3. HORIZONTAL ALIGNMENT

CIRCULAR CURVES

3.1 When vehicles negotiate a curve, a sideways frictional force is developed between the tyres and road surface. This friction must be less than the maximum available friction if the bend is to be traversed safely. For any given curve and speed, superelevation may be introduced to enable a component of the vehicle’s weight to reduce the frictional need. The general relationship for this effect is:

\[ R = \frac{2V}{127(e+f)} \]

where: 
- \( R \) = Radius of curve (metres)
- \( V \) = Speed of vehicles (km/h)
- \( e \) = Crossfall of road (metres per metre)
- \( f \) = Coefficient of side friction force developed between the vehicle's tyres and road pavement.

The value of \( e \) may represent the simple removal of adverse crossfall or include superelevation.

3.2 The side friction factor may be considered to be the lateral force developed by the driver on a level road. The technical evidence indicates that lateral accelerations, and hence side friction factors, increase with reduced radii of curvature and increased speed. The range is considerable and values of \( 'f' \) found from public road measurements have varied from just over 0.1 for high speed roads to over 0.5 on lower speed roads. The results of empirical studies have indicated 0.22 as a value of \( 'f' \) above which passengers experience some discomfort. The much higher values found on low radius curves indicate that drivers and passengers have a much higher tolerance in these situations. The values of \( 'f' \) chosen to calculate minimum radii requirements in this guide range from 0.15 to 0.33. A substantial reserve exists between these comfort and control related values, and those at which the vehicle would start to slide sideways.

3.3 In this guide, it is recommended that curves are designed such that it is necessary for vehicles travelling at the design speed to steer into a bend.

3.4 The minimum radii values shown in Table 1.2 were derived on the basis of sideways friction factors and superelevation. In some situations with minimal lateral clearances, sight distance will be the factor controlling minimum radii. Sight distances may be improved by increasing curve radius or sight distance across the inside of the curve.

3.5 Where only small numbers of specialist vehicles are involved and the costs of improving the alignment are high, not all vehicles can expect to traverse a curve on a single lane road in a single manoeuvre and reversing may be necessary.

ADVERSE CROSSFALL

3.6 The normal crossfall on a road will result in a vehicles on the outside lane of a horizontal curve needing to develop high levels of frictional force to resist sliding; the amount of increase being dependent on speed, curve radius and crossfall. In order to achieve the necessary cornering stability, it is recommended that adverse crossfall is removed. The identification of speed and radius combinations at which this should occur is rather subjective as there is no evidence linking adverse crossfall to accident risk. A side friction factor of 0.07 has been taken as giving suitable minimum radii below which adverse crossfall should be removed. With a normal crossfall of 3 per cent, this value results in a minimum radii shown in Table 3.1. Values for unpaved roads are based on a 4 per cent crossfall which is the minimum crossfall that should be allowed before maintenance is carried out if effective cross-drainage is still to be provided.

**TABLE 3.1: MINIMUM RADII OF CURVES BELOW WHICH ADVERSE CROSSFALL SHOULD BE REMOVED**

<table>
<thead>
<tr>
<th>DESIGN SPEED (km/h)</th>
<th>MINIMUM RADIUS (metres)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>PAVED</td>
</tr>
<tr>
<td>120 (103)</td>
<td>2,800</td>
</tr>
<tr>
<td>100 (87)</td>
<td>2,000</td>
</tr>
<tr>
<td>85 (73)</td>
<td>1,400</td>
</tr>
<tr>
<td>70 (62)</td>
<td>1,000</td>
</tr>
<tr>
<td>60 (52)</td>
<td>700</td>
</tr>
<tr>
<td>&lt;50 (44)</td>
<td>500</td>
</tr>
</tbody>
</table>

* Values in the brackets are the design speeds in km/h with zero lateral accelerations for 3 per cent crossfall ie the speeds at which curve can be negotiated with "hands off" (approximately one speed design step lower).

3.7 The values shown in the table are approximate and cut-off levels should be varied to offer consistency to the driver. For example, two adjacent horizontal curves on a road link, one of which is marginally above the cut-off whilst the other is marginally below the minimum radii given, should be treated in a similar manner in the design.
3.8 Removal and restoration of adverse crossfall should take place over similar distances to superelevation as described in the following Section.

SUPERELEVATION

3.9 For small radius curves and at higher speeds, the removal of adverse crossfall alone will be insufficient to reduce frictional needs to an acceptable level, and crossfall should be increased by the application of superelevation. A minimum radius is reached when the maximum acceptable frictional and superelevation derived forces have been developed. These minimum radii values are identified in Figure 3.1 for maximum levels of superelevation of 10 per cent. These relate to paved roads only. Although this percentage is rather arbitrary, it is widely considered to be a value above which drivers may find it difficult to remain centred in lane as they negotiate a bend.

3.10 On unpaved roads, the crossfall is designed to remove rainwater quickly and effectively, and will be dependent on local conditions and materials. Values of superelevation lower than the value of the crossfall will fail to drain the surface, whilst higher values will be likely to result in erosion. On unpaved roads, the maximum superelevation will therefore be the elimination of adverse crossfall (see Table 3.1).

3.11 Where transition curves are used (paras 3.14-19), superelevation should be applied over the length of the transition curves. Otherwise it should be introduced such that two thirds are applied prior to the start of the circular curve.

3.12 For curves with radii above the minimum values, but below the values at which adverse crossfall should be eliminated, it is advisable to improve passenger comfort by introducing superelevation and reducing the sideways force. Intermediate values of superelevation are given in Figure 3.1.

3.13 On paved roads with unsealed shoulders, the shoulders should drain away from the paved area to avoid loose material being washed across the road.

TRANSITION CURVES

3.14 The characteristic of a transition curve is that it has a constantly changing radius. Transition curves may be inserted between tangents and circular curves to reduce the abrupt introduction of the lateral acceleration. They may also be used to link straights or two circular curves.

3.15 In practice, drivers employ their own transition on entry to a circular curve and transition curves contribute to the comfort of the driver in only a limited number of
situations. However, they also provide convenient sections over which superelevation or pavement widening may be applied, and can improve the appearance of the road by avoiding sharp discontinuities in alignment at the beginning and end of circular curves. For large radius curves, the rate of change of lateral acceleration is small and transition curves are not normally required.

3.16 Several methods exist for the calculation of transition curves and any may be used in most situations. The rate of pavement rotation method has been adopted here. The rate of pavement rotation is defined as the change in crossfall divided by the time taken to travel along the length of transition at the design speed. The length of transition curve is derived from the formula:

$$L_s = \frac{e \cdot V}{3.6n}$$

where $L_s =$ Length of transition curve (metres)
$e =$ Superelevation of the curve (metres per metre)
$V =$ Design speed (km/h)
$n =$ Rate of pavement rotation (metres per metre per second)

3.17 The same values of rate of change of pavement rotation should be used to calculate the minimum length ($L_c$) over which adverse camber should be removed on a tangent section prior to the transition:

$$L_c = \frac{e \cdot n \cdot V}{3.6n}$$

Where $L_c =$Length of section over which adverse camber is removed
$en =$Normal crossfall of the pavement (metres per metre).

3.18 The length of transition curve ($L_s$) is used to apply the superelevation, with the adverse camber removed on the preceding section of tangent ($L_c$). The change from normal cross-section to full superelevation at the start of the circular curve is achieved over the superelevation run-off distance which is the sum of $L_5$ and $L_c$.

3.19 Several relationships are available to calculate the coordinates of a transition curve. The shift, ie the offset of the start of the circular curve from the line of the tangent, should be at least 0.25 metres for appearance purposes. The transition should be omitted if the shift is less than this value.

OTHER CONSIDERATIONS

3.20 For small changes of direction, it is often desirable to use large radius curves. This improves the appearance of the road by removing rapid changes in edge profile. It also reduces the tendency for drivers to cut the corners of small radius curves. Providing the curve radii are sufficiently large, visibility should not be restricted enough to prevent safe overtaking.

3.21 The use of long curves of tight radii should be avoided where possible, as drivers at speeds other than the design speed will find it difficult to remain in lane. Curve widening reduces such problems. In such situations, it will usually be more important to provide adequate overtaking opportunities with longer straight sections and tighter curves, and to overcome terrain constraints, than to allow for detailed operational problems.

3.22 Abrupt changes in direction from successive curves should be avoided where possible by the inclusion of a tangent section in between. This will allow appropriate changes to be made in crossfall and superelevation.

3.23 Successive curves in the same direction should also be separated by an appropriate tangent, as drivers are unlikely to anticipate what may be an abrupt change in radial acceleration.