

CHAPTER FIVE
HORIZONTAL ALIGNMENT

Volume I
- Highway Design Guide –
National Standards

December 2004

Chapter Five

TABLE OF CONTENTS

	<u>Page</u>
5-1	DEFINITIONS 5-1
5-2	RURAL HIGHWAYS AND HIGH-SPEED URBAN HIGHWAYS 5-2
5-2.01	<u>Types of Horizontal Curves</u> 5-2
5-2.02	<u>Maximum Degree of Curve</u> 5-2
5-2.03	<u>Widening of Travelway</u> 5-6
5-2.04	<u>Length of Curve</u> 5-6
5-2.05	<u>Superelevation Development</u> 5-10
5-2.06	<u>Horizontal Sight Distance</u> 5-20
5-3	LOW-SPEED URBAN STREETS 5-27
5-3.01	<u>Horizontal Curves</u> 5-27
5-3.02	<u>Length of Curve</u> 5-27
5-3.03	<u>Superelevation Development</u> 5-28
5-3.04	<u>Horizontal Sight Distance</u> 5-33

Chapter Five

HORIZONTAL ALIGNMENT

Section 5-2 presents the Department's horizontal alignment criteria for all rural highways and high-speed urban highways ($V > 45$ mph). Section 5-3 presents the Department's criteria for horizontal alignment on low-speed urban streets ($V \leq 45$ mph).

5-1 DEFINITIONS

1. **Simple Curve.** A simple curve is that portion of the arc of a circle which achieves the desired deflection without using an entering or exiting transition.
2. **Compound Curve.** A compound curve (with deflections in the same direction) is a combination of any number of individual simple curves (e.g., 2-centered or 3-centered) and may be symmetrical or asymmetrical.
3. **Point of Intersection (PI).** The PI is the point of intersection of two tangents.
4. **Point of Curvature (PC).** The PC is the point of change from tangent to circular curve.
5. **Point of Tangent (PT).** The PT is the point of change from circular curve to tangent.
6. **Deflection Angle (Δ).** The deflection angle is the intersection angle between the two tangents forming the circular curve (also referred to as the central angle of curve).
7. **Degree of Curve (D).** The degree of curve is the central angle which subtends an arc length of 100 feet (arc definition). The maximum degree of curve is a limiting value for a given design speed based on the maximum rate of superelevation and maximum allowable side friction factor.

5-2 RURAL HIGHWAYS AND HIGH-SPEED URBAN HIGHWAYS

5-2.01 Types of Horizontal Curves

Deflectional changes in horizontal alignment may be accomplished by using a simple curve or a compound curve. The following discusses each of the horizontal curvature types.

Simple Curves

Figure 5-1 illustrates a typical simple curve layout. Considering their simplicity and ease of design, survey and construction, the simple curve is the type of curve used most often.

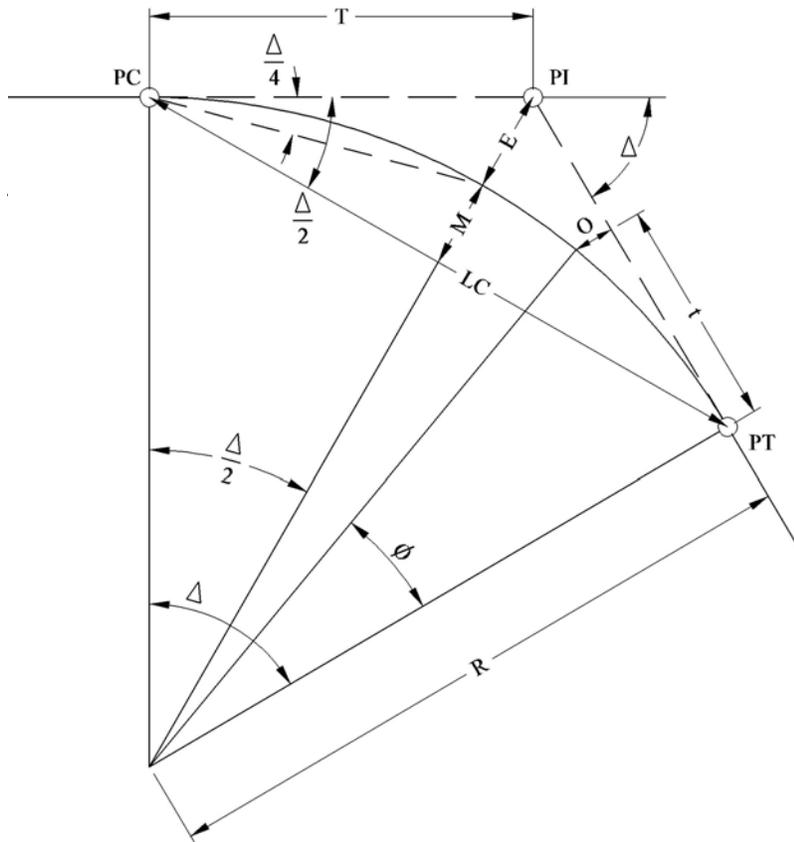
Compound Curves

Compound curves are used to establish alignment where a controlling obstruction cannot be relocated. They may occasionally be used to transition into and out of a simple curve. Table 5-1 provides the suggested criteria for considering a compound curve for transitions where the design speed is 50 mph or higher. Figure 5-2 illustrates the layout of a symmetrical 3-centered compound curve.

When a compound curve is used on a highway main line, the radius of the flatter circular arc (R_1) should not be more than 50 percent greater than the radius of the sharper circular arc (R_2). In other words, $R_1 \leq 1.5 R_2$. For degree of curve, the equation becomes $D_1 \geq 0.67 D_2$.

5-2.02 Maximum Degree of Curve

Table 5-2 provides the maximum degree of curve for each design speed on all rural highways and high-speed urban highways. The designer should provide flatter horizontal curves where practical. The designer may also need to provide flatter curvature where the proposed degree of curve will not provide the necessary stopping sight distance for horizontal curves. See Section 5-2.06.



$$R = \frac{5729.5780}{D}$$

$$L = 100 \frac{\Delta}{D} = \frac{\Delta R}{57.2958}$$

$$T = R \tan \frac{\Delta}{2}$$

$$E = T \tan \frac{\Delta}{4}$$

$$M = R \left(1 - \cos \frac{\Delta}{2} \right)$$

$$LC = 2R \sin \frac{\Delta}{2}$$

$$O = R - \sqrt{R^2 - t^2}$$

$$O = R (1 - \cos \phi)$$

- PI = Point of Intersection of tangents
 PC = Point of Curvature
 PT = Point of Tangency
 Δ = Central angle of curve (deflection angle)
 D = Degree of curvature
 L = Length of curve (ft); arc length from PC to PT
 R = Radius of curve (ft)
 T = Tangent length (ft) from PC to PI or from PT to PI
 E = External distance (ft) from PI to midpoint of circular arc
 M = Middle ordinate (ft) connecting midpoints of circular arc and long chord
 LC = Long chord (ft) from PC to PT
 ϕ = Deflection angle from PT to any point on curve
 t = Tangent distance (ft) from PT to any point on curve along tangent
 O = Tangent distance (ft) from tangent to any point on curve

TYPICAL SIMPLE CURVE LAYOUT

Figure 5-1

Design Speed (mph)	Consider Compound Curve When
50	R < 1130 ft
55	R < 1455 ft
60	R < 1800 ft
65	R < 2175 ft
70	R < 2775 ft

Note: The limiting Radius (R) suggested for a compound curve is based on 75% of the maximum radius for a given design speed.

SUGGESTED CRITERIA FOR CONSIDERING A COMPOUND CURVE

Table 5-1

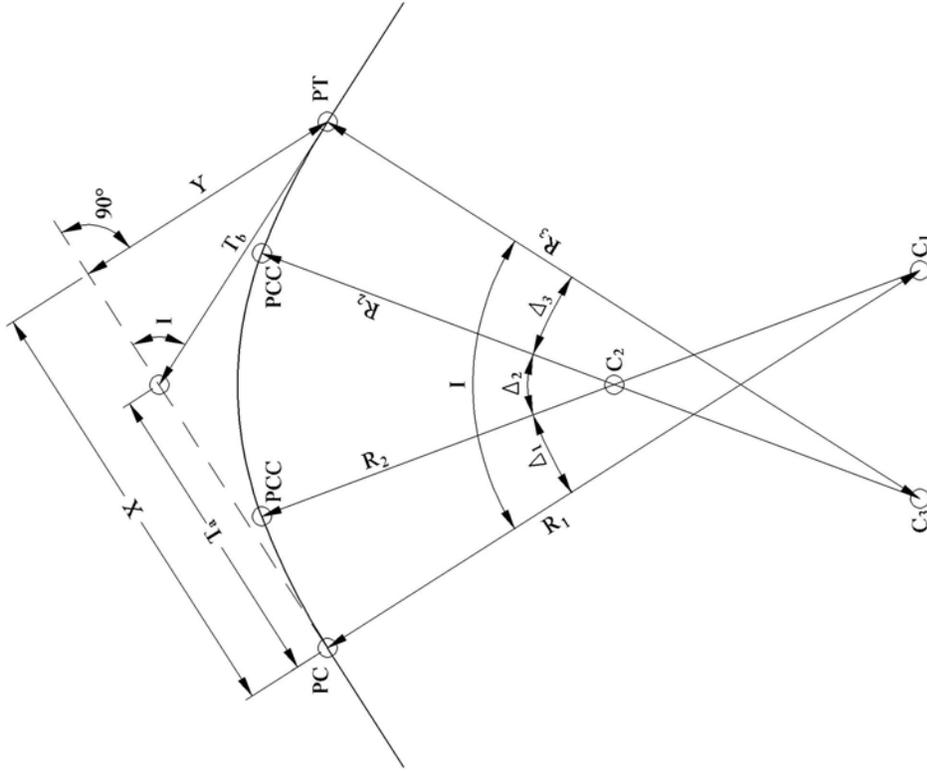
Design Speed (mph)	Minimum Radius (ft)
30	275
40	510
45	660
50	835
55	1065
60	1340
65	1660
70	2050

Note: $e_{\max} = 6.0\%$

Minimum Radius (Rural Highways and High-Speed Urban Highways)

Table 5-2

<p>Equations for Any Two-Centered Compound Curves:</p> <p>$I = \text{Total Deflection Angle} = \Delta_1 + \Delta_2$</p> <p>$X = R_2 \sin I + (R_1 - R_2) \sin \Delta_1$</p> <p>$Y = R_1 - R_2 \cos I - (R_1 - R_2) \cos \Delta_1$</p> <p>$T_b = Y / \sin I$</p> <p>$T_a = X - T_b \cos I$</p>	
<p>Equations for Any Three-Centered Compound Curves:</p> <p>$I = \text{Total Deflection Angle} = \Delta_1 + \Delta_2 + \Delta_3$</p> <p>$X = (R_1 - R_2) \sin \Delta_1 + (R_2 - R_3) \sin (\Delta_1 + \Delta_2) + R_3 \sin I$</p> <p>$Y = R_1 - R_3 \cos I - (R_1 - R_2) \cos \Delta_1 - (R_2 - R_3) \cos (\Delta_1 + \Delta_2)$</p> <p>$T_b = Y / \sin I$</p> <p>$T_a = X - T_b \cos I$</p>	
<p>Equations for Symmetrical Three-Centered Compound Curve ($R_1 = R_3$; $\Delta_1 = \Delta_3$, as shown in Figure):</p> <p>$I = \text{Total Deflection Angle} = 2 \Delta_1 + \Delta_2$</p> <p>$X = (R_1 - R_2) \sin \Delta_1 + (R_2 - R_1) \sin (\Delta_1 + \Delta_2) + R_1 \sin I$</p> <p>$Y = R_1 - R_2 \cos I - (R_1 - R_2) \cos \Delta_1 - (R_2 - R_1) \cos (\Delta_1 + \Delta_2)$</p> <p>$T_b = Y / \sin I$</p> <p>$T_a = X - T_b \cos I$</p> <p>Note: $R_1 \leq 1.5 R_2$</p>	



Note: This is only one example of how a compound curve can be designed.

SYMMETRICAL THREE-CENTERED COMPOUND CURVE

Figure 5-2

5-2.03 Widening of Travelway

Widening of the traveled way may be desirable on the inside edge of horizontal curves to make operating conditions on the curves comparable to those on tangent. This feature may be especially applicable to 3R projects (See Chapter Eleven). The designer should evaluate the need for widening on a case-by-case basis considering the functional class, type of shoulder, traffic volumes, truck volumes and urban/rural location. In some cases, it may be warranted to reduce the shoulder width for the purpose of widening the travel lanes.

Table 5-3 presents design values of travelway widening on highway curves for 2-lane highways. This applies to either 1-way or 2-way operation. A recommended minimum widening of 2 feet should be used. Widening may be warranted in known problem areas (e.g., where inside shoulder has broken up because of traffic), even when not warranted by the criteria in the table.

Widening should be applied to the inside edge of pavement only. Desirably, the transition distance for traveled way widening will equal the superelevation transition length, and it will be applied coincident with the superelevation transition. Figure 5-3 illustrates the application of travelway widening to a horizontal curve. Note also that the figure indicates the proper pavement marking for the curve.

5-2.04 Length of Curve**Calculated vs. Minimum**

The length of a horizontal curve is calculated by:

$$L = 100 \frac{\Delta}{D} = \frac{\Delta R}{57.2958}$$

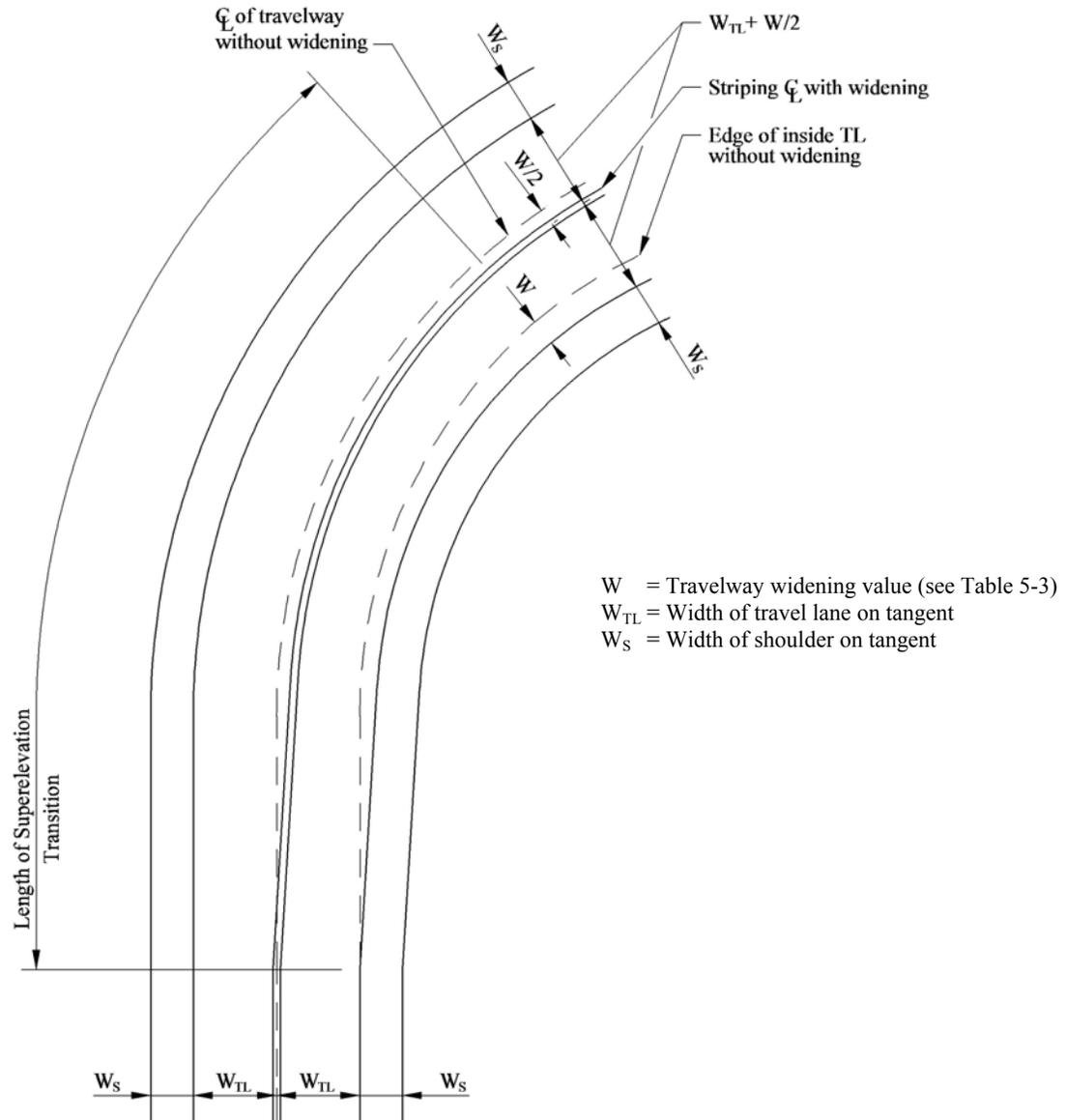
For small deflection angles, the calculated lengths may produce undesirably short curves. For major roads, it is desirable that the length of curve be approximately 15V regardless of the calculated length (V = design speed in mph). The designer should use a flatter degree of curve to achieve the necessary deflection. Table 5-4 presents recommended criteria for the lengths of horizontal curves, and these should be met if practical.

Radius of Curve (ft)	24-ft Travelway							22-ft Travelway							20-ft Travelway							
	Design Speed (mph)							Design Speed (mph)							Design Speed (mph)							
	30	35	40	45	50	55	60	30	35	40	45	50	55	60	30	35	40	45	50	55	60	
7000	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
6500	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2.0
6000	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2.0	2.0
5500	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2.0	2.1
5000	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2.0	2.1	2.1
4500	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2.0	2.1	2.1	2.1	2.2
4000	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2.0	2.1	2.2	2.2	2.2	2.3
3500	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2.0	2.1	2.2	2.3	2.3	2.3	2.4
3000	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2.0	2.1	2.2	2.3	2.4	2.5	2.5	2.6
2500	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2.2	2.3	2.4	2.5	2.6	2.7	2.7	2.8
2000	-	-	-	-	-	-	-	-	-	-	-	2.0	2.1	-	2.4	2.5	2.6	2.7	2.8	3.0	3.0	3.1
1800	-	-	-	-	-	-	-	-	-	-	2.0	2.1	2.2	-	2.5	2.6	2.8	2.9	3.0	3.1	3.1	3.2
1600	-	-	-	-	-	-	-	-	-	2.0	2.2	2.3	2.4	-	2.7	2.8	2.9	3.0	3.2	3.3	3.3	3.4
1400	-	-	-	-	-	-	-	-	2.0	2.1	2.2	2.4	2.5	2.6	2.8	3.0	3.1	3.2	3.4	3.5	3.5	3.6
1200	-	-	-	-	-	-	-	2.1	2.2	2.4	2.5	2.7	2.8	2.9	3.1	3.2	3.4	3.5	3.7	3.8	3.8	3.9
1000	-	-	-	-	2.0	2.2	2.4	2.4	2.6	2.7	2.9	3.0	3.2	3.4	3.4	3.6	3.7	3.9	4.0	4.2	4.2	4.4
900	-	-	2.0	2.1	2.3	2.5	-	2.6	2.8	3.0	3.1	3.3	3.5	-	3.6	3.8	4.0	4.1	4.3	4.3	4.5	-
800	-	2.1	2.2	2.4	2.6	2.8	-	2.9	3.1	3.2	3.4	3.6	3.8	-	3.9	4.1	4.2	4.4	4.6	4.6	4.8	-
700	2.2	2.4	2.6	2.8	3.0	-	-	3.2	3.4	3.6	3.8	4.0	-	4.2	4.4	4.6	4.8	5.0	-	-	-	-
600	2.7	2.9	3.1	3.3	3.5	-	-	3.7	3.9	4.1	4.3	4.5	-	4.7	4.9	5.1	5.3	5.5	-	-	-	-
500	3.3	3.5	3.7	3.9	-	-	-	4.3	4.5	4.7	4.9	-	-	5.3	5.5	5.7	5.9	-	-	-	-	-
450	3.7	3.9	4.1	-	-	-	-	4.7	4.9	5.1	-	-	-	5.7	5.9	6.1	-	-	-	-	-	-
400	4.2	4.4	4.7	-	-	-	-	5.2	5.4	5.7	-	-	-	6.2	6.4	6.7	-	-	-	-	-	-
350	4.8	5.1	5.3	-	-	-	-	5.8	6.1	6.3	-	-	-	6.8	7.1	7.3	-	-	-	-	-	-
300	5.6	5.9	-	-	-	-	-	6.6	6.9	-	-	-	-	7.6	7.9	-	-	-	-	-	-	-
250	6.8	-	-	-	-	-	-	7.8	-	-	-	-	-	8.8	-	-	-	-	-	-	-	-
200	8.5	-	-	-	-	-	-	9.5	-	-	-	-	-	10.5	-	-	-	-	-	-	-	-

- Notes:**
1. Minimum widening should be 2 ft on all highways.
 2. For 3-lane pavements, multiply table values by 1.5.
 3. For 4-lane pavements, multiply table values by 2.

**DESIGN VALUES FOR WIDENING THE TRAVELWAY ON HIGHWAY CURVES (FT)
(Two-Lane Pavements)**

Table 5-3



- Notes:**
1. Figure applies to both ends of the highway curve.
 2. All widening occurs on inside of curve.
 3. Solid lines in figure indicate pavement marking.
 4. Desirably, the shoulder width will remain constant through the curve. When the shoulder width is decreased for travelway widening, the pavement structure should be increased accordingly in this area of the shoulder.

APPLICATION OF TRAVELWAY WIDENING ON HORIZONTAL CURVES
Figure 5-3

Functional Class	Design Speed (mph)	Deflection Angle (Δ)		
		$< 0^\circ 30'$	$0^\circ 30' - 5^\circ$	$> 5^\circ$
Arterials and Freeways	45	(2)	500	675
	50	(2)	500	750
	55	(2)	500	825
	60	(2)	500	900
	65	(2)	500	925
	70	(2)	500	1050
Rural Collector and Local Roads	30-60	(2)	300	500

- Notes:**
1. The length of the curve in feet, should be its calculated length ($\Delta R/57.2958$) or $(100 \Delta/D)$ or the recommended length in the table, whichever is longer.
 2. For $\Delta < 0^\circ 30'$, consider providing no horizontal curve. See discussion in Section 5-2.04

**RECOMMENDED MINIMUM LENGTH OF CURVE (FT) (1)
(Rural Highways and High-Speed Urban Highways)**

Table 5-4

Sharpest Deflection with No Curve

For a deflection angle less than about 30 minutes, the designer should evaluate the visual impact of not providing a horizontal curve; i.e., allowing the angle point to remain. The top of a crest vertical curve and a signal-controlled intersection are examples of where a small deflection angle may not be visible and may not impact driver response. These types of locations should be evaluated on a case-by-case basis. However, no angle points should be permitted on bridge structures.

5-2.05 Superelevation Development

Definitions

1. **Superelevation.** Superelevation is the amount of cross slope or "bank" provided on a horizontal curve to help counterbalance the outward pull of a vehicle traversing the curve. The maximum rate of superelevation (e_{\max}) depends on several factors including climatic conditions, terrain conditions and type of area (rural or urban).
2. **Superelevation Transition Length.** The superelevation transition length is the distance required to transition the roadway from a normal crown section to the full superelevation needed. Superelevation transition length is the sum of the tangent runout and superelevation runoff.
 - a. **Tangent Runout.** AASHTO defines tangent runout as the change from a normal crown section to a point where the adverse cross slope of the outside lane or lanes is removed (i.e., the outside lane(s) is level).
 - b. **Superelevation Runoff.** AASHTO defines superelevation runoff as the change in cross slope from the end of tangent runout (adverse crown removed) to a section that is fully superelevated.
3. **Axis of Rotation.** The superelevation axis of rotation is the line about which the pavement is revolved to superelevate the roadway. This line will maintain the normal highway profile throughout the curve, and it is known as the construction centerline or control edge.
4. **Superelevation Rollover.** Superelevation "rollover" is the algebraic difference between the travel lane cross slope and shoulder cross slope on the outside of a horizontal curve.
5. **Normal Crown (NC).** The typical cross section on a tangent section (i.e., no superelevation).
6. **Remove Crown (RC).** A superelevated cross section which is sloped across the entire traveled way in the same direction and at a rate equal to the typical cross slope on a tangent section (e.g., 2.0%)

Superelevation Rate

The Department has adopted $e_{\max} = 6.0\%$ for the design of rural highways and high-speed urban highways ($V > 45$ mph). Table 5-6 provides superelevation rates for various combinations of curvature and design speed.

A horizontal curve with a very small degree of curve does not require superelevation. For a given design speed, the normal crown section (NC) used on tangent sections (2.0%) can be maintained throughout a very flat curve. On sharper curves for the same design speed, a point is reached where a slope across the total pavement width is desirable (RC). Table 5-5 provides the threshold (or maximum) degree of curve for a normal crown section and a remove crown section at various design speeds. Examples 1 and 2 illustrate how to use Tables 5-5 and 5-6 to determine the superelevation rate and cross slope bank for a given degree of curve.

Design Speed (mph)	Degree of Curve		
	Normal Crown	Remove Crown	See Table 5-6
30	$R > 3185$ ft	$3185 \text{ ft} \geq R \geq 2150$ ft	$R < 2150$ ft
35	$R > 4140$	$4140 \geq R \geq 2795$	$R < 2795$
40	$R > 5290$	$5290 \geq R \geq 3580$	$R < 3580$
45	$R > 6485$	$6485 \geq R \geq 4465$	$R < 4465$
50	$R > 7995$	$7995 \geq R \geq 5370$	$R < 5370$
55	$R > 9550$	$9550 \geq R \geq 6485$	$R < 6485$
60	$R > 11090$	$11090 \geq R \geq 7640$	$R < 7640$
65	$R > 12735$	$12735 \geq R \geq 8595$	$R < 8595$
70	$R > 14325$	$14325 \geq R \geq 9825$	$R < 9825$

**DEGREE OF CURVE FOR NORMAL CROWN SECTION
AND REMOVE CROWN SECTION
(Rural Highways and High-Speed Urban Highways)**

Table 5-5

D	R (ft)	V=30 (mph)	V=35 (mph)	V=40 (mph)	V=45 (mph)	V=50 (mph)	V=55 (mph)	V=60 (mph)	V=65 (mph)	V=70 (mph)
0° 15'	22,918	NC	NC	NC	NC	NC	NC	NC	NC	NC
0° 30'	11,459	NC	NC	NC	NC	NC	NC	NC	NC	NC
0° 45'	7,639	NC	NC	NC	NC	RC	RC	2.1	2.4	2.6
1° 00'	5,730	NC	NC	NC	RC	RC	2.4	2.7	3.0	3.3
1° 30'	3,820	NC	RC	RC	2.5	2.8	3.3	3.7	4.1	4.6
2° 00'	2,865	RC	RC	2.5	3.0	3.5	4.0	4.5	5.0	5.5
2° 30'	2,292	RC	2.5	3.0	3.5	4.0	4.6	5.1	5.6	5.9
3° 00'	1,910	2.3	2.9	3.4	4.0	4.5	5.0	5.5	5.9	R_{max} = 2050
3° 30'	1,637	2.6	3.2	3.8	4.3	4.8	5.4	5.8	6.0	
4° 00'	1,432	2.9	3.5	4.1	4.7	5.2	5.7	6.0		
5° 00'	1,146	3.4	4.0	4.6	5.1	5.6	5.9	R_{min} = 1340	R_{min} = 1660	
6° 00'	955	3.8	4.4	5.0	5.5	5.9	R_{min} = 1065			
7° 00'	819	4.1	4.7	5.3	5.8	R_{min} = 835'				
8° 00'	716	4.3	5.0	5.6	6.0					
9° 00'	637	4.6	5.3	5.8	R_{min} = 660'					
10° 00'	573	4.8	5.5	5.9						
11° 00'	521	5.0	5.7	6.0						
12° 00'	477	5.2	5.8	R_{min} = 510'						
13° 00'	441	5.4	5.9							
14° 00'	409	5.5	6.0							
16° 00'	358	5.8	R_{min} = 380'							
18° 00'	318	5.9								
20° 00'	286	6.0								
21° 00'	273	6.0								R_{min} = 275'

Key:
 R = Radius of Curve
 V = Design Speed, mph
 e = Superelevation Rate (%)
 NC = Normal Crown (2.0% crown slope)
 RC = Remove Crown (superelevate at normal crown slope)

**SUPERELEVATION RATE
 (Rural Highways and High-Speed Urban Highways)**

Table 5-6

Example 1

Given: Design speed = 50 mph
 Radius = 4045 feet
 Tangent Cross Slope = 2.0%

Problem: Determine the superelevation rate.

Solution: For intermediate superelevation rates between the radius provided in Table 5-6, use a straight-line interpolation.

From Table 5-5, when $R < 5370$ ft at $v = 50$ mph, use table 5-6

From Table 5-6, when $R = 4045$ ft, it is between;
 5730 ft where $e = RC$ (2% in this case) and 3820 ft where $e = 2.8\%$

Therefore, when $R = 4045$ ft $e =$ what?:

$$e = \left(\frac{4045 - 5730}{3820 - 5730} \right) (2.8 - 2.0) + 2.0$$

$$e = (0.88)(0.8) + 2.0$$

$$e = 0.2704$$

Use $e = 2.7\%$.

Example 2

Given: Design speed = 50 mph
 Radius = 2292 ft
 Two-lane roadway
 12 ft travel lanes

Problem: Determine "B," the elevation differential between the edge of travel lanes.

Solution: From Table 5-6, the superelevation rate is $4.0\% = 0.040$ ft/ft.

The total horizontal distance from low side of bank to high side of bank is 24 ft.

$$B_{\text{Total}} = (0.040 \text{ ft/ft}) (24 \text{ ft}) = 0.96 \text{ ft} = 11.52 \text{ in.}$$

$$B/2 = 5.76 \text{ in.}$$

This distance should be rounded to the nearest $\frac{1}{4}$ ". Therefore, the elevation differential will be $5\frac{3}{4}$ " from the crown point to the high side edge of travel lane and $5\frac{3}{4}$ " from the crown point to the low side edge of travel lane.

* * * * *

Superelevation Transition

Superelevation should be introduced and removed uniformly over a length adequate for a given design speed. The superelevation transition length (L_T) is the distance measured from the normal crown section to the full superelevation section. It is a function of the pavement width of rotation. Table 5-7 presents the minimum superelevation transition lengths for a 1 or 2 lane width of rotation.

The following procedure should be used to determine the distribution of the superelevation transition length between the tangent and curve:

- Step 1: Determine the minimum superelevation transition length from Table 5-7 for a given design speed and width of rotation.
- Step 2: For a 1-lane width of rotation, all curves should have full superelevation from the first 50-foot station occurring a minimum distance of 25 feet after the PC to the last 50-foot station occurring a minimum distance of 25 feet before the PT. For a 2-lane width of rotation, all curves should have full superelevation from the first 100-foot station occurring a minimum distance of 50 feet after the PC to the last 100-foot station occurring a minimum distance of 50 feet before the PT.
- Step 3: Locate the beginning of the entering transition. This will be a distance equal to the superelevation transition length (Step 1) in advance of the station determined in Step 2. The end of the exiting transition will be a distance equal to the transition length (Step 1) beyond the last fully superelevated station determined in Step 2.

Example 3 illustrates the distribution of transition length on a simple horizontal curve.

Design Speed (mph)	Width of Rotation	
	L_T (1 - lane each way)	L_T (2 - lanes each way)
$V \leq 55$	200 ft	300 ft
$V > 55$	250 ft	400 ft

- Notes:**
1. A 1-lane width of rotation applies where 2 lanes are rotated about the centerline.
 2. A 2-lane width of rotation applies where 4 lanes are rotated about the centerline or where 3 lanes are rotated about one of the edges of the interior lane or construction centerline.
 3. For a 3-lane width of rotation: $L_T (3 \text{ lanes}) = 2.0 \times L_T (1\text{-lane})$.
 4. For a 4-lane width of rotation: $L_T (4 \text{ lanes}) = 2.5 \times L_T (1\text{-lane})$.

**MINIMUM SUPERELEVATION TRANSITION LENGTH (L_T)
(Rural Highways and High-Speed Urban Highways)**

Table 5-7

Example 3

Given: Figure 5-4 illustrates the horizontal curve and stationing.
 Design Speed = 50 mph.
 2-lane roadway (rotated about the centerline).

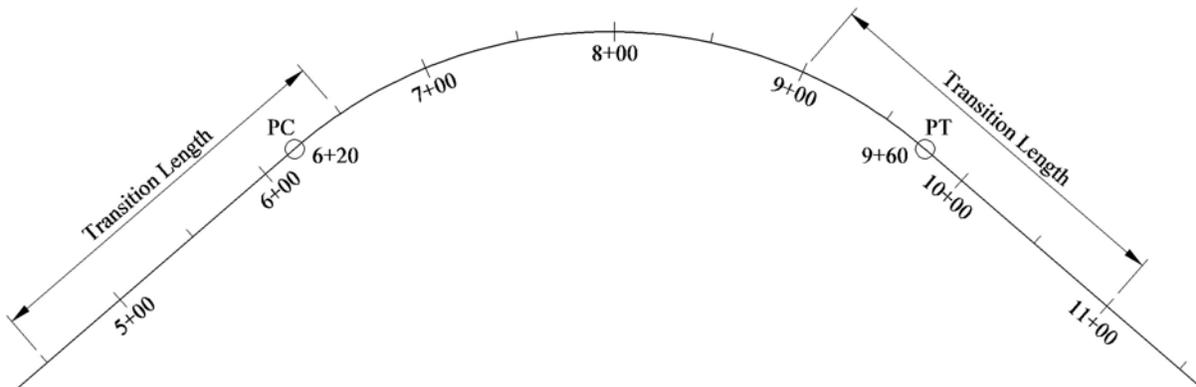
Problem: Determine the superelevation transition length and the beginning and ending stations.

Solution: From Table 5-7, the minimum superelevation transition length is 200 ft.

Entering transition: From Figure 5-4, the first full 50-ft station at least 25 ft beyond the PC is station 6+50 (full superelevation).

Exiting transition: From Figure 5-4, the last fully superelevated section will be at station 9+00.

Beginning and ending transitions: Measure 200 ft back from station 6+50 to station 4+50 (begin superelevation transition) and measure 200 ft ahead from station 9+00 to station 11+00 (end superelevation transition).



Data: $V = 50$ mph
 $L_T = 200$ ft
 Rotate about centerline

DISTRIBUTION OF SUPERELEVATION TRANSITION LENGTH (Example 3)

Figure 5-4

* * * * *

Reverse Curves

For closely spaced reverse curves, it may not be practical to achieve a normal crown section between the curves. A plane section continuously rotating about its axis (e.g., centerline) can be maintained between the two curves, if they are close enough together. However, the designer should adhere to the superelevation development criteria for each individual curve. The following will apply to reverse curves:

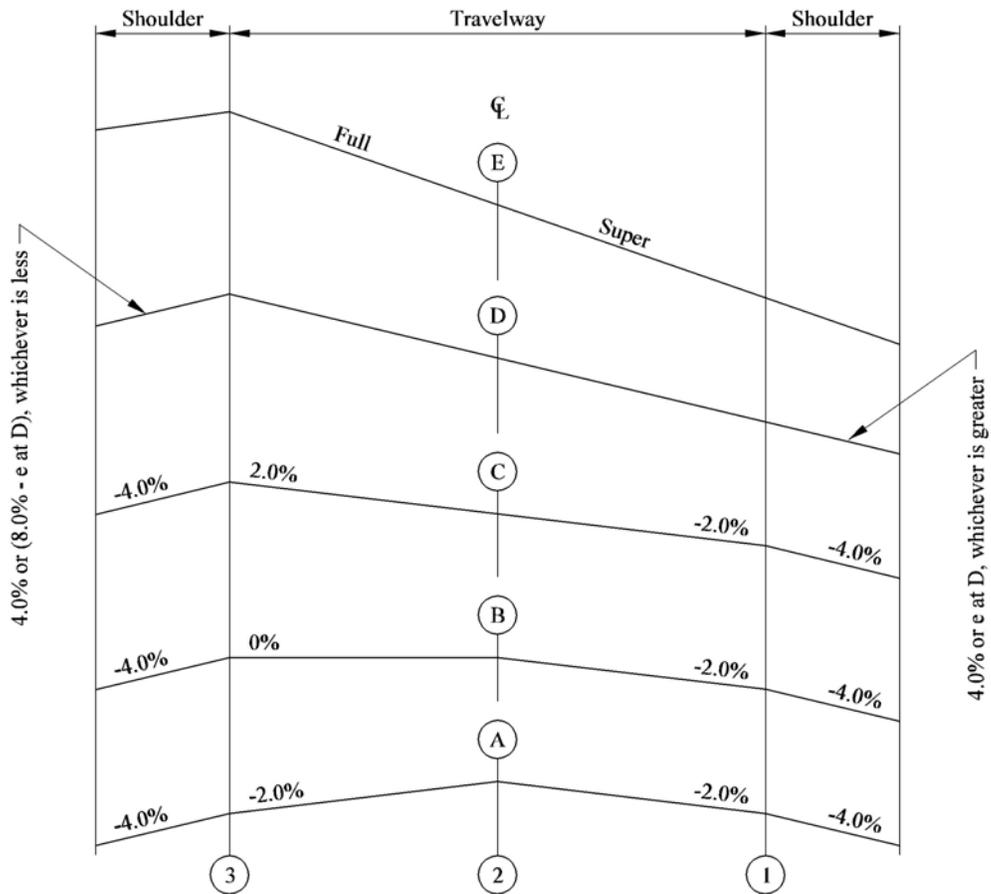
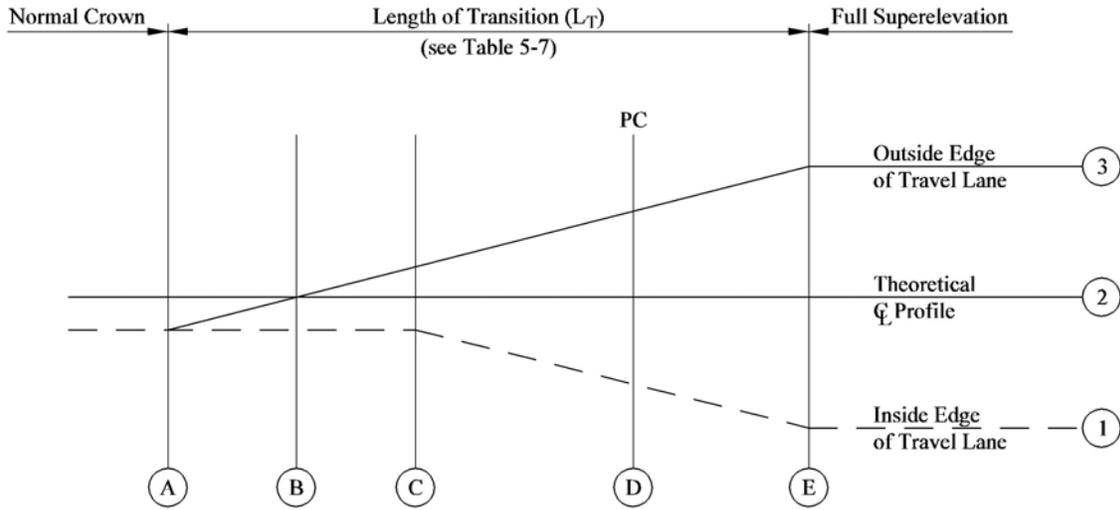
1. The designer should not attempt to achieve a normal crown section between reverse curves unless the normal section can be maintained for at least 150 feet ($45 \leq V \leq 55$) or 200 feet ($V > 55$ mph) and the superelevation transition requirements can be met for both curves.
2. When a normal crown section is not provided and 1-lane is being rotated, the minimum recommended distance between the PT (first curve) and PC (second curve) is 200 feet. The pavement will remain in a plane throughout the tangent section continuously rotating about its axis.
3. When a normal crown section is not provided and two lanes are being rotated, the minimum recommended tangent distance is 300 feet. The pavement will remain in a plane throughout the tangent section.

Axis of Rotation

1. **Undivided Highways.** On 2-lane highways and undivided multilane highways, the axis of rotation will be the centerline of the roadway. Rotation about the centerline profile is illustrated in Figure 5-5. On a 2-lane roadway with an auxiliary lane, such as a climbing lane, the axis of rotation will be the centerline of the two through lanes.
2. **Divided Highways.** Divided highways with medians require special consideration. Table 5-8 presents the recommended axis of rotation for divided highways based on median widths. The designer should select an axis based on the specific site conditions at the curve.

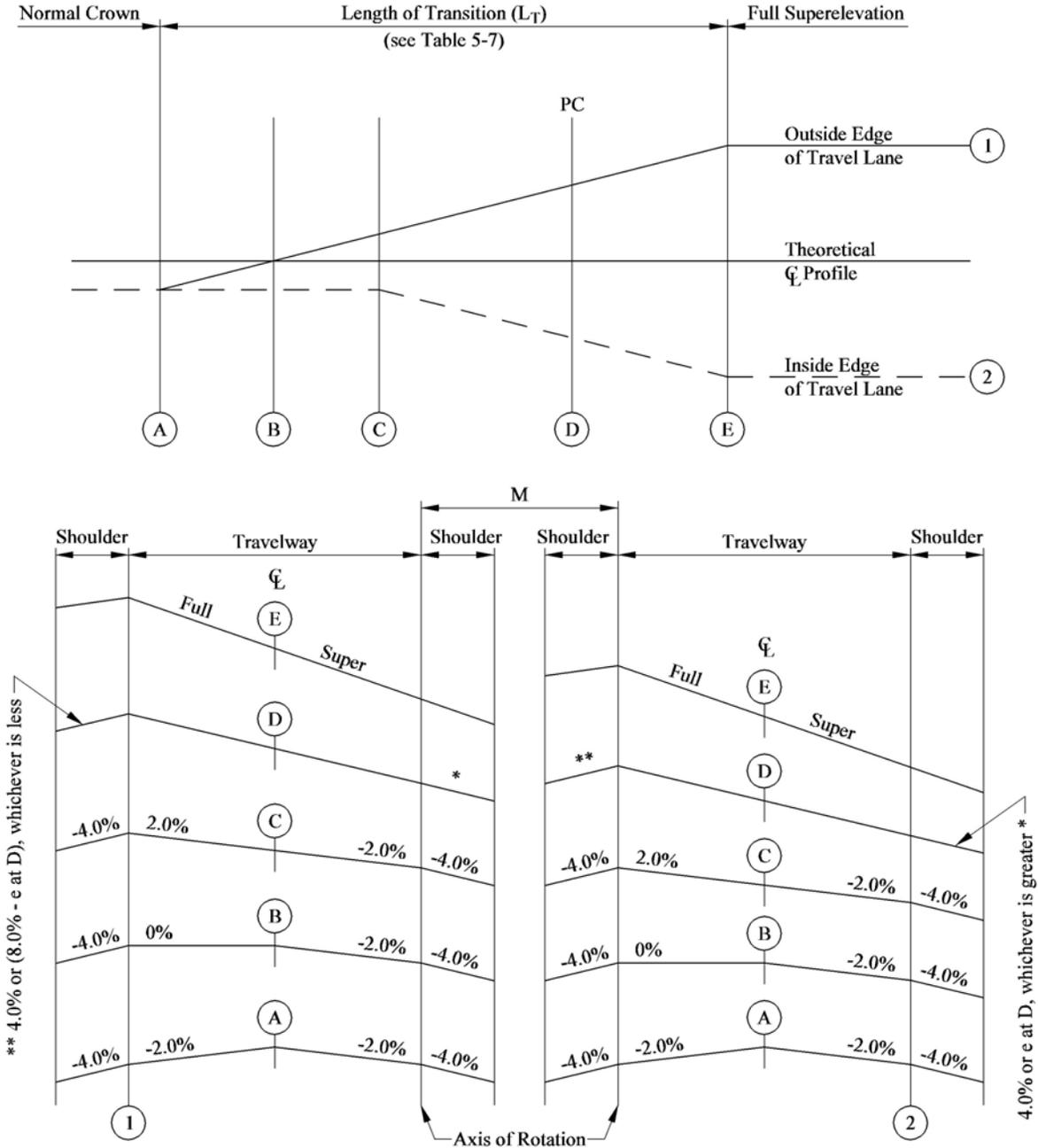
Shoulder Superelevation

The algebraic difference between the travel lane slope and the shoulder slope ("rollover") should not exceed 8.0%. Details of shoulder superelevation are illustrated for various points along the superelevation transition length in Figures 5-5 and 5-6.



**ROTATION ABOUT CENTERLINE
(Undivided Highways)**

Figure 5-5



Notes:

1. For distribution of transition length, see Section 5-2.05.
2. “Rollover” between travel lane and shoulder should not exceed 8.0%.
3. For paved medians less than 20 ft, the shoulder slope rates and median edge profiles may need to be adjusted for drainage purposes. This adjustment should be achieved in the transition length.

**ROTATION ABOUT MEDIAN EDGE OF INSIDE TRAVEL LANE
(Divided Highway – $M \leq 40$ ft)**

Figure 5-6

Median Width	Axis of Rotation	Figure
$M \leq 40$ ft	median edge of inside travel lane	5-6
$M > 40$ ft	separately about centerline of each roadway	5-5

Note: For treatment of superelevated curves with median barriers, see Chapter Ten "Roadside Safety."

RECOMMENDED AXIS OF ROTATION (Divided Highways)

Table 5-8

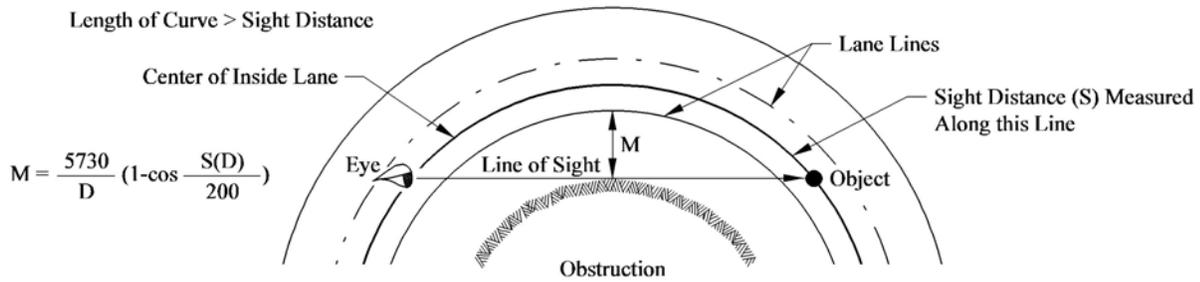
5-2.06 Horizontal Sight Distance

The designer should evaluate the impact on sight distance of obstructions which are on the inside of horizontal curves. These include walls, cut slopes, wooded areas, buildings and sometimes guardrail.

Stopping Sight Distance

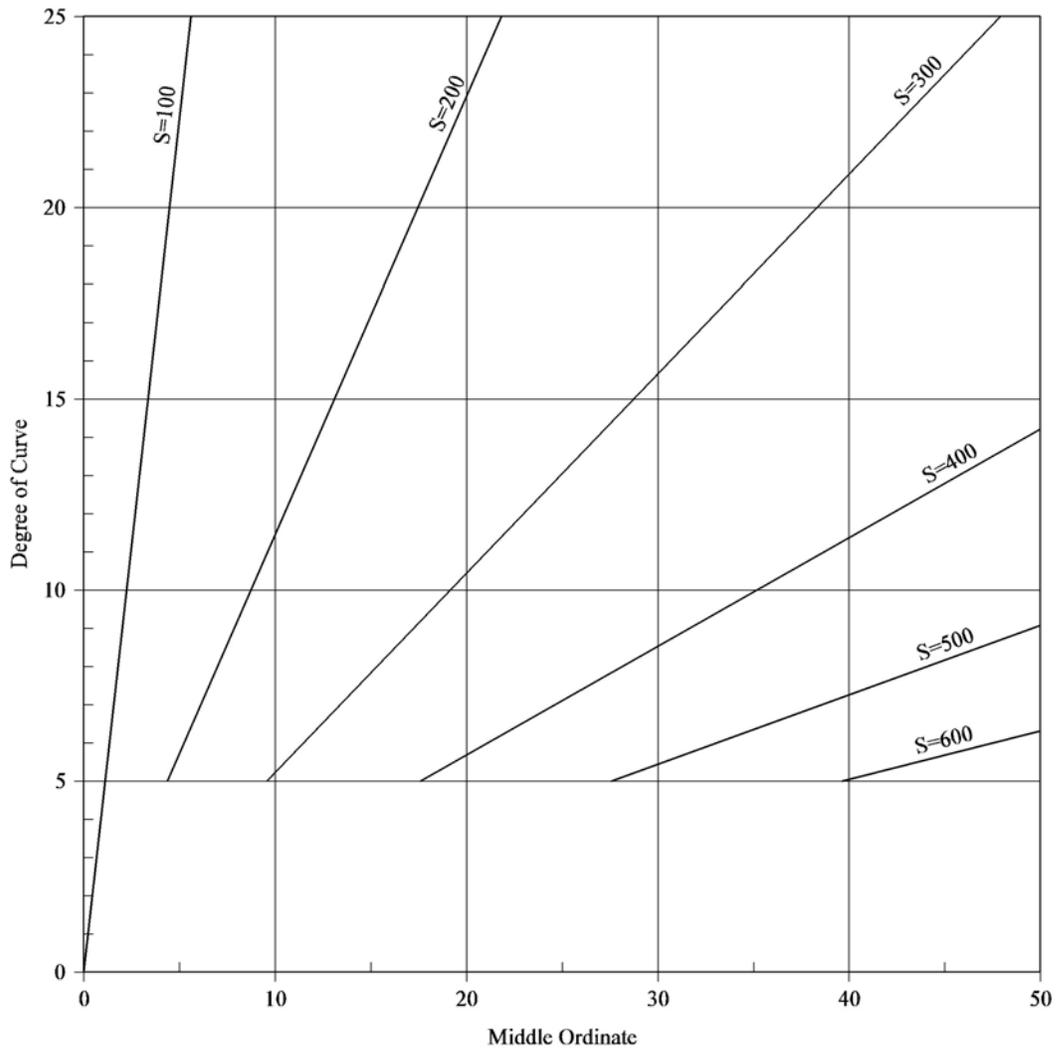
The designer should provide an adequate "middle ordinate" (M) between the center of the inside travel lane and the sight obstruction. Figures 5-7a, 5-7b and 5-8 provide the criteria for various combinations of curve radius and sight distance. The stopping sight distances (SSD) in both figures are based on the level criteria. To determine the middle ordinate for the grade-adjusted SSD, the equation in the figure may be used directly to calculate the value.

The M values from Figures 5-7a, 5-7b and 5-8 apply between the PC and PT. This area should be free of all sight obstructions. In addition, some transition is needed on either side of the curve. This is illustrated in Figure 5-9. The designer should use the following procedure:



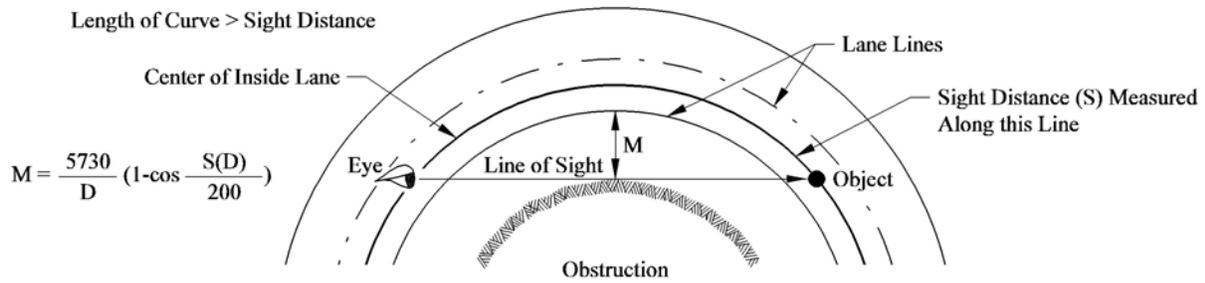
$$M = \frac{5730}{D} \left(1 - \cos \frac{S(D)}{200}\right)$$

Where: M = Middle Ordinate, distance from the line of measure (center of inside lane) to the obstruction, ft
 D = Degree of Curve
 S = Sight Distance, ft

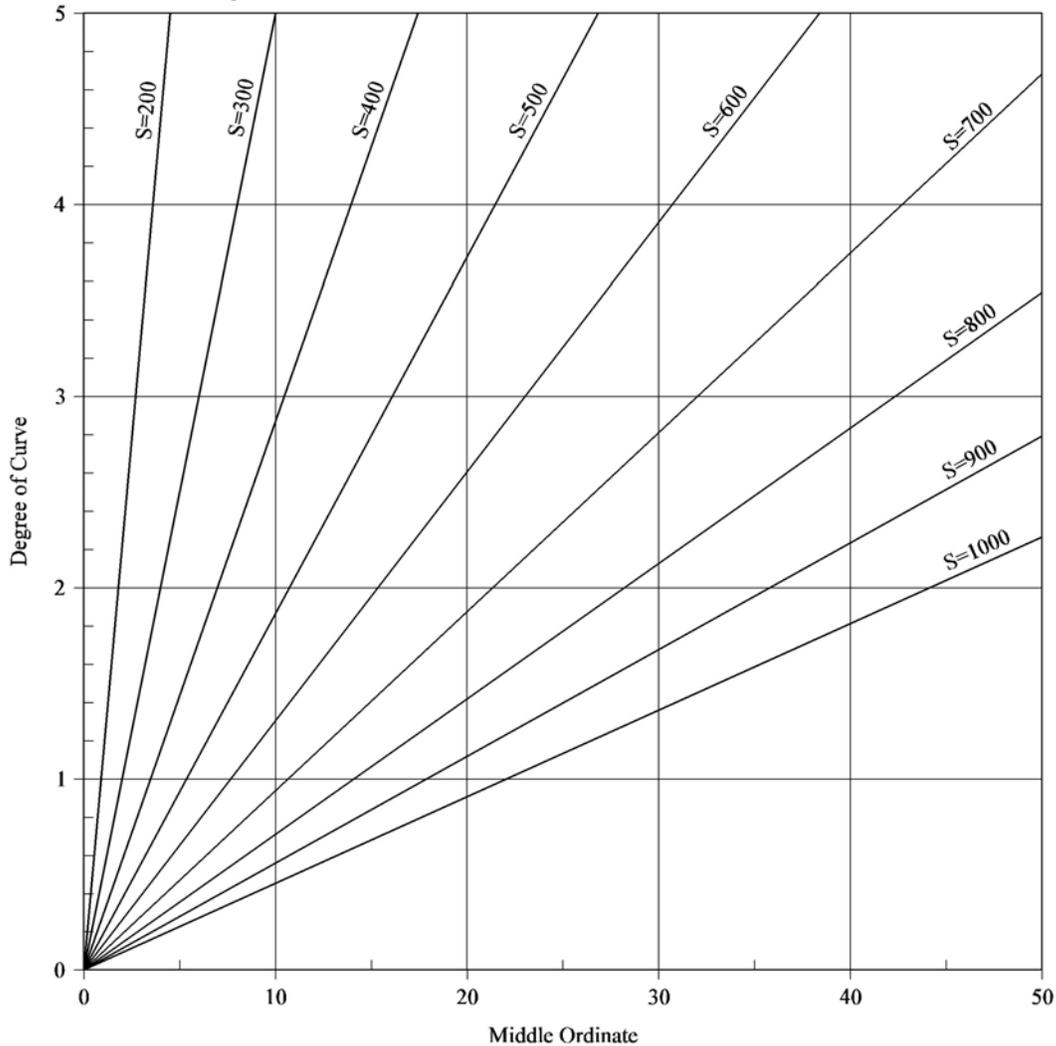


**STOPPING SIGHT DISTANCE AT HORIZONTAL CURVES
 (Range of Lower Values – D > 5°)**

Figure 5-7a

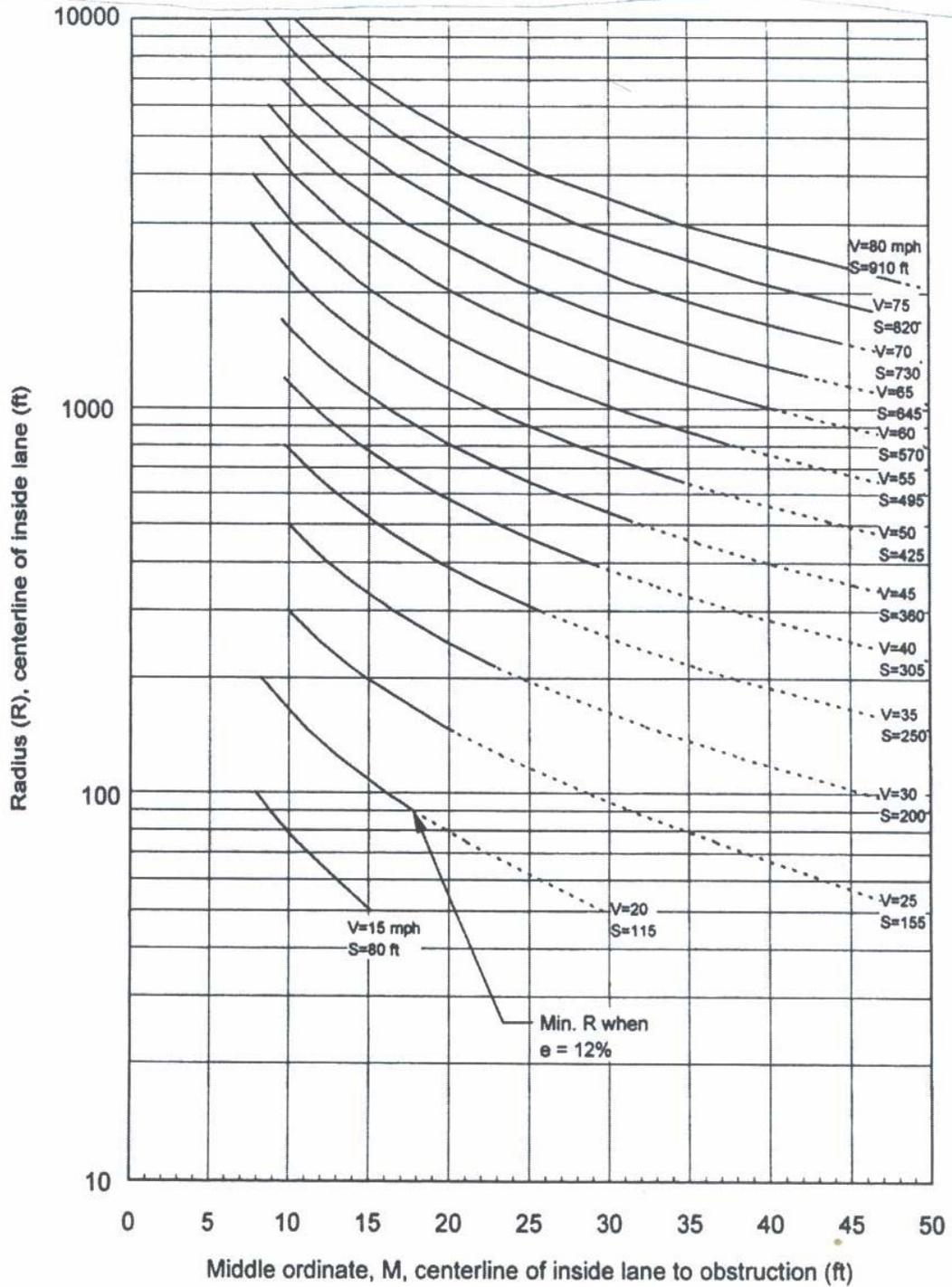


Where: M = Middle Ordinate, distance from the line of measure (center of inside lane) to the obstruction, ft
 D = Degree of Curve
 S = Sight Distance, ft



**STOPPING SIGHT DISTANCE AT HORIZONTAL CURVES
 (Range of Upper Values – D < 5°)**

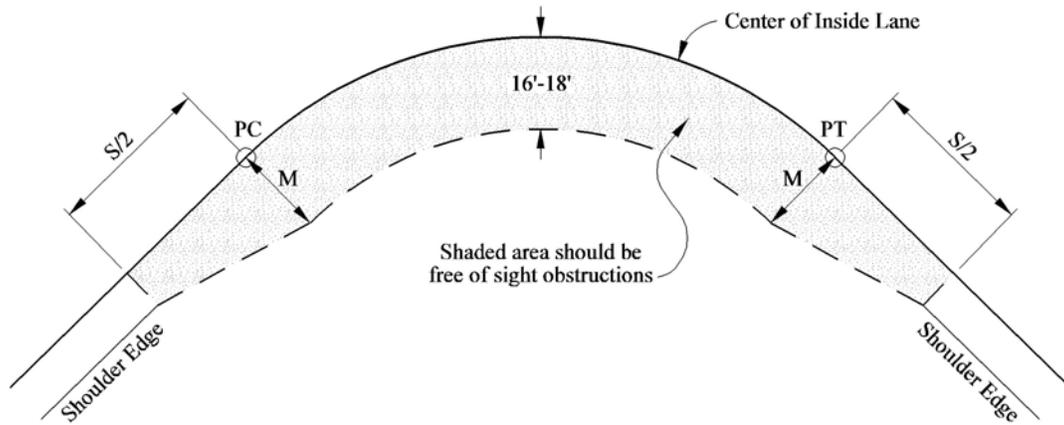
Figure 5-7b



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

STOPPING SIGHT DISTANCE (RADIUS) ON HORIZONTAL CURVES

Figure 5-8

**Example**

Given: Urban Freeway
 Design speed = 60 mph
 Degree of curve = $2^{\circ} 15'$ Radius = 2546 ft
 Grade = 3% downgrade
 SSD = 570' (without grade adjustment)
 SSD = 600' (with grade adjustment)

Problem: Determine the stopping sight distance clearance requirements for the horizontal curve for both SSD values.

Solution: From Figure 5-7b, the middle ordinate distance applied between the PC and PT of the curve is 18 ft for SSD = 600' and 16 ft for SSD = 570'. The application of the clearance requirements throughout the entire curve, including the entering and exiting transition, is illustrated above.

OR

From Figure 5-8, using $V=60$ mph or $SSD=570$ ft yields an M value of 17 ft.

MINIMUM CLEARANCE REQUIREMENTS FOR HORIZONTAL SIGHT DISTANCE

Figure 5-9

- Step 1: Locate the point which is on the outside edge of shoulder and a distance of $SSD/2$ before the PC.
- Step 2: Locate the point which is a distance M measured laterally from the center of the inside travel lane at the PC.
- Step 3: Connect the two points located in Steps 1 and 2. The area between this line and the roadway should be clear of all obstructions.
- Step 4: A symmetrical application of Steps 1-3 should be used beyond the PT.

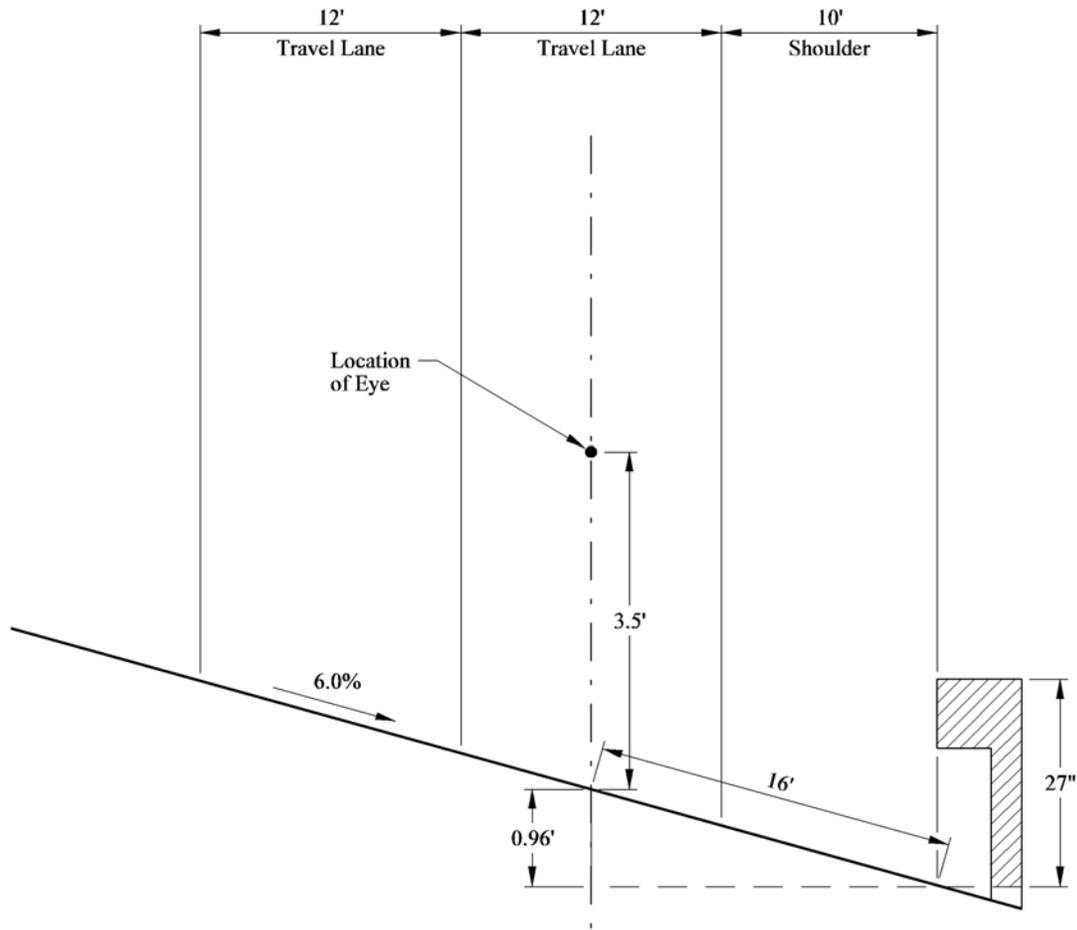
For application, the height of eye is 3.5 feet and the height of object is 2 feet. The line-of-sight intercept with the obstruction is at the midpoint of the sight line and 2.75 feet above the center of the inside lane. The designer should consider the height advantage afforded by a superelevated curve. As illustrated in Figure 5-10, this elevates the center of the inside travel lane by as much as 1 foot when compared to the edge of the inside shoulder. This will greatly reduce the probability that guardrail will present a sight obstruction on the inside of a horizontal curve.

Decision Sight Distance

Table 4-3 provides values for decision sight distance. At a horizontal curve, for example, decision sight distance may be appropriate for a traffic signal located just beyond a curve on a rural arterial. Where decision sight distance is used, the designer should use the equation in Figure 5-7a to calculate the clearance requirements.

Passing Sight Distance

On high-volume, 2-lane roadways, it may occasionally be warranted to provide passing sight distance around horizontal curves to achieve a higher PSD percentage on the highway. Table 4-4 provides values for passing sight distance. These values yield large numbers for the required clearance, and their application should be limited to flat curves where the right-of-way impacts will be a minimum. Where passing sight distance is used, the designer should use the equation to calculate the clearance requirements.



ELEVATION DIFFERENTIAL ON SUPERELEVATED CURVES

Figure 5-10

5-3 LOW-SPEED URBAN STREETS

The operating conditions on low-speed urban streets (design speed of 45 mph or less) are significantly different from those on rural highways and high-speed urban highways. In addition, urban areas present different physical constraints which should be considered.

5-3.01 Horizontal Curves

Criteria and definitions presented in Sections 5-1 and 5-2 will apply to low-speed urban streets. However, the following additional guidance is offered specifically for these facilities:

1. **Types of Curvature.** The simple curve is the most common type of horizontal curve used on low-speed urban streets. Compound curves may be warranted where a physical obstruction prevents the use of a simple curve. They will rarely be used for transition purposes.
2. **Maximum Degree of Curve.** Table 5-9 provides the maximum degree of curve for each design speed on low-speed urban streets. The designer should provide flatter horizontal curves where possible.
3. **Travelway Widening.** Travelway widening on curves is rarely warranted on low-speed urban streets.

5-3.02 Length of Curves

Calculated versus Minimum

The criteria for "Collector and Local Roads" in Table 5-4 will also apply to low-speed urban streets. An exception to this is the criteria for sharpest deflection with no curve, which is discussed in the following paragraph.

Sharpest Deflection with No Curve

On low-speed urban streets, a deflection angle of less than 1 degree without a horizontal curve may not have a significant effect on driver response or aesthetics. Therefore, the designer should consider leaving in the angle point when the deflection is less than about 1 degree.

Design Speed (mph)	Minimum Radius
20	80 ft
25	145 ft
30	230 ft
35	350 ft
40	500 ft

Note: $e_{\max} = 4.0\%$

**MINIMUM RADIUS
(Low-Speed Urban Streets)**

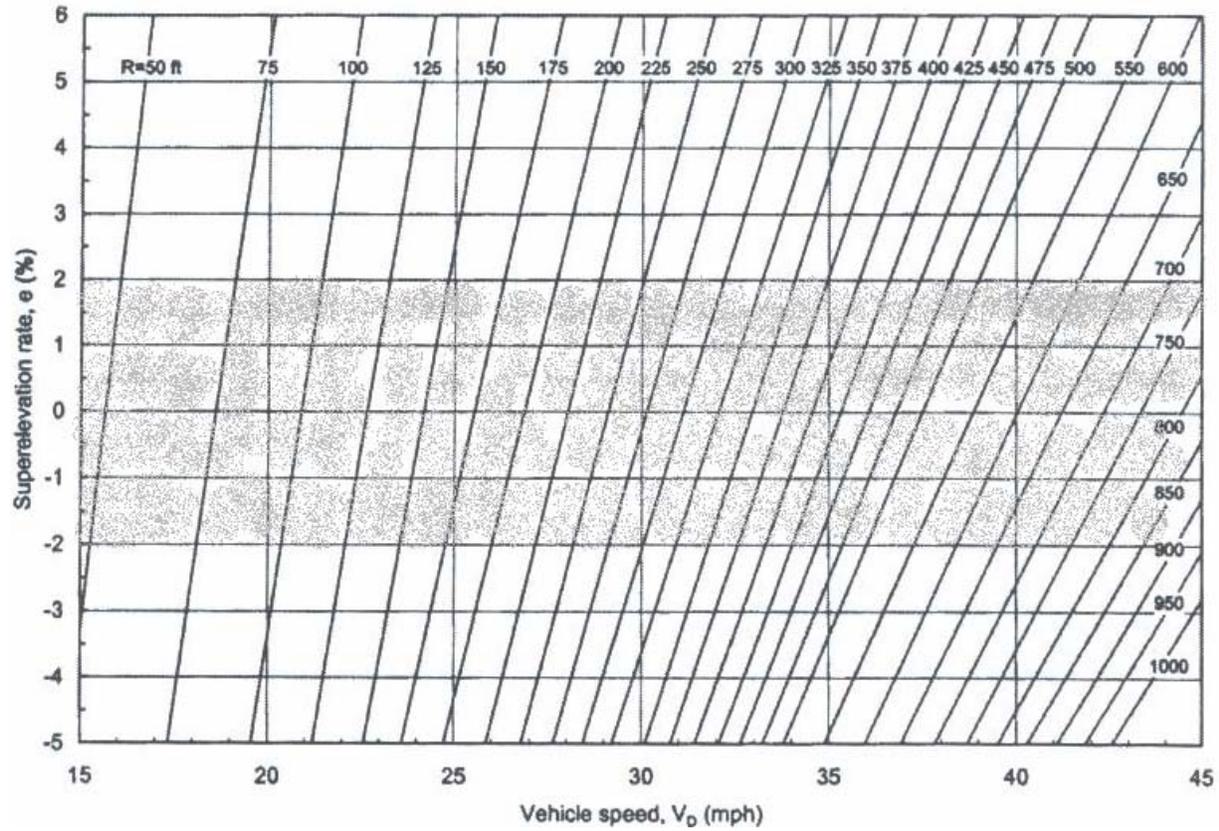
Table 5-9

5-3.03 Superelevation Development

Superelevation Rate

The Department has adopted $e_{\max} = 4.0\%$ for the design of low-speed urban streets. Figure 5-11 provides the criteria for superelevation rates for urban streets based on design speed and radius

The designer should exercise special care when the "theoretical" superelevation rate is between -2.0% and $+2.0\%$ (typical cross slope). In this range, the curve should be superelevated at the rate of the cross slope (2.0% typical) toward the inside of the curve. This is referred to as remove crown (RC). This range is highlighted on Figure 5-11. Table 5-10 provides the corresponding degree of curve for a normal crown section and a remove crown section for a cross slope of 2.0% . Examples 4, 5 and 6 illustrate the use of Figure 5-11 and Table 5-10 to determine the proper superelevation rate.



- Notes:**
1. $e_{\max} = 4.0\%$
 2. For curves within the shaded area, superelevate the entire traveled way at the rate of cross slope (2.0%) toward the inside of the curve.
 3. D = Degree of Curve

**RATE OF SUPERELEVATION
(Low-Speed Urban Streets)**

Figure 5-11

Design Speed (mph)	Radius		
	Normal Crown	Remove Crown*	See Figure 5-11
20	R > 95 ft	95 ft ≥ R ≥ 85 ft	R < 85 ft
25	R > 180	180 ≥ R ≥ 155	R < 155
30	R > 300	300 ≥ R ≥ 250	R < 250
35	R > 465	465 ≥ R ≥ 375	R < 375
40	R > 680	680 ≥ R ≥ 535	R < 535

* The flatter curve is based on a theoretical superelevation rate of -2.0%. The sharper curve is based on a theoretical superelevation rate of +2.0%.

**DEGREE OF CURVE FOR NORMAL
CROWN SECTION AND REMOVE CROWN SECTION
(Low-Speed Urban Streets)**

Table 5-10

Example 4

Given: Design speed = 30 mph
 Radius = 347 ft
 Cross slope (on tangent) = 2.0%

Problem: Determine the superelevation rate.

Solution: Table 5-10 indicates that a normal crown section should be used.

Example 5

Given: Design speed = 35 mph
 Radius = 425 ft

Problem: Determine the superelevation rate.

Solution: From Table 5-10, a remove crown section applies. The pavement should be superelevated at a rate of 2.0% across the entire pavement.

Example 6

Given: Design speed = 40 mph
Radius = 500 ft

Problem: Determine the superelevation rate.

Solution: Table 5-10 directs the designer to Figure 5-11 to determine the superelevation rate. Figure 5-11 yields a required superelevation rate of +3.0%. Therefore, the entire pavement should be transitioned to this rate.

* * * * *

Superelevation Transition Length

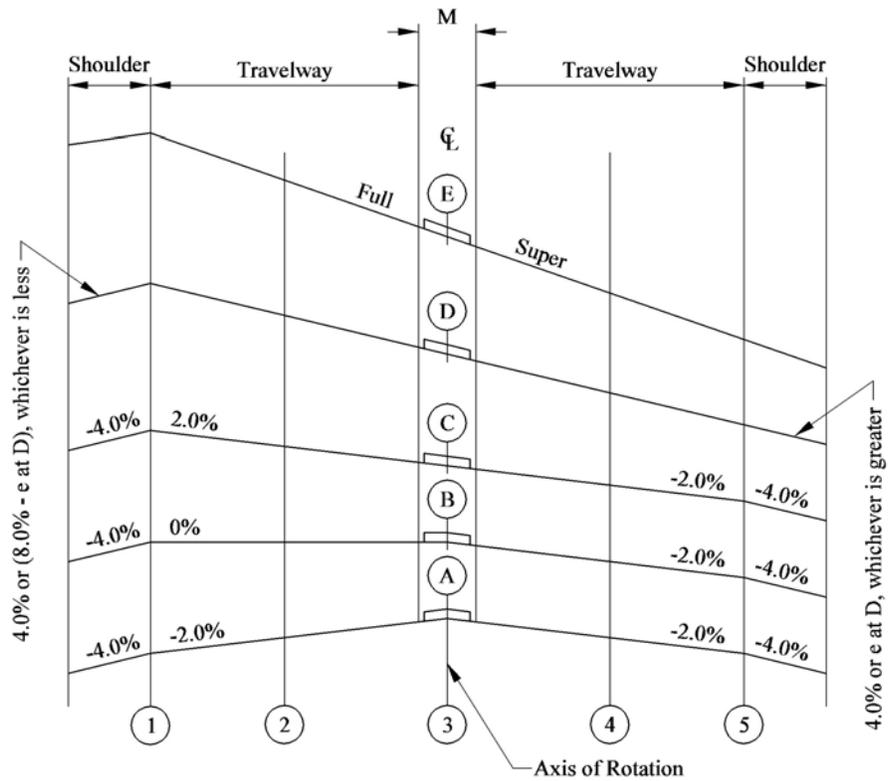
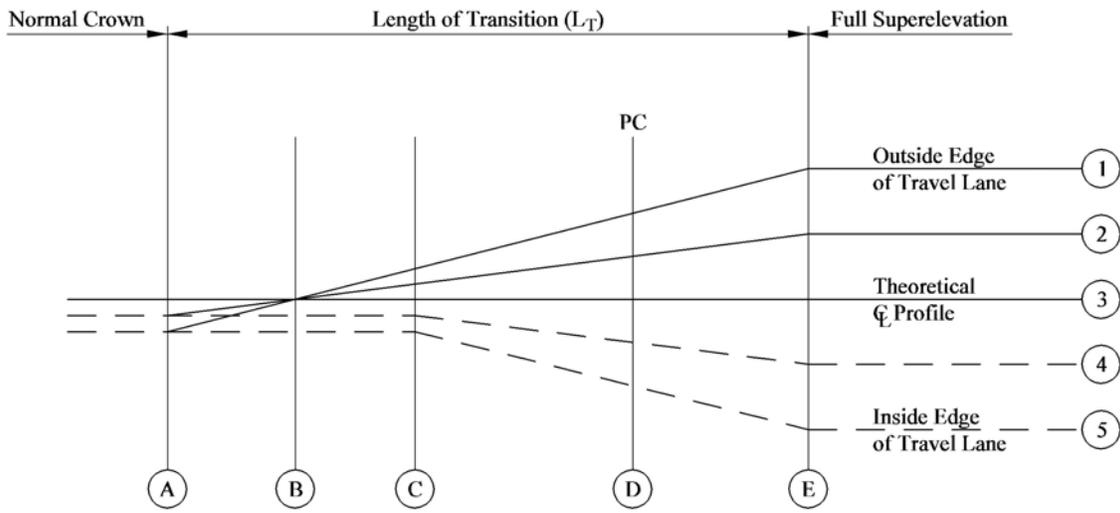
For low-speed urban streets, the minimum superelevation transition length for a 1-lane width of pavement rotation is 125 feet. For a 2-lane width of rotation, the transition length is 200 feet. The distribution of transition length on low-speed urban streets should follow the same procedure as discussed in Section 5-2.05.

Reverse Curves

Reverse curves may be used in urban areas. The designer should not attempt to achieve a normal crown section between curves unless the normal crown section can be maintained for at least 100 feet. See Section 5-2.05 for more information on superelevation transition on reverse curves.

Axis of Rotation

The criteria in Section 5-2.05 also apply to low-speed urban streets. However, on divided urban streets with median widths less than 15 feet, the axis of rotation will be the centerline. This is illustrated in Figure 5-12. Additionally, on a curbed street, it may occasionally be preferable to rotate about the outside or inside edge of travel lane because of drainage, right-of-way or other considerations.



Notes:

1. For distribution of transition length, see Section 5-2.05.
2. "Rollover" between travel lane and shoulder should not exceed 8.0%.

**ROTATION ABOUT CENTERLINE
(Divided Highway $M < 15$ ft)**

Figure 5-12

Shoulder Superelevation

The criteria in Section 5-2.05 also apply to low-speed urban streets. The designer should note, however, that 4 feet is the minimum shoulder width which should be sloped away from the travel lane on the outside of a superelevated curve. For lesser shoulder widths, or "offsets", the outside shoulder should be sloped in the same direction as the travel lane.

5-3.04 Horizontal Sight Distance

The criteria presented in Section 5-2.06 also apply to horizontal sight distance on low-speed urban streets.