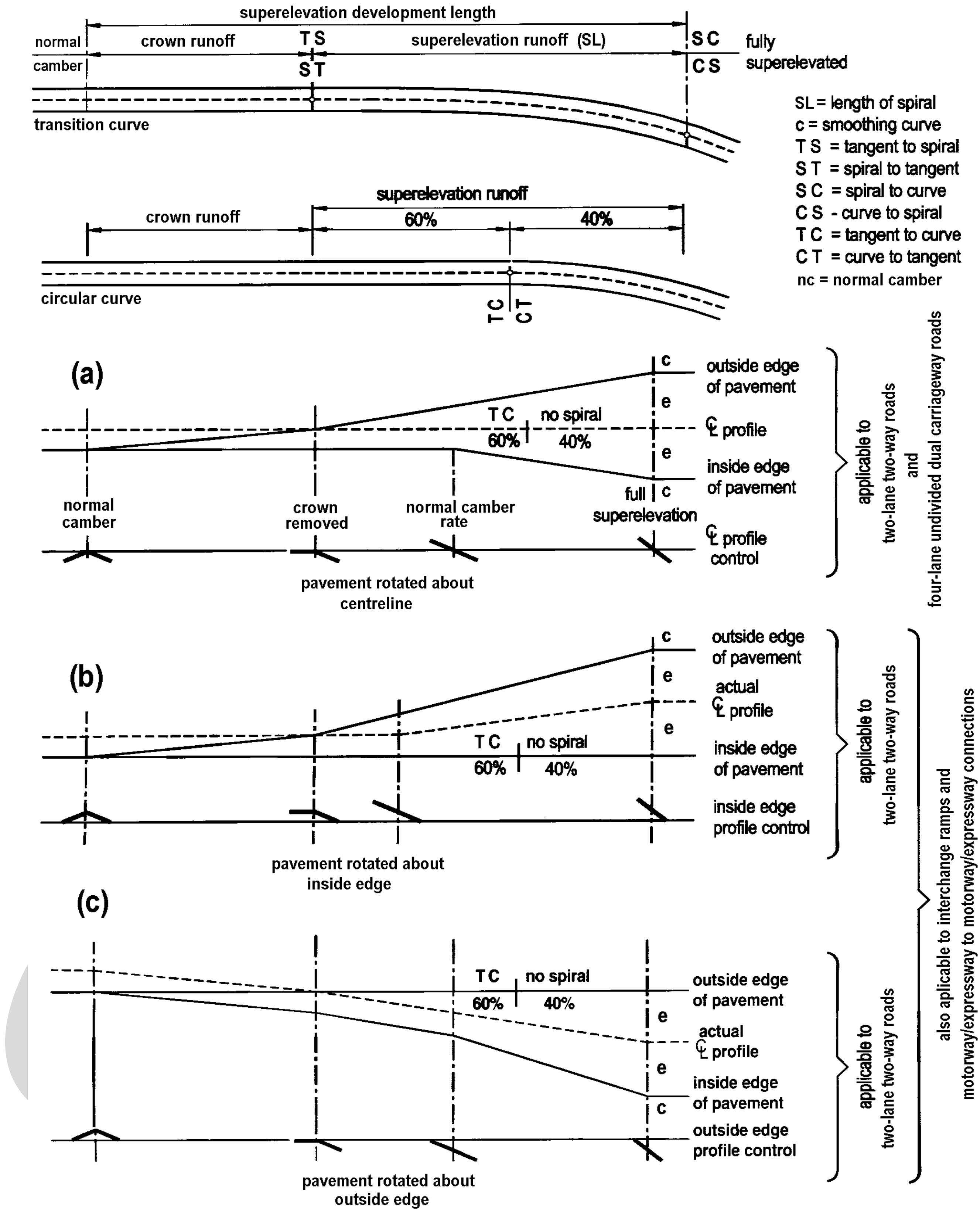
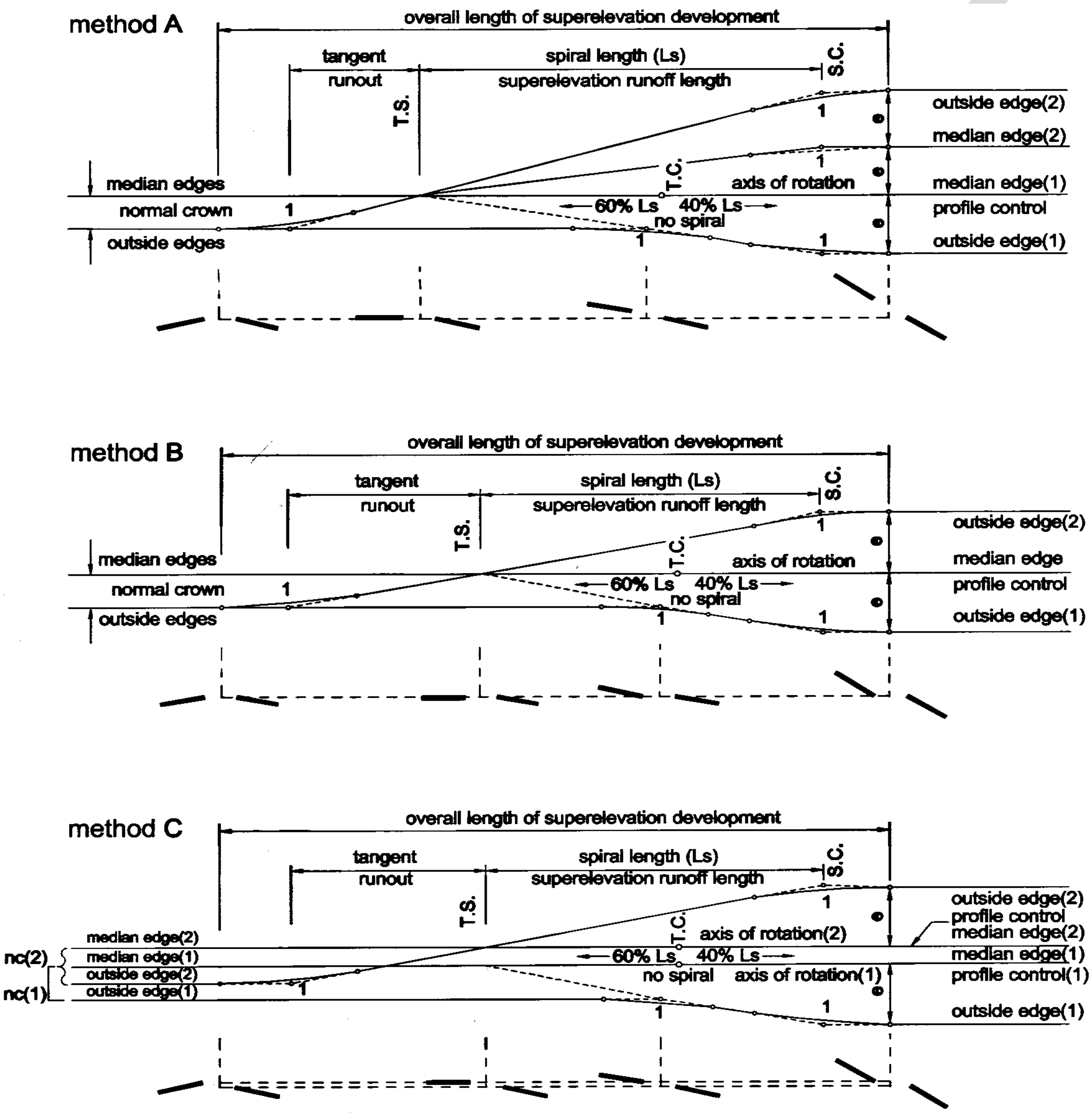



**Figure 4.12:** Superelevation Development on Two-lane Two-way Roads, Interchange Ramps and Motorway / Expressway to Motorway / Expressway Connections




Note: Smoothing curve may be a calculated vertical curve or drawn with a spline.
T.S. = tangent to spiral point S.C. = spiral to curve point
T.C. = tangent to curve point nc = normal crown

**Figure 4.13: Superelevation Development on Dual Carriageway Roads**

In urban situations where drivers are more adaptable to changes in radius, superelevation and transverse friction, the use of adverse crossfall on small radii curves is tolerable.

The minimum radii that may be used with an adverse crossfall of 3%, for various design speeds, are listed in Table 2.7.

***Notes:***

1. ***Radii larger than those in Table 2.7 should be used wherever possible.***
2. ***The radii recommended in Table 2.7 are based on curves which have been found to be generally appropriate in level terrain.***
3. ***Adverse crossfall must not be used in combination with any other factor which could increase the force on the tyre or reduce the friction forces which can be developed at the tyre road interface, eg. adverse crossfall should not be used in the following circumstances:***
    - ***on the approaches to intersections because of the friction forces required for braking,***
    - ***in areas subject to aquaplaning or icing, and***
    - ***on downhill grades.***
3. ***For aesthetic reasons, short arc lengths should not be used with adverse crossfall.***

### (iv) Intersections

Where a side road joins a main road on the outside of a horizontal curve, a compromise is often necessary between adequate superelevation on the main road and safe conditions for vehicles turning against the adverse crossfall. The situation is worse if the horizontal curve is located on a steep grade and the intersection must be modified to ensure safe turning conditions.

Generally, if the side road is important or the curve has a steep longitudinal grade, ie. over 5%, the superelevation must not exceed 5% and should preferably be limited to 3%.

The problem does not exist where the junction is on the inside of a horizontal curve as the superelevation then favours the turning movements.

### (v) Steep Downhill Grades

The use of maximum superelevation rates on steep grades may unacceptably increase the longitudinal grade on the outer lanes. Usually, superelevation is the only geometric element which can be varied in these situations and it will sometimes be necessary to either reduce the superelevation or extend the length of the superelevation development.

Superelevation should however be increased on downhill grades to counter the effect of the combination of grade and curvature on the stability of motor vehicles - particularly articulated trucks.

In comparison to the downward forces that act on a vehicle on a level grade, the downward force on the front axle is increased and decreased on the rear axle when the vehicle travels on a downhill grade.

This load shift effectively reduces the lateral force which can be supplied by the rear axle so that when the vehicle is travelling close to the maximum safe speed for a superelevated curve on a downhill grade, and its brakes are applied, the back wheels are likely to lose traction and this can lead to the vehicle spinning.

To minimise this problem, higher superelevation rates should be used on roads with downhill grades of 3% or more. The increase in superelevation is obtained using the following equation:

$$\text{Superelevation increase (\%)} = \frac{(g + e)}{6}$$

Where:

$g$ = downhill grade (%)

$e$ = curve superelevation (%)

***NOTE:*** ***Fractions of any significance should be rounded up.***

### (vi) Compound Curves

A compound curve is a curve formed by joining two or more contiguous unidirectional curves of different radius. Compound curves are generally undesirable because:

- drivers have difficulty estimating the curvature of the road and there is a danger that they may not notice a reduction in radius,
- vehicle tracking problems can, and do, occur where the change of radius is not obvious to drivers,
- braking on curves can be hazardous for articulated trucks and this problem is made worse on downhill grades, and
- the visual appearance of a *'broken-back'* alignment can be created when an intermediate curve has a radius significantly larger than the adjacent curves.

When a compound curve must be used the smaller curve radius should not be less than ⅔ of the larger curve radius. This relationship between curve radii also applies to similar curves.

### (vii) Reverse Curves

#### 1. General

Reverse curves can introduce problems in achieving a suitable superelevation development pavement rotation rate, unless the curves have spiral transitions and the tangent points are adequately separated. Wherever possible a straight or spiral should be provided between reverse curves to allow for:

- The time taken to turn the steering wheel. Times of two to four seconds have been recorded for this driver action and in this period a vehicle travels along a spiral path for a distance of between $0.8\ V$ and $1.1\ V$ metres, where $V$ is in km/h.
  This enables the length of straight or spiral between the reverse curves to be reduced to $0.6\ V$ metres. In steep to mountainous areas where it is not practical to provide this separation between the curves, sufficient width should be provided to enable drivers to negotiate a spiral path within the width of the traffic lane or sealed pavement.
- The development of superelevation.

In mountainous country it is often necessary to have coincident tangent points but it is generally preferable to reduce the curve radii so that the minimum tangent length can be provided between curves.

#### 2. Important Checks

Two important points must be checked in all reverse curves situations:

*(i)* Surface drainage at the curve reversal point. As a general rule, the longitudinal road grade at this point should be between 1% and 3%.

*(ii)* When fully circular curves are used their radii must be at least equal to, and desirably well above, the radius required for zero crossfall, ie. $e = 0$, at the horizontal alignment's design speed.

#### 3. Truck Instability

Reverse curves can, and often do, create instability problems for articulated trucks and, for this reason, they should only be used as a last resort. The instability is created by:

- the high yaw forces which are developed at the curve tangent points which can cause steering problems for drivers of trucks, particularly articulated trucks, and
- the loss of superelevation on the approach to the curve tangent points. Drivers tend to negotiate curves at speeds close to the limits of stability and any reduction in road standard, such as a reduction in crossfall, can lead to loss of control.

#### 4. Circular Curves separated by a Short Tangent

The length of straight tangent between reverse circular curves should be sufficient to allow full superelevation to be developed at the start of the curve. In practice this is often not possible and a shorter distance has to be used. As a general rule, the minimum tangent length should not be less than $0.6V$ metres when $V$ is in km/h.

#### 5. Transition Curves

Where minimum radius curves are used, full superelevation should be achieved at the start of the circular arc sections of those curves.

Where large radii circular curves are used, some superelevation may be developed within the curves, provided ⅔ of the full superelevation rate is achieved at curve tangent points.

#### 6. Transition Curves separated by a Short Tangent

A straight between adjacent curve spirals usually allows each traffic lane to be rotated independently avoiding the development of a flat pavement surface across both traffic lanes. This type of design is appropriate for use in flat terrain where pavement drainage is often a problem.

### (viii) Similar Curves

Two horizontal curves in the same direction, sometimes joined by a short straight, can form an unsightly alignment which is commonly known as a *'broken back'* alignment.

Similar curves should not normally be used because:

- it is very difficult to produce a visually pleasing vertical alignment for the edges of the road pavement,
- is often impossible to provide the correct amount of superelevation throughout both curves, and
- truck drivers can experience problems related to sight distance and braking conditions on the approaches to similar curve sections of road.

***NOTE:*** ***The appearance and safety problems can usually be avoided by replacing similar curves with a single curve.***

Refer to Section 3.6.5 for more details on problems related to similar curve situations.

## (ix) Pavement Surface Drainage

### 1. General

For effective road drainage the minimum grades are:

- 0.3% for concrete kerb and channel, and
- 1% for open ditches.

Where these grades can be achieved there are usually no problems in draining the edge of the road pavement but there may be pavement surface drainage problems. Checks must therefore be made to ensure there are no potential aquaplaning and spray problems due to surface water build up.

On flat grades pavement surface drainage problems are likely to occur on chip sealed surfaces where the crossfall is less than 2.5%, and on smooth asphalt surfaces where it is less than 2%.

Pavement surface drainage problems may also occur:

- on steep grades because of the increase in length of the drainage flow path through the combination of crossfall and grade,
- at entry and exit lanes where merging and braking manoeuvres are common, and
- on the approaches to intersections and low radius curves where a lot of heavy braking occurs.

In view of the potential drainage problems in superelevation development areas, the length of surface drainage flows and water depths in these areas must be checked on all new projects as well as all rehabilitation projects involving geometric improvements. The solution to surface drainage problems will usually involve a change to the horizontal alignment, to the grading or to both.

For more details on pavement surface drainage refer to the Transit New Zealand publication *Highway Surface Drainage*.

### 2. Surface Drainage Problem Treatments

- Realign the road. The superelevation development can sometimes be moved to a location which provides improved surface drainage.
- Re-grade the road.
- Shorten the superelevation development.
- Move the design line (grading) away from the traffic lanes.
- Provide one or more longitudinal (parallel) crowns. Skew crowns are not recommended because they can create stability problems for trucks and, more importantly, they are very difficult to construct with sufficient accuracy to correct the surface drainage problem.
- Provide a grated drain across the road pavement.

### 3. Flat Grades

The most dangerous areas on flat grades are those located within the traffic lanes of wide pavements where relatively deep puddles can develop. Flat spots located at the outer edge of the shoulder are less of a problem because water can usually drain away over the pavement edge.

Flat spot locations can be predicted using contour diagrams and they can also be located diagrammatically using relative grade diagrams.

### 4. Steep Grades

On steep grades the main drainage problem is the length of the surface water flow paths at the points of zero crossfall in superelevation development areas.

Whenever a superelevation development is located on a grade steeper than 5% the length of the surface drainage flow path(s) needs to be checked.

## 4.7 Two-way Two-lane Road Design

### 4.7.1 General

#### (a) Speed Environment

The speed environment of a section of an existing two-way two-lane road with reasonably consistent geometric standard which runs through terrain having relatively consistent characteristics can be determined by:

- speed studies, or
- estimated from a consideration of its topography and the range of existing horizontal curve radii.

A length of road which is to be realigned or upgraded has the speed environment of the section of road within which it lies. The speed environment does not change rapidly and it takes some distance before drivers recognise a change because of a difference in terrain, geometric standard or both of these parameters.

The speed environment for a new road may be estimated from Table 4.6 once the terrain type and the range of horizontal curve radii likely to be used have been determined.

#### (b) High Speed Environments

In high speed environments drivers will adopt relatively uniform travel speeds. Design speeds should therefore be at least equal to the speed environment, and may even exceed it. A constant design speed, which is in keeping with the terrain type should be used for ***all*** aspects of two-way two-lane road design in these situations.

#### (c) Intermediate and Low Speed Environments

In intermediate and low speed environments drivers tend to vary their speeds in a direct relationship to the characteristics of the road and its surroundings. In these environments there is a need for some iteration in the selection of horizontal curve elements because individual curve geometry is determined by, and also helps to determine, the speed environment.

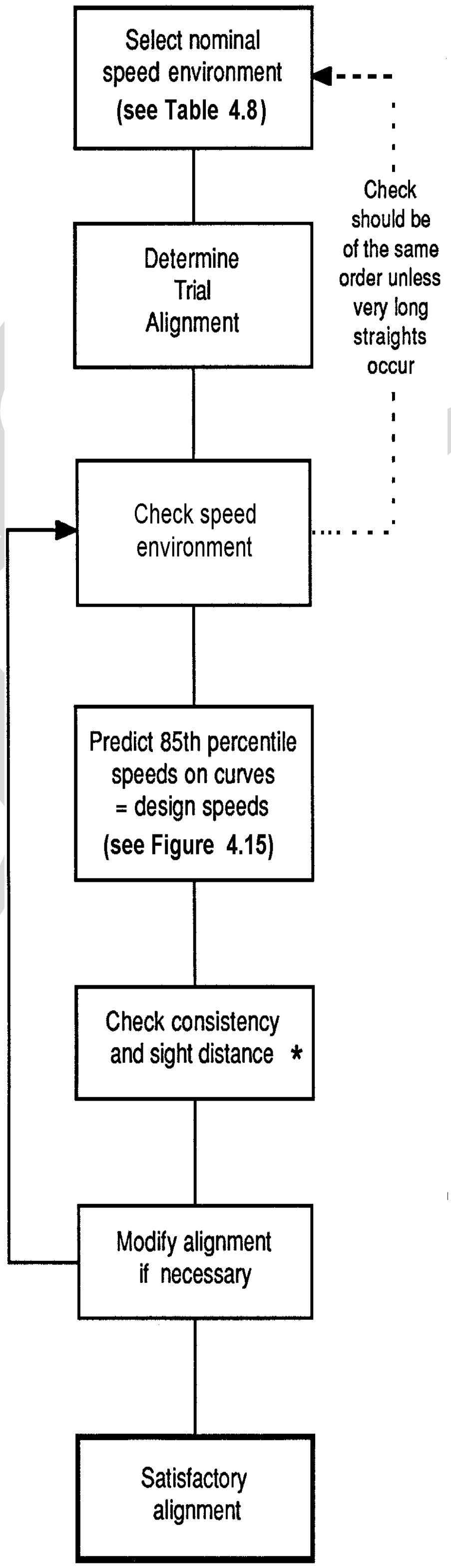
The 85$^{th}$ percentile speed must be used in intermediate and low speed environments to co-ordinate the geometric features of a two-way two-lane road alignment. A recommended design procedure is described in Section 4.7.2 below.

### 4.7.2 Two-lane Road Design Procedure

The seven step iteration procedure for two-lane road design shown in Figure 4.14 will ensure a safe and consistent road alignment. The procedure is summarised as follows:

### Step 1. Select Nominal Speed Environment

Determine the speed environment for the length of road under consideration. The speed environment is regarded as constant for a section of road with reasonably consistent geometric standards and terrain characteristics so, ***the speed environment for the length of road under consideration is therefore equal to that of the section of road within which it is located.***




* The more consideration given to consistency at the trial alignment stage, the fewer modifications required later.

*Source: Austroads Rural Road Design*

**Figure 4.14: Two-lane Roads - Horizontal Alignment Design Procedure**

***NOTES:***

1. ***The speed environment for a section of road can be determined by:***
   - ***speed studies carried out on the longer straight and/or very large radii sections of the existing road, or***
   - ***estimated from an assessment of the overall geometric standard of the horizontal alignment and the terrain type by using Table 4.6.***
2. ***It takes some time for drivers to recognise and react to a change in the speed environment because of a change in terrain characteristics or the overall geometric standard of the road.***

   ***The length of road needed before drivers recognise an increase in speed environment is approximately:***
   - ***3 km in a 110 km/h speed environment,***
   - ***1 km in a 90 km/h speed environment, and***
   - ***250 m in a 70 km/h speed environment.***

   ***A decrease in speed environment is usually far more easily recognised and the length of road needed for this is approximately:***
   - ***< 3 km in a 110 km/h speed environment,***
   - ***500 m to 1 km in a 90 km/h speed environment, and***
   - ***250 m in a 70 km/h speed environment.***

## Step 2. Determine Trial Alignment(s)

Prepare trial alignments, using radii within the range given in Table 4.6, for the speed environment selected in Step 1 above. Good design practice will avoid the use of minimum radii.

Trial grade lines should also be devised at this stage.

## Step 3. Check Speed Environment

Check the speed environment of trial alignments using Table 4.6. This will only differ from the nominal speed environment initially chosen if significantly different horizontal curve radii have been used.

Occasional very large radii curves should be ignored when assessing the speed environment. They should be considered as being equivalent to a short straight section within the overall speed environment.

## Step 4. Determine the Design Speed(s)

In high speed environments a constant design speed should be used. This must be equal to the speed environment and may even exceed it.

In low and intermediate speed environments drivers will tend to vary their speeds on horizontal curves in a direct relationship to the perceived curve radii. Design speeds may therefore vary but great care must be taken to check that their design parameters, ie. design speed, side friction and superelevation, are reasonably consistent and lie within acceptable variation limits.

Speed environment value as a function of terrain type and overall geometric for single carriageway two-lane rural roads. [a]

| Approximate Range of Horizontal Curve Radius (m) [b] | Terrain Type / Speed Environment (km/h) [c] | | | |
|---|---|---|---|---|
| | Flat | Undulating | Hilly | Mountainous |
| < 75 | | | 75 | 70 |
| 75 - 300 | | 90 [d] | 85 | [e] |
| 150 500 | | 100 | 95 | |
| > 300 - 500 | 115 [d] | 110 | [e] | |
| > 600 - 700 | 120 | [e] | | |

[a] Can also be used for divided roads when the geometric standards are constrained, ie. design speeds < 120 km/h.

[b] These values represent the general overall horizontal geometric standard of the section of road under consideration.

[c] The maximum speed regarded as acceptable by most drivers in the particular environment and also the 85th percentile speed on the unconstrained sections of road, eg. the longer straights and curves with radii well above those listed.

[d] An overall horizontal geometric standard of < R300 m (flat) or < R l00 m (undulating) will not be normal and speed environments below about 115 km/h and 90 km/h respectively should not be used. Where low design speed curves are necessary refer to Section 2.7.5 (v).

[e] Use the speed environment of the next less severe terrain type when a more liberal geometry is used in undulating and mountainous terrain.

*Source: Austroads Rural Road Design*

**Table 4.6: Terrain Type / Horizontal Curve Radius Range / Speed Environment Relationship for Two-lane Roads**

Special care must also be taken when determining design speeds for curves at the ends of straighter sections of road because high speeds are likely in these areas.

The design speed of a curve can be considered equal to the speed environment when the length of preceding straight, or very large radius curve, is at least:

- 250m in a 70 km/h speed environment,
- 1 km in a 90 km/h speed environment, and
- 3 km in a 110 km/h speed environment.

The appropriate design speed, or 85th percentile operating speed, for a horizontal curve in a given speed environment can be determined from Figure 4.15.

The superelevation required for horizontal curves on two-lane two-way state highways can be determined from Figures 4.16 and 4.17.

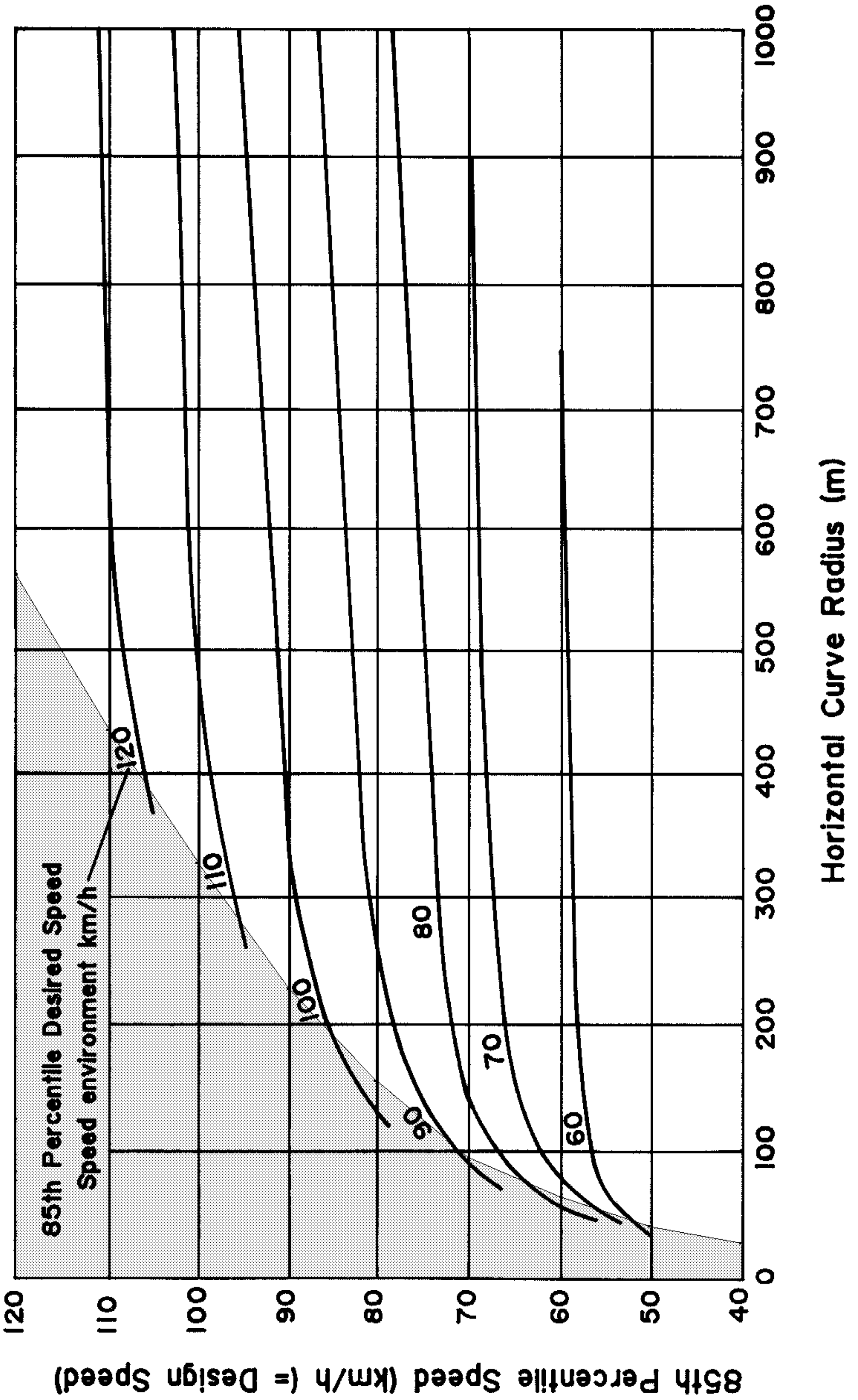



**Figure 4.14: Horizontal Curve Radius / Design Speed / Speed Environment Relationship**

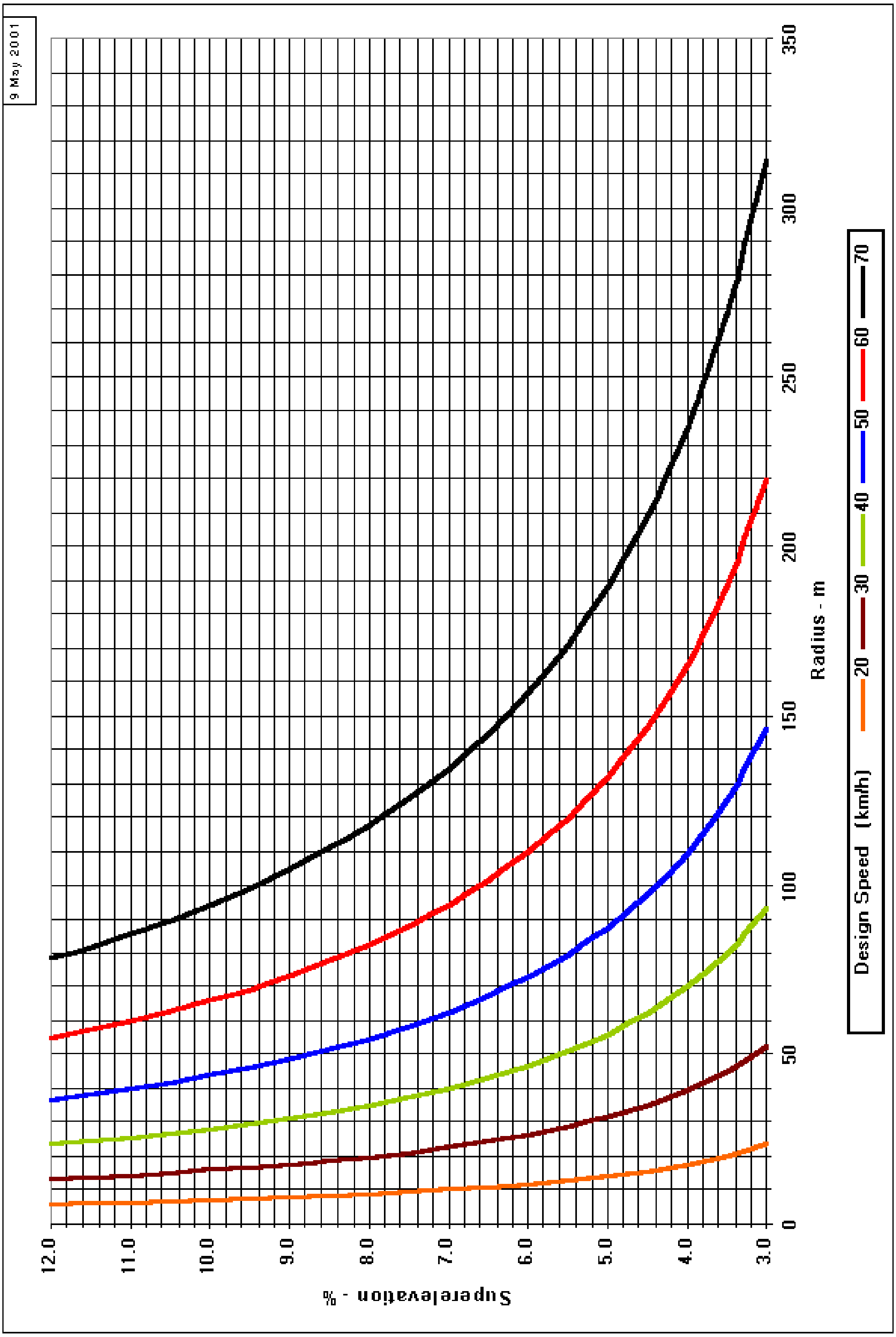



**Figure 4.16: Low Speed Two-lane Two-way State Highways where the Design Speed ≤ 70 km/h**
**Design Speed / Horizontal Curve Radius / Superelevation Relationship**

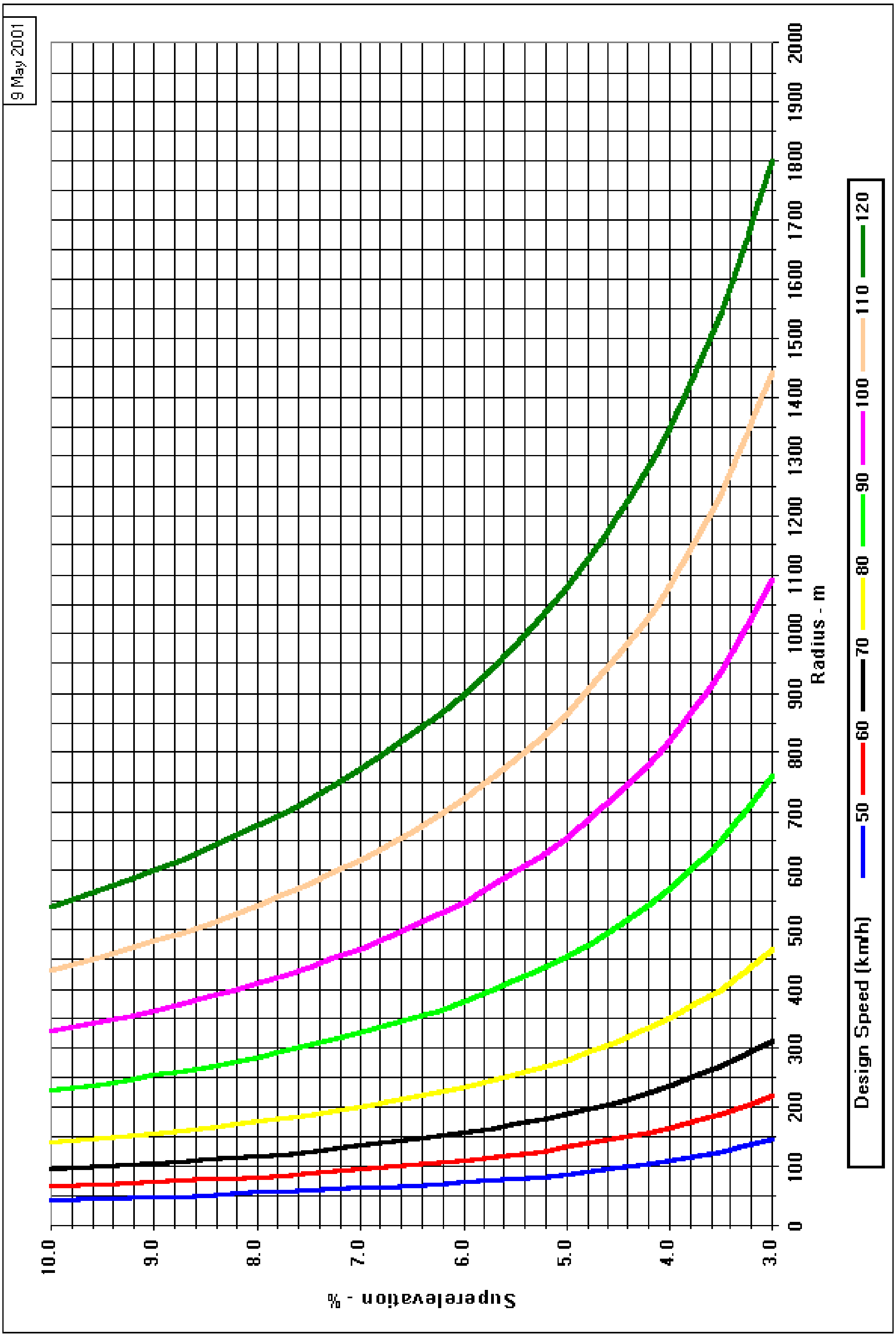



**Figure 4.17: Standard Two-lane Two-way State Highways**
**Design Speed / Horizontal Curve Radius / Superelevation Relationship**

### Step 5. Check Alignment Consistency and Sight Distance, and

### Step 6. Modify Alignment if necessary

Drivers do not expect, or readily accept, having to travel at low speeds in a high speed environment and any geometric element which allows a higher speed to be achieved, such as a long straight or very large radius curve, will be used to advantage. This type of feature tends to raise the overall speed environment of a section of road and means that the design speeds of adjacent geometric elements must be very carefully checked. In many cases design speeds will have to be increased to match the higher speed environment.

Conversely, any geometric element that requires drivers to reduce their travel speed more than 10 to 15 km/h below the speed environment is likely to create a hazardous situation because most drivers do not significantly reduce their travel speed until they can actually see the hazard, even when the appropriate advance warning signs are erected.

Normally, design speeds should not differ by more than about 10 km/h, and never more than 15 km/h, between successive geometric elements. However, where the terrain or the general standard of the road dictates a reduction in the speed environment the geometric elements connecting the two speed environments must be carefully designed to provide a safe transition between them.

A safe reduction in operating speeds can be achieved in some circumstances by using a sequence of horizontal curves whose design speeds do not vary by more than 10 km/h. This is may be done by using the design, or predicted 85$^{th}$ percentile, speed of each horizontal curve as the speed environment for the succeeding curve and then deriving that curve's design speed from Figure 4.14.

Where a local constraint is not sufficiently large to define a new speed environment for a section of road, and it cannot be bypassed, a design speed reduction in excess of 10 to 15 km/h will occasionally have to be accepted and the appropriate warning devices should be installed as an integral part of the new roadworks.

Both horizontal and vertical sight distances must be consistent with design speeds and side friction demands should not vary excessively on successive horizontal curves.

Stopping sight distance requirements based on a reaction time of 2.5 seconds are used for most design conditions. However, in difficult terrain and other constrained conditions where design speeds of 70 km/h and less are used, shorter sight distances based on a 1.5 second reaction time may be used because drivers are considered to be in a more alerted state in these conditions.

Table 2.12 lists the stopping sight distances required on a level grade. Adjustments must be made for the actual gradients used in each design.

***NOTE:***

***Horizontal sight distance rather than side friction and superelevation may fix the minimum radius for the design speed where side clearances are limited.***

Where it is not feasible to achieve a design fully compatible with the speed environment of the section of road, because of topographical, environmental and/or economic reasons, careful thought must be given to the installation of traffic management measures which will reliably alert drivers to unexpected changes in operating conditions on that section of road. These measures cannot be considered good design practice and should only be necessary on very rare occasions.

***NOTE:***

***Two-lane two-way roads must be checked for consistency in both directions of travel. This is particularly important where there are speed change situations similar to those described above.***

### Step 7. Satisfactory Alignment / Final Design

The process described in Steps 1 to 6 above will ensure the geometric elements of trial alignments have design speeds equivalent to operating speeds. The design speed may vary along the section of road under consideration but the procedure will ensure that, between successive geometric elements, design speed differences lie within acceptable and safe operational limits.

The trial alignments should be analysed and the best one refined into a final design by ensuring that:

- horizontal and vertical curve designs are consistent with the predicted 85$^{th}$ percentile operating speeds at all locations,
- a safe join-in to the existing road at each end of the new alignment must be provided in all cases and the extent of the work may need to be extended to achieve this in some situations,
- horizontal/vertical alignments are co-ordinated with the design speed of the vertical alignment being at least equal to its associated horizontal alignment design speed, and preferably 10 or more km/h higher,
- earthworks are minimised, and
- all other controlling criteria are satisfied, eg. special consideration given to the location of intersections and points of access to ensure that minimum sight distances and critical crossfall controls are met.

***NOTES:***

1. ***Horizontal alignment design is not often a straightforward matter and the process described above can not always be followed. Design standards can prove impossible to achieve and compromises may have to be made. In these situations a broad understanding of basic traffic engineering theory as well as the principles and assumptions used in the development of roading standards is essential to enable safe and realistic design compromises to be made.***
2. ***In ALL circumstances any variation of state highway design standards must be approved in writing by the State Highway Policy Division Design and Traffic Manager before they can be implemented.***

## 4.8 Dual Carriageway Road Design

### 4.8.1 General

All dual carriageway roads are considered to be high standard roads by the majority of drivers. Therefore, to achieve safe, consistent operating conditions a constant speed must be used as the main design control for all geometric elements.

The design speed for a dual carriageway state highway must be at least:

- numerically equal to the proposed speed limit for that section of road, and
- at least numerically equal, and generally exceed, the speed environment for the section of road within which it is located.

The design speed should not normally vary along the entire length of a dual carriageway road, unless there is some definite change in terrain type which alters the speed environment for a significant section of the road.

### 4.8.2 Design Speed

The minimum design speeds for dual carriageway state highways are shown in Table 4.7.

| Environment | Rural | | | Urban |
|---|---|---|---|---|
| Terrain | Flat | Rolling | Mountainous | All |
| Design Speed (km/h) | | | | |
| Motorway | 120+ | 110+ | 100 | 70 - 80 |
| Expressway | 110 | 100 | 80 | 60 |

**Table 4.7: Minimum Design Speeds for Dual Carriageway State Highways**

### 4.8.3 Horizontal Alignment

Horizontal alignments should be developed using a series of straights and circular curves and/or transition curves.

***NOTE:***

***The length of a transition curve spiral must be sufficient to give a shift distance of 250 to 500 mm generally, and at least 500 mm in flat terrain.***

As a general rule, curves must be used whenever a dual carriageway road changes direction. However, very small changes in alignment without horizontal curves are not noticed by drivers and in some cases it might not be necessary to provide curves between adjacent straight sections. The maximum allowable deflection angle between adjacent straight sections without the need for a horizontal curve is:

- 0° 00' for motorways,
- 0° 15' for expressways.

***NOTE:***

***It is not permissible to use a succession of small deflection angles to avoid the need for a horizontal curve on any dual carriageway road.***

Horizontal curves must also be of sufficient length to avoid the appearance of a kink. The minimum curve length to avoid an unsightly kink is:

- 250 m for motorways, and
- 200 m for expressways.

### 4.8.4 Superelevation

**(a) General**

Dual carriageway roads generally have wide pavements. It is therefore desirable to minimise superelevation for aesthetic reasons, and also because of the long superelevation transition lengths that are often necessary.

**(b) Minimum Superelevation**

It is desirable to superelevate all dual carriageway curves to a rate equal to that of the crossfall used on the straight sections. This is usually 3%.

However, if the radius of a curve is greater than that given in Table 2.7 it can be regarded as straight and normal crossfall, or -3% reverse superelevation, may be used.

**(c) Maximum Superelevation**

The maximum superelevation rates for dual carriageway state highways, in relation to design speed, terrain type and environment are given in Table 4.8.

| Design Speed (km/h) | Maximum Superelevation e (%) | | |
|---|---|---|---|
| | Rural Environment Terrain | | Urban Environment |
| | Flat | Rolling and Mountainous | |
| 60 | - | - | 8 |
| 70 | - | - | 8 |
| 80 | - | 8 | 8 |
| 90 | - | 8 | - |
| 100 | 6 | 8 | - |
| 110 | 6 | - | - |
| ≥ 120 | 6 | - | - |

**Table 4.8: Maximum Superelevation Rates for Dual Carriageway State Highways**

The superelevation required for horizontal curves on dual carriageway state highways can be determined from Figure 4.18.

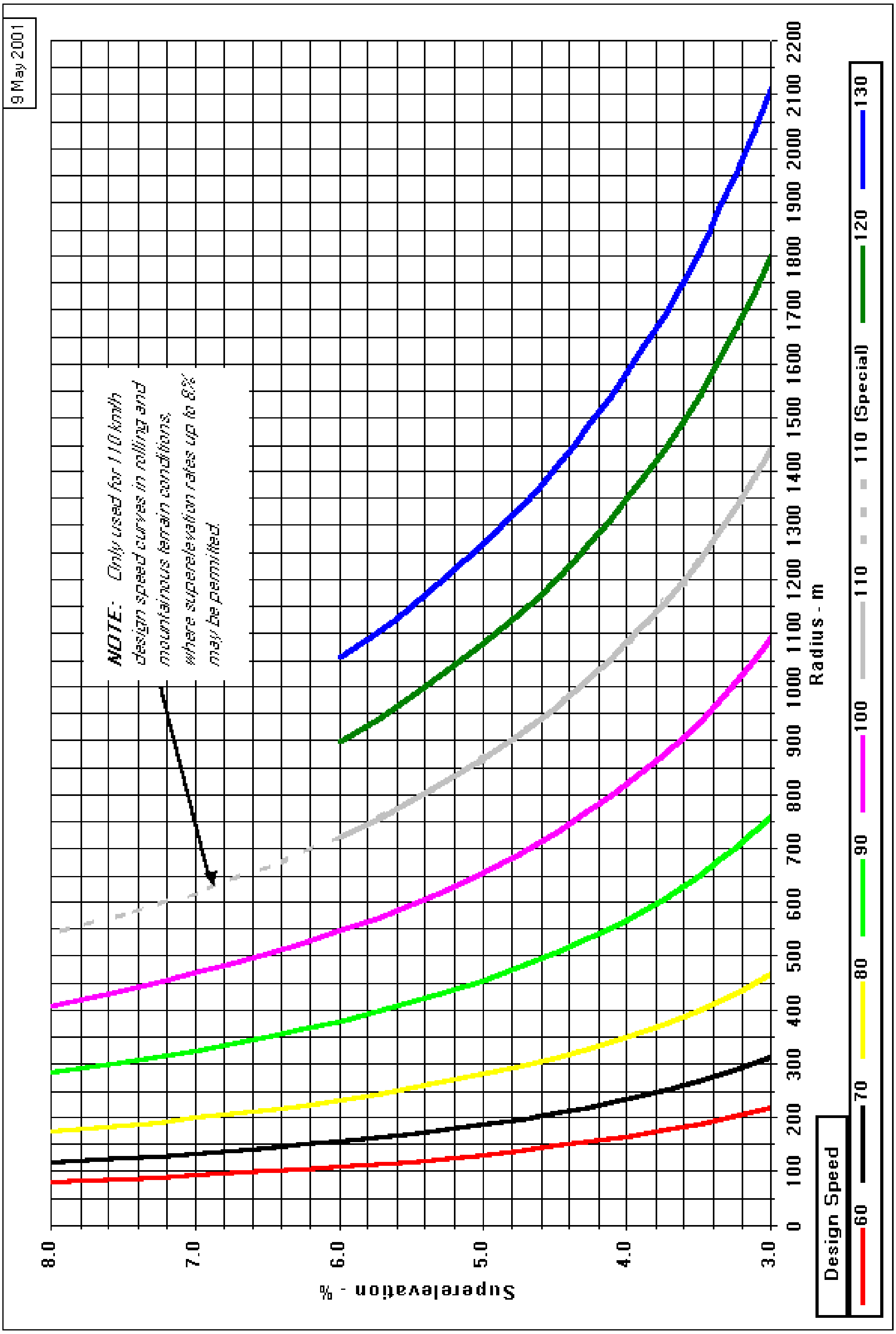



**Figure 4.17: Dual Carriageway State Highways**

**Design Speed / Horizontal Curve Radius / Superelevation Relationship**

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