CHAPTER 43

Horizontal Alignment

NOTE: This chapter is currently being re-written and its content will be included in Chapter 302 in the future.

Design Memorandum	Revision Date	Sections Affected
13-11	May 2013	Figure 43-3D

TABLE OF CONTENTS

LIST OF FIGURES

CHAPTER 43

HORIZONTAL ALIGNMENT

43-1.0 DEFINITIONS

The definitions for basic elements of horizontal alignment are shown below. Section 43-6.0 provides mathematical details for a horizontal curve (e.g., deflection angle, point of curvature).

1. Simple Curve. This is a continuous arc of constant radius which achieves the necessary highway deflection without an entering or exiting transition.

2. Compound Curves. This is a series of two or more simple curves with deflections in the same direction immediately adjacent to each other.

3. Reverse Curves. This is two simple curves with deflections in opposite directions which are joined by a relatively short tangent distance.

4. Broken-Back Curves. This is two closely-spaced horizontal curves with deflection angles in the same direction with an intervening, short tangent section.

5. Superelevation. Superelevation is the amount of cross slope or banking provided on a horizontal curve to help counterbalance the centrifugal force of a vehicle traversing the curve.

6. Maximum Superelevation, e_{max}. This is an overall superelevation control used on a specific facility. Its selection depends on factors including climatic conditions, terrain conditions, type of area (rural or urban), and highway functional classification.

7. Superelevation Transition Length. This is the distance required to transition the roadway from a normal crown section to full superelevation. It is the sum of the tangent runout, *TR*, and superelevation runoff, *L*, distances, as follows:

    a. Tangent Runout, *TR*. This is the distance required to 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 is level).

b. Superelevation Runoff, *L*. This is the distance required 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.

8. Axis of Rotation. This is the line about which the pavement is revolved to superelevate the roadway. This line will maintain the normal highway profile throughout the curve.

9. Superelevation Rollover. This is the algebraic difference, *A*, between the superelevated travel-lane slope and shoulder slope on the outside of a horizontal curve.

10. Normal Crown (NC). This is the typical cross section on a tangent section (i.e., no superelevation).

11. Remove Adverse Crown (RC). This is a superelevated roadway section which is sloped across the entire traveled way in the same direction and at a rate equal to the cross slope on a tangent section.

12. Relative Longitudinal Slope. In a superelevation-transition portion of a two-lane facility, this is the relative gradient between the profile grade and edge of traveled way.

43-2.0 HORIZONTAL CURVE

43-2.01 General Theory

A horizontal curve is, in effect, a transition between two tangents. These deflectional changes are necessary in virtually all highway alignments to avoid impacts on a variety of field conditions (e.g., right-of-way, natural features, man-made features). The following provides a brief overview of the general theory of horizontal alignment. The designer should reference the AASHTO *A Policy on Geometric Design of Highways and Streets* for more information.

43-2.01(01) 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 as follows:

$$R = \frac{V^2}{15(e + f)}$$

Where:

R	=	radius of curve, ft
e	=	superelevation rate
f	=	side-friction factor
V	=	vehicular speed, mph

43-2.01(02) Theoretical Approaches

Establishing horizontal-curvature criteria requires a determination of the theoretical basis for the various factors in the basic curvature equation. These include the side-friction factor, *f*, and the distribution method between side friction and superelevation. The theoretical basis will be one of the following.

1. Open-Roadway Condition. The theoretical basis includes the following:

    a. relatively low side-friction factor (i.e., a relatively small level of driver discomfort); and

    b. the use of AASHTO Method 5 to distribute side friction and superelevation.

    Open-roadway condition applies to a rural facility or an urban facility where the design speed $V \geq 50$ mph.

2. Low-Speed Urban Street. The theoretical basis includes the following:

    a. relatively high side-friction factor to reflect a higher level of driver acceptance of discomfort; and

    b. the use of AASHTO Method 2 to distribute side friction and superelevation.

    A low-speed urban street is defined as that within an urban or urbanized area where the design speed $V \leq 45$ mph.

3. Turning-Roadway Condition. The theoretical basis includes the following:

    a. higher side-friction factor than open-roadway condition to reflect a higher level of driver acceptance of discomfort; and

b. a range of acceptable superelevation rates for combinations of curve radius and design speed to reflect the need for flexibility to meet field conditions for a turning roadway.

This applies to a turning roadway at an intersections at-grade. See Chapter Forty-six.

43-2.01(03) Superelevation

Superelevation allows a driver to negotiate a curve at a higher speed than would otherwise be comfortable. Superelevation and side friction work together to offset the outward pull of the vehicle as it traverses the horizontal curve. It is necessary to establish a limiting value of superelevation rate, e_{max}, based on the operational characteristics of the facility. Values of e_{max} used by INDOT are discussed in Section 43-3.0.

43-2.01(04) Side Friction

AASHTO has established limiting side-friction factors, *f*, for various design speeds and various highway operating conditions. The *f* value represents a threshold of driver discomfort, and not the point of impending skid. Different sets of *f* values have been established for different operating conditions (i.e., open roadway, low-speed urban street, or turning roadway). The basis for the distinction is that drivers, through conditioning, will accept a different level of discomfort on each different facility.

43-2.02 Selection of Horizontal-Curve Type

Because of its simplicity and ease of design, survey, and construction, a simple curve is nearly always used on the highway mainline. A simple curve may rarely be inconsistent with field conditions; therefore, an alternative arrangement such as a compound curve should be used. Spiral curves should not be used.

43-2.03 Minimum Radius

The following figures provide the minimum radius, R_{min}, for an open-roadway facility or a low-speed urban street. Criteria for a turning roadway are provided in Chapter Forty-six. To define R_{min}, a maximum superelevation rate, e_{max}, must be selected. These are as follows:

1. Figure 43-2A is applicable to a facility where e_{max} = 8% and open-roadway conditions apply.

2. Figure 43-2B is applicable to a low-speed urban street where e_{max} = 4% or 6% is applied.

See Section 43-3.0 for the selection of e_{max} for various facility types.

43-2.04 Maximum Deflection Without Curve

It may be appropriate to design a facility without a horizontal curve where small a deflection angle is present. As a guide, the designer may retain a deflection angle of about 1 deg or less (urban), or 0.5 deg or less (rural) for the highway mainline. The absence of a horizontal curve will not likely affect driver response or aesthetics.

43-2.05 Minimum Length of Curve

A short horizontal curve may provide the driver the appearance of a kink in the alignment. To improve the aesthetics of the highway, the designer should lengthen each short curve, if practical, even if not necessary for engineering reasons. The following guidance should be used to compare the calculated curve length to the recommended minimum length.

1. General. The minimum length of curve on an open roadway should be based on the deflection angle, Δ, as follows:

Δ (deg)	Minimum Curve Length (ft)
≤ 1	100
1 < Δ ≤ 2	200
2 < Δ ≤ 3	300
3 < Δ ≤ 4	400
4 < Δ ≤ 5	500
> 5	Calculated Length

The minimum length of curve on a low-speed urban street will be determined as required.

2. Freeway or Rural Highway. The minimum length of curve in feet should be 15*V* for aesthetics. *V* is design speed in mph.

43-2.06 Shoulder Treatment

On a facility with a relatively sharp horizontal curve, the calculated and design values for traveled-way-widening on an open-highway curve (two-lane highway, one-way, or two-way), shown in the AASHTO *A Policy on Geometric Design of Highways and Streets*, and truck volume greater than 1000, a full-structural strength shoulder should be provided on both sides of the curve in lieu of pavement widening. The following will apply.

1. Strengthened Length. The strengthened shoulder should be available from the beginning of the superelevation transition before the curve to the end of the transition beyond the curve.

2. Asphalt Traveled Way. The pavement structure of the strengthened shoulder should match that of the traveled way.

3. Concrete Traveled Way with Asphalt Shoulder. The Office of Pavement Engineering will determine the pavement structure of the strengthened shoulder.

4. Concrete Traveled Way with Concrete Shoulder. The pavement structure of the strengthened shoulder should match that of the traveled way.

See AASHTO *A Policy on Geometric Design of Highways and Streets* for more information on pavement widening.

43-3.0 SUPERELEVATION

43-3.01 Superelevation Rate, Open-Roadway Condition

43-3.01(01) General

The open-roadway condition is used for each rural highway, or each urban facility where $V \geq 50$ mph. This type of facility exhibits relatively uniform traffic operations. Therefore, for superelevation development, the flexibility exists to design a horizontal curve with the more conservative AASHTO Method 5 (for distribution of superelevation and side friction). The following provides the specific design criteria for superelevation rate assuming the open-roadway condition.

43-3.01(02) Maximum Superelevation Rate

The selection of a maximum rate of superelevation, e_{max}, depends upon urban or rural location and prevalent climatic conditions. For the open-roadway condition, INDOT has adopted the following for the selection of e_{max}.

1. Rural Facility. An e_{max} = 8% is used. An exception should be evaluated as required.

2. Urban Facility ($V \geq 50$ mph). An e_{max} = 8% is used. A rate of 6% or 4% may be used where $V \leq 45$ mph or where site-specific conditions warrant.

43-3.01(03) Superelevation Rate

Based on the selection of e_{max} = 8%, 6%, or 4% and the use of AASHTO Method 5 to distribute *e* and *f*, Figures 43-3A(1), 43-3A(2), and 43-3A(3) allow the designer to select the superelevation rate for any combination of curve radius, *R*, and design speed, *V*. The design speed selected for determining the superelevation rate will be the same as that used for the overall project design. However, site-specific factors may indicate a need to use a higher design speed specifically to determine the superelevation rate. This may be appropriate if the designer anticipates that travel speeds higher than the project design speed will occur at the horizontal curve with some frequency. Examples include the following.

1. Transition Area. Where a highway is transitioning from a predominantly rural environment to an urban environment, travel speeds in the transition area within the urban environment may be higher than the urban design speed.

2. Downgrade. Where a horizontal curve is located at the bottom of a downgrade, travel speeds at the curve may be higher than the overall project design speed. As suggested adjustments, the design speed used for the horizontal curve may be 5 mph (grade of 3% to 5%) or 10 mph (grade >5%) higher than the project design speed. This adjustment may be more appropriate for a divided facility than for a 2-lane, 2-way highway.

3. Long Tangent. Where a horizontal curve is located at the end of a long tangent section, a design speed of up to 10 mph higher than the project design speed may be appropriate.

43-3.01(04) Minimum Radius Without Superelevation

A horizontal curve with a very large radius does not require superelevation, and the normal crown section (NC) used on the tangent section can be maintained throughout the curve. On a sharper curve for the same design speed, a point is reached where a superelevation rate of 2% across the total traveled way width is appropriate. Figure 43-3B provides the threshold (or minimum) radius for a normal crown section at various design speeds. The figure also provides the curve-radius range where remove (adverse) crown (RC) applies. This table applies to where the open-roadway condition is used.

43-3.02 Superelevation Rate, Low-Speed Urban Street

43-3.02(01) General

In a built-up area, the combination of wide pavements, proximity of adjacent development, control of cross slope, profile for drainage, frequency of cross streets, and other urban features make superelevation impractical and undesirable. Superelevation is not provided on a local street in a residential area. It may be considered on a local street in an industrial area to facilitate operation. If superelevation is used, the curve should be designed for a maximum superelevation rate of 4%. If terrain dictates sharp curvature, a maximum superelevation rate of 6% is justified if the curve is long enough to provide an adequate superelevation transition.

The low-speed urban street condition may be used for a superelevating street in an urban or urbanized area where $V \leq 45$ mph. A superelevation rate of 6% is considered the maximum desirable rate for low-speed urban street design. On such a facility, providing superelevation at a horizontal curve is frequently impractical because of roadside conditions and may result in undesirable operational conditions. The following lists some of the characteristics of a low-speed urban street which often complicate superelevation development.

1. Roadside Development, Intersection, or Drive. Built-up roadside development is commonly adjacent to a low-speed urban street. Matching a superelevated curve with a drive, intersection, sidewalk, etc., creates considerable complications. This may also require re-shaping a parking lot, lawn, etc., to compensate for the higher elevation of the high side of the superelevated curve.

2. Non-Uniform Travel Speed. 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 if snow or ice is present.

3. Limited Right of Way. Superelevating a curve often results in more right-of-way impacts than would otherwise be necessary. Right of way is often restricted.

4. <u>Wide Pavement Area</u>. A low-speed urban street may have wide pavement areas because of high traffic volume in a built-up area, the absence of a median, or the presence of parking lanes. The wider the pavement area, the more complicated will be the development of superelevation.

5. <u>Surface Drainage</u>. Proper pavement drainage can be difficult with a normal crown. Superelevation introduces another complicating factor.

As discussed in Section 43-2.0, AASHTO Method 2 is used to distribute superelevation and side friction in determining the superelevation rate for the design of a horizontal curve on a low-speed urban street. A relatively high side-friction factor is used. The practical impact is that superelevation is rarely warranted on such a facility.

The higher side-friction factor for a low-speed urban street is consistent with driver acceptance of more discomfort in an urban area.

43-3.02(02) Superelevation Rate

Figure 43-3C is used to determine the superelevation rate for a horizontal curve of given radius on a low-speed urban street of given design speed. The figure is divided into three areas. The following examples illustrate how to use Figure 43-3C for site conditions within each area.

* * * * * * * * *

<u>Example 43-3.1</u>

Given: Design speed = 35 mph
Radius = 600 ft
Cross slope (on tangent) = 2%

Problem: Determine the superelevation rate.

Solution: From Figure 43-3C the required superelevation rate = -0.043. Since this value is negative, a normal crown section should be maintained throughout the curve (i.e., e = -0.020).

Example 43-3.2

Given: Design speed = 35 mph
Radius = 450 ft

Problem: Determine the superelevation rate.

Solution: From Figure 43-3C, the required superelevation rate = +0.006. This occurs in the area where the roadway may be uniformly superelevated at the cross slope of the roadway on tangent (typically 0.020). This is the desirable treatment. However, it is acceptable to superelevate the roadway at the theoretical superelevation rate (+0.006), if this is consistent with field conditions (e.g., surface drainage will work properly).

Example 43-3.3

Given: Design speed = 35 mph
Radius = 390 ft

Problem: Determine the superelevation rate.

Solution: Figure 43-3C yields a required superelevation rate = +0.03. Therefore, the entire pavement should be transitioned to this rate.

* * * * * * * * *

43-3.02(03) Minimum Radius Without Superelevation

On a low-speed urban street, a horizontal curve with a sufficiently large radius does not require superelevation; therefore, the normal crown section can be maintained around a curve. The threshold exists where the theoretical superelevation equals -0.02. The lower boundary of the shaded area in Figure 43-3C illustrates this threshold. For convenience, see Figure 43-3D, Curve Radius for Normal-Crown Section and Remove (Adverse)-Crown Section (Low-Speed Urban Street).

43-3.03 Transition Length, Open-Roadway Condition

As defined in Section 43-1.0, the superelevation transition length is the distance required to transition the roadway from a normal crown section to the full design superelevation (as determined from the figures based on the selected e_{max}). The superelevation transition length is the sum of the tangent runout distance, *TR*, and superelevation runoff length, *L*.

43-3.03(01) Two-Lane Roadway

1. Superelevation Runoff. Figure 43-3A(1) shows the superelevation runoff length, L_2, for various combinations of curve radius and design speed. The length is calculated as follows:

$$L_2 = We(RS) \quad \text{(Equation 43-3.1)}$$

Where:

L_2 = Superelevation runoff length (assuming the axis of rotation is about the roadway centerline), ft

W = Width of rotation (assumed to be 12 ft)

e = Superelevation rate

RS = Reciprocal of relative longitudinal slope between the profile grade and outside edge of roadway (see Figure 43-3E)

The superelevation runoff length applies to the following:

a. a 2-lane, 2-way roadway rotated about its centerline; or

b. either directional roadway of a 4-lane divided facility, rotated about its centerline independently of the other roadway [see Section 43-3.03(02)].

2. <u>Tangent Runout</u>. The tangent runout distance is calculated as follows:

$$TR = \frac{L_2 S_{normal}}{e} \qquad \text{(Equation 43-3.2)}$$

Where:

TR = Tangent runout distance, ft

L_2 = Superelevation runoff length, ft (Equation 43-3.1)

S_{normal} = Travel lane cross slope on tangent (typically 0.02)

e = Design superelevation rate (i.e., full superelevation for horizontal curve)

This will ensure that the relative longitudinal gradient of the tangent runout equals that of the superelevation runoff.

43-3.03(02) Highway with 4 or More Lanes

1. <u>Superelevation Runoff</u>. The superelevation runoff distance is calculated as follows:

$$L = \frac{w n_1 e b_w}{G} \qquad \text{(Equation 43-3.3)}$$

Where:

L = Superelevation runoff length, ft, rounded up to the next 15-ft increment

w = Width of one traffic lane, ft

n_1 = Number of lanes rotated

e = Design superelevation rate, %

b_w = Adjustment factor for number of lanes rotated (see Figure 43-3G)

G = Maximum relative gradient, %

2. Tangent Runout. The tangent runout distance is calculated from Equation 43-3.2, same as for a two-lane roadway.

   The length of tangent runout is determined by the amount of adverse cross slope to be removed and the rate at which it is removed. To effect a smooth edge of pavement profile, the rate of removal should equal the relative gradient used to define the superelevation runoff length.

   The cross slope may not be constant across all lanes. If there are three lanes sloped in the same direction, the first two lanes will be sloped at 2% and the third will be sloped at 3%. See Section 45-1.01(02) Item 2.b.

   This will ensure that the relative longitudinal gradient of the tangent runout equals that of the superelevation runoff.

43-3.03(03) Application of Transition Length

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

1. Simple Curve. Typically, 75% of the superelevation runoff length will be placed on the tangent and the remainder on the curve. Exceptions to this practice may be necessary to meet field conditions. The superelevation runoff may be distributed 50% to 70% on the tangent and 50% to 30% on the curve. It is acceptable to use Figure 43-3F to determine the percent of superelevation runoff to place on the tangent before the PC.

2. Reverse Curve. See Section 43-3.07 for a discussion on superelevation development for a reverse curve.

3. Vertical Profile. At the beginning and ending of the superelevation transition, angular breaks would occur in the profile if it is not smoothed. These abrupt angular breaks should be smoothed by the insertion of short vertical curves at the two angle points. As a guide, the transitions should have a length of 60 ft.

4. Ultimate Development. If the facility is planned for ultimate development to an expanded facility, the designer should, where practical, reflect this in the initial superelevation-transition application. For example, a four-lane divided facility may be planned to ultimately be a six-lane divided facility. Therefore, the superelevation runoff

length for the initial four-lane facility should be consistent with the future requirements of the six-lane facility. See Section 43-3.05.

43-3.03(04) Superelevation-Development Figures

Figures 43-3H, 43-3 I, 43-3J, and 43-3K are the figures for superelevation development. The following describes each figure.

1. Two-Lane Roadway. Figure 43-3H illustrates the superelevation development for a 2-lane roadway. The axis of rotation is about the centerline of the roadway.

2. Four-Lane Divided with No Future Third Lane. Figure 43-3 I illustrates the superelevation development for this situation. The axes of rotation are about the two median edges.

3. Six-Lane Divided or Four-Lane Divided with Future Third Lane. Figure 43-3J illustrates the superelevation development for this situation. The axes of rotation are about the two median edges or, where the future third lane is anticipated in the median, about the two future median edges. The figure illustrates how to treat the travel lane with a steeper cross slope (i.e., 3%).

4. Median Barrier. Figure 43-3K illustrates the superelevation development for a divided highway with a median barrier. The axes of rotation are about the two edges of the median barrier, which allows the barrier to remain within a horizontal plane throughout the horizontal curve. The figure illustrates how to treat the two inside shoulders in the superelevation development.

These figures provide acceptable methods for superelevation development which will often be applicable to typical site conditions. Other superelevation methods or strategies should be developed as required to meet specific field conditions. For example, several highway features may significantly influence superelevation development for a divided highway. These include guardrail, median barrier, drainage, or other field conditions. The designer should consider the intended functions of these features and ensure that the superelevated section and selected axis of rotation does not compromise their operation. The acceptability of superelevation-development methods other than those in the figures should be judged individually.

For a divided facility, the figures provide the superelevation development for the inside and outside roadways separately. The coordination between the two roadways for a given station number will be determined individually. The superelevation development for each roadway should begin such that full superelevation for each roadway is reached simultaneously (i.e., at the same station).

43-3.04 Transition Length, Low-Speed Urban Street

A low-speed urban street is an urban facility where $V \leq 45$ mph. If the open-roadway condition is used to determine the superelevation rate, the superelevation transition length should be determined by means of the criteria for the open-roadway condition (Section 43-3.03). If the superelevation rate is determined by means of the low-speed urban street condition, the superelevation transition length may be determined by means of the criteria described below.

43-3.04(01) Two-Lane Roadway

1. Superelevation Runoff. Figure 43-3L provides the minimum superelevation runoff length, L_2, for a 2-lane roadway. Using a straight-line interpolation to determine an intermediate superelevation rate, the superelevation runoff may be calculated for any design speed and superelevation rate.

   If L_2 is less than the value of L_r shown in AASHTO *Policy on Geometric Design of Highways and Streets* Exhibit 3-32, use the value shown in the Exhibit.

   For a site-specific situation, the Exhibit 3-32 value of L_r may not be attainable. If so, a Level One design exception request should be submitted for approval.

2. Tangent Runout. The tangent runout distance can be calculated from Equation 43-3.2, using L_2 from Figure 43-3L. This will ensure that the relative longitudinal gradient of the tangent runout equals that of the superelevation runoff.

43-3.04(02) Highway with 4 or More Lanes

Section 43-3.03 provides criteria for superelevation transition length for such a highway assuming the open-roadway condition. This is accomplished by providing an adjustment factor, C, to apply to the transition length, L_2, for a 2-lane, 2-way roadway. The procedures and formulas in Section 43-3.03 also apply to a highway with 4 or more lanes assuming the low-speed urban street condition, except that L_2 will be based on Figure 43-3L.

43-3.04(03) Application of Transition Length

The criterion provided in Section 43-3.03 for the open-roadway condition also applies to a low-speed urban street.

43-3.05 Axis of Rotation

The following discusses the axis of rotation for a 2-lane, 2-way highway or highway with 4 or more lanes. Section 43-3.03 provides figures illustrating the application of the axis of rotation in superelevation development.

43-3.05(01) Two-Lane, Two-Way Highway

The axis of rotation will be about the centerline of the roadway. This method will yield the least amount of elevation differential between the pavement edges and their normal profiles. It is acceptable to rotate about the inside or outside edge of the travelway. This may be necessary to meet field conditions (e.g., drainage on a curbed facility, roadside development).

On a 2-lane highway with an auxiliary lane (e.g., a climbing lane), the axis of rotation will be about the centerline of the two through lanes.

43-3.05(02) Divided Highway

If no future travel lanes are planned, the axes of rotation will be about the two median edges. Where these are used as the axes, the median will remain in a horizontal plane throughout the curve. Depending upon field conditions, the axes of rotation may be about the centerlines of the two roadways. Unless the two roadways are on independent alignments, this method results in different elevations at the median edges and, therefore, a compensating slope is necessary across the median. On a narrow median, the axis of rotation may be about the centerline of the entire roadway cross section.

The figures in Section 43-3.03 illustrate the axis of rotation for a divided highway.

43-3.06 Shoulder Superelevation

43-3.06(01) High-Side Shoulder

The following will apply to the shoulder slope.

1. Application. The high-side shoulder will be sloped as follows:

   a. If the superelevation rate on the curve is 4% or less, use 4% (its normal cross slope).

   b. If the superelevation rate on the curve is greater than 4% but less than or equal to 6%, use 2% down away from the traveled way.

   c. If the superelevation rate on the curve is greater than 6%, use 1% towards the traveled way.

   d. Where the paved median shoulder is the high-side shoulder and is 4 ft or narrower, it should be sloped in the same plane as the travelway. See Figure 43-3M, Paved-Shoulder Cross Slopes, Superelevated Section, With Underdrains; or Figure 43-3N, Paved-Shoulder Cross Slopes, Superelevated Section, Without Underdrains, for more-specific information.

2. Maximum Rollover. Where the typical application cannot be provided, the high-side shoulder must be sloped such that the algebraic difference between the shoulder and adjacent travel lane will not exceed 8%.

3. Shoulder as Deceleration Lane. A driver may use a paved shoulder as a right-turn lane on a superelevated horizontal curve. Chapter Forty-six provides cross-slope breakover criteria between a turning roadway and a through travel lane at an intersection at-grade. Where the shoulder is used by a turning vehicle, the designer should limit the shoulder rollover to the turning roadway breakover criteria (4% to 5%).

43-3.06(02) Low-Side (Inside) Shoulder

The normal shoulder slope should be retained until the adjacent superelevated travel lane reaches that slope. The shoulder is then superelevated concurrently with the travel lane until the design superelevation is reached (i.e., the inside shoulder and travel lane will remain in a plane section).

43-3.07 Reverse Curve

A reverse curve is two closely-spaced simple curves with deflections in opposite directions. For this situation, 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 used between the two curves, if they are close enough together. The applicable superelevation-development criteria should be used for each curve. The following will apply to a reverse curve.

1. Normal Section. The designer should not attempt to achieve a normal tangent section between the two curves unless the normal section can be maintained for a minimum of two seconds of travel time, and the superelevation-transition requirements can be met for both curves.

2. Continuously-Rotating Plane. If a normal section is not provided, the pavement will be continuously rotated in a plane about its axis. The minimum distance between the PT and PC will be that needed to meet the superelevation-transition requirements for the two curves (e.g., distribution of superelevation runoff between the tangent and curve).

43-3.08 Bridge

If practical, a horizontal curve or superelevation transition should be avoided on a bridge. A bridge should be placed within a curve if this results in a more desirable alignment on either approaching roadway. If a superelevation transition is unavoidable on a bridge, see Section 59-1.01(01) for recommendations. However, if properly designed and constructed, a bridge will function adequately where this occurs.

43-4.0 HORIZONTAL SIGHT DISTANCE

43-4.01 Sight Obstruction Definition

A sight obstruction on the inside of a horizontal curve is defined as an obstacle of considerable length which continuously interferes with the line of sight. This includes a guardrail, bridge railing, median barrier, wall, cut slope, wooded area, building, or tall farm crop. A barrier to the line of sight should be assumed to be constructed on the right-of-way line. A point obstacle such as a traffic sign or utility pole is not considered a sight obstruction. The designer must examine each curve individually to determine whether it is necessary to remove an obstruction, increase the offset to the obstruction, or increase the radius to obtain the required sight distance. However, the shoulder width should not exceed 12 ft.

43-4.02 Curve Length Relative to Stopping Sight Distance

1. Curve Length > Stopping Sight Distance. Where the length of curve, *L*, is greater than the stopping sight distance, *S*, used for design, the needed clearance on the inside of the horizontal curve is calculated as follows:

$$M = R\left[1 - \cos\left(\frac{28.65S}{R}\right)\right] \qquad \text{(Equation 43-4.1)}$$

Where:

M = Middle ordinate, or distance from the center of the inside travel lane to the obstruction, ft

R = Radius of curve, ft

S = Stopping sight distance, ft

2. Curve Length ≤ Stopping Sight Distance. Where the length of curve is less than or equal to the stopping sight distance, the design should be checked graphically or by utilizing a computational method.

43-4.02(01) Stopping Sight Distance (SSD)

At a minimum, SSD will be available throughout the horizontal curve. Figure 43-4A provides the horizontal clearance criteria (i.e., middle ordinate) for various combinations of stopping sight distance and curve radius. For those selections of *S* which appear outside of the range of values in the figure (i.e., $M > 50$ ft or $R < 165$ ft), the designer should use Equation 43-4.1 to calculate the needed clearance. The Example in Figure 43-4C illustrates the determination of clearance requirements for entering or exiting from a horizontal curve.

43-4.02(02) Other Sight Distance Criteria

It may be warranted to provide SSD for trucks, or decision sight distance or passing sight distance at the horizontal curve. Chapter Forty-two discusses candidate sites and provides design values for such sight-distance criteria. These *S* values should be used in the basic equation to calculate *M* (Equation 43-4.1).

43-4.02(03) Entering and Exiting Portions

The *M* value from Figure 43-4A applies between the PC and PT. Some transition is needed on the entering and exiting portions of the curve. The procedure is as follows.

1. Locate the point which is on the outside edge of shoulder and a distance of *S*/2 before the PC.

2. Locate the point which is a distance *M* measured laterally from the center of the inside travel lane at the PC.

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.

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

The Example in Figure 43-4C illustrates the determination of clearance requirements for entering or exiting from a curve.

43-4.03 Application

For application, the height of eye is 3.5 ft and the height of object is 2 ft. Both the eye and object are assumed to be in the center of the inside travel lane. If the lane width for a ramp is wider than 12 ft, the horizontal stopping sight distance should be calculated by placing the eye and object 6 ft from the edge of the lane on the inside of the curve.

43-4.04 Longitudinal Barrier

A longitudinal barrier (e.g., bridge railing, guardrail, median barrier) can cause sight distance problems at a horizontal curve, since a barrier is placed relatively close to the travel lane (often, 10 ft or less) and its height is greater than 2 ft.

The designer should check the line of sight over a barrier along a horizontal curve and attempt, if practical, to locate the barrier such that it does not block the line of sight. The following should be considered.

1. Superelevation. The designer should account for the superelevation in the calculations.

2. Grade. The line of sight over a barrier may be improved for a driver on an upgrade or lessened on a downgrade.

3. Barrier Height. The higher the barrier, the more obstructive it will be to the line of sight.

Each barrier location on a horizontal curve will require an individual analysis to determine its impacts on the line of sight. The designer must determine the height of the driver's eye, the height of the object, and the height of the barrier where the line of sight intercepts the barrier run. If the barrier does block the line of sight to a 2-ft height object, the designer should consider relocating the barrier or revising the horizontal alignment. If the barrier blocks the sight distance needed for minimum SSD on the mainline, it will be necessary to obtain a design exception.

43-5.0 DESIGN CONTROLS AND PROCEDURE

43-5.01 General Controls

As discussed in Chapter Forty-three, the design of horizontal alignment involves complying with specific limiting criteria. These include minimum radius, superelevation rate, and sight distance around a curve. Certain design principles and controls should be considered which will determine the overall safety of the facility and will enhance the aesthetic appearance of the highway. These design principles include the following.

1. Consistency. Alignment should be consistent. A sharp curve at the end of a long tangent, or a sudden change from gently- to sharply-curving alignment should be avoided.

2. Direction. Alignment should be as directional as possible, consistent with physical and economic constraints. On a divided highway, a flowing line that conforms generally to

the natural contours is preferable to one with long tangents that slash through the terrain. Directional alignment will be achieved by using the smallest practical central angle.

3. Use of Minimum Radius. The use of the minimum radius should be avoided if practical.

4. High Fill. Avoid a sharp curve on a long, high fill. Under this condition, it is difficult for a driver to perceive the extent of horizontal curvature.

5. Alignment Reversal. Avoid an abrupt reversal in alignment, such as an S or reverse curve. Provide a sufficient tangent distance between two curves to ensure proper superelevation transitions for both curves.

6. Broken-Back Curvature. Avoid this where possible. This arrangement is not aesthetically pleasing, it violates driver expectancy, and it creates undesirable superelevation-development requirements.

7. Compound Curve. Avoid the use of a compound curve on the highway mainline. This may fool the driver when judging the sharpness of a horizontal curve.

8. Coordination with Natural or Man-Made Feature. The horizontal alignment should be properly coordinated with the existing alignment at the ends of the project, natural topography, available right-of-way, utilities, roadside development, or natural or man-made drainage patterns.

9. Environmental Impact. Horizontal alignment should be properly coordinated with environmental impact (e.g., encroachment onto wetlands).

10. Intersection. Horizontal alignment through an intersection may present problems (e.g., intersection sight distance, superelevation development). See Chapter Forty-six for the design of an intersection at-grade.

11. Coordination with Vertical Alignment. Chapter Forty-four discusses design principles for the coordination between horizontal and vertical alignments.

43-5.02 Coordination

In the design of horizontal alignment, the designer should be aware of the responsibility to communicate properly with other INDOT personnel (e.g., drafting, field survey):

1. Preparation of Plans. Part II discusses the content and format of plans sheets, abbreviations, symbols, scales, and the use of the Department's CADD system. The designer must ensure that the design of the horizontal alignment is consistent with Department practices.

2. Surveying. Part III provides the Department's procedures and criteria for surveying practice.

3. Mathematical Computations. Section 43-6.0 provides figures which include the needed mathematical equations and techniques to make various computations for a horizontal curve.

43-6.0 MATHEMATICAL DETAILS FOR HORIZONTAL CURVE

This Section provides mathematical details used for various applications to the design of a horizontal curve. Figure 43-6A summarizes the figures in the Section.

Design Speed, V (mph)	f_{max}	Minimum Radius, R_{min} (ft)
15	0.32	40
20	0.27	75
25	0.23	135
30	0.20	215
35	0.18	315
40	0.16	445
45	0.15	585
50	0.14	760
55	0.13	960
60	0.12	1200
65	0.11	1480
70	0.10	1810

$$R_{\min} = \frac{V^2}{15(e + f_{\max})} \quad \text{where } e = 0.08$$

Note: The value of R_{min} *for design has been rounded to the nearer 5-ft increment.*

MINIMUM RADIUS
Open-Roadway Conditions

Figure 43-2A

Back

Design Speed, *V* (mph)	*e*	f_{max}	Minimum Radius, R_{min} (ft)
15	0.04	0.32	40
20		0.27	85
25		0.23	155
30		0.20	250
35		0.18	370
40		0.16	535
45		0.15	710
15	0.06	0.32	40
20		0.27	80
25		0.23	145
30		0.20	230
35		0.18	340
40		0.16	485
45		0.15	645

$$R_{\min} = \frac{V^2}{15(e + f_{\max})}$$

Note: The value of R_{min} *for design has been rounded up to the nearer 5-ft increment*

MINIMUM RADIUS
Low-Speed Urban Street, $V \leq 45$ mph

Figure 43-2B

Back

e (%)	V_d = 15 mph R (ft)	V_d = 20 mph R (ft)	V_d = 25 mph R (ft)	V_d = 30 mph R (ft)	V_d = 35 mph R (ft)	V_d = 40 mph R (ft)	V_d = 45 mph R (ft)	V_d = 50 mph R (ft)	V_d = 55 mph R (ft)	V_d = 60 mph R (ft)
1.5	796	1410	2050	2830	3730	4770	5930	7220	8650	10300
2.0	506	902	1340	1880	2490	3220	4040	4940	5950	7080
2.2	399	723	1110	1580	2120	2760	3480	4280	5180	6190
2.4	271	513	838	1270	1760	2340	2980	3690	4500	5410
2.6	201	388	650	1000	1420	1930	2490	3130	3870	4700
2.8	157	308	524	817	1170	1620	2100	2660	3310	4060
3.0	127	251	433	681	982	1370	1800	2290	2860	3530
3.2	105	209	363	576	835	1180	1550	1980	2490	3090
3.4	88	175	307	490	714	1010	1340	1720	2170	2700
3.6	73	147	259	416	610	865	1150	1480	1880	2350
3.8	61	122	215	348	512	730	970	1260	1600	2010
4.0	42	86	154	250	371	533	711	926	1190	1500

Note: *Use of* e_{max} = 4% should be limited to urban conditions.
e = *1.5* is Normal Crown.
e = *2.0* is Remove (Adverse) Crown

MINIMUM RADIUS, *R*, FOR DESIGN SUPERELEVATION RATE, *e*, DESIGN SPEED, V_d, AND e_{max} = 4%

Figure 43-3A(1)

Back

e (%)	V_d = 15 mph R (ft)	V_d = 20 mph R (ft)	V_d = 25 mph R (ft)	V_d = 30 mph R (ft)	V_d = 35 mph R (ft)	V_d = 40 mph R (ft)	V_d = 45 mph R (ft)	V_d = 50 mph R (ft)	V_d = 55 mph R (ft)	V_d = 60 mph R (ft)	V_d = 65 mph R (ft)	V_d = 70 mph R (ft)
1.5	868	1580	2290	3130	4100	5230	6480	7870	9410	11100	12600	14100
2.0	614	1120	1630	2240	2950	3770	4680	5700	6820	8060	9130	10300
2.2	543	991	1450	2000	2630	3370	4190	5100	6110	7230	8200	9240
2.4	482	884	1300	1790	2360	3030	3770	4600	5520	6540	7430	8380
2.6	430	791	1170	1610	2130	2740	3420	4170	5020	5950	6770	7660
2.8	384	709	1050	1460	1930	2490	3110	3800	4580	5440	6200	7030
3.0	341	635	944	1320	1760	2270	2840	3480	4200	4990	5710	6490
3.2	300	566	850	1200	1600	2080	2600	3200	3860	4600	5280	6010
3.4	256	498	761	1080	1460	1900	2390	2940	3560	4250	4890	5580
3.6	209	422	673	972	1320	1740	2190	2710	3290	3940	4540	5210
3.8	176	358	583	864	1190	1590	2010	2490	3040	3650	4230	4860
4.0	151	309	511	766	1070	1440	1840	2300	2810	3390	3950	4550
4.2	131	270	452	684	960	1310	1680	2110	2590	3140	3680	4270
4.4	116	238	402	615	868	1190	1540	1940	2400	2920	3440	4010
4.6	102	212	360	555	788	1090	1410	1780	2210	2710	3220	3770
4.8	91	189	324	502	718	995	1300	1640	2050	2510	3000	3550
5.0	82	169	292	456	654	911	1190	1510	1890	2330	2800	3330
5.2	73	152	264	413	595	833	1090	1390	1750	2160	2610	3120
5.4	65	136	237	373	540	759	995	1280	1610	1990	2420	2910
5.6	58	121	212	335	487	687	903	1160	1470	1830	2230	2700
5.8	51	106	186	296	431	611	806	1040	1320	1650	2020	2460
6.0	39	81	144	231	340	485	643	833	1060	1330	1660	2040

$e = 1.5$ is Normal Crown.

$e = 2.0$ is Remove (Adverse) Crown

MINIMUM RADIUS, R, FOR DESIGN SUPERELEVATION RATE, e, DESIGN SPEED, V_d, AND e_{max} = 6%

Figure 43-3A(2)

Back

e (%)	V_d = 15 mph R (ft)	V_d = 20 mph R (ft)	V_d = 25 mph R (ft)	V_d = 30 mph R (ft)	V_d = 35 mph R (ft)	V_d = 40 mph R (ft)	V_d = 45 mph R (ft)	V_d = 50 mph R (ft)	V_d = 55 mph R (ft)	V_d = 60 mph R (ft)	V_d = 65 mph R (ft)	V_d = 70 mph R (ft)
1.5	932	1640	2370	3240	4260	5410	6710	8150	9720	11500	12900	14500
2.0	676	1190	1720	2370	3120	3970	4930	5990	7150	8440	9510	10700
2.2	605	1070	1550	2130	2800	3570	4440	5400	6450	7620	8600	9660
2.4	546	959	1400	1930	2540	3240	4030	4910	5870	6930	7830	8810
2.6	496	872	1280	1760	2320	2960	3690	4490	5370	6350	7180	8090
2.8	453	796	1170	1610	2130	2720	3390	4130	4950	5850	6630	7470
3.0	415	730	1070	1480	1960	2510	3130	3820	4580	5420	6140	6930
3.2	382	672	985	1370	1820	2330	2900	3550	4250	5040	5720	6460
3.4	352	620	911	1270	1690	2170	2700	3300	3970	4700	5350	6050
3.6	324	572	845	1180	1570	2020	2520	3090	3710	4400	5010	5680
3.8	300	530	784	1100	1470	1890	2360	2890	3480	4140	4710	5350
4.0	277	490	729	1030	1370	1770	2220	2720	3270	3890	4450	5050
4.2	255	453	678	955	1280	1660	2080	2560	3080	3670	4200	4780
4.4	235	418	630	893	1200	1560	1960	2410	2910	3470	3980	4540
4.6	215	384	585	834	1130	1470	1850	2280	2750	3290	3770	4210
4.8	193	349	542	779	1060	1390	1750	2160	2610	3120	3590	4100
5.0	172	314	499	727	991	1310	1650	2040	2470	2960	3410	3910
5.2	154	284	457	676	929	1230	1560	1930	2350	2820	3250	3740
5.4	139	258	420	627	870	1160	1480	1830	2230	2680	3110	3570
5.6	126	236	387	582	813	1090	1390	1740	2120	2550	2970	3420
5.8	115	216	358	542	761	1030	1320	1650	2010	2430	2840	3280
6.0	105	199	332	506	713	965	1250	1560	1920	2320	2710	3150
6.2	97	184	308	472	669	909	1180	1480	1820	2210	2600	3020
6.4	89	170	287	442	628	857	1110	1400	1730	2110	2490	2910
6.6	82	157	267	413	590	808	1050	1330	1650	2010	2380	2790
6.8	76	146	248	386	553	761	990	1260	1560	1910	2280	2690
7.0	70	135	231	360	518	716	933	1190	1480	1820	2180	2580
7.2	64	125	214	336	485	672	878	1120	1400	1720	2070	2470
7.4	59	115	198	312	451	628	822	1060	1320	1630	1970	2350
7.6	54	105	182	287	417	583	765	980	1230	1530	1850	2230
7.8	48	94	164	261	380	533	701	901	1140	1410	1720	2090
8.0	38	76	134	214	314	444	587	758	960	1200	1480	1810

$e = 1.5$ is Normal Crown.

$e = 2.0$ is Remove (Adverse) Crown

MINIMUM RADIUS, *R*, FOR DESIGN SUPERELEVATION RATE, *e*, DESIGN SPEED, V_d, AND e_{max} = 8%

Figure 43-3A(3)

Back

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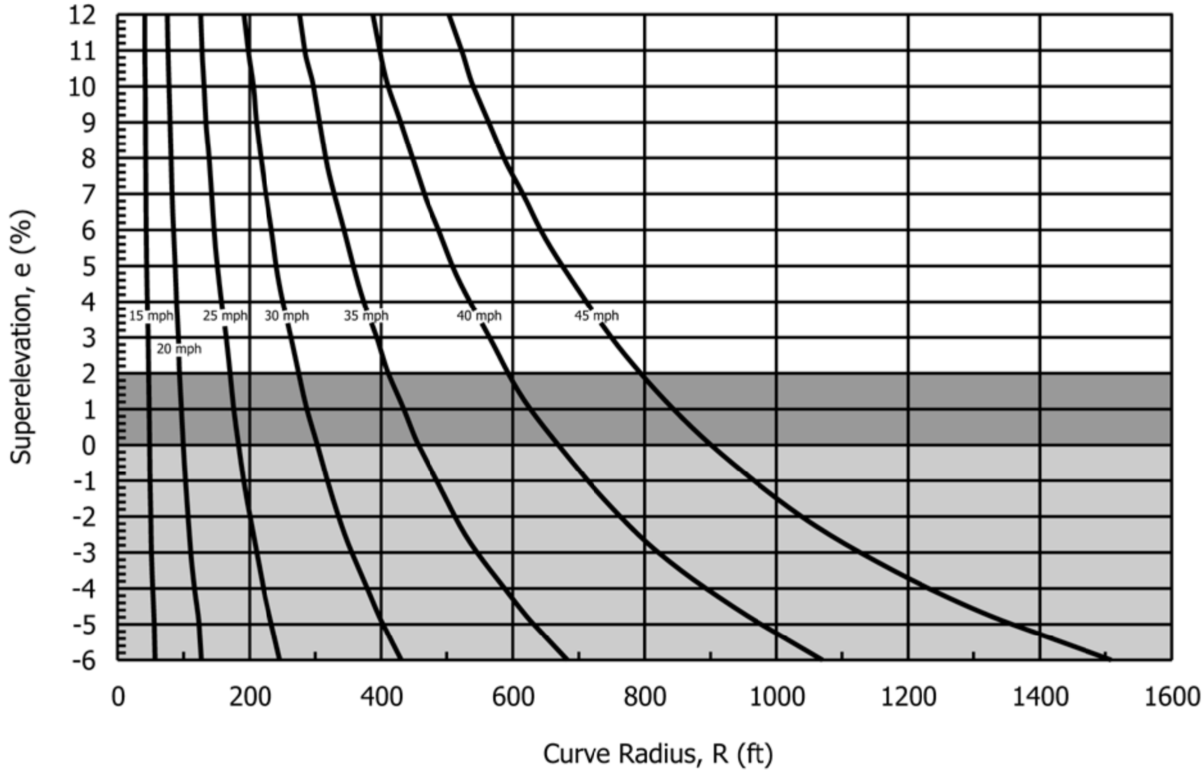
Normal Crown and Remove (Adverse) Crown curve radii can be found on Figures 43-3A(1), 43-3A(2), and 43-3A(3).

CURVE RADII FOR NORMAL CROWN AND REMOVE CROWN SECTIONS

Figure 43-3B

Back



Notes:

1. Figure denotes three areas for the determination of superelevation rates. See Section 43-3.02 for examples on how to use the figure.

2. The basic equation for the figure is: $R = \dfrac{V^2}{15\,(e + f)}$

   Where:
   R = curve radius, ft.
   V = design speed, mph
   e = super elevation rate
   f = side-friction factor

3. Negative superelevation values beyond -2.0 percent should be used for a low-type surface such as gravel, crushed stone, or earth. However a normal cross slope of -2.5 percent can be used on a high-type surface in an area with intense rainfall.

SUPERELEVATION RATE FOR
LOW-SPEED URBAN STREET

Figure 43-3C

Back

Design Speed, V (mph)	Curve Radius, R (ft)		
	[See Figure 43-3C]	Remove (Adverse) Crown *	Normal Crown
20	< 92	$92 \leq R < 107$	≥ 107
25	< 167	$167 \leq R < 198$	≥ 198
30	< 273	$273 \leq R < 333$	≥ 333
35	< 408	$408 \leq R < 510$	≥ 510
40	< 593	$593 \leq R < 762$	≥ 762
45	< 794	$794 \leq R < 1038$	≥ 1038

* The shaded area in Figure 43-4C reflects these radius ranges. In one of these ranges, it is desirable to remove the crown and superelevate the roadway at a uniform cross slope, *e*, of +0.02. However, it is acceptable to superelevate at the theoretical rate from Figure 43-3C, if consistent with field conditions.

Note: The limit for normal crown is based on a theoretical superelevation rate, *e*, of -0.02. The upper limit for remove (adverse) crown is based on a theoretical superelevation rate, *e*, of +0.02. The radius is calculated from the formula as follows:

$$R = \frac{V^2}{15(e + f)}$$

RADIUS FOR NORMAL-CROWN SECTION
AND REMOVE (ADVERSE)-CROWN SECTION
(Low-Speed Urban Street)

Figure 43-3D

Back

Design Speed (mph)	Equivalent Max. *RS*	Edge-of-Travelway Slope Relative to Centerline G_{max} (%)
15	128	0.78
20	135	0.74
25	143	0.70
30	152	0.66
35	161	0.62
40	172	0.58
45	185	0.54
50	200	0.50
55	213	0.47
60	222	0.45
65	233	0.43
70	250	0.40

$$G_{\max} = \frac{100}{RS}$$

RELATIVE LONGITUDINAL SLOPES
(Two-Lane Roadway)

Figure 43-3E

Back

V (mph)	Number of Lanes Rotated			
	1	1.5	2 or 2.5	3 or 3.5
15 - 45	80%	85%	90%	90%
50 - 70	70%	75%	80%	85%

PORTION OF SUPERELEVATION RUNOFF ON TANGENT, %

Figure 43-3F

Back

Number of Lanes Being Rotated*	b_w
1	1.0
1½	0.83
2	0.75
2½	0.70
3	0.67
3½	0.64

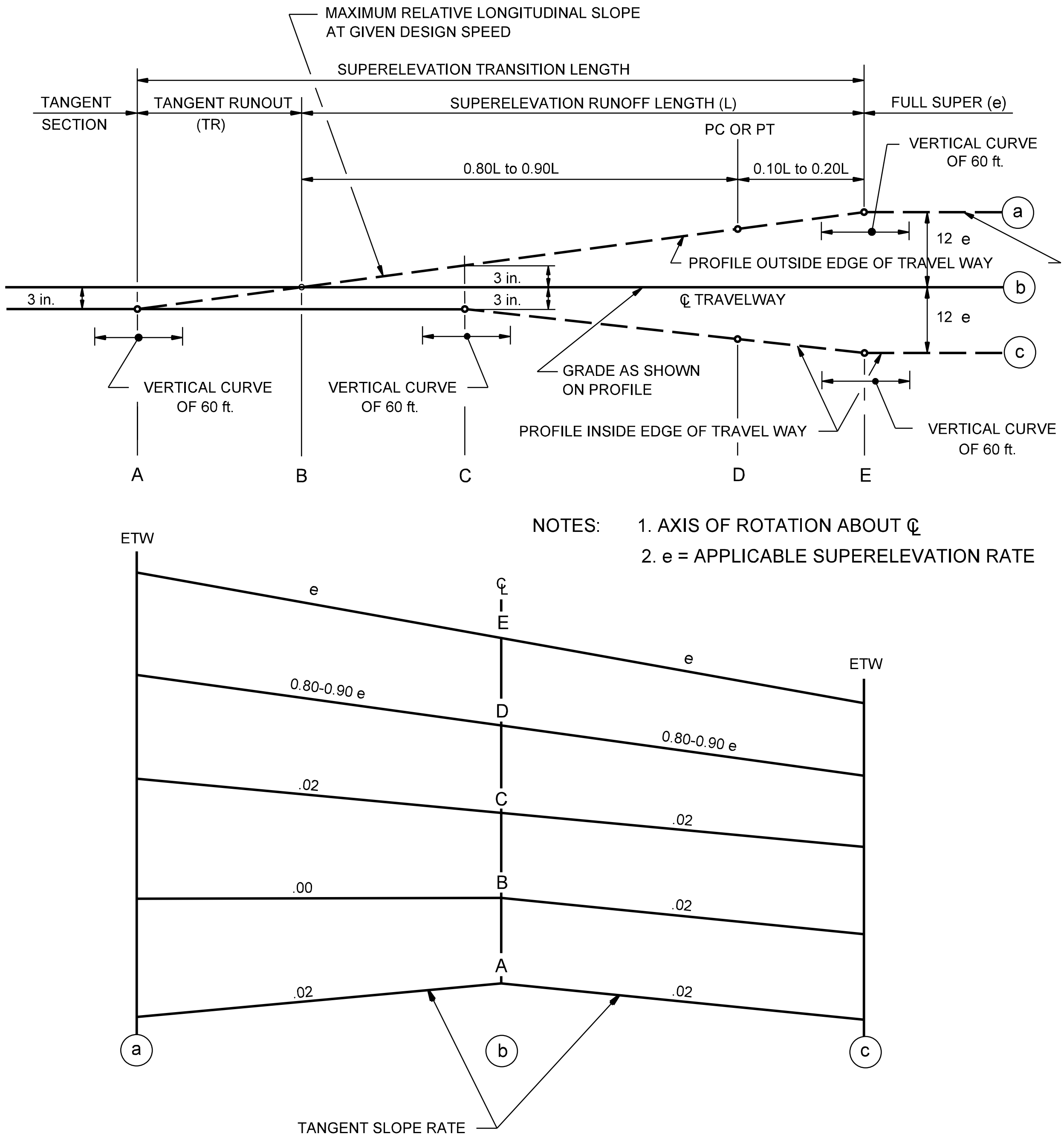
* *This column refers to the number of lanes being rotated on either side of the axis rotation. Select the higher value.*

As an example, consider a 5-lane roadway (i.e., four through lanes and a two-way, left-turn lane (TWLTL) with the axis of rotation in the center of the TWLTL. In this case, the number of lanes being rotated is 2.5; therefore, $b_w = 0.70$.

bw VALUES
(Superelevation Runoff Lengths, Multilane Highways)

Figure 43-3G

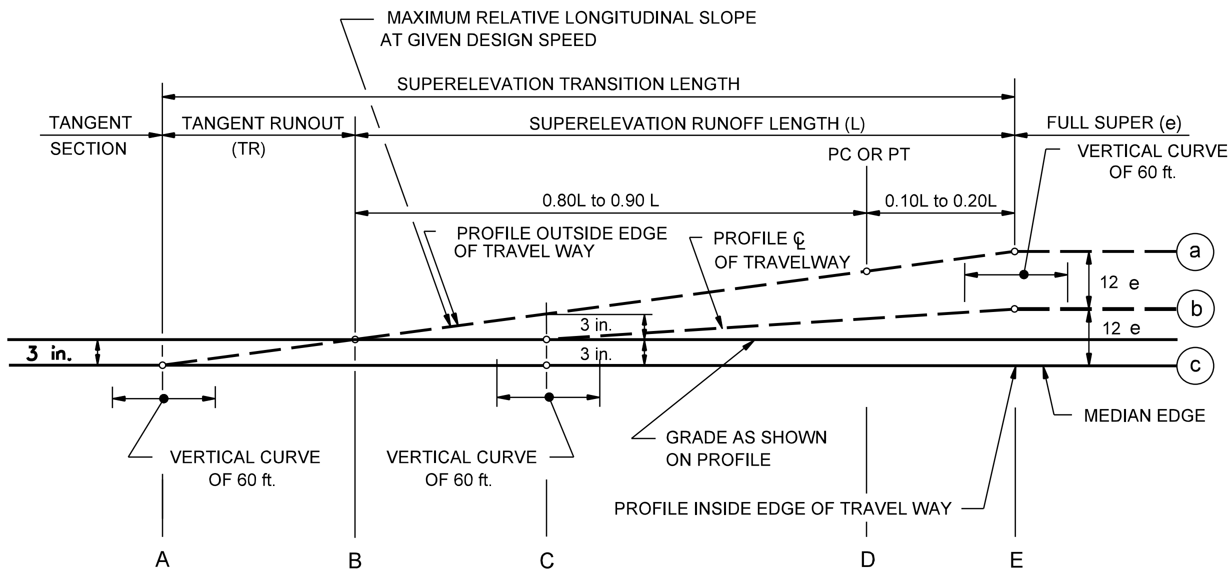
Back



SUPERELEVATION DEVELOPMENT
(Two-Lane Roadways)

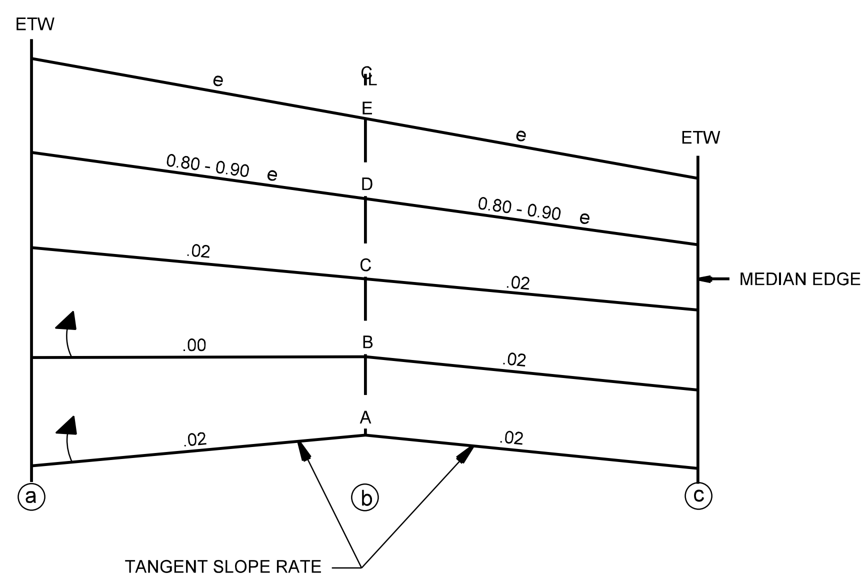
Figure 43-3H

Back



OUTSIDE ROADWAY

NOTES:
1. AXES OF ROTATION ABOUT TWO MEDIAN EDGES
2. e = APPLICABLE SUPERELEVATION RATE

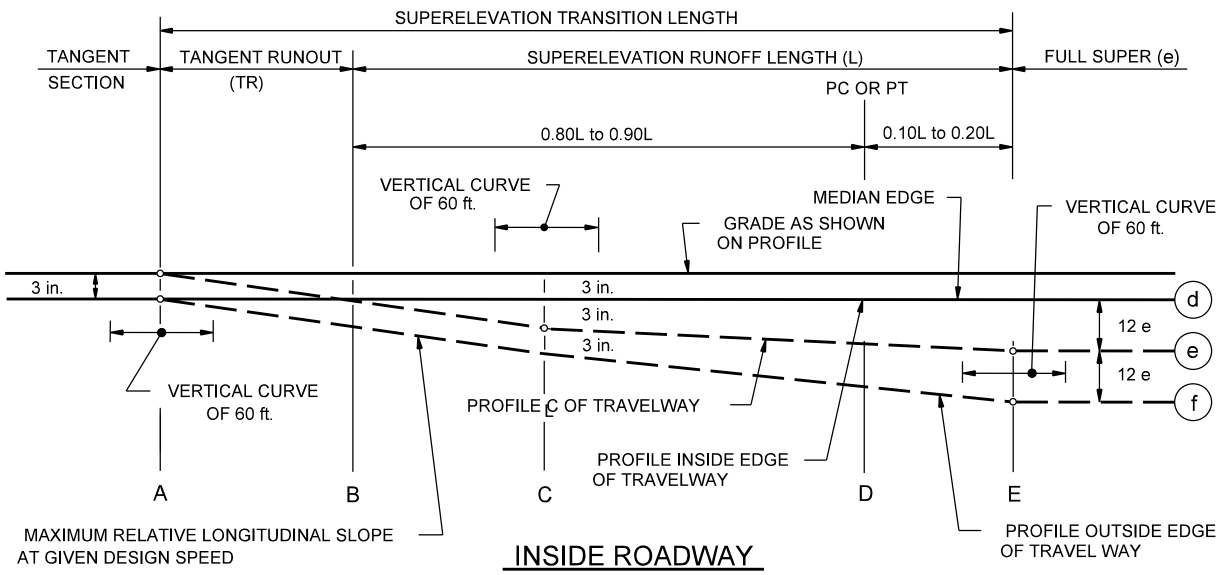


OUTSIDE ROADWAY

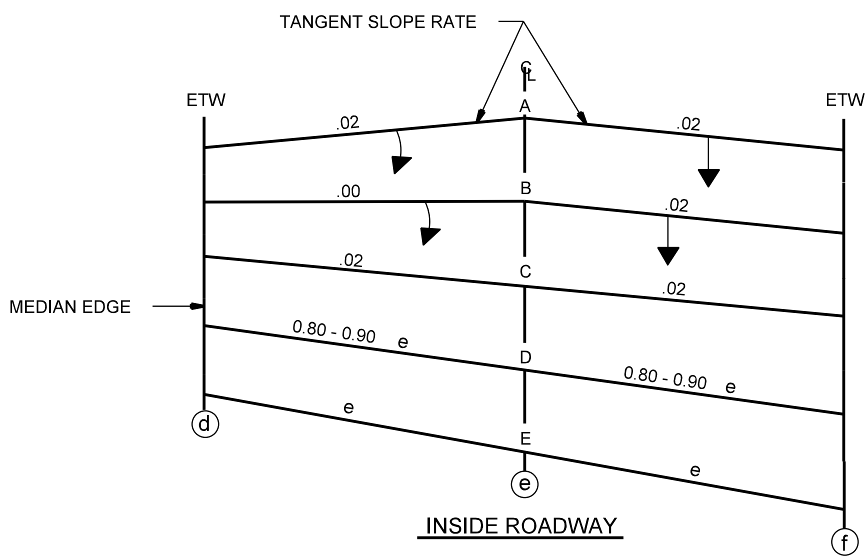
SUPERELEVATION DEVELOPMENT
(Four-Lane Divided, No Future Third Lane)

Figure 43-3 I

Back



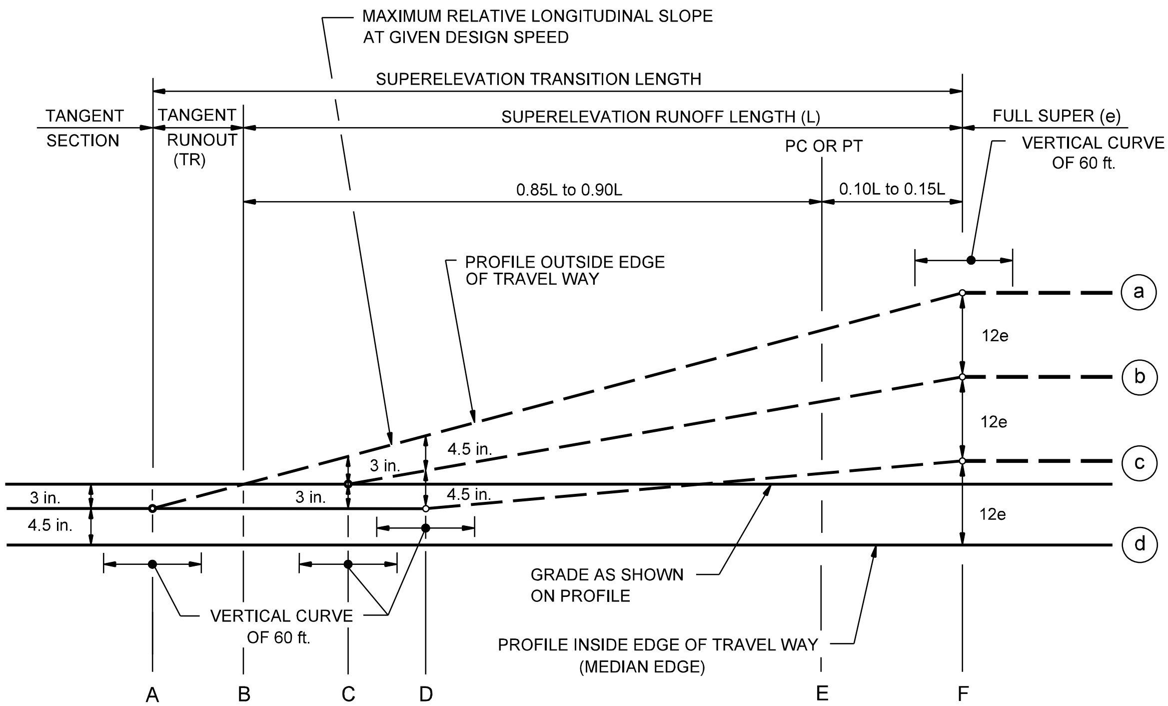
NOTES:
1. AXES OF ROTATION ABOUT TWO MEDIAN EDGES
2. e = APPLICABLE SUPERELEVATION RATE



SUPERELEVATION DEVELOPMENT
(Four-Lane Divided, No Future Third Lane)

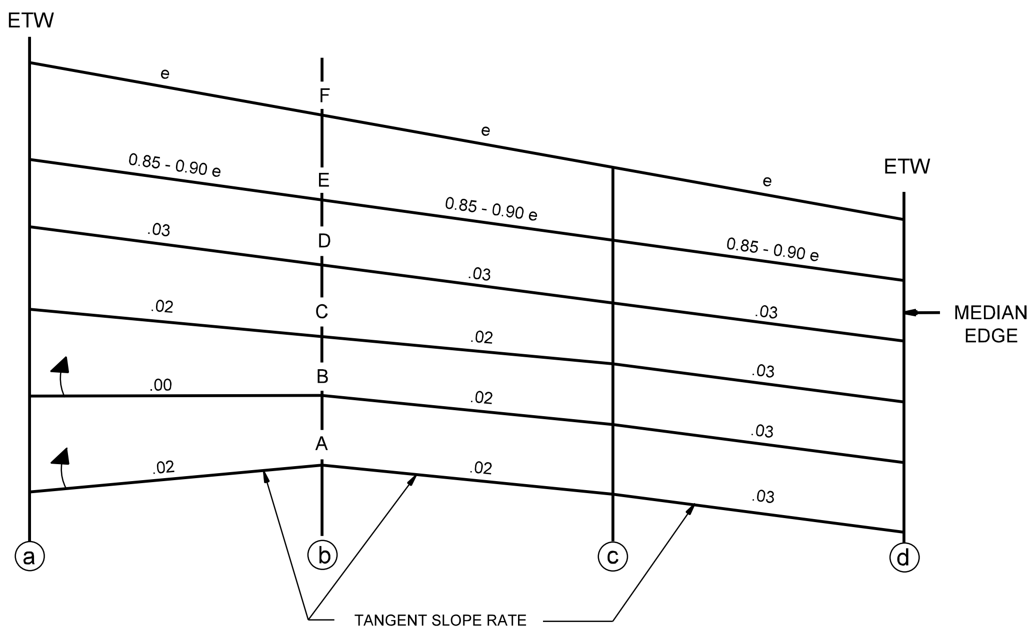
Figure 43-3 I
(Continued)

Back



OUTSIDE ROADWAY

NOTES:
1. AXES OF ROTATION ABOUT TWO MEDIAN EDGES
2. e = APPLICABLE SUPERELEVATION RATE

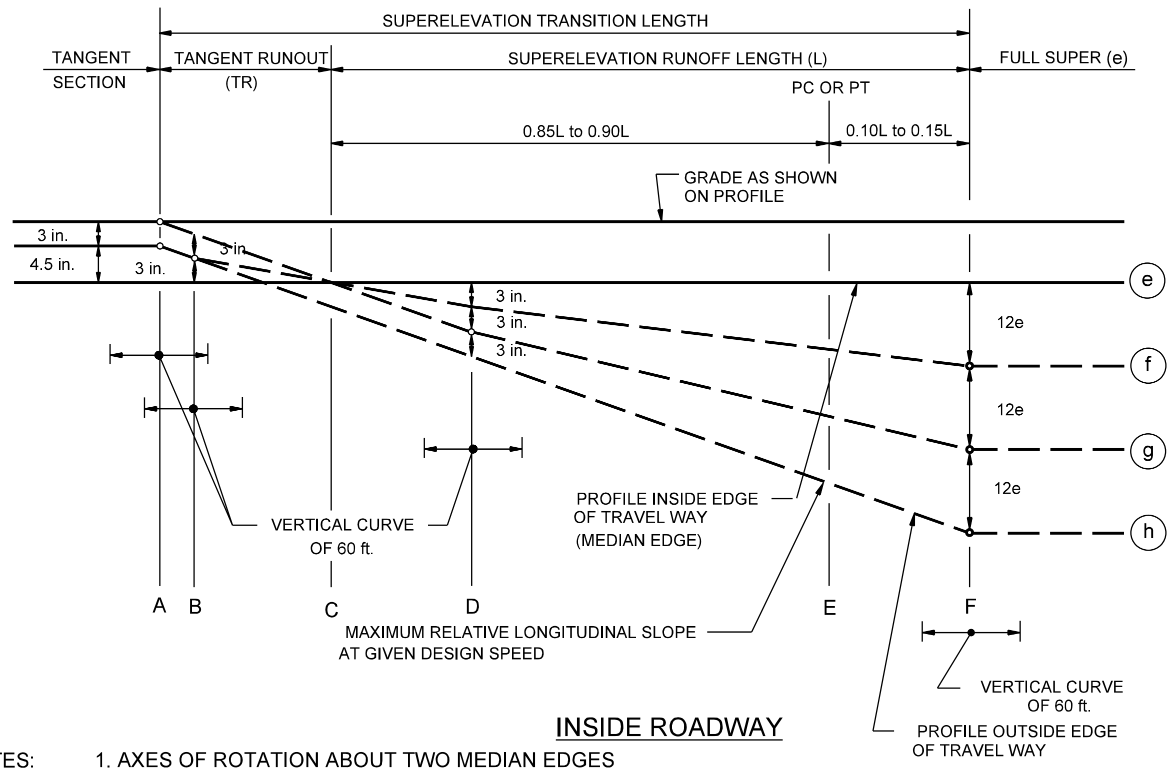


OUTSIDE ROADWAY

SUPERELEVATION DEVELOPMENT
(Six-Lane (or more) Divided)
(Four-Lane Divided with Future Additional Lanes)

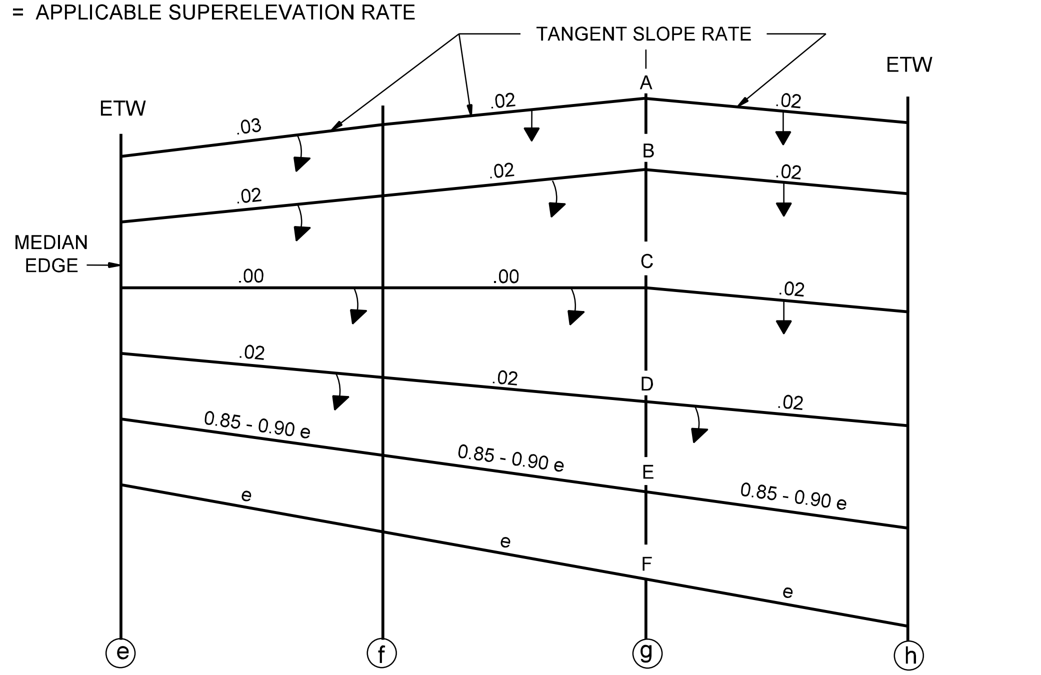
Figure 43-3J

Back



INSIDE ROADWAY

NOTES:
1. AXES OF ROTATION ABOUT TWO MEDIAN EDGES
2. e = APPLICABLE SUPERELEVATION RATE

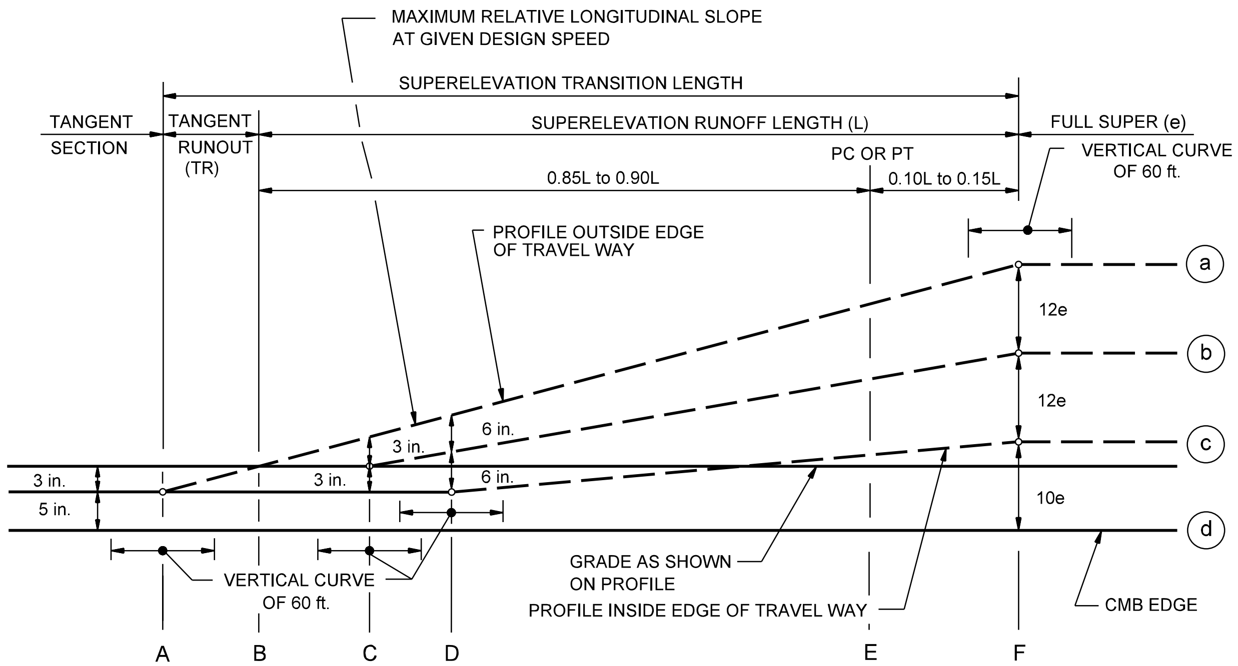


INSIDE ROADWAY

SUPERELEVATION DEVELOPMENT
(Six-Lane (or more) Divided)
(Four-Lane Divided with Future Additional Lanes)

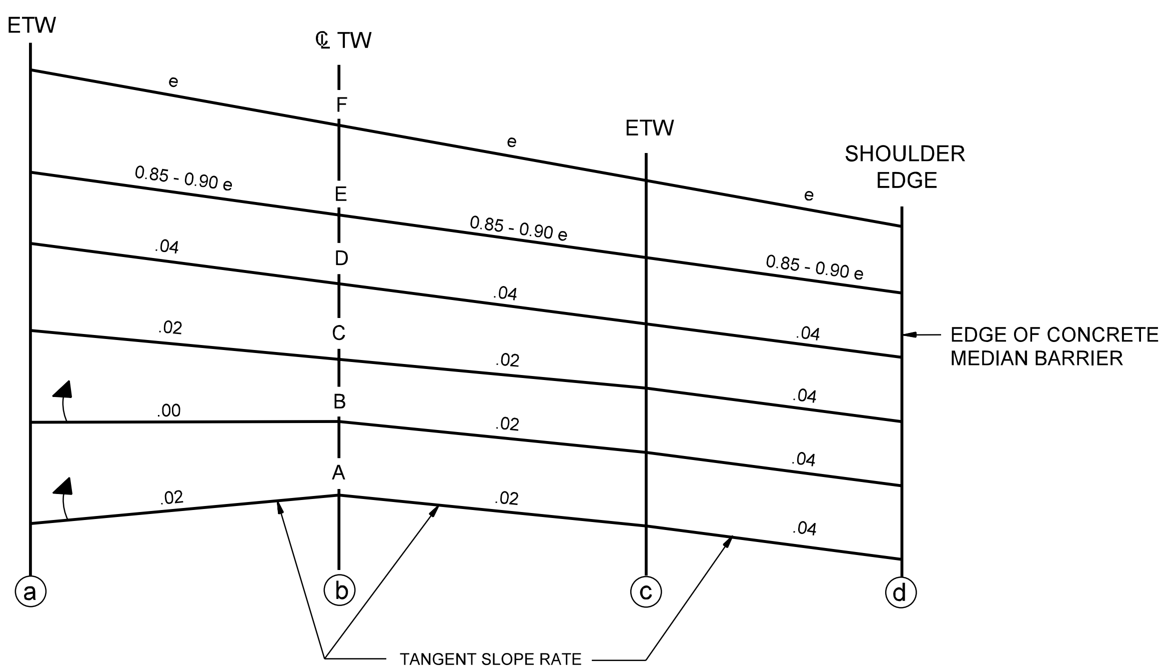
Figure 43-3J
(Continued)

Back



OUTSIDE ROADWAY

NOTES: 1. AXES OF ROTATION ABOUT EDGES OF CMB
2. e = APPLICABLE SUPERELEVATION RATE

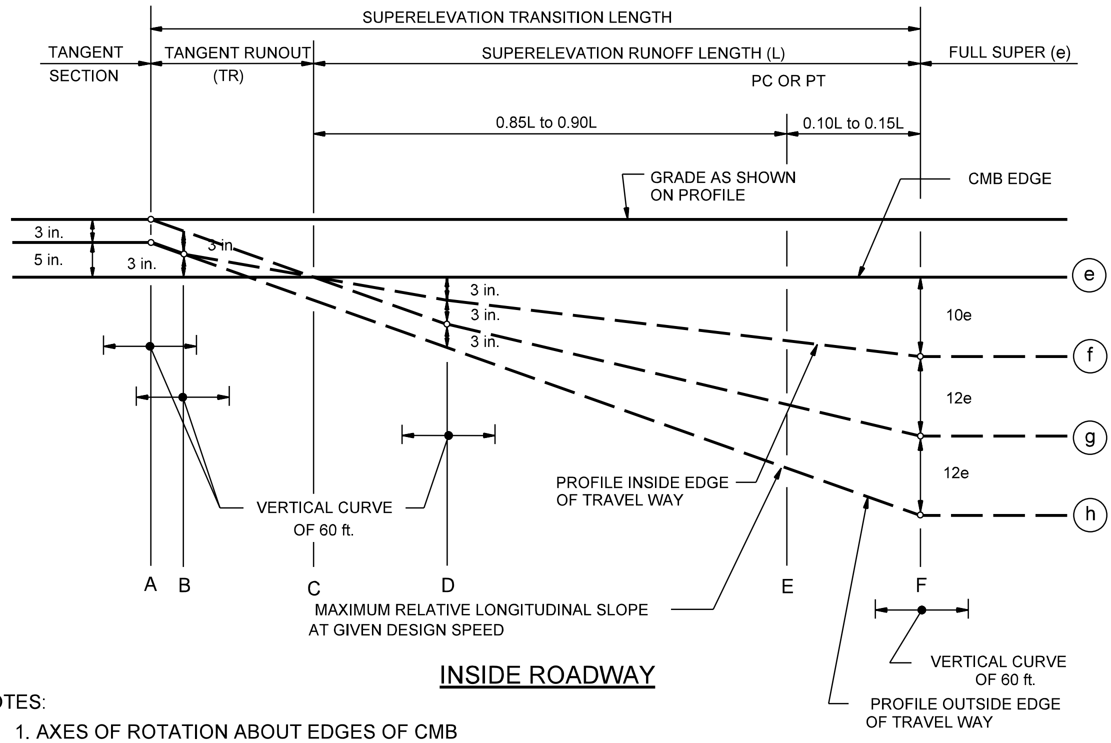


OUTSIDE ROADWAY

SUPERELEVATION DEVELOPMENT
(With Concrete Median Barrier)

Figure 43-3K
(Page 1 of 2)

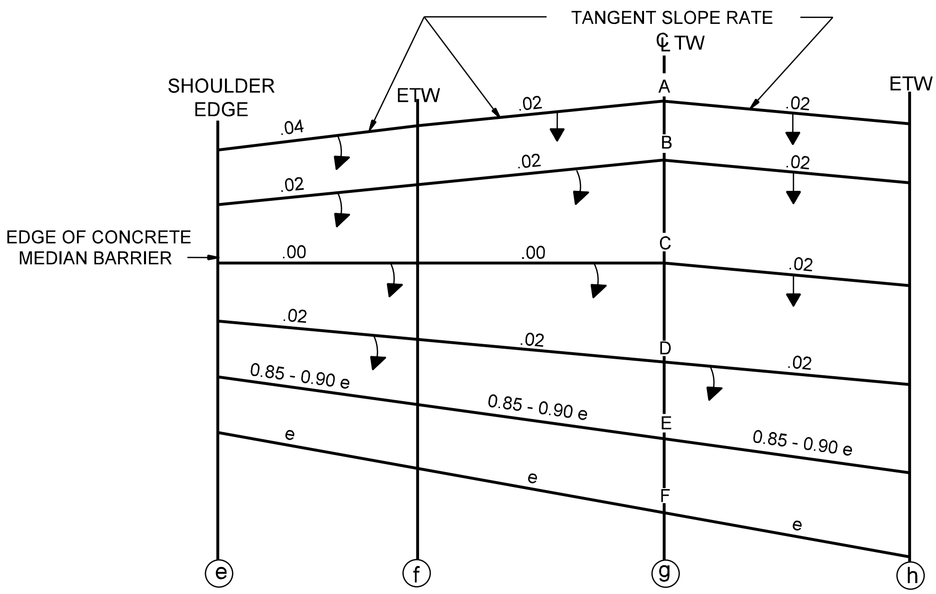
Back



INSIDE ROADWAY

NOTES:

1. AXES OF ROTATION ABOUT EDGES OF CMB
2. e = APPLICABLE SUPERELEVATION RATE



INSIDE ROADWAY

SUPERELEVATION DEVELOPMENT
(with Concrete Median Barrier)

Figure 43-3K
(Page 2 of 2)

Back

Design Speed (mph)	Superelevation Rate, *e*	Minimum Superelevation Runoff, L_2 (ft)
25	0.02	34
	0.03	51
	0.04	69
	0.05	86
	0.06	103
30	0.02	36
	0.03	54
	0.04	73
	0.05	91
	0.06	109
35	0.02	39
	0.03	58
	0.04	77
	0.05	96
	0.06	116
40	0.02	41
	0.03	62
	0.04	83
	0.05	103
	0.06	124
45	0.02	44
	0.03	66
	0.04	89
	0.05	111
	0.06	133

Note: For a superelevation rate intermediate between those in table, use a straightline interpolation to calculate the superelevation runoff length.

SUPERELEVATION RUNOFF LENGTH
(Low-Speed Two-Lane Urban Street)

Figure 43-3L

Back

Paved Shld. Width, *w* (ft)	High-Side-Shoulder Cross Slope	Low-Side-Shoulder Cross Slope
$2 \le w \le 4$	*e*	*e*
$w > 4$	*e* for 2 ft Closest to Travel Lane, then **	*e* for 2 ft Closest to Travel Lane, then ***

e = superelevation rate for travelway
** as outlined in Section 43-3.06(01)
*** as outlined in Section 43-3.06(02)

PAVED-SHOULDER CROSS SLOPES
SUPERELEVATED SECTION, WITH UNDERDRAINS

Figure 43-3M

Back

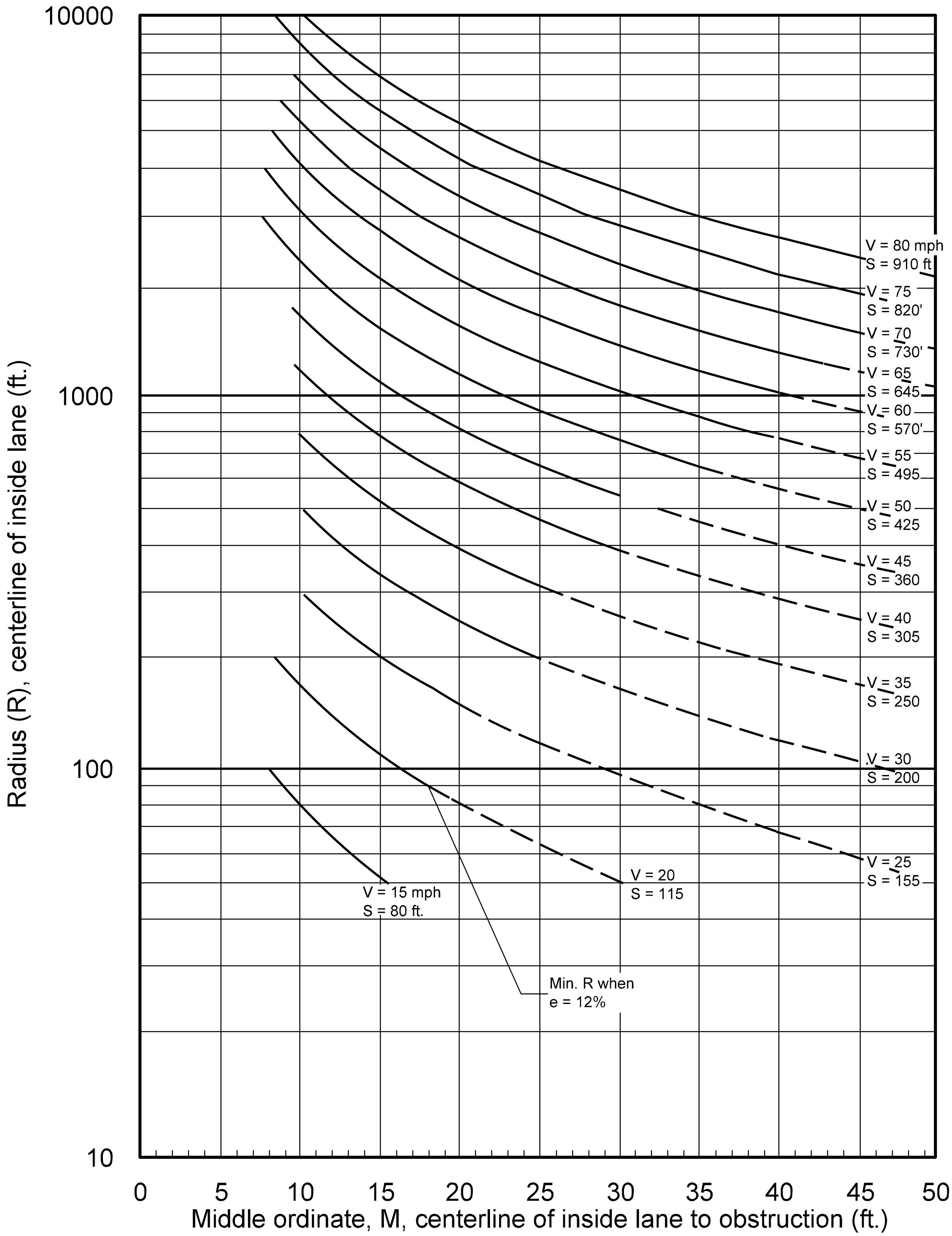
Paved Shld. Width, *w* (ft)	High-Side-Shoulder Cross Slope	Low-Side-Shoulder Cross Slope
$0 \le w \le 2$	*e*	*e*
$2 < w \le 4$	*e*	*e*
$w > 4$	**	***

e = superelevation rate for travelway
** as outlined in Section 43-3.06(01)
*** as outlined in Section 43-3.06(02)

PAVED-SHOULDER CROSS SLOPES
SUPERELEVATED SECTION, WITHOUT UNDERDRAINS

Figure 43-3N

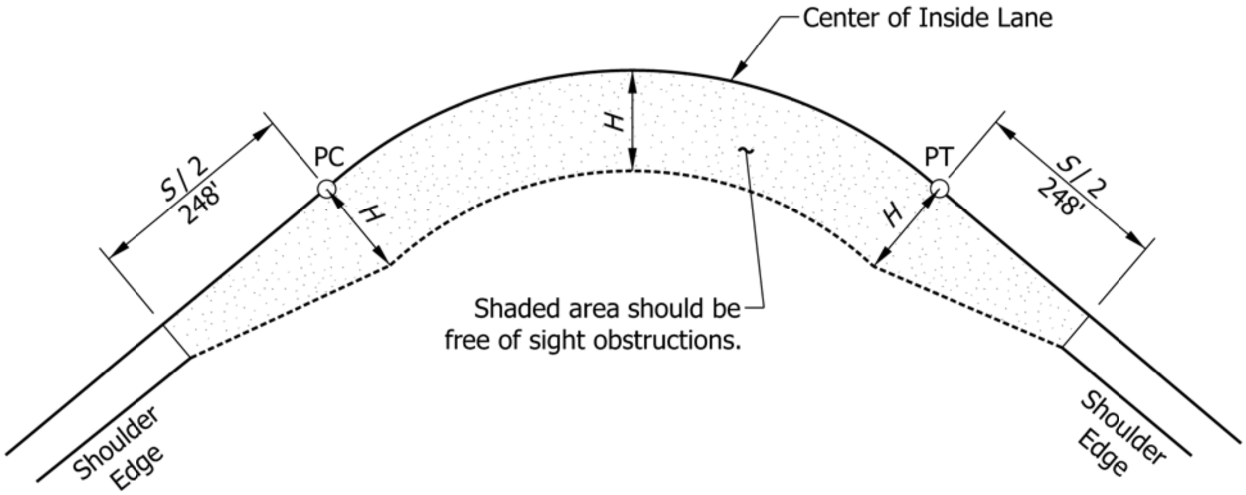
Back



DESIGN CONTROLS FOR STOPPING SIGHT DISTANCE ON HORIZONTAL CURVE

Figure 43-4A

Back



KEY:

H = Horizontal Sight Line Offset (ft)
S = Stopping Sight Distance (ft)
R = Radius of Curve (ft)

EXAMPLE:

Given: Design Speed = 55 mph, R = 1000 ft

Problem: Determine the horizontal clearance requirements for the horizontal curve.

Solution: Use the equation for horizontal clearance ($L > S$) to obtain

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

$$H = 1000\left[1 - \cos\left(\frac{28.65 \cdot 495}{1000}\right)\right] = 30.5 \text{ ft}$$

NOTE: This figure also illustrates the horizontal clearance requirements for the entering and exiting portion of the horizontal curve.

HORIZONTAL SIGHT DISTANCE CLEARANCE REQUIREMENTS

Figure 43-4C

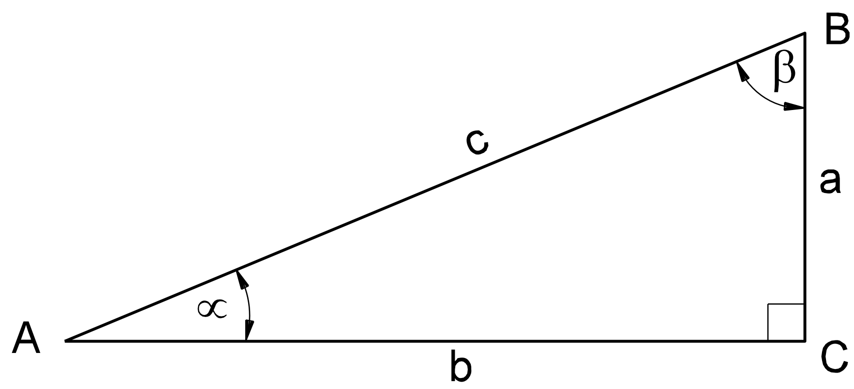
Back

Figure Number	Figure Title
Figure 43-6B	Basic Trigonometric Functions
Figure 43-6C	Simple Curve Computation
Figure 43-6D	Curve Symbols, Abbreviations and Formulas
Figure 43-6E	Simple Curve Computation (Example)
Figure 43-6F	Simple Curves (Stationing)

MATHEMATICAL DETAILS FOR HORIZONTAL CURVES

Figure 43-6A

Back



Let BC = a, AC = b, AB = c. Then:

1. $\sin \propto \; = \frac{a}{c}$

2. $\cos \propto \; = \frac{b}{c}$

3. $\tan \propto \; = \frac{a}{b}$

4. $\csc \propto \; = \frac{1}{\sin \propto} \; = \frac{c}{a}$

5. $\sec \propto \; = \frac{1}{\cos \propto} \; = \frac{c}{b}$

6. $\cot \propto \; = \frac{1}{\tan \propto} \; = \frac{b}{a}$

7. $\text{vers} \propto \; = 1 - \cos \propto$

8. $\text{covers} \propto \; = 1 - \sin \propto$

9. $\text{exsec} \propto \; = (\sec \propto) - 1$

10. $\text{coexsec} \propto \; = (\csc \propto) - 1$

11. $a^2 + b^2 = c^2$

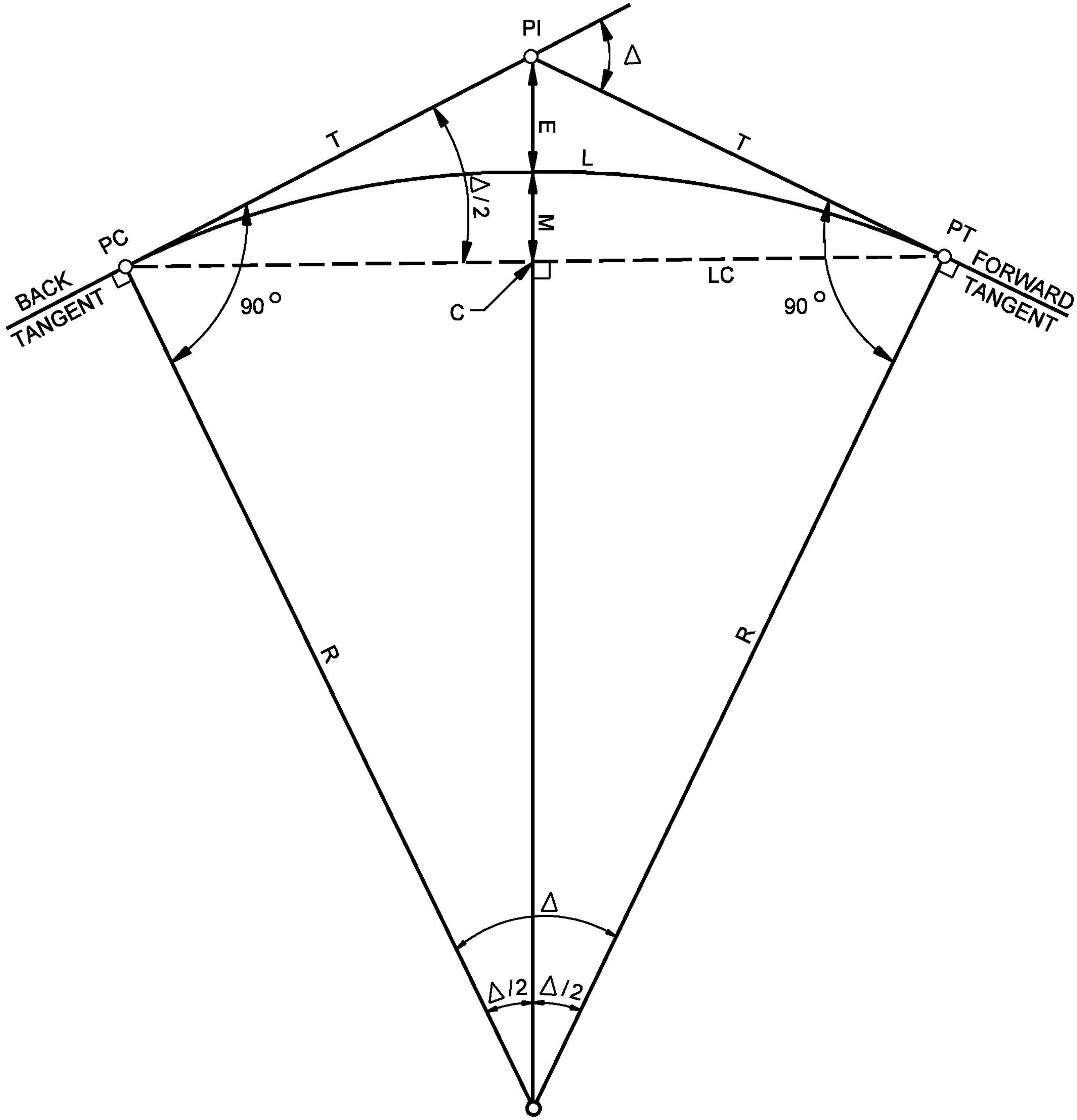
12. $\propto + \beta \; = 90°$

13. $\text{Area} = \frac{1}{2} ab$

BASIC TRIGONOMETRIC FUNCTIONS

Figure 43-6B

Back



SIMPLE CURVE COMPUTATION

Figure 43-6C

Back

CONTROL-POINT ABBREVIATIONS

PC = Point of Curvature (beginning of curve)

PI = Point of Intersection of tangents

PT = Point of Tangency (end of curve)

PRC = Point of Reverse Curvature

PCC = Point of Compound Curvature

SYMBOLS

Δ = Deflection angle (deg)

T = Tangent length (distance from PC to PI, or from PI to PT) (ft)

L = Length of curve (distance from PC to PT along curve) (ft)

R = Radius of curve (ft)

E = External distance (transverse distance from PI to midpoint of curve) (ft)

LC = Long Chord length (straight-line distance from PC to PT) (ft)

C = midpoint of long Chord

M = Middle ordinate distance (transverse distance from midpoint of L to point C (ft)

FORMULAS

$$L = \frac{\Delta R \pi}{180}$$

$$T = R \tan\left(\frac{\Delta}{2}\right)$$

$$E = T \tan(\Delta / 4) = \left[\frac{R}{\cos(\Delta / 2)}\right] - R$$

$$LC = 2R \sin(\Delta / 2)$$

$$M = R[1 - \cos(\Delta / 2)] = E \cos(\Delta / 2)$$

LOCATING THE PC OR PT

Station of PC = Station of PI – T/100

Station of PT = Sta. of PC + L/100

1 station = 100 ft. For example, Sta. 13+54.86 is 1354.86 ft from Sta. 0+00.00.

HORIZONTAL CURVE ABBREVIATIONS, SYMBOLS, AND FORMULAS

Figure 43-6D

Back

Sample Problem:

With the alignment information given below, determine the basic curve data.

Solution:

From the information given, find L and T:

L = PT Sta. - PC Sta. = (20 + 77.72) - (16 + 64.78) = 412.94 ft
T = PI Sta. - PC Sta. = (18 + 55.36) - (16 + 64.78) = 190.58 ft

Using horizontal curve formulas from Figure 43-6D, solve for E, M, and R:

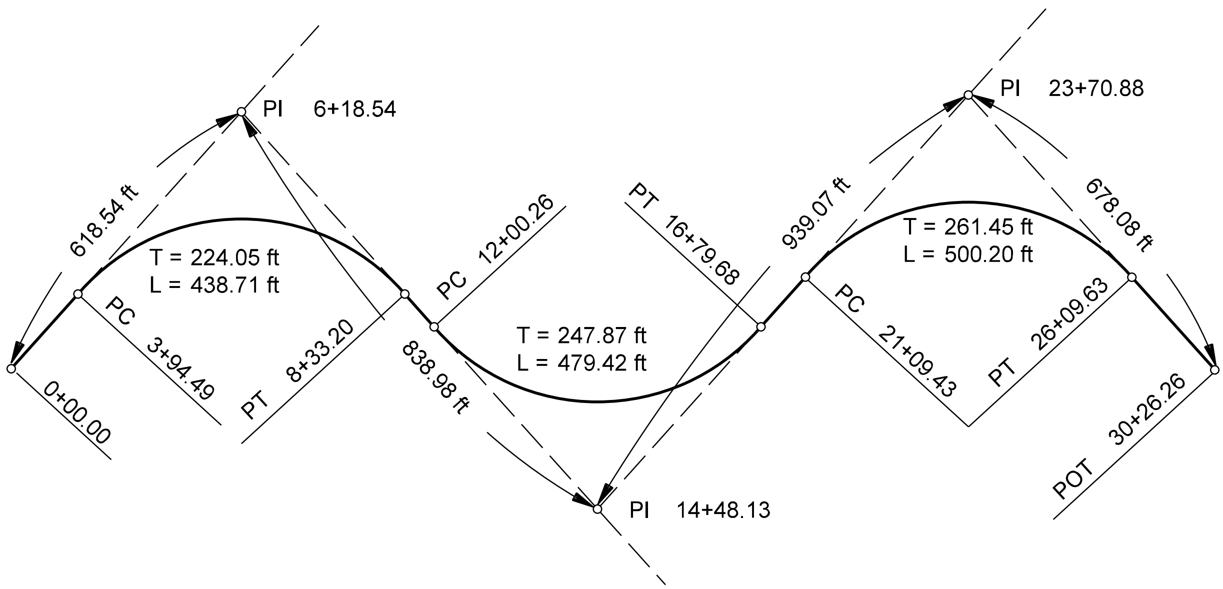
$$R = \frac{T}{\tan(\Delta/2)} = \frac{190.58}{\tan 19.17°} = \frac{190.58}{0.34765} = 548.20\ ft$$

E = T tan (Δ/4) = (190.58)(tan 9.585E) = (190.58)(0.16887) = 32.18 ft
M = R (1 - cos Δ/2) = (412.94)(1 - cos 19.17E) = (412.94)(0.05545) = 22.90 ft

SIMPLE CURVE COMPUTATION
(Example)

Figure 43-6E

Back



1. The station at the first PI is 6+18.54.
2. The station at the first PC = 618.54 224.05 = 3+94.49.
3. The station at the first PT = 394.49 + 438.71 = 8+33.20.
4. The station at the second PC = 833.20 + (838.98 224.05 247.87) = 12+00.26.
5. The station at the second PI = 1200.26 + 247.87 = 14+48.13.
6. The station at the second PT = 1200.26 + 479.42 = 16+79.68.
7. The station at the third PC = 1679.68 + 939.07 247.87 261.45 = 21+09.43.
8. The station at the third PI = 2109.43 + 261.45 = 23+70.88.
9. The station at the third PT = 2109.54 + 500.20 = 26+09.63.
10. The station at the final POT = 2609.63 + 678.08 261.45 = 30+26.26.
11. Check: (618.54 + 838.98 + 939.07 + 678.08) - (2 x 224.05 + 2 x 247.87 + 2 x 261.45 - 438.71 479.42 500.20) = 3026.26.

SIMPLE CURVES STATIONING

Figure 43-6F

Back