Chapter 29

HORIZONTAL ALIGNMENT

BUREAU OF LOCAL ROADS AND STREETS MANUAL

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Chapter 29
HORIZONTAL ALIGNMENT

Chapter 29 presents Bureau of Local Roads and Streets (BLRS) criteria for the design of horizontal alignment elements. This includes horizontal curvature and superelevation for both rural and urban local facilities.

29-1 DEFINITIONS

This Section presents definitions for the basic elements of horizontal alignment:

1. Axis of Rotation. The line about which the pavement is revolved to superelevate the roadway. This line will maintain the normal roadway profile throughout the curve.
2. Broken-Back Curves. Closely spaced horizontal curves with deflection angles in the same direction with an intervening, short tangent section (less than 1500 ft (500 m)).
3. Compound Curves. A series of two or more simple curves with deflections in the same direction immediately adjacent to each other.
4. Deflection Angle (Δ). The external angle between the two projected tangents (beyond the point of intersection) of a simple curve.
5. Low-Speed Urban Streets. All streets within urbanized or small urban areas with a design speed of 45 mph (70 km/h) or less.
6. Maximum Superelevation (e_{max}). The upper limit for the superelevation rate used in the design of horizontal curves. Its selection depends on several factors including climatic conditions, terrain conditions, type of area (e.g., rural or urban), pavement type, and functional classification.
7. Normal Crown (NC). The cross slope on a tangent section of roadway (i.e., no superelevation).
8. Open Roadway Conditions. Rural facilities for all design speeds and urban facilities with a design speed ≥ 50 mph (80 km/h).
9. Relative Longitudinal Gradient. For superelevation transition sections on two-lane facilities, the difference in grade between the centerline profile grade and the grade of the edge of traveled way.
10. Remove Adverse Cross Slope. The outside lane has been rotated from normal crown (NC) to a point prior to Remove Adverse Crown (RC). This is shown in Figure 29-3E transitioning from Section A to Section C.
11. Remove Adverse Crown (RC). A superelevated roadway section that is sloped across the entire traveled way in the same direction and at a rate equal to the cross slope on

the tangent section (typically, 1.5% or 2.0%). This is shown in Figure 29-3E for Section C.

12. Reverse Curves. Two simple curves with deflections in opposite directions that are joined by a relatively short tangent distance or which have no intervening tangent (i.e., the Point of Tangent (PT) and Point of Curve (PC) are coincident).

13. Simple Curves. Continuous arcs of constant radius that achieve the necessary roadway deflection without an entering or exiting transition.

14. Superelevation (e). The amount of cross slope or "bank" provided on a horizontal curve to counterbalance, in combination with the side friction, the centrifugal force of a vehicle traversing the curve.

15. Superelevation Rollover. The algebraic difference (A) between the superelevated travel lane slope and shoulder slope on the high side of a horizontal curve.

16. Superelevation Transition Length. The distance transitioning the roadway from a normal crown section to the design superelevation rate. Superelevation transition length is the sum of the tangent runout (TR) and superelevation runoff (L) distances:

    - Tangent Runout (TR). Tangent runout is the distance needed to change from a normal crown section to a point where the adverse cross slope of the outside lane is removed (i.e., the outside lane is level).

    - Superelevation Runoff (L). Superelevation runoff is the distance needed to change the cross slope from the end of the tangent runout (adverse cross slope removed) to a section that is sloped at the design superelevation rate (e).

17. Traveled Way. The portion of the roadway used for the movement of vehicles, exclusive of shoulders and auxiliary lanes.

29-2 HORIZONTAL CURVES

Horizontal curves are circular arcs that provide transitions between two tangents. The radius (R) defines the circular arc that a curve will transcribe. These changes in deflection are necessary in virtually all roadway alignments to avoid impacts on a variety of field conditions (e.g., right-of-way, natural features, and man-made features).

29-2.01 Types of Horizontal Curves

Section 29-2.01 discusses the types of horizontal curves that may be used to achieve the necessary roadway deflection.

29-2.01(a) Simple Curves

Because of their simplicity and ease of design, survey, and construction, it is strongly recommended to use simple curves on local facilities.

29-2.01(b) Compound Curves

The use of compound curves on roadway mainline is recommended only in special circumstances to meet field conditions (e.g., to avoid obstructions that cannot be relocated) where a simple curve cannot meet this need. When a compound curve is used on mainline, the radius of the flatter circular arc (R_1) should not be more than 50% greater than the radius of the sharper circular arc (R_2), therefore; $R_1 \leq 1.5\ R_2$.

Chapter 34 discusses the use of compound curves for intersections at-grade (e.g., for curb radii).

29-2.01(c) Reverse Curves

Where reverse curves are used, a distance adequate to provide the superelevation transition should be provided between the PT and PC of the two curves. Superelevation development for reverse curves requires special attention. This is discussed in Section 29-3.

29-2.01(d) Broken-Back Curves

Broken-back curves should be avoided on the roadway mainline because of the potential for confusing a driver, problems with superelevation development, and the unpleasant view of the roadway that is created. Instead, it is recommended that a single, flat simple curve be used. In rural and suburban areas, a minimum tangent length of 500 ft (150 m) should be provided between two horizontal curves with deflections in the same direction.

29-2.02 Basic Curve Equation

The point-mass formula is used to define vehicular operation around a curve. Where the curve is expressed using its radius, the basic equation for a simple curve is:

$$R = \frac{V^2}{15\,(e + f)} \quad \text{(US Customary) Equation 29-2.1}$$

$$R = \frac{V^2}{127(e + f)} \quad \text{(Metric) Equation 29-2.1}$$

where:

- R = radius of curve, ft (m)
- V = design speed, mph (km/h)
- e = superelevation rate, decimal
- f = side friction factor (constant based on design speed)

29-2.03 Minimum Radii

Figures 29-2A (e_{max} = 8.0%), 29-2B (e_{max} = 6.0%), and 29-2C (e_{max} = 4.0%) present the minimum radii for open-roadway conditions. See Section 29-3.01 for the selection of e_{max}. In most cases, the designer should avoid the use of minimum radii because this results in the use of maximum superelevation rates. These rates should be avoided because the facility must often accommodate vehicles traveling over a wide range of speeds. This is particularly true in Illinois where the entire State is subject to ice and snow. Where vehicular speeds are slow or stopped and the rate of superelevation is high, vehicles could slide down the cross slope when the pavement is icy.

29-2.04 Side Friction Factor

The side friction factor (f) represents the contribution of the roadway/tire interface to counterbalance the centrifugal force of a vehicle traversing the curve. This factor varies according to design speed and open-roadway or low-speed urban street conditions. It is important to recognize that the side friction factor represents a threshold of driver discomfort and not the point of impending skid. Figure 29-2D presents the side friction factors used in Equation 29-2.1 for open-roadway conditions.

29-2.05 Maximum Deflection Without Curve

It may be appropriate to omit a horizontal curve where very small deflection angles are present. As a guide, the designer may retain deflection angles of approximately 1° or less (urban) and 0°15′ (rural) on local agency facilities without providing a horizontal curve. For these angles, the absence of a horizontal curve should not affect operations or aesthetics.

US Customary		Metric	
Design Speed (mph)	Minimum Radii R_{min} (ft) *	Design Speed (km/h)	Minimum Radii R_{min} (m) *
20	76	30	20
25	134	40	41
30	214	50	73
35	314	60	113
40	444	70	168
45	587	80	229
50	758	90	304
55	960	100	394
60	1200		

MINIMUM RADII
(e_{max} = 8.0%, Open-Roadway Conditions)

Figure 29-2A

US Customary		Metric	
Design Speed (mph)	Minimum Radii R_{min} (ft) *	Design Speed (km/h)	Minimum Radii R_{min} (m) *
20	81	30	21
25	144	40	43
30	231	50	79
35	340	60	123
40	485	70	184
45	643	80	252
50	833	90	336
55	1060	100	437
60	1330		

MINIMUM RADII
(e_{max} = 6.0%, Open-Roadway Conditions)

Figure 29-2B

US Customary		Metric	
Design Speed (mph)	Minimum Radii R_{min} (ft) *	Design Speed (km/h)	Minimum Radii R_{min} (m) *
20	86	30	22
25	154	40	47
30	250	50	86
35	371	60	135
40	533	70	203
45	711	80	280
50	926	90	---
55	---	100	---
60	---		

MINIMUM RADII
(e_{max} = 4.0%, Open-Roadway Conditions)

Figure 29-2C

US Customary		Metric	
Design Speed (mph)	Side Friction Factor (f)	Design Speed (km/h)	Side Friction Factor (f)
20	0.27	30	0.28
25	0.23	40	0.23
30	0.20	50	0.19
35	0.18	60	0.17
40	0.16	70	0.15
45	0.15	80	0.14
50	0.14	90	0.13
55	0.13	100	0.12
60	0.12		

Note: The SFF values are based on a paved roadway surface.

SIDE FRICTION FACTORS
(Open-Roadway Conditions)

Figure 29-2D

29-2.06 Minimum Length of Curve

The radius is used to calculate the length of curve by using the following equation:

$$L = \frac{2\pi R\Delta}{360}$$ Equation 29-2.2

where:

L = length of curve, ft (m)

Δ = deflection angle, degrees

R = radius of curve, ft (m)

A longer than calculated length of curve may be necessary depending on the design speed. Figure 29-2E provides design values for the minimum length of curve based on design speed.

For small deflection angles, horizontal curves should be sufficiently long to avoid the appearance of a kink. With a deflection angle of 5°, the minimum length of curve should be 350 ft (120 m) for a design speed of 55 mph (100 km/h). Where the deflection angle is 5° or less, the minimum length of curve in Figure 29-2E should be adjusted by the factor in Figure 29-2F.

US Customary			Metric		
Design Speed V (mph)	Minimum Length of Curve, L (ft)	Curve Radius, R* (ft)	Design Speed, V (km/h)	Minimum Length of Curve, L (m)	Curve Radius, R* (m)
20	100	1145	30	30	344
25	100	1145	40	30	344
30	100	1145	50	30	344
35	150	1720	60	50	573
40	200	2290	70	70	802
45	250	2865	80	90	1031
50	300	3440	90	110	1260
55	350	4010	100	130	1490
60	400	4585			

* R = 360L / 2πΔ

MINIMUM LENGTHS OF CURVE
(Δ = 5°)

Figure 29-2E

Central Deflection Angle * (Δ)	**Adjustment Factor Applied to Figure 29-2E**
5°	1.00
4°	0.80
3°	0.60
2°	0.40
1°	0.20

* *For intermediate central deflection angles, use a straight-line interpolation.*

ADJUSTMENTS FOR MINIMUM LENGTHS OF CURVE (Δ < 5°)

Figure 29-2F

29-2.07 Maximum Length of Curve

To improve driver tolerance by reducing steering time in a circular path, the maximum curve length for high-speed, two-lane highways should not exceed 1 mile (1.6 km). On low-speed, two-lane highways, the maximum curve length should be limited to approximately ¼ mile (0.5 km). Lengths in excess of these values should be avoided.

29-3 SUPERELEVATION DEVELOPMENT (OPEN-ROADWAY CONDITIONS)

This Section presents criteria for superelevation development, which apply to all rural facilities and to urban facilities where V ≥ 50 mph (80 km/h). See Section 29-4 for low-speed urban streets.

29-3.01 Superelevation Rates

29-3.01(a) Maximum Superelevation Rate

The selection of a maximum allowable rate of superelevation (e_{max}) depends upon several factors. These include urban/suburban/rural location (see Section 27-4), type of existing or expected roadside development, type of pavement surface, and prevalent climatic conditions within Illinois. For open-roadway conditions, the following typical e_{max} values apply:

1. Rural. Use e_{max} = 8.0% for all rural facilities, except for facilities with aggregate surfaces.
2. Urban/Suburban. Where V ≥ 50 mph (80 km/h), use e_{max} = 6.0% for urban/suburban facilities.
3. Aggregate Surface. For rural facilities with an aggregate surface, use e_{max} = 4.0%.
4. Seal Coat Surface. For all facilities with a seal coat surface, when newly placed by construction or maintenance may exhibit traits of an aggregate surface for a short time period. However, the e_{max} value should be based on the seal coat having characteristics similar to a hard surface roadway.

For Items 1 and 2, the designer may use a lower e_{max}.

29-3.01(b) Superelevation Tables

Based on the selection of e_{max}, Figures 29-3B, 29-3C, and 29-3D allow the designer to select the appropriate superelevation rate (e) for any combination of curve radius (R) and design speed (V). Note that the superelevation rates in the figures are expressed as a percent. The values in the figures should be calculated based on the curve radius and/or the superelevation rate to be used.

29-3.01(c) Use of Normal Crown and Remove Adverse Crown

A horizontal curve with a sufficiently large radius does not require superelevation, and the normal crown section (NC) used on tangent can be maintained throughout the curve. On sharper curves for the same design speed, a point is reached where a superelevation rate of 1.5% to 2.0% across the total traveled way is appropriate. This is called "remove adverse crown" (RC). Figures 29-3B, 29-3C, and 29-3D indicate the radii ranges where NC and RC apply.

29-3.02 Transition Lengths

As defined in Section 29-1, the superelevation transition length is the distance required to transition the roadway from a normal crown section to the full design superelevation rate. The superelevation transition length is the sum of the tangent runout distance (TR) and superelevation runoff length (L_1).

29-3.02(a) Two-Lane Roadways

1. Superelevation Runoff. The e_{max} tables (Figures 29-3B, 29-3C, and 29-3D) present the superelevation runoff lengths (L_1) for two-lane roadways for various combinations of curve radii and design speed. These lengths are calculated as follows:

$$L_1 = (e)(W)(RS) \quad \text{Equation 29-3.1}$$

where:

L_1	=	superelevation runoff length for a two-lane roadway (assuming the axis of rotation is about the roadway centerline), ft (m)
e	=	design superelevation rate (ft/ft (m/m)), decimal
W	=	width of rotation for one lane (assumed to be 11 ft (3.3 m))
RS	=	reciprocal of relative longitudinal gradient between the profile grade and outside edge of two-lane roadway; see Figure 29-3A

2. Tangent Runout. The tangent runout (TR) distance should be calculated using the tangent cross slope and the maximum relative longitudinal gradient based on the selected design speed; as shown in Figure 29-3A. TR is calculated as follows:

$$TR = (NC)(W)(RS) \quad \text{Equation 29-3.2}$$

where:

TR	=	tangent runout length for a two-lane roadway, (assuming the axis of rotation is about the roadway centerline), ft (m)
NC	=	normal crown slope (assumed to be 0.015 ft/ft (m/m)), decimal
W	=	width of rotation for one lane (assumed to be 11 ft (3.3 m))
RS	=	reciprocal of relative longitudinal gradient between the profile grade and outside edge of two-lane roadway; see Figure 29-3A

3. Superelevation Transition Length. The total of the tangent runout (TR) distance and superelevation runoff length (L_1) equals the minimum superelevation transition length used for a two-lane roadway at an isolated horizontal curve.

US Customary			Metric		
Design Speed (mph)	Maximum Relative (G) Gradient (%)	Reciprocal (RS)	Design Speed (km/h)	Maximum Relative (G) Gradient (%)	Reciprocal (RS)
20	0.74	135	30	0.75	133
25	0.70	143	40	0.70	143
30	0.66	152	50	0.65	150
35	0.62	161	60	0.60	167
40	0.58	172	70	0.55	182
45	0.54	185	80	0.50	200
50	0.50	200	90	0.47	213
55	0.47	213	100	0.44	227
60	0.45	222			

MAXIMUM RELATIVE LONGITUDINAL GRADIENTS

Figure 29-3A

29-3.02(b) Multilane Roadways

For superelevation transition lengths for multilane roadways, see Section 32-3 of the *BDE Manual*.

29-3.02(c) Application of Transition Length

Once the superelevation runoff and tangent runout have been calculated, the designer must determine how to fit the length into the horizontal and vertical planes. The following will apply:

1. Tangent/Curve. To simplify procedures, the total superelevation transition length should be distributed to be 75% on tangent and 25% on the curve. However, exceptions to this practice may be necessary to meet field conditions. The generally accepted range is 50% to 80% on tangent and 20% to 50% on curve. In extreme cases (e.g., to avoid placing any superelevation transition on a bridge or approach slab), the superelevation runoff may be distributed up to 100% on the tangent. This will usually occur only in urban or suburban areas with highly restricted right-of-way conditions. The ratio should be rounded up or down as needed to simplify design and layout in construction.

2. Typical Figure. Figure 29-3E presents one method for superelevation development on a two-lane highway. Other methods may also be acceptable.

29-3.03 Axis of Rotation

29-3.03(a) Two-Lane Roadways

The axis of rotation will typically be about the centerline of the roadway on two-lane, two-way roadways. This method will yield the least amount of elevation differential between the pavement edges and their normal profiles. Occasionally, it may be necessary to rotate about the inside or outside edge of the traveled way. This may be necessary to meet field conditions (e.g., drainage, roadside development).

29-3.03(b) Multilane Roadways

For axis of rotation on a multilane roadway, see Section 32-3 of the *BDE Manual*.

e	V = 20 mph	Trans. Length		V = 25 mph	Trans. Length		V = 30 mph	Trans. Length	
	R (ft)	L_1 (ft)	TR (ft)	R (ft)	L_1 (ft)	TR (ft)	R (ft)	L_1 (ft)	TR (ft)
NC	≥ 1640	0	0	≥ 2370	0	0	≥ 3240	0	0
RC	1190	22	22	1720	24	24	2370	25	25
2.5%	915	37	22	1360	39	24	1845	42	25
3.0%	730	45	22	1070	47	24	1480	50	25
3.5%	596	52	22	878	55	24	1225	59	25
4.0%	490	59	22	729	63	24	1030	67	25
4.5%	401	67	22	608	71	24	864	75	25
5.0%	314	74	22	499	79	24	727	84	25
5.5%	247	82	22	404	87	24	605	92	25
6.0%	199	89	22	332	94	24	506	100	25
6.5%	163	97	22	277	102	24	428	109	25
7.0%	135	104	22	231	110	24	360	117	25
7.5%	110	111	22	190	118	24	300	125	25
8.0%	76	119	22	134	126	24	214	134	25
	R_{min} = 76 ft			R_{min} = 134 ft			R_{min} = 214 ft		

e	V = 35 mph	Trans. Length		V = 40 mph	Trans. Length		V = 45 mph	Trans. Length	
	R (ft)	L_1 (ft)	TR (ft)	R (ft)	L_1 (ft)	TR (ft)	R (ft)	L_1 (ft)	TR (ft)
NC	≥ 4260	0	0	≥ 5410	0	0	≥ 6710	0	0
RC	3120	27	27	3970	28	28	4930	31	31
2.5%	2430	44	27	3100	47	28	3860	51	31
3.0%	1960	53	27	2510	57	28	3130	61	31
3.5%	1630	62	27	2095	66	28	2610	71	31
4.0%	1370	71	27	1770	76	28	2220	81	31
4.5%	1165	80	27	1515	85	28	1905	92	31
5.0%	991	89	27	1310	95	28	1650	102	31
5.5%	842	97	27	1125	104	28	1435	112	31
6.0%	713	106	27	965	114	28	1250	122	31
6.5%	605	115	27	833	123	28	1080	132	31
7.0%	518	124	27	716	132	28	933	142	31
7.5%	434	133	27	604	142	28	794	153	31
8.0%	314	142	27	444	151	28	587	163	31
	R_{min} = 314 ft			R_{min} = 444 ft			R_{min} = 587 ft		

e	V = 50 mph	Trans. Length		V = 55 mph	Trans. Length		V = 60 mph	Trans. Length	
	R (ft)	L_1 (ft)	TR (ft)	R (ft)	L_1 (ft)	TR (ft)	R (ft)	L_1 (ft)	TR (ft)
NC	≥ 8150	0	0	≥ 9720	0	0	≥ 11,500	0	0
RC	5990	33	33	7150	35	35	8440	37	37
2.5%	4700	55	33	5620	59	35	6640	61	37
3.0%	3820	66	33	4580	70	35	5420	73	37
3.5%	3195	77	33	3840	82	35	4550	85	37
4.0%	2720	88	33	3270	94	35	3890	98	37
4.5%	2345	99	33	2830	105	35	3380	110	37
5.0%	2040	110	33	2470	117	35	2960	122	37
5.5%	1785	121	33	2175	129	35	2615	134	37
6.0%	1560	132	33	1920	141	35	2320	147	37
6.5%	1365	143	33	1690	152	35	2060	159	37
7.0%	1190	154	33	1480	164	35	1820	171	37
7.5%	1020	165	33	1275	176	35	1580	183	37
8.0%	758	176	33	960	187	35	1200	195	37
	R_{min} = 758 ft			R_{min} = 960 ft			R_{min} = 1200 ft		

SUPERELEVATION RATES/TRANSITION LENGTHS (US Customary) (e_{max} = 8.0%)

Figure 29-3B

(See Figures 29-3C or 29-3D for Key and Note)

e	V = 30 km/h R (m)	Trans. Length L1 (m)	TR (m)	V = 40 km/h R (m)	Trans. Length L1 (m)	TR (m)	V = 50 km/h R (m)	Trans. Length L1 (m)	TR (m)
NC	≥ 443	0	0	≥ 784	0	0	≥ 1090	0	0
RC	322	7	7	571	7	7	791	7	7
2.5%	249	11	7	442	12	7	616	12	7
3.0%	199	13	7	354	14	7	496	15	7
3.5%	163	15	7	291	17	7	410	17	7
4.0%	134	18	7	241	19	7	344	20	7
4.5%	111	20	7	200	21	7	291	22	7
5.0%	87	22	7	163	24	7	246	25	7
5.5%	68	24	7	131	26	7	206	27	7
6.0%	55	26	7	106	28	7	172	30	7
6.5%	45	29	7	88	31	7	146	32	7
7.0%	37	31	7	73	33	7	123	35	7
7.5%	30	33	7	60	35	7	103	37	7
8.0%	20	35	7	41	38	7	73	40	7
	R_{min} = 20 m			R_{min} = 41 m			R_{min} = 73 m		

e	V = 60 km/h R (m)	Trans. Length L1 (m)	TR (m)	V = 70 km/h R (m)	Trans. Length L1 (m)	TR (m)	V = 80 km/h R (m)	Trans. Length L1 (m)	TR (m)
NC	≥ 1490	0	0	≥ 1970	0	0	≥ 2440	0	0
RC	1090	8	8	1450	9	9	1790	10	10
2.5%	846	14	8	1135	15	9	1410	17	10
3.0%	684	17	8	916	18	9	1150	20	10
3.5%	568	19	8	766	21	9	956	23	10
4.0%	479	22	8	648	24	9	813	26	10
4.5%	408	25	8	557	27	9	702	30	10
5.0%	349	28	8	480	30	9	611	33	10
5.5%	298	30	8	417	33	9	535	36	10
6.0%	253	33	8	360	36	9	469	40	10
6.5%	217	36	8	313	39	9	411	43	10
7.0%	185	39	8	270	42	9	358	46	10
7.5%	156	41	8	229	45	9	307	50	10
8.0%	113	44	8	168	48	9	229	53	10
	R_{min} = 113 m			R_{min} = 168 m			R_{min} = 229 m		

e	V = 90 km/h R (m)	Trans. Length L1 (m)	TR (m)	V = 100 km/h R (m)	Trans. Length L1 (m)	TR (m)
NC	≥ 2970	0	0	≥ 3630	0	0
RC	2190	11	11	2680	11	11
2.5%	1725	18	11	2110	19	11
3.0%	1410	21	11	1730	22	11
3.5%	1180	25	11	1455	26	11
4.0%	1010	28	11	1240	30	11
4.5%	871	32	11	1080	34	11
5.0%	762	35	11	947	37	11
5.5%	673	39	11	839	41	11
6.0%	595	42	11	746	45	11
6.5%	527	46	11	666	49	11
7.0%	464	49	11	591	52	11
7.5%	402	53	11	515	56	11
8.0%	304	56	11	394	60	11
	R_{min} = 304 m			R_{min} = 394 m		

SUPERELEVATION RATES/TRANSITION LENGTHS (Metric) (e_{max} = 8.0%)

Figure 29-3B

(See Figures 29-3C or 29-3D for Key and Note)

e	**V = 20 mph**	Trans. Length		**V = 25 mph**	Trans. Length		**V = 30 mph**	Trans. Length	
	R (ft)	L_1 (ft)	TR (ft)	R (ft)	L_1 (ft)	TR (ft)	R (ft)	L_1 (ft)	TR (ft)
NC	≥ 1580	0	0	≥ 2290	0	0	≥ 3130	0	0
RC	1120	22	22	1630	24	24	2240	25	25
2.5%	838	37	22	1235	39	24	1700	42	25
3.0%	635	45	22	944	47	24	1320	50	25
3.5%	460	52	22	717	55	24	1026	59	25
4.0%	309	59	22	511	63	24	766	67	25
4.5%	225	67	22	381	71	24	585	75	25
5.0%	169	74	22	292	79	24	456	84	25
5.5%	129	82	22	225	87	24	354	92	25
6.0%	81	89	22	144	94	24	231	100	25
	R_{min} = 81 ft			R_{min} = 144 ft			R_{min} = 231 ft		

e	**V = 35 mph**	Trans. Length		**V = 40 mph**	Trans. Length		**V = 45 mph**	Trans. Length	
	R (ft)	L_1 (ft)	TR (ft)	R (ft)	L_1 (ft)	TR (ft)	R (ft)	L_1 (ft)	TR (ft)
NC	≥ 4100	0	0	≥ 5230	0	0	≥ 6480	0	0
RC	2950	27	27	3770	28	28	4680	31	31
2.5%	2245	44	27	2885	47	28	3595	51	31
3.0%	1760	53	27	2270	57	28	2840	61	31
3.5%	1390	62	27	1820	66	28	2290	71	31
4.0%	1070	71	27	1440	76	28	1840	81	31
4.5%	828	80	27	1140	85	28	1475	92	31
5.0%	654	89	27	911	95	28	1190	102	31
5.5%	514	97	27	723	104	28	949	112	31
6.0%	340	106	27	485	114	28	643	122	31
	R_{min} = 340 ft			R_{min} = 485 ft			R_{min} = 643 ft		

e	**V = 50 mph**	Trans. Length		**V = 55 mph**	Trans. Length		**V = 60 mph**	Trans. Length	
	R (ft)	L_1 (ft)	TR (ft)	R (ft)	L_1 (ft)	TR (ft)	R (ft)	L_1 (ft)	TR (ft)
NC	≥ 7870	0	0	≥ 9410	0	0	≥ 11,100	0	0
RC	5700	33	33	6820	35	35	8060	37	37
2.5%	4385	55	33	5270	59	35	6245	61	37
3.0%	3480	66	33	4200	70	35	4990	73	37
3.5%	2825	77	33	3425	82	35	4095	85	37
4.0%	2300	88	33	2810	94	35	3390	98	37
4.5%	1860	99	33	2305	105	35	2815	110	37
5.0%	1510	110	33	1890	117	35	2330	122	37
5.5%	1220	121	33	1540	129	35	1910	134	37
6.0%	833	132	33	1060	141	35	1330	147	37
	R_{min} = 8335 ft			R_{min} = 1060 ft			R_{min} = 1330 ft		

Key:
V = Design speed, mph
R = Radius of curve, ft
e = Superelevation rate, %
L_1 = Minimum length of superelevation runoff, ft (from adverse slope removed to full super)
TR = Tangent runout from NC to adverse slope removed, ft
NC = Normal crown = 1.5% typical
RC = Remove adverse crown; superelevate at typical cross slope (1.5% typical)

Note: *The values are based on an 11 ft lane width and a NC of 1.5%*

SUPERELEVATION RATES/TRANSITION LENGTHS (US Customary) (e_{max} = 6.0%)

Figure 29-3C

e	**V = 30 km/h**	Trans. Length		**V = 40 km/h**	Trans. Length		**V = 50 km/h**	Trans. Length	
	R (m)	L_1 (m)	TR (m)	R (m)	L_1 (m)	TR (m)	R (m)	L_1 (m)	TR (m)
NC	≥ 421	0	0	≥ 738	0	0	≥ 1050	0	0
RC	299	7	7	525	7	7	750	7	7
2.5%	224	11	7	394	12	7	570	12	7
3.0%	170	13	7	300	14	7	443	15	7
3.5%	123	15	7	223	17	7	347	17	7
4.0%	82	18	7	155	19	7	261	20	7
4.5%	60	20	7	115	21	7	200	22	7
5.0%	45	22	7	88	24	7	156	25	7
5.5%	34	24	7	67	26	7	122	27	7
6.0%	21	26	7	43	28	7	79	30	7
	R_{min} = 21 m			R_{min} = 43 m			R_{min} = 79 m		

e	**V = 60 km/h**	Trans. Length		**V = 70 km/h**	Trans. Length		**V = 80 km/h**	Trans. Length	
	R (m)	L_1 (m)	TR (m)	R (m)	L_1 (m)	TR (m)	R (m)	L_1 (m)	TR (m)
NC	≥ 1440	0	0	≥ 1910	0	0	≥ 2360	0	0
RC	1030	8	8	1380	9	9	1710	10	10
2.5%	786	14	8	1055	15	9	1320	17	10
3.0%	615	17	8	831	18	9	1050	20	10
3.5%	488	19	8	669	21	9	848	23	10
4.0%	380	22	8	535	24	9	690	26	10
4.5%	297	25	8	427	27	9	561	30	10
5.0%	235	28	8	343	30	9	457	33	10
5.5%	186	30	8	274	33	9	369	36	10
6.0%	123	33	8	184	36	9	252	40	10
	R_{min} = 123 m			R_{min} = 184 m			R_{min} = 252 m		

e	**V = 90 km/h**	Trans. Length		**V = 100 km/h**	Trans. Length	
	R (m)	L_1 (m)	TR (m)	R (m)	L_1 (m)	TR (m)
NC	≥ 2880	0	0	≥ 3510	0	0
RC	2090	11	11	2560	11	11
2.5%	1620	18	11	1985	19	11
3.0%	1290	21	11	1590	22	11
3.5%	1060	25	11	1310	26	11
4.0%	870	28	11	1090	30	11
4.5%	719	32	11	906	34	11
5.0%	594	35	11	755	37	11
5.5%	485	39	11	621	41	11
6.0%	336	42	11	437	45	11
	R_{min} = 336 m			R_{min} = 437 m		

Key:
V = Design speed, km/h
R = Radius of curve, m
e = Superelevation rate, %
L_1 = Minimum length of superelevation runoff, m (from adverse slope removed to full super)
TR = Tangent runout from NC to adverse slope removed, m
NC = Normal crown = 1.5% typical
RC = Remove adverse crown; superelevate at typical cross slope (1.5% typical)

Note: *The values are based on a 3.3 m lane width and a NC of 1.5%*

SUPERELEVATION RATES/TRANSITION LENGTHS (Metric) (e_{max} = 6.0%)

Figure 29-3C

e	**V = 20 mph**	Trans. Length		**V = 25 mph**	Trans. Length		**V = 30 mph**	Trans. Length	
	R (ft)	L_1 (ft)	TR (ft)	R (ft)	L_1 (ft)	TR (ft)	R (ft)	L_1 (ft)	TR (ft)
NC	≥ 1410	0	0	≥ 2050	0	0	≥ 2830	0	0
RC	902	22	22	1340	24	24	1880	25	25
2.5%	451	37	22	744	39	24	1135	42	25
3.0%	251	45	22	433	47	24	681	50	25
3.5%	161	52	22	283	55	24	458	59	25
4.0%	86	59	22	154	63	24	250	67	25
	R_{min} = 86 ft			R_{min} = 154 ft			R_{min} = 300 ft		

e	**V = 35 mph**	Trans. Length		**V = 40 mph**	Trans. Length		**V = 45 mph**	Trans. Length	
	R (ft)	L_1 (ft)	TR (ft)	R (ft)	L_1 (ft)	TR (ft)	R (ft)	L_1 (ft)	TR (ft)
NC	≥ 3730	0	0	≥ 4770	0	0	≥ 5930	0	0
RC	2490	27	27	3220	28	28	4040	31	31
2.5%	1590	44	27	2135	47	28	2735	51	31
3.0%	982	53	27	1370	57	28	1800	61	31
3.5%	662	62	27	938	66	28	1245	71	31
4.0%	371	71	27	533	76	28	711	81	31
	R_{min} = 371 ft			R_{min} = 533 ft			R_{min} = 711 ft		

e	**V = 50 mph**	Trans. Length		**V = 55 mph**	Trans. Length		**V = 60 mph**	Trans. Length	
	R (ft)	L_1 (ft)	TR (ft)	R (ft)	L_1 (ft)	TR (ft)	R (ft)	L_1 (ft)	TR (ft)
NC	≥ 7220	0	0	≥ 8650	0	0	≥ 10,300	0	0
RC	4940	33	33	5950	35	35	7080	37	37
2.5%	3410	55	33	4185	59	35	5055	61	37
3.0%	2290	66	33	2860	70	35	3530	73	37
3.5%	1600	77	33	1925	82	35	2525	85	37
4.0%	926	88	33	1190	94	35	1500	98	37
	R_{min} = 926 ft			R_{min} = 1190 ft			R_{min} = 1500 ft		

Key:
V = Design speed, mph
R = Radius of curve, ft
e = Superelevation rate, %
L_1 = Minimum length of superelevation runoff, ft (from adverse slope removed to full super)
TR = Tangent runout from NC to adverse slope removed, ft
NC = Normal crown = 1.5% typical
RC = Remove adverse crown; superelevate at typical cross slope (1.5% typical)

Note: *The values are based on an 11 ft lane width and a NC of 1.5%*

SUPERELEVATION RATES/TRANSITION LENGTHS (US Customary) (e_{max} = 4.0%)

Figure 29-3D

e	V = 30 km/h	Trans. Length		V = 40 km/h	Trans. Length		V = 50 km/h	Trans. Length	
	R (m)	L_1 (m)	TR (m)	R (m)	L_1 (m)	TR (m)	R (m)	L_1 (m)	TR (m)
NC	≥ 371	0	0	≥ 679	0	0	≥ 951	0	0
RC	237	11	7	441	7	7	632	7	7
2.5%	116	11	7	241	12	7	390	12	7
3.0%	64	13	7	137	14	7	236	15	7
3.5%	42	15	7	89	17	7	157	17	7
4.0%	22	18	7	47	19	7	86	20	7
	R_{min} = 22 m			R_{min} = 47 m			R_{min} = 86 m		

e	V = 60 km/h	Trans. Length		V = 70 km/h	Trans. Length		V = 80 km/h	Trans. Length	
	R (m)	L_1 (m)	TR (m)	R (m)	L_1 (m)	TR (m)	R (m)	L_1 (m)	TR (m)
NC	≥ 1310	0	0	≥ 1740	0	0	≥ 2170	0	0
RC	877	8	8	1180	9	9	1490	10	10
2.5%	567	14	8	793	15	9	1027	17	10
3.0%	356	17	8	516	18	9	690	20	10
3.5%	241	19	8	356	21	9	483	23	10
4.0%	135	22	8	203	24	9	280	26	10
	R_{min} = 135 m			R_{min} = 214 m			R_{min} = 280 m		

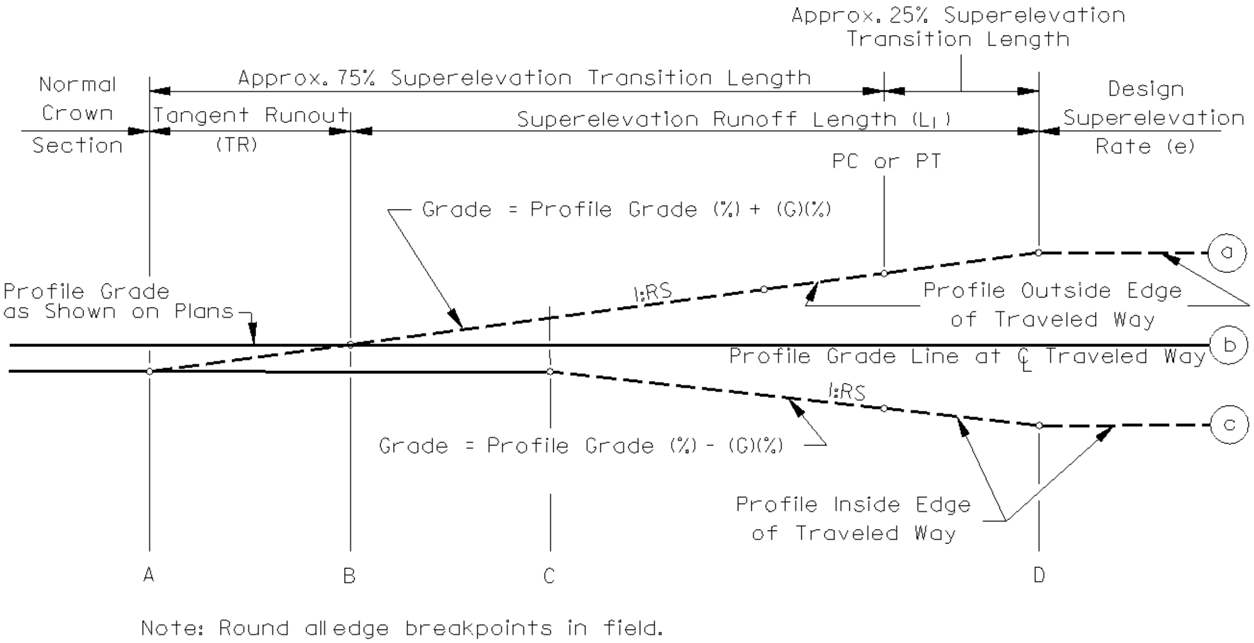
e	V = 90 km/h	Trans. Length		V = 100 km/h	Trans. Length	
	R (m)	L_1 (m)	TR (m)	R (m)	L_1 (m)	TR (m)
NC	≥ 2640	0	0	≥ 3250	0	0
RC	1830	11	11	2260	11	11
2.5%	1295	18	11	1620	19	11
3.0%	893	21	11	1150	22	11
3.5%	636	25	11	823	26	11
4.0%	375	28	11	492	30	11
	R_{min} = 375 m			R_{min} = 492 m		

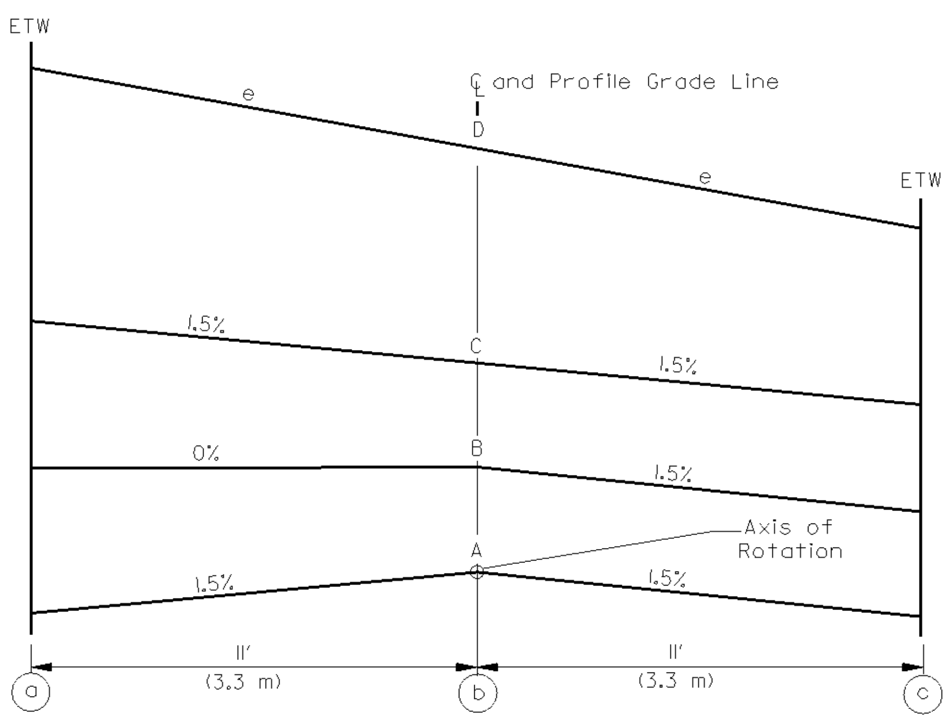
Key:
- V = Design speed, km/h
- R = Radius of curve, m
- e = Superelevation rate, %
- L_1 = Minimum length of superelevation runoff, m (from adverse slope removed to full super)
- TR = Tangent runout from NC to adverse slope removed, m
- NC = Normal crown = 1.5% typical
- RC = Remove adverse crown; superelevate at typical cross slope (1.5% typical)

Note: *The values are based on a 3.3 m lane width and a NC of 1.5%*

SUPERELEVATION RATES/TRANSITION LENGTHS (Metric) (e_{max} = 4.0%)

Figure 29-3D





AXIS OF ROTATION ABOUT CENTERLINE
(Two-Lane Highway)

Figure 29-3E

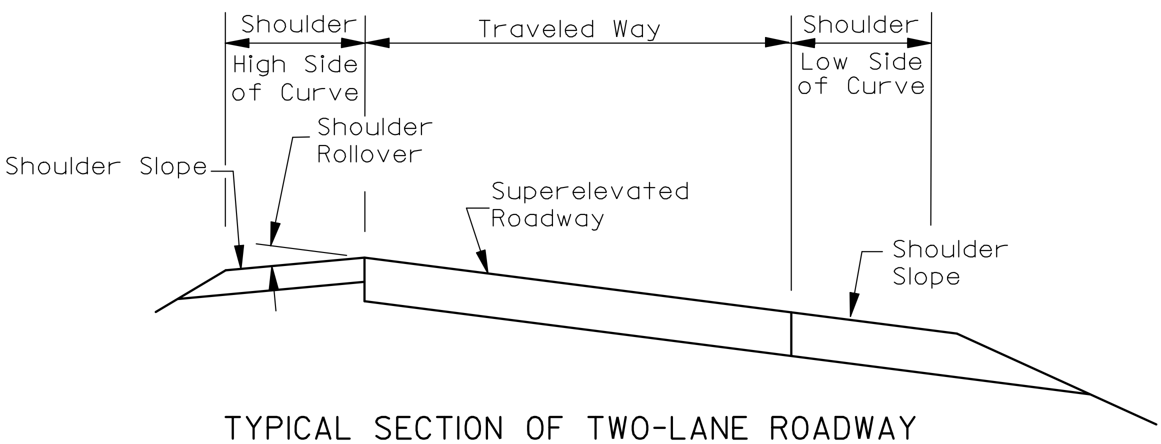
29-3.04 Shoulder Superelevation

Figure 29-3F illustrates the shoulder treatment on superelevated sections. The following discusses specific criteria.

29-3.04(a) Shoulder (High Side of Curve)

On the high side of superelevated sections, there will be a break in the cross slopes of the travel lane and shoulder. The following criteria will apply to the shoulder rollover:

1. Rollover Factor. The rollover factor is the algebraic difference between the traveled way and the shoulder cross slopes. The acceptable values depend on the design traffic volumes. See the Geometric Design Tables in Section 32-2 for new/reconstruction projects and Section 33-3 for 3R projects.
2. Minimum Shoulder Slope. On the high side of a curve, the shoulder slope may be designed for 0% so that maximum rollover is not exceeded. However, in this case, the longitudinal gradient at the edge of the traveled way should not be less than 0.5% for proper shoulder drainage.
3. Direction of Slope. The shoulder should slope away from the travel lane.



SHOULDER TREATMENT THROUGH SUPERELEVATED CURVE

Figure 29-3F

29-3.04(b) Shoulder (Low Side of Curve)

On the low side of a superelevated section, the typical practice is to retain the normal shoulder slope (4% typical) until the adjacent superelevated travel lane reaches that slope. The shoulder is then superelevated concurrently with the travel lane until the design superelevation rate is reached (i.e., the inside shoulder and travel lane will remain in the same plane section).

29-3.05 Reverse Curves

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

1. Normal Crown Section. The designer should not attempt to achieve a normal crown between reverse curves unless the normal crown can be maintained for a minimum of two seconds of travel time, and the superelevation transition requirements can be met for both curves. These criteria yield the following minimum tangent distance (between PT of first curve and PC of second curve):

   $$L_{tan} = 0.75(L_{1A} + TR_A) + 2(1.467V) + 0.75(L_{1B} + TR_B)$$ (US Customary) Equation 29-3.3

   $$L_{tan} = 0.75(L_{1A} + TR_A) + 2(0.278V) + 0.75(L_{1B} + TR_B)$$ (Metric) Equation 29-3.3

   where:

   L_{tan} = tangent distance between PT and PC, ft (m)

   L_{1A} = superelevation runoff length for first curve, ft (m)

   TR_A = tangent runout length for first curve, ft (m)

   V = design speed, mph (km/h)

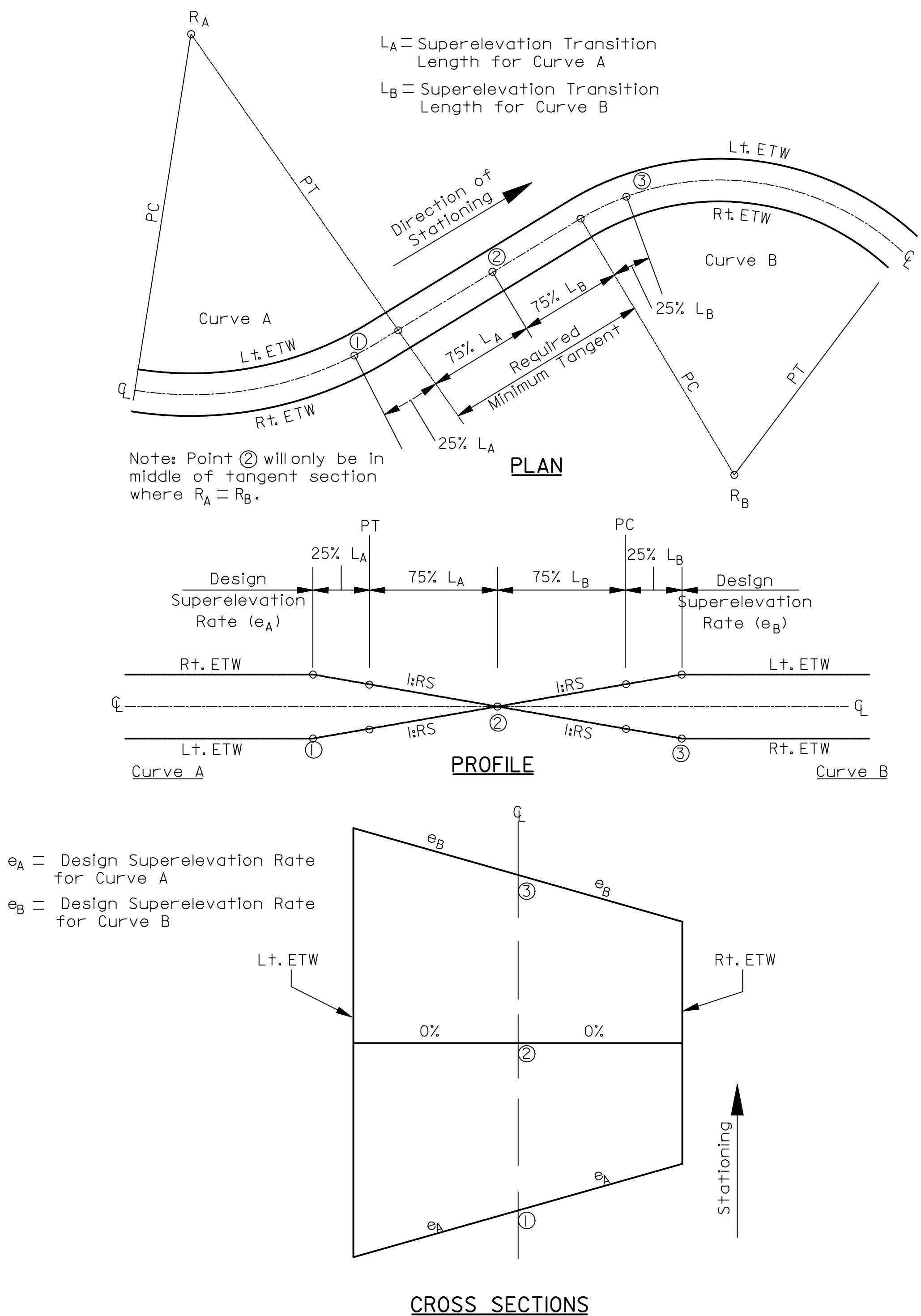
   L_{1B} = superelevation runoff length for second curve, ft (m)

   TR_B = tangent runout length for second curve, ft (m)

2. Continuously Rotating Plane. If a normal section is not provided, the pavement will be continuously rotated in a plane about its axis. In this case, the minimum distance between the PT and PC will be 75% of each superelevation transition requirement added together:

   $$L_{tan} = 0.75(L_{1A}) + 0.75(L_{1B})$$ Equation 29-3.4

Figure 29-3G illustrates superelevation development for reverse curves using a continuously rotating plane.



SUPERELEVATION DEVELOPMENT FOR REVERSE CURVES
(Continuously Rotating Plane)

Figure 29-3G

29-3.06 Bridges

Superelevation transitions should be avoided on bridges and their approaches. Where a curve is necessary on a bridge, the desirable treatment is to place the entire bridge and its approaches on a flat horizontal curve with minimum superelevation. In this case, a uniform superelevation rate is provided throughout (i.e., the superelevation transition is not on the bridge). In some cases, however, superelevation transitions are unavoidable due to right-of-way constraints, especially on urban bridges.

Where a bridge is located within a superelevated horizontal curve, the entire bridge roadway will be sloped in the same direction and at the same rate (i.e., the shoulder and travel lanes will be in a plane section). This also applies to the approach slab and approach slab shoulders before and after the back of the abutment. However, as discussed in Section 29-3.04, the high-side shoulder on a roadway section will slope away from the traveled way at a rate so that the maximum rollover is not exceeded. This will require the high-side shoulder on the roadway section to be transitioned to the high-side shoulder of either the approach slab or bridge.

Therefore, it is necessary to transition the longitudinal shoulder slope adjacent to the roadway travel lanes to meet the shoulder slope adjacent to the travel lanes on the bridge. This transition should be accomplished by using a maximum relative longitudinal gradient of 0.40% between the edge of traveled way and outside edge of shoulder.

29-3.07 Compound Curves

See Section 32-3 of the *BDE Manual* for a discussion on superelevation development for compound curves on mainline.

29-4 HORIZONTAL ALIGNMENT (LOW-SPEED URBAN STREETS)

29-4.01 General Application

For low-speed urban and suburban streets, the application of horizontal alignment criteria will differ from that for open-roadway conditions. Section 29-4 discusses the application to these facilities where $V \leq 45$ mph (70 km/h).

29-4.02 General Superelevation Considerations

For low-speed urban streets, the operational conditions and physical constraints are significantly different than those on rural roadways and high-speed urban roadways. The following lists some of the characteristics of low-speed urban streets that often complicate superelevation development:

1. Roadside Development/Intersections/Driveways. Built-up roadside development is common adjacent to low-speed urban streets. Matching superelevated curves with many driveways, intersections, sidewalks, etc., creates considerable complications. For example, this may require reconstructing the profile on side streets, and re-grading parking lots, lawns, etc., to compensate for the higher elevation on the high side of the superelevated curve.
2. Non-Uniform Travel Speeds. On low-speed urban streets, travel speeds are often non-uniform because of frequent signalization, stop signs, vehicular conflicts, etc. It is undesirable for traffic to stop on a superelevated curve, especially when snow or ice is present.
3. Limited Right-of-Way. Superelevated curves often result in more right-of-way impacts than would otherwise be necessary. Right-of-way is often restricted along low-speed urban streets.
4. Wide Pavement Areas. Many low-speed urban streets have wide pavement areas because of the number of traffic lanes, the use of a flush-type median, or the presence of parking lanes. In general, the wider the pavement area, the more complicated is the development of superelevation.
5. Surface Drainage. Proper cross slope drainage on low-speed urban streets can be difficult even on sections with a normal crown. Curves with superelevation introduce another complicating factor in controlling drainage.

29-4.03 Horizontal Curves

29-4.03(a) Design Procedures

Because of the different operational conditions for low-speed urban streets, it is appropriate to use a modified theoretical basis for horizontal alignment criteria when compared to open-roadway conditions. The net effect is:

- smaller minimum radii,
- fewer superelevated curves, and
- shorter superelevation runoff distances.

The practical benefit is that most horizontal curves can be designed with little or no superelevation on low-speed urban streets when compared to the criteria for open-roadway conditions in Section 29-3.

29-4.03(b) Maximum Superelevation Rate

For new construction projects, e_{max} is 4.0% for low-speed urban streets. For urban reconstruction projects, existing horizontal curves can remain in place with a superelevation rate up to 6.0%.

29-4.03(c) Minimum Radii

Figure 29-4A presents for various design speeds for low-speed urban streets the:

- minimum radii for a normal crown section,
- minimum radii for e_{max} = 4.0%, and
- minimum radii for e_{max} = 6.0%.

Note that an e_{max} = 6.0% may only be used to retain an existing superelevated curve on a reconstruction project.

29-4.03(d) Superelevation Rate

For any given design speed, Figure 29-4B allows the designer to use either a normal crown through the curve, to remove crown through the curve (i.e., superelevate at the typical cross slope), or to provide a curve with superelevation steeper than the typical cross slope.

US Customary					
Design Speed (mph)	Side Friction Factor (f)	R_{min} (ft) for Normal Crown (e = -1.5%)	R_{min} (ft) for Remove Crown (e = +1.5%)	R_{min} (ft) for e_{max} = 4.0%	R_{min} (ft) for e_{max} = 6.0%
20	0.27	105	94	86	81
25	0.23	194	170	154	144
30	0.20	324	279	250	231
35	0.18	495	419	371	340
40	0.16	736	610	533	485
45	0.15	1000	818	711	643
Metric					
Design Speed (km/h)	Side Friction Factor (f)	R_{min} (m) for Normal Crown (e = -1.5%)	R_{min} (m) for Remove Crown (e = +1.5%)	R_{min} (m) for e_{max} = 4.0%	R_{min} (m) for e_{max} = 6.0%
30	0.28	27	24	22	21
40	0.23	59	51	47	43
50	0.19	113	96	86	79
60	0.17	183	153	135	123
70	0.15	286	234	203	184

MINIMUM RADII FOR LIMITING VALUES OF e
(Low-Speed Urban Streets)

Figure 29-4A

* *

Example 29-4.1

Given: Design speed = 25 mph
Radius = 200 ft
Cross slope (on tangent) = 1.5%

Problem: Determine if superelevation is needed.

Solution: From Figure 29-4B, the normal crown section can be maintained throughout the horizontal curve.

* *

e	V = 20 mph R (ft)	Trans. Length L_1 (ft)	Trans. Length TR (ft)	V = 25 mph R (ft)	Trans. Length L_1 (ft)	Trans. Length TR (ft)	V = 30 mph R (ft)	Trans. Length L_1 (ft)	Trans. Length TR (ft)
NC	≥ 105	0	0	≥ 194	0	0	≥ 324	0	0
RC	94	20	20	170	22	22	279	24	24
2.0%	92	27	20	167	29	22	273	32	24
2.5%	91	33	20	164	36	22	267	41	24
3.0%	89	41	20	160	44	22	261	49	24
3.5%	88	47	20	158	51	22	255	57	24
4.0%	86	54	20	154	59	22	250	65	24
4.5%	85	61	20	151	66	22	245	73	24
5.0%	83	67	20	149	73	22	240	81	24
5.5%	82	74	20	147	81	22	235	89	24
6.0%	81	80	20	144	88	22	231	97	24

e	V = 35 mph R (ft)	Trans. Length L_1 (ft)	Trans. Length TR (ft)	V = 40 mph R (ft)	Trans. Length L_1 (ft)	Trans. Length TR (ft)	V = 45 mph R (ft)	Trans. Length L_1 (ft)	Trans. Length TR (ft)
NC	≥ 495	0	0	≥ 736	0	0	≥ 1000	0	0
RC	419	26	26	610	27	27	818	29	29
2.0%	408	34	26	593	36	27	794	39	29
2.5%	398	43	26	577	45	27	772	49	29
3.0%	389	51	26	561	54	27	750	59	29
3.5%	380	60	26	547	63	27	730	68	29
4.0%	371	69	26	533	72	27	711	78	29
4.5%	363	77	26	521	81	27	693	88	29
5.0%	355	86	26	508	90	27	675	98	29
5.5%	348	94	26	496	99	27	659	107	29
6.0%	340	103	26	485	108	27	643	117	29

Key:
R = Radius of curve, ft
V = Design speed, mph
e = Superelevation rate, %
L_1 = Minimum length of superelevation runoff (from adverse slope removed to full super), ft
TR = Tangent runout from NC to adverse slope removed, ft
NC = Normal crown = 1.5% typical
RC = Remove adverse crown; superelevate at typical cross slope (1.5% typical)

Notes:

1. *For new construction projects, e_{max} = 4.0%.*
2. *For reconstruction projects, e_{max} = 6.0%*
3. *The values are based on a 13 ft lane width.*

SUPERELEVATION RATES
(Low-Speed Urban Streets) (US Customary)

Figure 29-4B

e	V = 30 km/h	Trans. Length		V = 40 km/h	Trans. Length		V = 50 km/h	Trans. Length	
	R (m)	L_1 (m)	TR (m)	R (m)	L_1 (m)	TR (m)	R (m)	L_1 (m)	TR (m)
NC	≥ 27	0	0	≥ 59	0	0	≥ 113	0	0
RC	24	6	6	51	7	7	96	8	8
2.0%	24	8	6	50	9	7	94	10	8
2.5%	23	10	6	50	11	7	92	13	8
3.0%	23	12	6	48	13	7	89	15	8
3.5%	23	14	6	48	16	7	88	18	8
4.0%	22	16	6	47	18	7	86	20	8
4.5%	22	18	6	46	20	7	84	23	8
5.0%	21	20	6	45	22	7	82	25	8
5.5%	21	22	6	44	25	7	81	28	8
6.0%	21	24	6	43	27	7	79	30	8

e	V = 60 km/h	Trans. Length		V = 70 km/h	Trans. Length	
	R (m)	L_1 (m)	TR (m)	R (m)	L_1 (m)	TR (m)
NC	≥ 183	0	0	≥ 286	0	0
RC	153	8	8	234	9	9
2.0%	149	11	8	227	12	9
2.5%	146	14	8	221	15	9
3.0%	142	16	8	214	18	9
3.5%	139	19	8	209	21	9
4.0%	135	22	8	203	24	9
4.5%	132	24	8	198	27	9
5.0%	129	27	8	193	30	9
5.5%	126	30	8	188	33	9
6.0%	123	33	8	184	36	9

Key:
R = Radius of curve, m
V = Design speed, km/h
e = Superelevation rate, %
L_1 = Minimum length of superelevation runoff (from adverse slope removed to full super), m
TR = Tangent runout from NC to adverse slope removed, m
NC = Normal crown = 1.5% typical
RC = Remove adverse crown; superelevate at typical cross slope (1.5% typical)

Notes:

1. *For new construction projects, e_{max} = 4.0%.*
2. *For reconstruction projects, e_{max} = 6.0%.*
3. *The values are based on a 4.0 m lane width.*

SUPERELEVATION RATES
(Low-Speed Urban Streets) (Metric)

Figure 29-4B

* *

<u>Example 29-4.2</u>

Given: Design speed = 35 mph
Radius = 450 ft
Cross slope (on tangent) = 1.5%

Problem: Determine if superelevation is needed.

Solution: From Figure 29-4B, the curve radius falls in the RC range. Therefore, the roadway must be uniformally superelevated at the cross slope of the roadway on tangent (i.e., e = +1.5%).

* *

<u>Example 29-4.3</u>

Given: Design speed = 40 mph
Radius = 500 ft
Cross slope (on tangent) = 1.5%

Problem: Determine if superelevation is needed.

Solution: From Figure 29-4B, the required superelevation rate is between +5.0% to +5.5%. Therefore, the entire traveled way should be transitioned and superelevated at this rate.

Using Equation 29-2.1 and given f = 0.16 from Figure 29-4A, the superelevation rate is calculated as +5.33%.

$$R = \frac{V^2}{15\,(e+f)} \quad \Longrightarrow \quad 500 = \frac{40^2}{15\,(e+0.16)} \quad \Longrightarrow \quad e = 0.0533$$

* *

29-4.04 <u>Superelevation Development</u>

29-4.04(a) Transition Length

The superelevation transition length is the distance required to transition the traveled way from a normal crown section to the full design superelevated section. The superelevation transition length is the sum of the tangent runout distance (TR) and superelevation runoff length (L_1). See Section 29-3.

Section 29-3 presents the methodology for calculating the superelevation runoff and tangent runout for open-roadway conditions. This methodology also applies to superelevation transition lengths on low-speed urban streets, except that Figure 29-4C presents revised relative longitudinal gradients.

Based on values from Figure 29-4C, Figure 29-4B presents superelevation runoff lengths (L_1) for a two-lane urban street, assuming the axis of rotation is about the roadway centerline; i.e., the width of rotation is one travel lane of 13 ft (4.0 m). The 13 ft travel lane is based on a typical two-lane two-way urban roadway width of 30 ft from face of curb to face of curb with 2 ft gutters. See Section 29-3 for determining the tangent runout distance. See Section 32-3 of the *BDE Manual* for determining superelevation transition lengths on multilane facilities.

US Customary			Metric		
Design Speed (mph)	Maximum Relative Gradient (%)	Reciprocal (RS)	Design Speed (km/h)	Maximum Relative Gradient (%)	Reciprocal (RS)
20	0.97	103	30	0.98	102
25	0.90	112	40	0.90	112
30	0.81	124	50	0.80	125
35	0.76	132	60	0.74	136
40	0.72	139	70	0.68	148
45	0.67	150			

RELATIVE LONGITUDINAL GRADIENTS
(Low-Speed Urban Streets)

Figure 29-4C

Typically, 75% of the superelevation transition length will be placed on tangent and 25% on curve. Exceptions to this practice may be necessary to meet field conditions. Generally, the accepted range is 50% to 80% on tangent and 20% to 50% on curve.

29-4.04(b) Axis of Rotation

On low-speed urban streets, the axis of rotation for horizontal curves is as follows:

1. Two-Lane Facilities. The axis of rotation is typically about the centerline of the roadway.
2. Multilane Facilities (Median Width ≤ 15 ft (5.0 m)). The axis of rotation is typically about the centerline of roadway or median.
3. Multilane Facilities (Median Width > 15 ft (5.0 m)). The axis of rotation is typically about the two median edges.

Low-speed urban streets may also present special problems because of the presence of two-way, left-turn lanes; turning lanes at intersections; intersections with major crossroads; drainage; etc. For these reasons, the axis of rotation may be determined on a case-by-case basis.

29-5 HORIZONTAL SIGHT DISTANCE

Horizontal curves must be designed with sufficient clearance on the inside of the curve to allow a driver to see a distance equal to the stopping sight distance (SSD) for the design speed; see Chapter 28.

29-5.01 Sight Obstruction (Definition)

Sight obstructions on the inside of a horizontal curve are defined as obstacles of considerable length that interfere with the line of sight on a continuous basis. These include walls, cut slopes, wooded areas, and buildings. In general, point obstacles (e.g., traffic signs, utility poles) are not considered sight obstructions on the inside of horizontal curves. While high farm crops are not present on a continuous basis, the designer may also want to take this into consideration when designing for sight distance. The designer must examine each curve individually to determine whether it is necessary to remove an obstruction or adjust the horizontal alignment to obtain the required sight distance.

29-5.02 Application

For sight distance applications at horizontal curves, the height of eye is 3.5 ft (1080 mm) and the height of object is 2 ft (600 mm). Both the eye and object are assumed to be in the center of the inside travel lane. The line-of-sight intercept with the obstruction is at the midpoint of the sightline and 2.75 ft (840 mm) above the center of the inside lane.

29-5.03 Curve Length > Sight Distance

Where the length of curve (L) is greater than the sight distance (S) used for design, the needed clearance on the inside of the horizontal curve is calculated using the following equation:

$$M = R\left(1 - \cos\frac{(28.65S)}{R}\right) \qquad \text{Equation 29-5.1}$$

where:

M = middle ordinate, or distance from the center of the inside travel lane to the obstruction, ft (m)

R = radius of curve, ft (m)

S = sight distance, ft (m)

At a minimum, SSD will be available throughout the horizontal curve. Figure 29-5A provides the horizontal clearance criteria (i.e., middle ordinate) for various combinations of sight distance (see Figure 28-1A) and curve radii. For those selections of S, that fall outside of the figures (i.e., M > 40 ft (12 m) and/or R < 100 ft (50 m)), the designer should use Equation 29-5.1 to calculate the needed clearance.

The M values from Figure 29-5A apply between the PC and PT. In addition, some transition is needed on the entering and exiting portions of the curve. The designer should typically use the following steps:

Step 1: Locate the point that is on the outside edge of shoulder and a distance of S/2 before the PC.

Step 2: Locate the point that 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 continuous obstructions.

Step 4: A symmetrical application of Steps 1 through 3 should be used beyond the PT.

The example in Figure 29-5B illustrates the determination of clearance requirements for the entering and exiting portions of a curve.

29-5.04 Curve Length < Sight Distance

When the length of curve is less than the sight distance used in design, the M value from the basic equation will never be reached. As an approximation, the horizontal clearance for these curves should be determined as follows:

Step 1: For the given R and S, calculate M assuming L > S.

Step 2: The maximum M′ value will be needed at a point of L/2 beyond the PC. M′ is calculated from the following proportion:

$$\frac{M'}{M} = \frac{1.2L}{S} \qquad \text{Equation 29-5.2}$$

$$M' = \frac{1.2(L)(M)}{S}$$

where:

M′ = middle ordinate for a curve where L < S, ft (m)

M = middle ordinate for the curve based on Equation 29-5.1, ft (m)

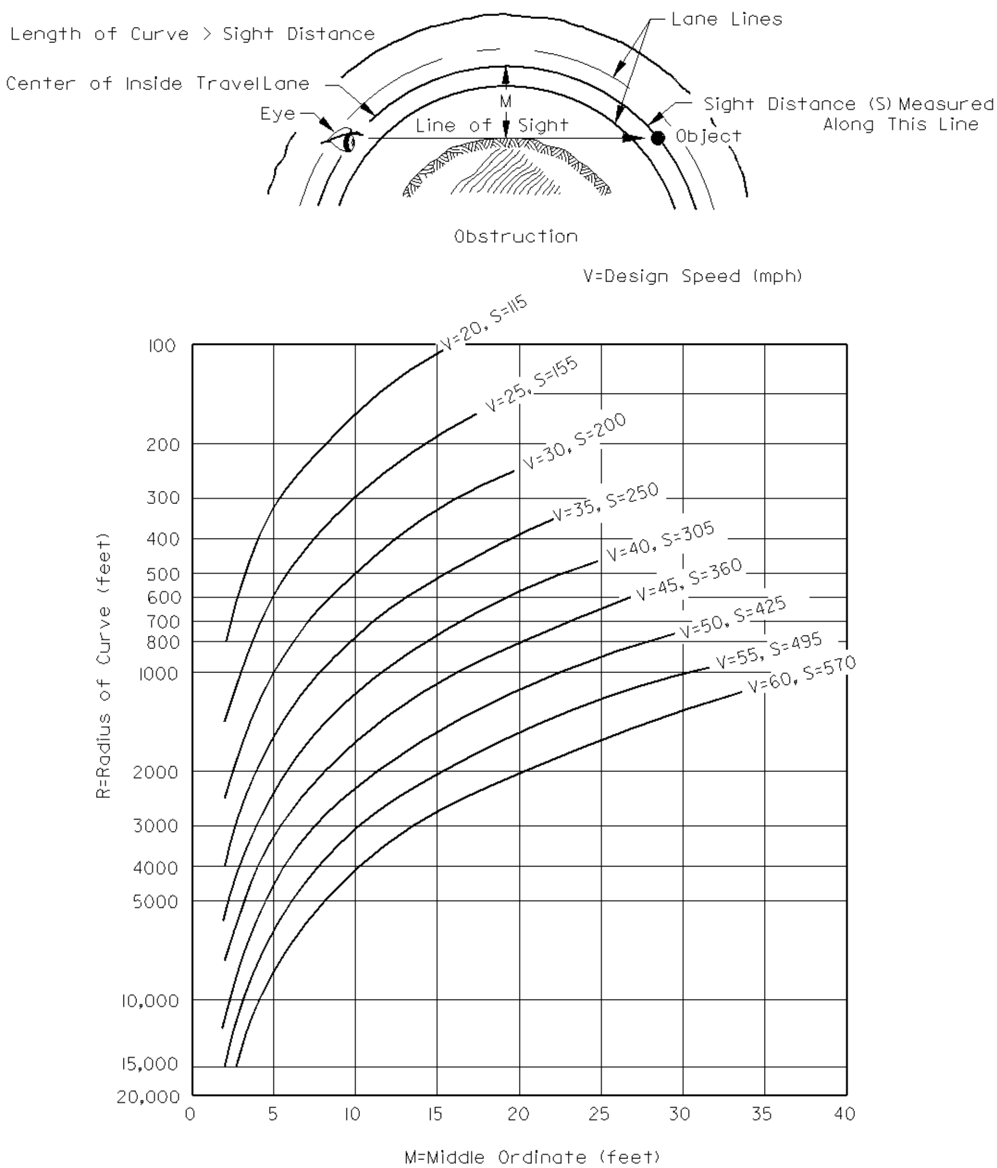
L = length of the curve, ft (m)

S = sight distance, ft (m)

Step 3: Locate the point that is on the outside edge of shoulder and a distance of S/2 before the PC.

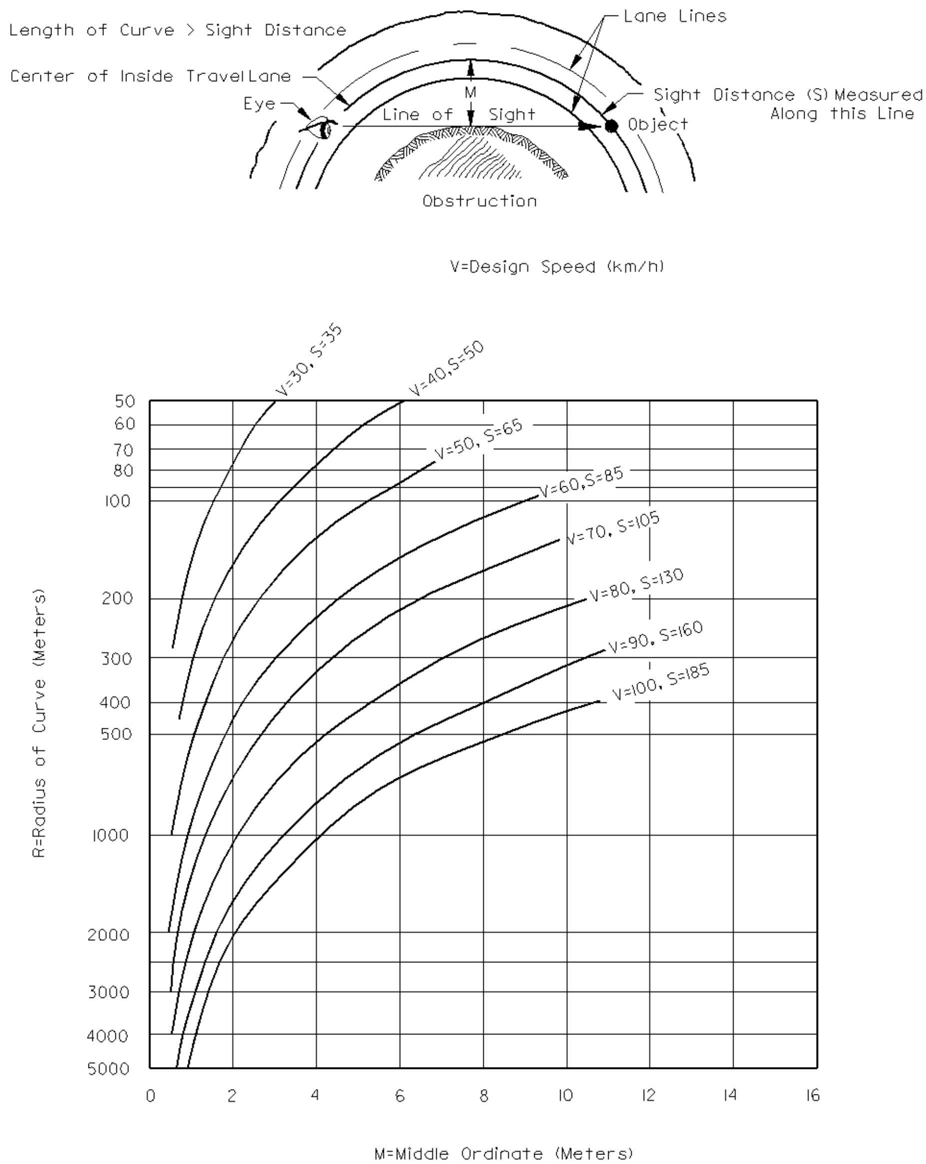
Step 4: Connect the two points located in Steps 2 and 3. The area between this line and the roadway should be clear of all continuous obstructions.

Step 5: A symmetrical application of Steps 2 through 4 should be used on the exiting portion of curve.



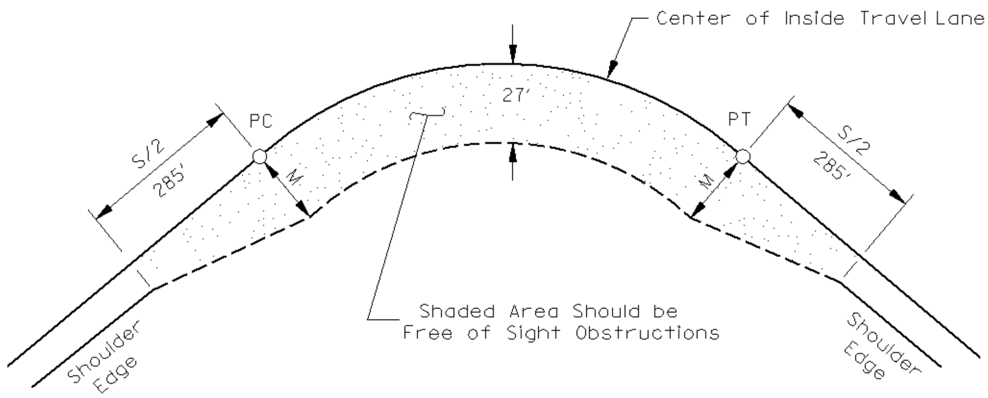
SIGHT DISTANCE AT HORIZONTAL CURVES (SSD) (US Customary)

Figure 29-5A



SIGHT DISTANCE AT HORIZONTAL CURVES (SSD) (Metric)

Figure 29-5A



SIGHT CLEARANCE REQUIREMENTS FOR HORIZONTAL CURVES
(L > S)

Figure 29-5B

* *

Example 29-5.1

Given: Design Speed = 60 mph
R = 1500 ft

Problem: Determine the horizontal clearance requirements for a horizontal curve on a 2-lane highway that meets the SSD requirements.

Solution: Figure 28-1A yields a SSD = 570 ft Using Equation 29-5.1 for horizontal clearance (L > S):

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

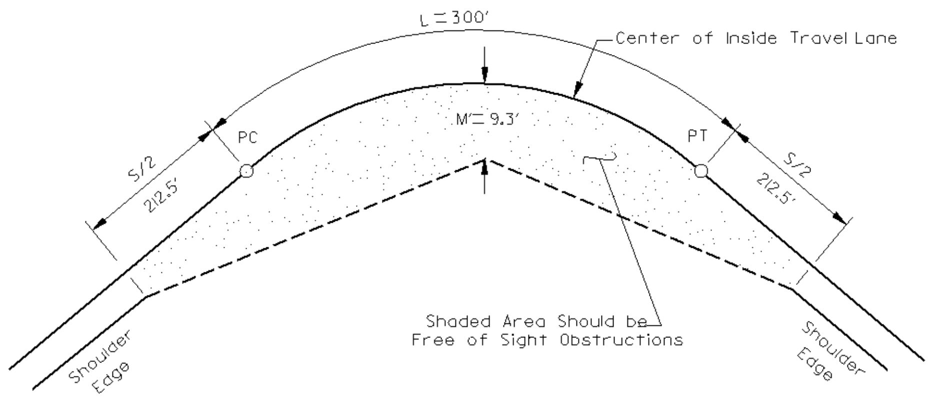
$$M = 1500\left(1 - \cos\left[\frac{(28.65)(570)}{1500}\right]\right) = 27\text{ ft}$$

This answer is verified by Figure 29-5A.

* *

Figure 29-5B above, also illustrates the horizontal clearance requirements for the entering and exiting portion of the horizontal curve.

The example on Figure 29-5C below, illustrates the determination of clearance requirements for the entering and exiting portions of a curve where L < S.



SIGHT CLEARANCE REQUIREMENTS FOR HORIZONTAL CURVES
(L < S)

Figure 29-5C

* *

Example 29-5.2

Given: Design Speed = 50 mph
R = 2050 ft
L = 300 ft

Problem: Determine the clearance requirements for the horizontal curve on a 2-lane highway that meets the SSD requirements.

Solution: Figure 28-1A yields a SSD of 425 ft for 50 mph. Therefore, L < S (300 ft < 425 ft), and the horizontal clearance is calculated from Equation 29-5.2 as follows:

$$M\,(L > S) = 2050\left[1 - \cos\frac{(28.65)(425)}{2050}\right] = 11.01\text{ ft}$$

$$M'\ (L < S) = \frac{1.2(300)(11.01)}{425}$$

$$M' = 9.3\text{ ft}$$

Therefore, a minimum clearance of 9.3 ft should be provided at a distance of L/2 = 150 ft beyond the PC. The obstruction-free triangle around the horizontal curve would be defined by M′ (9.3 ft) at L/2 and by points at the shoulder edge at S/2 = 212.5 ft before the PC and beyond the PT.

* *

29-6 ACRONYMS

This is a summary of the acronyms used within this chapter.

3R	Rehabilitation, Restoration, and/or Resurfacing
AASHTO	American Association of State Highway and Transportation Officials
BDE	Bureau of Design and Environment
CBLRS	Central Bureau of Local Roads and Streets
IDOT	Illinois Department of Transportation
NC	Normal Crown
PC	Point of Curve
PT	Point of Tangent
RC	Remove Adverse Crown
SSD	Stopping Sight Distance
TR	Tangent Runout

29-7 REFERENCES

1. *A Policy on Geometric Design of Highways and Streets*, AASHTO, 2011.

2. Chapter 32 “Horizontal Alignment”, Chapter 43 “Highway Systems”, and Chapter 48 “Urban Highways and Streets (New Construction/Reconstruction),” *Bureau of Design and Environment Manual*, IDOT.