1.6.3 Superelevation

Superelevation or cant or banking is the transverse slope provided at horizontal curve to counteract the centrifugal force, by raising the outer edge of the pavement with respect to the inner edge, throughout the length of the horizontal curve.

When vehicles approaching a horizontal curve, there will be force resulted centripetal acceleration trying to push this vehicle outside the curve. This force is normally balanced by the force resulted from the friction between vehicles' tires and road surface. At high speeds and/ or low radius, the frictional force is not generally sufficient to balance the centrifugal force. For this reason, the carriageway should be super-elevated to increase the resistance as shown below. In order to find out how much this raising should be, the following analysis may be done as presented in Figure 1.24 whereas; Figure 1.23 shows a general example of superelevation.

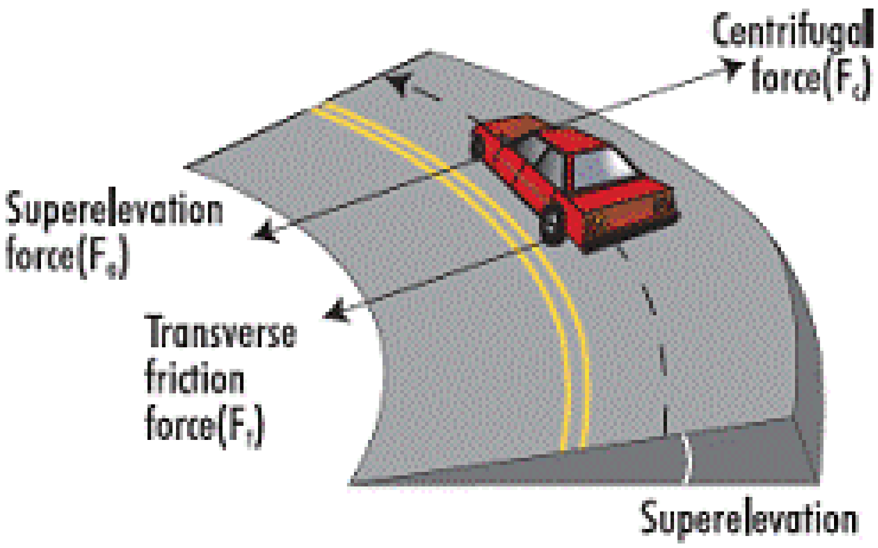


Figure 1.23: Superelevation

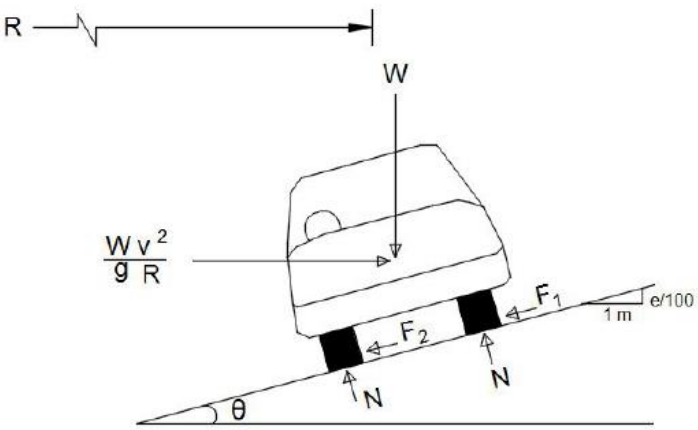


Figure 1.24: Vehicle on curves, acting forces

$\sum Fy = 0$

N= P sinθ + W cos θ $hint$ P sin $\theta \cong$ zero

N= W cos θ 18

$\sum Fy = 0$

W sin θ + N. f = P cos θ..19

W sin θ + w cos θ. f = P cos θ 20

$$P = \frac{wv^2}{gR}$$ 21

By dividing Eq. 20 by w. cos θ, we get

$$\tan\theta + f = \frac{v^2}{gR},$$ Hint: tan θ= e = superelevation

$$e + f = \frac{v^2}{gR}$$ (v in m/sec) 22

$$e + f = \frac{V^2}{127\ R}$$ (V in Km/hr) 23

where,

e = superelevation, f = coefficient of friction (side friction), V= Design Speed and R = Radius.

1.6.3.1 Minimum radius of curvature

In design consideration, when a minimum radius of curve is applied, the superelvation and coefficient of fraction have to be at maximum values. Therefore, the equation that governs the minimum radius of curvature is calculated based on the following equation;

$$R_{min} = \frac{V^2}{127(e_{max}+f_{max})} \quad \text{......24}$$

The maximum value for the rate of superelevation is affected by several factors such as:

1- Location of the highway (that is, whether it is in an urban or rural area),
2- Weather conditions (such as the occurrence of snow),
3- Distribution of slow moving traffic within the traffic stream.

In general, for highways located in rural areas where is no snow or ice, a maximum superelevation rate of 0.10 generally is used. For highways located in areas with snow and ice, values ranging from 0.08 to 0.10 are used; while for expressways in urban areas, a maximum superelevation rate of 0.08 is used. Values of 4% or 6% for e_{max} are preferred options for urban streets, as those roads are usually not superelevated because relatively low speeds on local urban roads are applied. Figure 1.25 shows a relation between side friction and design speed.

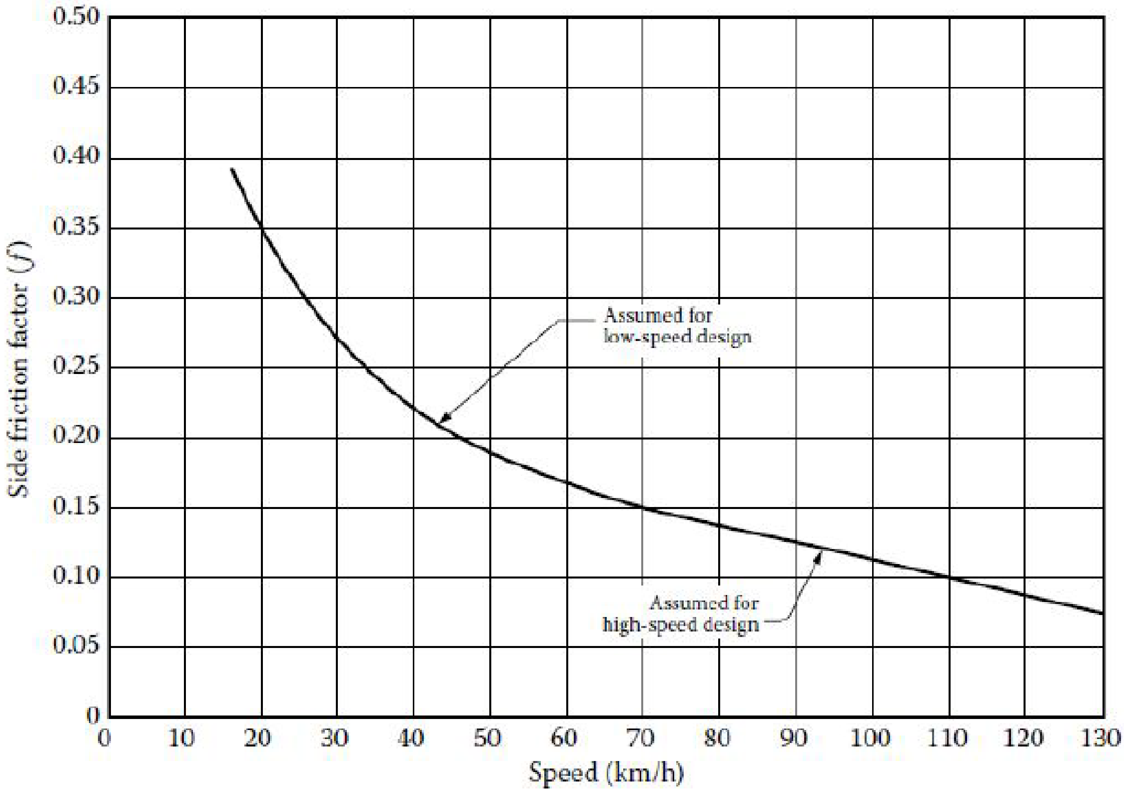


Figure 1.25: Recommended maximum side friction factors for different design speeds

1.6.3.2 Design superelevation rate

Indian Road Congress (IRC)

Indian road congress has formulated the a procedure to compute superelevation rate and minimum radius of horizontal curve as follows:

Step One: Find e for 75% design speed and neglecting the effect of coefficient of frication:

$$e_1 = \frac{(0.75v)^2}{127\ R} \quad \ldots\ldots\ldots\ldots 25$$

Step Two: If $e_1 \leq$ maximum superelvation (in Iraq emax = 0.08), then

$$e = e_1 = \frac{(0.75v)^2}{127\ R}$$ if elase, $e_1 > e_{max}$ then go next step

Step Three: Find f for design speed and e_{max}

$$f = \frac{v^2}{127\,R} - e \quad \text{..........26}$$

if $f < f_{\max}$ then $e = e_{max}$ is safe for the design speed, otherwise go to Step Four.

Step Four: Find the allowable speed V_a for $e = e_{max}$ and $f = f_{max}$

$$R = \frac{V^2}{127(e+f)} \quad \text{..........27}$$

If $V_a > V$ then the design is adequate otherwise apply speed control measures.

AASHTO Procedure

AASHTO's geometric design policy has developed charts for several superelevation (e_{max}) in both metric and English units. See the attached charts with handout

Questions

Q1*: The point of intersection (P.I.) of two tangents is at station 15+20. The radius of curvature is 275m deflection angle is 520. Find the length of the curve, the station for the TC (or PC) and TC (orPT), and all other relevant characteristics of the curve (i.e., C., M, and E).*

Q2*: A horizontal curve is designed with a 725m radius. The curve has a tangent lengthy 140m and PI is at station 3 + 103. Determine the stationing of the PT.*

Q3: *A national highway passing through a rolling terrain has two horizontal curves of 450 m and 150 m. Design the required superelevation for the curves which are applicable to accommodate speed of 80 km/h. and f value is 0.15? Use the IRC guidelines. Adopt* e_{max} *=0.07*

Q4: A highway in urban area has a design speed of 80Km/h and a maximum superelevation rate of 8%. Design a suitable horizontal curve. Use *f*= 0.14, road camber 2%.

Q5: *Solve the previous example using AASHTO procedure*

1.6.3.3 Attainment of superelevation

It is essential that the change from a crowned cross section to a superelevated one be achieved without causing any discomfort to motorists or creating unsafe conditions. One of three methods can be used to achieve this change on undivided highways.

1. A crowned pavement is rotated about the profile of the centreline.

2. A crowned pavement is rotated about the profile of the inside edge.

3. A crowned pavement is rotated about the profile of the outside edge.

Figures 1.26 and 1.27 is a schematic of Method 1. This is the most commonly used method since the distortion obtained is less than that obtained with other methods. The procedure used is first to raise the outside edge of the pavement relative to the centreline, until the outer half of the cross section is horizontal. The outer edge is then raised by an additional amount to obtain a straight cross section. Note that the inside edge is still at its original elevation. The whole cross section is then rotated as a unit about the centreline profile until the full superelevation is achieved.

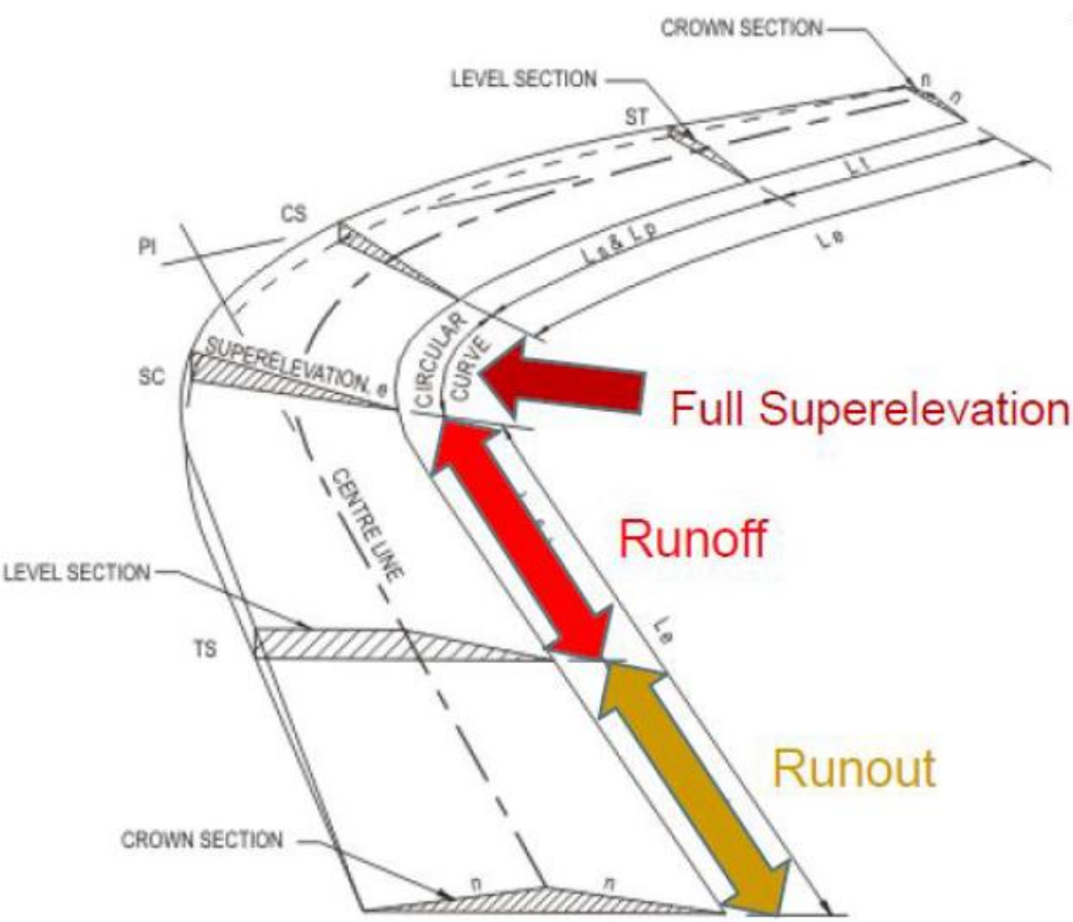


Figure 1.26: Attainment of superelevation

Figure 1.28 illustrates Method 2 where the centreline profile is raised with respect to the inside pavement edge to obtain half the required change, while the remaining half is achieved by raising the outside pavement edge with respect to the profile of the centreline. Note that the inside edge and centreline are still at their original elevations. The whole cross section is then rotated as a unit about the inside edge point until the full superelevation is achieved (the elevation of inside edge, remains constant from the beginning to the ending of rotation process).

Method 3, demonstrated by Figure 1.29, is similar to Method 2 with the only difference being a change affected below the outside edge profile.

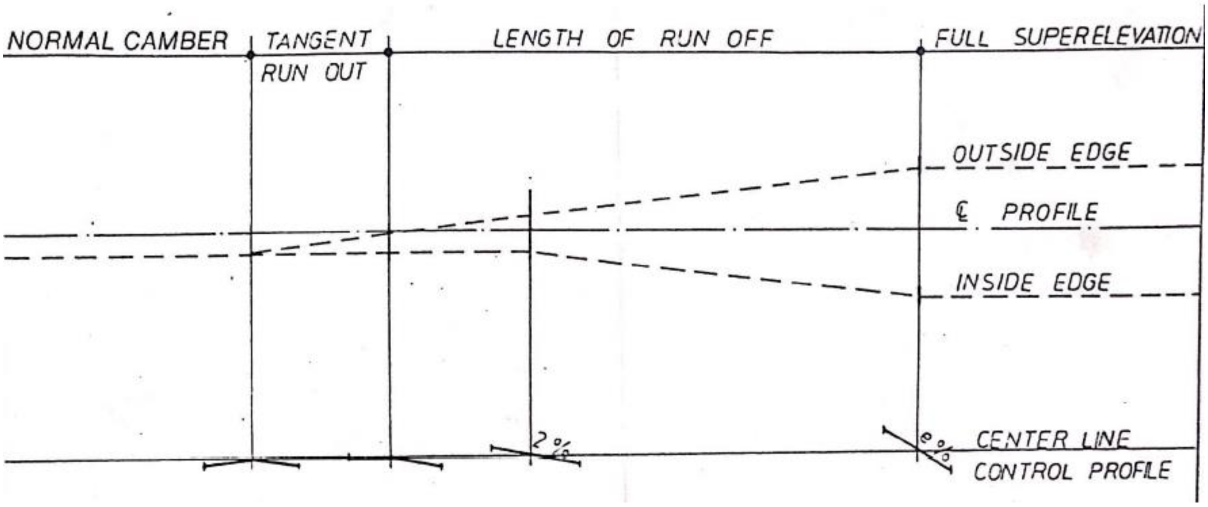


Figure 1.27: A crowned pavement is rotated about the profile of the centreline

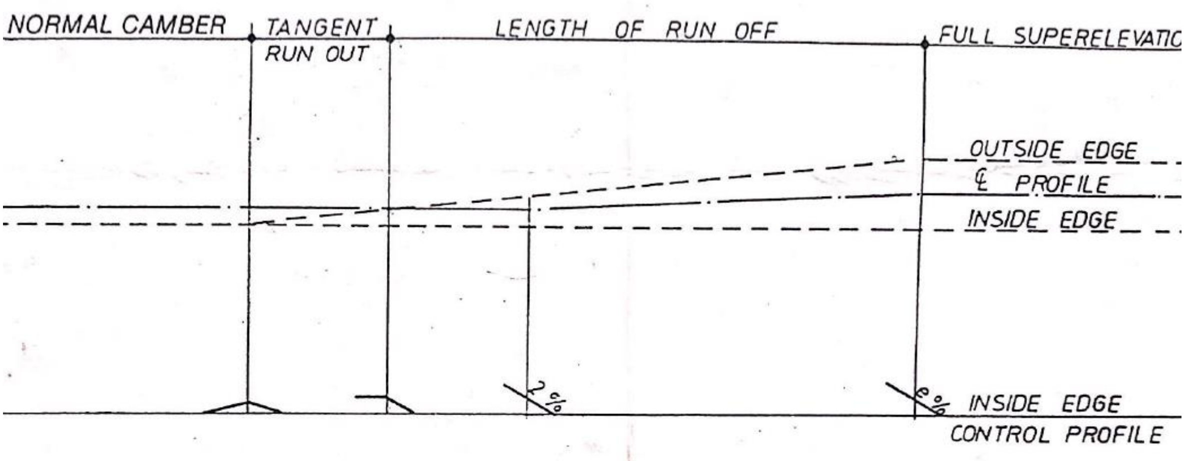


Figure 1.28: A crowned pavement is rotated about the profile of the outside edge

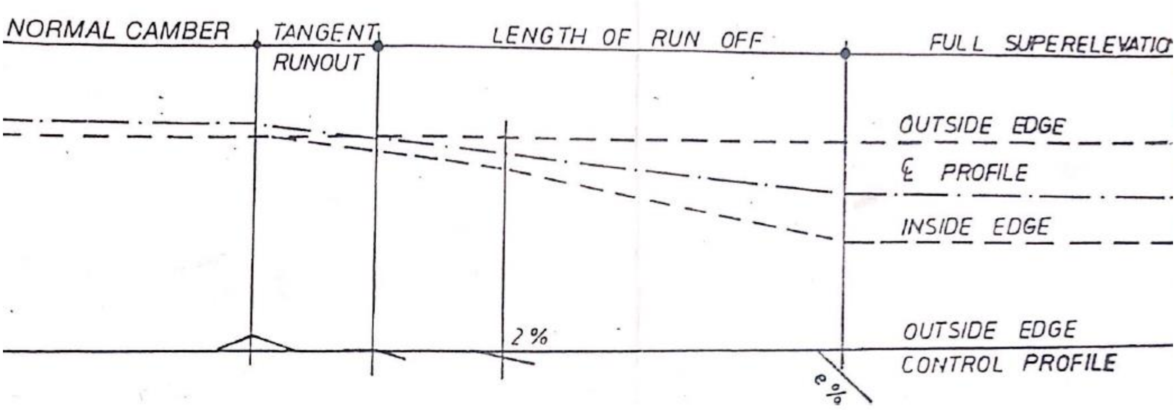


Figure 1.28: A crowned pavement is rotated about the profile of the inside edge

Tangent Runout Length

Length of tangent roadway needed to accomplish a change in outside-lane cross slope from normal cross slope rate to zero (flat).

Length of superelevation Runoff when spiral curves are not used

Superelevation is uniformly applied to provide a smooth transition from a normal crown section to a full superelevation section as shown in Figure 1.26. Two-thirds of superelevation runoff occurs on the tangent segment prior to the PC and then again, after the PT. One-third of the superelevation runoff occurs on the curve between the PC and the PT at each end of the curve. The rest of the curve is in a full superelevation section. The crown runoff that transitions from a normal crown to a flat crown (and vice versa) is placed outside each superelevation runoff section.

Minimum superelevation runoff length

It is the length required to change the cross-section from adverse crown removed to the full superelevated cross section. It can be estimated from the following formula

$$L_r = \left(\frac{3.6\,e}{G}\right).\,a \qquad \text{.....28}$$

Where: Lr is superelevation runoff length, e is full superelevation (%), G is relevant gradient (%) as presented in Table 1.4, a is multilane adjustment factor (dimensionless) as shown in Table 1.5

Table 1.4: Recommended relative gradient values

Metric			US Customary		
Design speed (km/h)	Maximum relative gradient (%)	Equivalent maximum relative slope	Design speed (mph)	Maximum relative gradient (%)	Equivalent maximum relative slope
20	0.80	1:125	15	0.78	1:128
30	0.75	1:133	20	0.74	1:135
40	0.70	1:143	25	0.70	1:143
50	0.65	1:150	30	0.66	1:152
60	0.60	1:167	35	0.62	1:161
70	0.55	1:182	40	0.58	1:172
80	0.50	1:200	45	0.54	1:185
90	0.47	1:213	50	0.50	1:200
100	0.44	1:227	55	0.47	1:213
110	0.41	1:244	60	0.45	1:222
120	0.38	1:263	65	0.43	1:233
130	0.35	1:286	70	0.40	1:250
			75	0.38	1:263
			80	0.35	1:286

Table 1.5: Recommended adjustment factors

Roadway Type	α
two-lane undivided highway (w = 3.6 m)	1
four-lane divided highway (w = 7.2 m)	1.5
standard ramp (w = 4.8 m)	1.167
standard loop (w = 5.5 m)	1.264

Minimum superelevation runoff length (AASHTO 2011)

The minimum superelevation runoff length is computed on the basis of comfort and aesthetic purposes according to AASTO's geometric design policy using the following formula. It should be however noted that the length calculated on the basis of the following equation represent the minimum value and it is desirable to use more length especially for high type alignments.

$$L_r = \frac{wn_1 * e_d * b_w}{\Delta} \qquad \text{...29}$$

Where:

Lr is the minimum length of superelevation runoff, m

w is width of one traffic lane, m

n_1 is the number of lanes rotated.

e_d is the design superelevation rate, %

b_w is the adgusement factor for number of lanes rotated

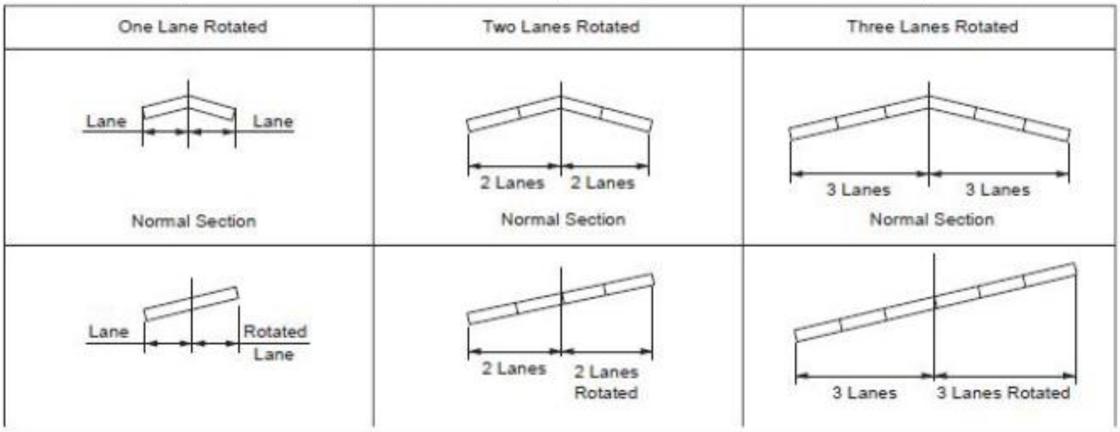
Δ is the mixumum relative gradient, %

Table 1.6: Maximum relative gradient (AASHTO method)

Metric		
Design Speed (km/h)	Maximum Relative Gradient (%)	Equivalent Maximum Relative Slope
20	0.80	1:125
30	0.75	1:133
40	0.70	1:143
50	0.65	1:154
60	0.60	1:167
70	0.55	1:182
80	0.50	1:200
90	0.47	1:213
100	0.44	1:227
110	0.41	1:244
120	0.38	1:263
130	0.35	1:286

Table 1.7: Adjustment factor for numbers of lanes rotated

Metric			U.S. Customary		
Number of Lanes Rotated, n_1	Adjustment Factor,* b_w	Length Increase Relative to One-Lane Rotated, $(= n_1 b_w)$	Number of Lanes Rotated, n_1	Adjustment Factor,* b_w	Length Increase Relative to One-Lane Rotated, $(= n_1 b_w)$
1	1.00	1.0	1	1.00	1.0
1.5	0.83	1.25	1.5	0.83	1.25
2	0.75	1.5	2	0.75	1.5
2.5	0.70	1.75	2.5	0.70	1.75
3	0.67	2.0	3	0.67	2.0
3.5	0.64	2.25	3.5	0.64	2.25



* $b_w = [1 + 0.5\,(n_1 - 1)]/n_1$