TABLE OF CONTENTS

LIST OF FIGURES

CHAPTER FORTY-THREE

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

Horizontal curves are, in effect, transitions 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 presents 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:

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

Where:

R	=	radius of curve, m
e	=	superelevation rate
f	=	side-friction factor
V	=	vehicular speed, km/h

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 $V \geq 70$ km/h.

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 $V \leq 70$ km/h.

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
≤ 1	30 m
1 < Δ ≤ 2	60 m
2 < Δ ≤ 3	90 m
3 < Δ ≤ 4	120 m
4 < Δ ≤ 5	150 m
> 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 meters should be 3*V* for aesthetics. *V* is design speed in km/h.

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 $V \leq 70$ km/h. 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. Any exceptions should be evaluated as required.

2. Urban Facility ($V \geq 80$ km/h). An e_{max} = 8% is used. A rate of 6% or 4% may be used where $V \leq 70$ km/h 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*, Figure 43-3A, 43-3A1, 43-3A2, 43-3A3, 43-3A4 or 43-3A5 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 10 km/h (grade of 3% to 5%) or 20 km/h (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 20 km/h 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 $V \leq 70$ km/h. 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. Wide Pavement Area. 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. Surface Drainage. 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.

* * * * * * * * *

Example 43-3.1

Given: Design speed = 60 km/h
Radius = 200 m
Cross slope (on tangent) = 2%

Problem: Determine the superelevation rate.

Solution: From Figure 43-3C the required superelevation rate = -0.039. Therefore, a normal crown section may be maintained throughout the curve (i.e., *e* = -0.020).

Example 43-3.2

Given: Design speed = 60 km/h
Radius = 150 m

Problem: Determine the superelevation rate.

Solution: From Figure 43-3C, the required superelevation rate = +0.009. This occurs in the area where the roadway should 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 (+0.009), if this is consistent with field conditions (e.g., surface drainage will work properly).

Example 43-3.3

Given: Design speed = 60 km/h

Radius = 135 m

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. Figures 43-3A and 43-3A1 show the superelevation runoff length, L_2, for various combinations of curve radius and design speed. The length is calculated as follows:

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

Where:

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

W = Width of rotation (assumed to be 3.6 m)

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. Tangent Runout. 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, m

L_2 = Superelevation runoff length, m (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. Superelevation Runoff. 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, m, rounded up to the next 3.9-m increment

w = Width of one traffic lane, m

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 20 m.

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, 43-3I, 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 $V \leq 70$ km/h. 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.

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 criteria provided in Section 43-3.03 for the open-roadway condition also apply 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 1.2 m 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 include 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 3.6 m.

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., $M > 15$ m or $R < 50$ m), 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 Figures 43-4A or 43-4B 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 1080 mm and the height of object is 600 mm. 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 3.6 m, the horizontal stopping sight distance should be calculated by placing the eye and object 1.8 m 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, 3 m or less) and its height is greater than 0.6 m.

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 600-mm 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 (km/h)	e	f_{max}	Minimum Radius, R_{min} (m)
20	0.08	0.40	3.7
30	0.08	0.35	7.3
40	0.08	0.28	19.7
50	0.08	0.23	40.6
60	0.08	0.19	72.9
70	0.08	0.17	113.4
80	0.08	0.15	167.8
90	0.08	0.14	229.1
100	0.08	0.13	303.7
110	0.08	0.12	393.7

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

MINIMUM RADIUS
(e_{max} = 8%, Open-Roadway Condition)

Figure 43-2A

e	Design Speed, V (km/h)	f_{max}	Minimum Radius, R_{min} (m)
0.04	20	0.35	8.1
	30	0.28	22.1
	40	0.23	46.7
	50	0.19	85.6
	60	0.17	135.0
	70	0.15	203.1
0.06	20	0.35	7.7
	30	0.28	20.8
	40	0.23	43.4
	50	0.19	78.7
	60	0.17	123.2
	70	0.15	183.7

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

MINIMUM RADIUS,
LOW-SPEED URBAN STREET

Figure 43-2B

e (%)	V_d = 20 km/h R (m)	V_d = 30 km/h R (m)	V_d = 40 km/h R (m)	V_d = 50 km/h R (m)	V_d = 60 km/h R (m)	V_d = 70 km/h R (m)	V_d = 80 km/h R (m)	V_d = 90 km/h R (m)	V_d = 100 km/h R (m)
1.5	163	371	679	951	1310	1740	2170	2640	3250
2.0	102	237	441	632	877	1180	1490	1830	2260
2.2	75	187	363	534	749	1020	1290	1590	1980
2.4	51	132	273	435	626	865	1110	1390	1730
2.6	38	99	209	345	508	720	944	1200	1510
2.8	30	79	167	283	422	605	802	1030	1320
3.0	24	64	137	236	356	516	690	893	1150
3.0	24	64	137	236	356	516	690	893	1150
3.2	20	54	114	199	303	443	597	779	1010
3.4	17	45	96	170	260	382	518	680	879
3.6	14	38	81	144	222	329	448	591	767
3.8	12	31	67	121	187	278	381	505	658
4.0	8	22	47	86	135	203	280	375	492

Note: Use of e_{max} *= 4% should be limited to urban conditions.*

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

Figure 43-3A(1)

e (%)	V_d = 20 km/h R (m)	V_d = 30 km/h R (m)	V_d = 40 km/h R (m)	V_d = 50 km/h R (m)	V_d = 60 km/h R (m)	V_d = 70 km/h R (m)	V_d = 80 km/h R (m)	V_d = 90 km/h R (m)	V_d = 100 km/h R (m)	V_d = 110 km/h R (m)
1.5	194	421	738	1050	1440	1910	2360	2880	3510	4060
2.0	138	299	525	750	1030	1380	1710	2090	2560	2970
2.2	122	265	465	668	919	1230	1530	1880	2300	2670
2.4	109	236	415	599	825	1110	1380	1700	2080	2420
2.6	97	212	372	540	746	1000	1260	1540	1890	2210
2.8	87	190	334	488	676	910	1150	1410	1730	2020
3.0	78	170	300	443	615	831	1050	1290	1590	1870
3.2	70	152	269	402	561	761	959	1190	1470	1730
3.4	61	133	239	364	511	697	882	1100	1360	1600
3.6	51	113	206	329	465	640	813	1020	1260	1490
3.8	42	96	177	294	422	586	749	939	1170	1390
4.0	36	82	155	261	380	535	690	870	1090	1300
4.2	31	72	136	234	343	488	635	806	1010	1220
4.4	27	63	121	210	311	446	584	746	938	1140
4.6	24	56	108	190	283	408	538	692	873	1040
4.8	21	50	97	172	258	374	496	641	812	997
5.0	19	45	88	156	235	343	457	594	755	933
5.2	17	40	79	142	214	315	421	549	701	871
5.4	15	36	71	128	195	287	386	506	648	810
5.6	13	32	63	115	176	260	351	463	594	747
5.8	11	28	56	102	156	232	315	416	537	679
6.0	8	21	43	79	123	184	252	336	437	560

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

Figure 43-3A(2)

e (%)	V_d = 20 km/h R (m)	V_d = 30 km/h R (m)	V_d = 40 km/h R (m)	V_d = 50 km/h R (m)	V_d = 60 km/h R (m)	V_d = 70 km/h R (m)	V_d = 80 km/h R (m)	V_d = 90 km/h R (m)	V_d = 100 km/h R (m)	V_d = 110 km/h R (m)
1.5	184	443	784	1090	1490	1970	2440	2970	3630	4180
2.0	133	322	571	791	1090	1450	1790	2190	2680	3090
2.2	119	288	512	711	976	1300	1620	1980	2420	2790
2.4	107	261	463	644	885	1190	1470	1800	2200	2550
2.6	97	237	421	587	808	1080	1350	1650	2020	2340
2.8	88	216	385	539	742	992	1240	1520	1860	2160
3.0	81	199	354	496	684	916	1150	1410	1730	2000
3.2	74	183	326	458	633	849	1060	1310	1610	1870
3.4	68	169	302	425	588	790	988	1220	1500	1740
3.6	62	156	279	395	548	738	924	1140	1410	1640
3.8	57	144	259	368	512	690	866	1070	1320	1540
4.0	52	134	241	344	479	648	813	1010	1240	1450
4.2	48	124	224	321	449	608	766	948	1180	1380
4.4	43	115	208	301	421	573	722	895	1110	1300
4.6	38	106	192	281	395	540	6982	847	1050	1240
4.8	33	96	178	263	371	509	645	803	996	1180
5.0	30	87	163	246	349	480	611	762	947	1120
5.2	27	78	148	229	328	454	579	724	901	1070
5.4	24	71	136	213	307	429	549	689	859	1020
5.6	22	65	125	198	288	405	521	656	819	975
5.8	20	59	115	185	270	382	494	625	781	933
6.0	19	55	106	172	253	360	469	595	746	894
6.2	17	50	98	161	238	340	445	567	713	857
6.4	16	46	91	151	224	322	422	540	681	823
6.6	15	43	85	141	210	304	400	514	651	789
6.8	14	40	79	132	198	287	379	489	620	757
7.0	13	37	73	123	185	270	358	464	591	724
7.2	12	34	68	115	174	254	338	440	561	691
7.4	11	31	62	107	162	237	318	415	531	657
7.6	10	29	57	99	150	221	296	389	499	621
7.8	9	26	52	90	137	202	273	359	462	579
8.0	7	20	41	73	113	168	229	304	394	501

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

Figure 43-3A(3)

Design Speed (km/h)	Curve Radius (m)		
	Normal Crown	Remove (Adverse) Crown	See Figure 43-3A(3)
40	R ≥ 782	782 > R ≥ 571	R < 571
50	R ≥1087	1087 >R ≥ 795	R < 795
60	R ≥ 1494	1494 > R ≥ 1095	R < 1095
70	R ≥ 1968	1968 >R ≥ 1445	R < 1445
80	R ≥ 2436	2436 > R ≥ 1790	R < 1790
90	R ≥ 2963	2963 > R ≥ 2182	R < 2182
100	R ≥ 3623	3623 > R ≥ 2672	R < 2672
110	R ≥ 4180	4180 > R ≥ 3091	R < 3091
120	R ≥ 4893	4893 > R ≥ 3632	R < 3632

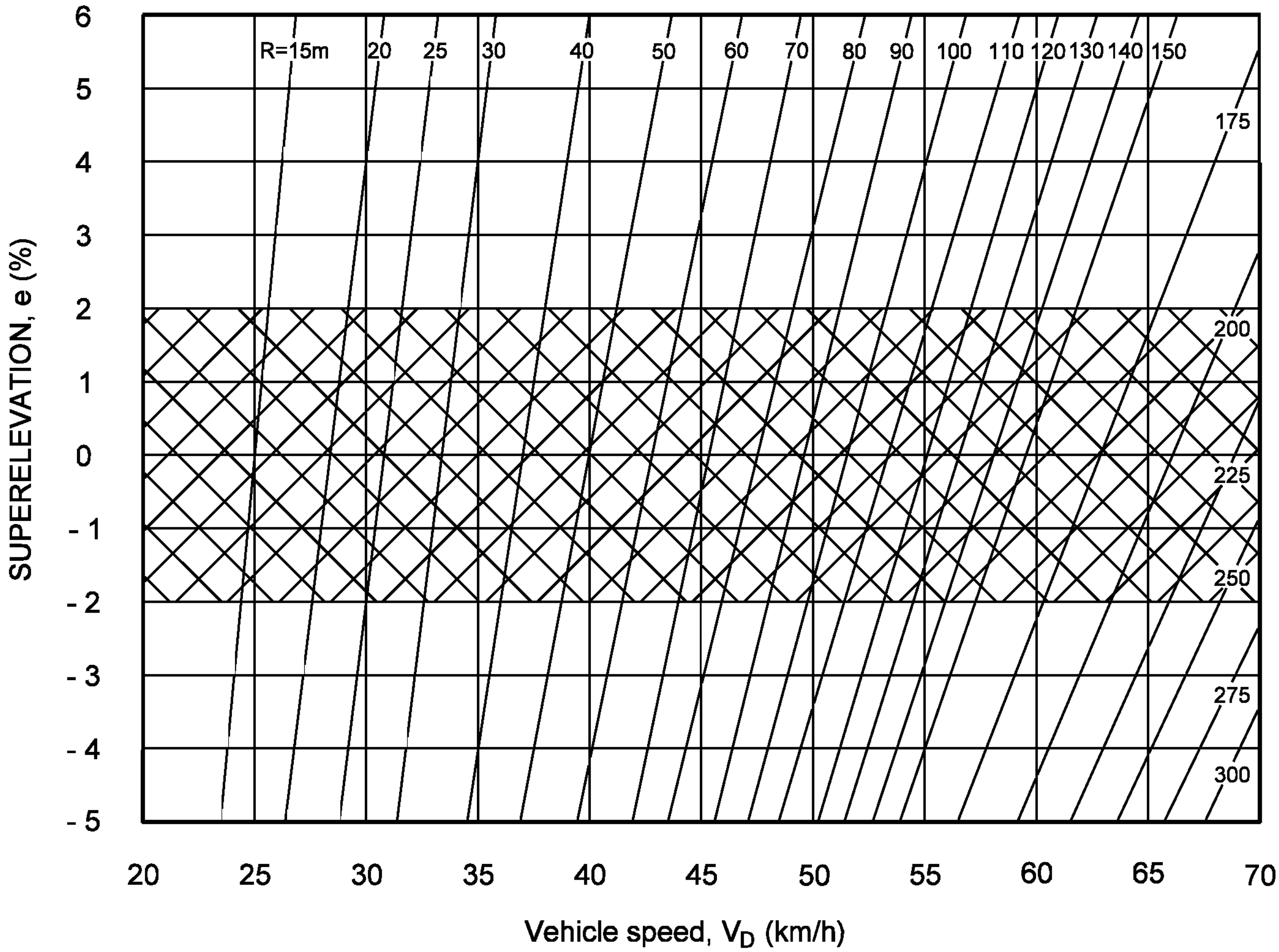
Notes:

1. *Table is based on* e_{max} *= 8%.*

2. *Remove (Adverse) Crown indicates that the entire traveled way width will be superelevated at a rate of 0.020.*

CURVE RADIUS FOR NORMAL-CROWN OR REMOVE-CROWN SECTION
(Open-Roadway Condition)

Figure 43-3B



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:* $$R = \frac{V^2}{127\,(e + f)}$$

Where:

R = curve radius, m
V = design speed, km/h
e = super elevation rate
f = side-friction factor

The values in the Figure are the calculated (unrounded) values. For design purposes, rounded minimum radii are used as follows:

	Design Speed, km/h					
	20	*30*	*40*	*50*	*60*	*70*
$R_{min.}$ *(m), e = 4%*	*10*	*20*	*43*	*77*	*125*	*185*
$R_{min.}$ *(m), e = 6%*	*5*	*19*	*40*	*72*	*115*	*170*

SUPERELEVATION RATES
(Low-speed urban streets)

Figure 43-3C

Design Speed, V (km/h)	Curve Radius, R (m)		
	See Figure 43-3C	Remove (Adverse) Crown *	Normal Crown
30	< 22	22 ≤ R <25	≥ 25
40	< 47	47 ≤ R < 55	≥ 55
50	< 86	86 ≤ R < 98	≥ 98
60	< 142	142 ≤ R < 167	≥ 167
70	< 204	204 ≤ R < 258	≥ 258

* *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:*

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

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

Figure 43-3D

Design Speed (km/h)	Equivalent Max. *RS*	Edge of Travelway Slope Relative to Centerline, *G* (%) (max.)
20	125	0.80
30	133	0.75
40	143	0.70
50	150	0.65
60	167	0.60
70	182	0.55
80	200	0.50
90	213	0.47
100	227	0.44
110	244	0.41
120	263	0.38

$$G = \frac{1}{RS} x\, 100$$

RELATIVE LONGITUDINAL SLOPE
(Two-Lane Roadway)

Figure 43-3E

V (km/h)	Number of Lanes Rotated			
	1	1.5	2 or 2.5	3 or 3.5
20 - 70	80%	85%	90%	90%
80 – 110	70%	75%	80%	85%

PORTION OF SUPERELEVATION RUNOFF ON TANGENT, %

Figure 43-3F

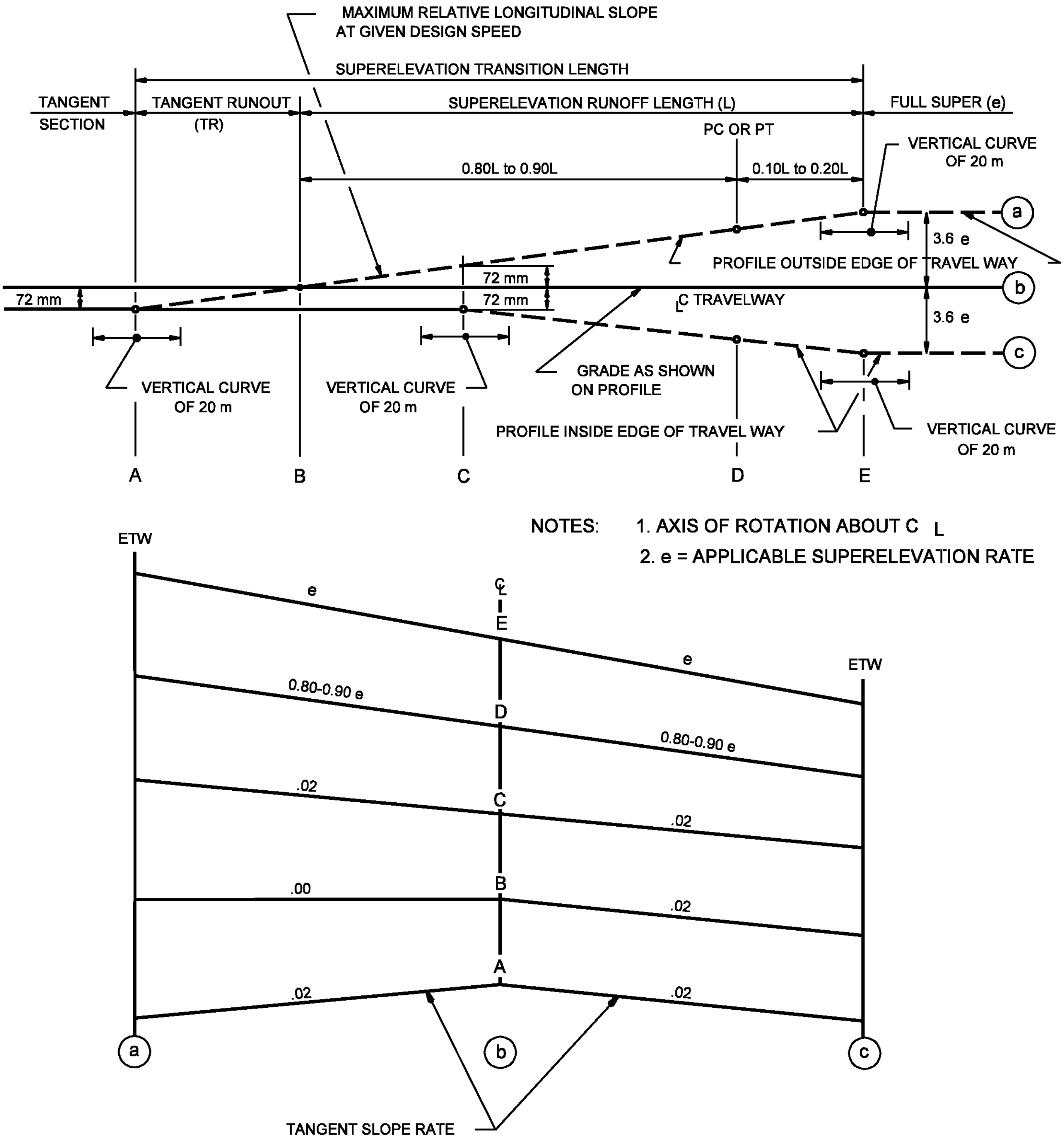
Number of Lanes Being Rotated*	b_w
1	1.0
1½	0.83
2	0.75
2½	0.70
3	0.67
3½	0.64

* *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. The number of lanes being rotated is 2½, therefore, $b_w = 0.70$.

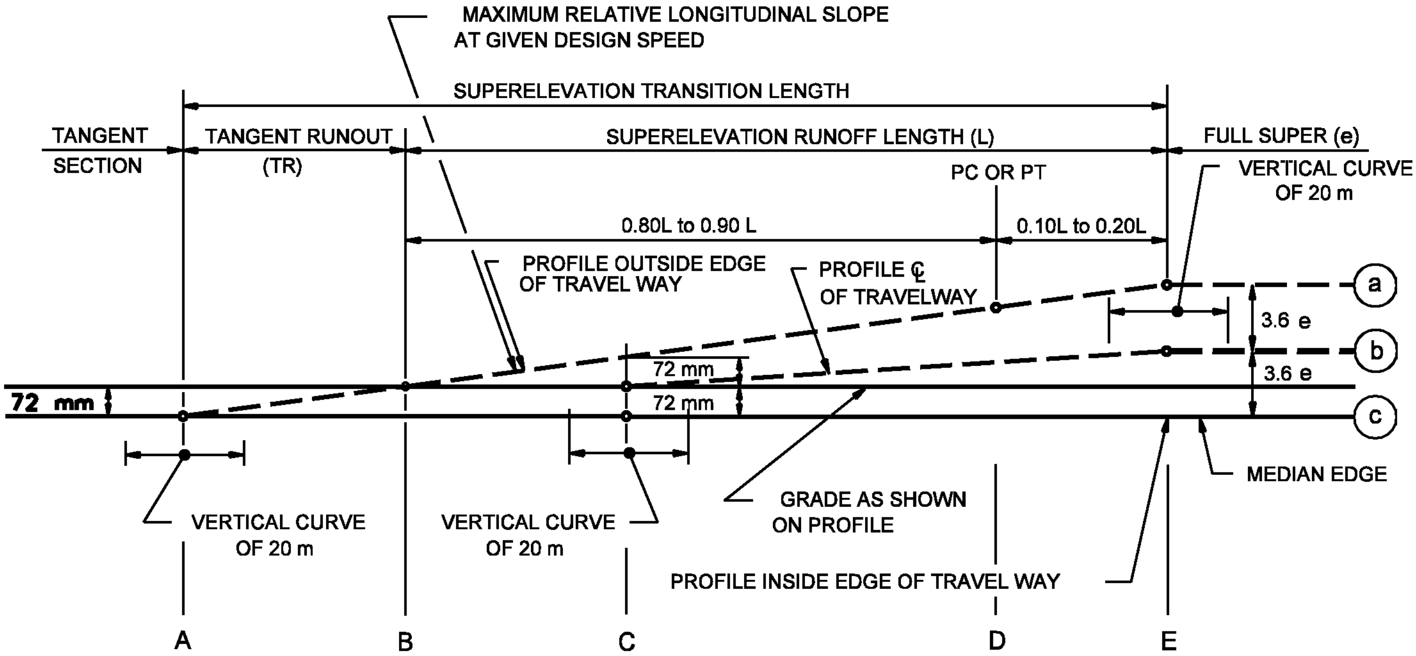
b_w VALUE
(Superelevation Runoff Length, Highway with 4 or More Lanes)

Figure 43-3G



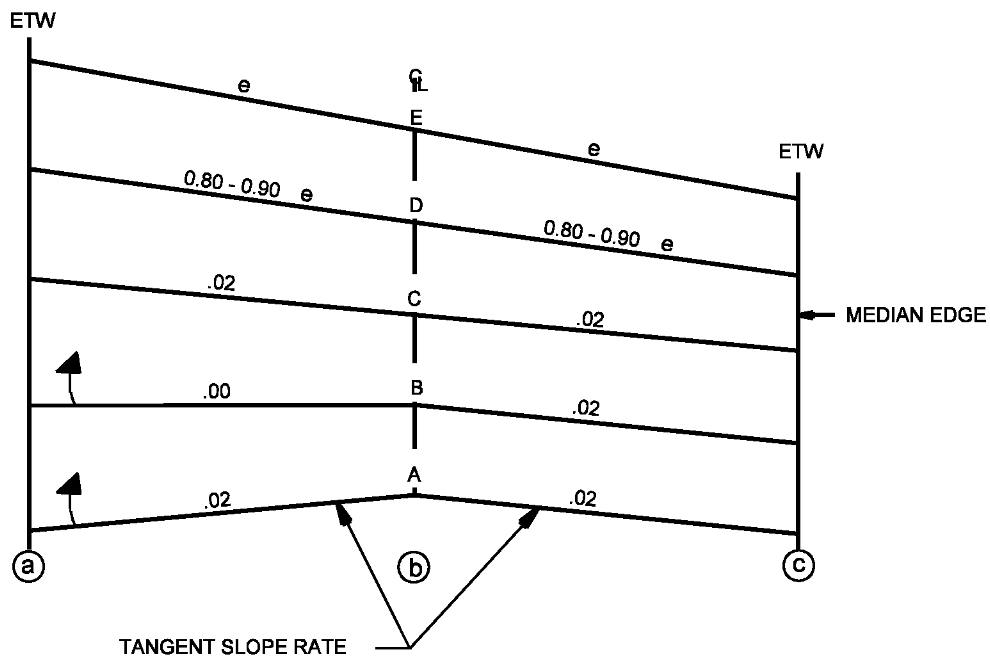
SUPERELEVATION DEVELOPMENT
(Two-Lane Roadways)

Figure 43-3H



OUTSIDE ROADWAY

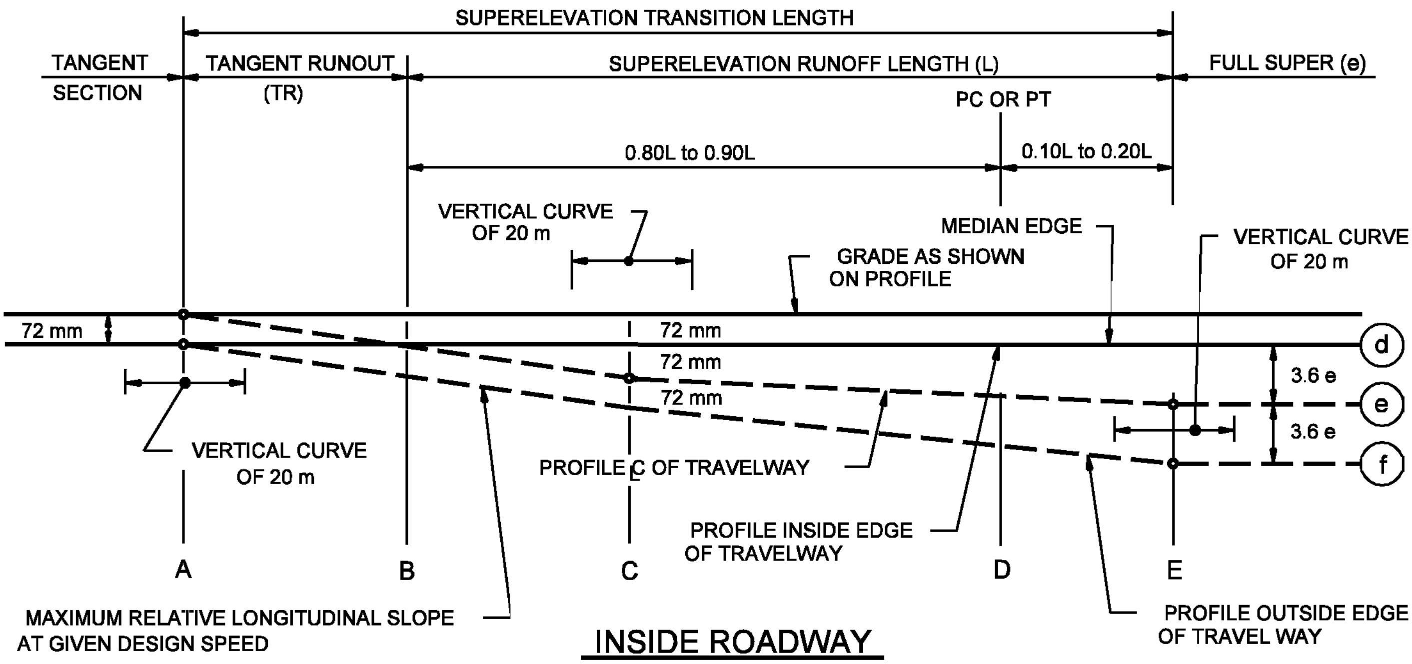
NOTES:
1. AXES OF ROTATION ABOUT TWO MEDIAN EDGES
2. e = APPLICABLE SUPERELEVATION RATE



OUTSIDE ROADWAY

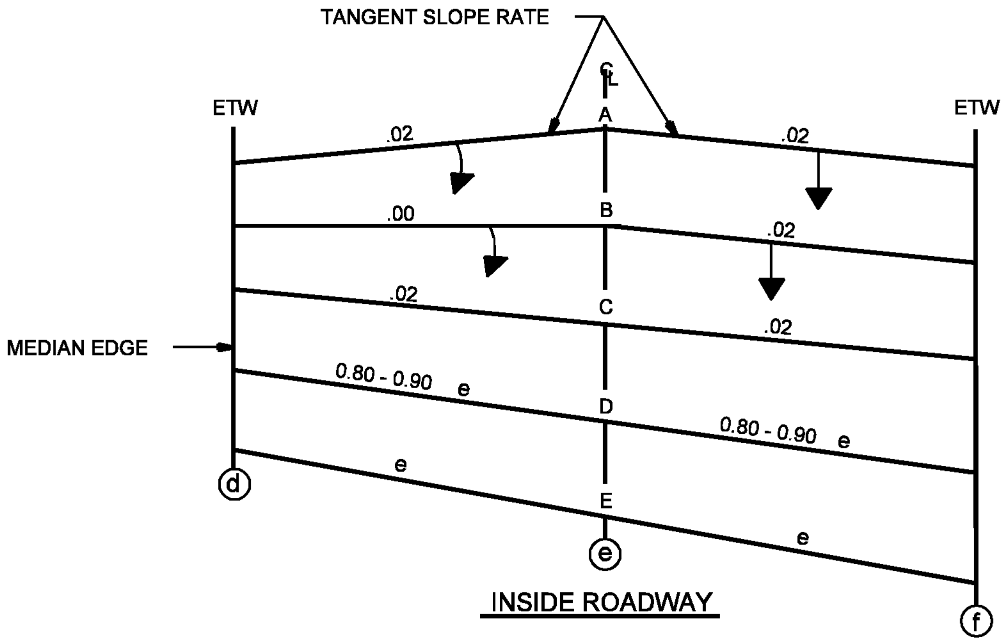
SUPERELEVATION DEVELOPMENT
(Four-Lane Divided, No Future Third Lane)

Figure 43-3I



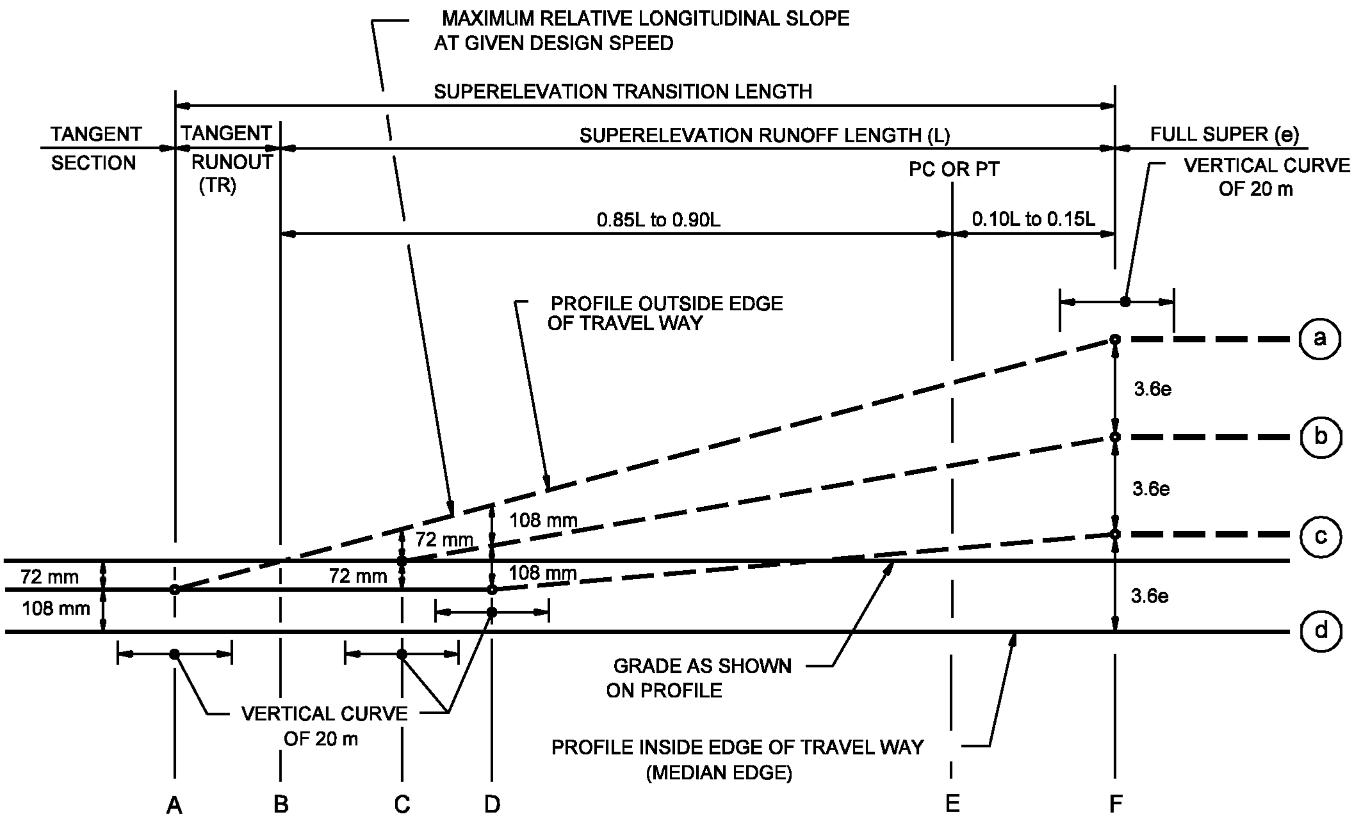
NOTES: 1. AXES OF ROTATION ABOUT TWO MEDIAN EDGES

2. e = APPLICABLE SUPERELEVATION RATE



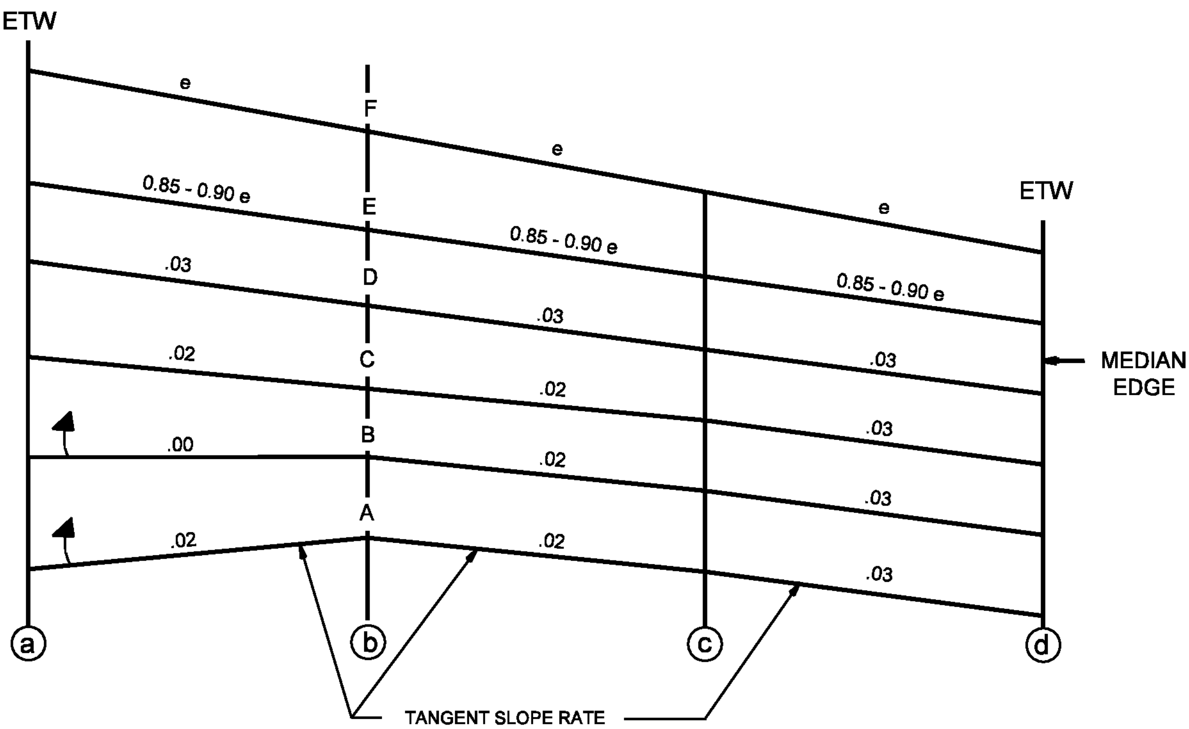
SUPERELEVATION DEVELOPMENT
(Four-Lane Divided, No Future Third Lane)

Figure 43-3I
(Continued)



OUTSIDE ROADWAY

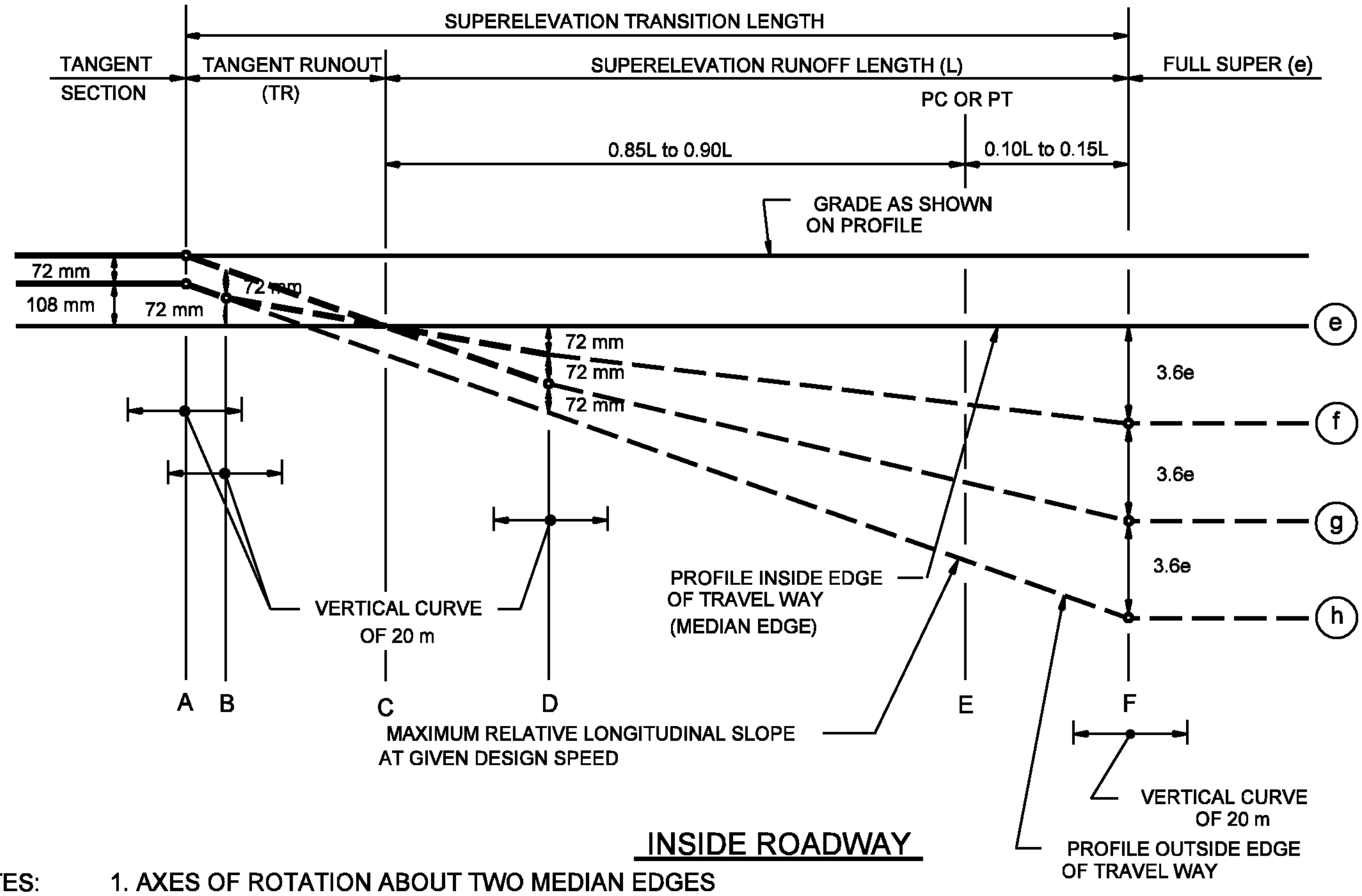
NOTES:
1. AXES OF ROTATION ABOUT TWO MEDIAN EDGES
2. e = APPLICABLE SUPERELEVATION RATE



OUTSIDE ROADWAY

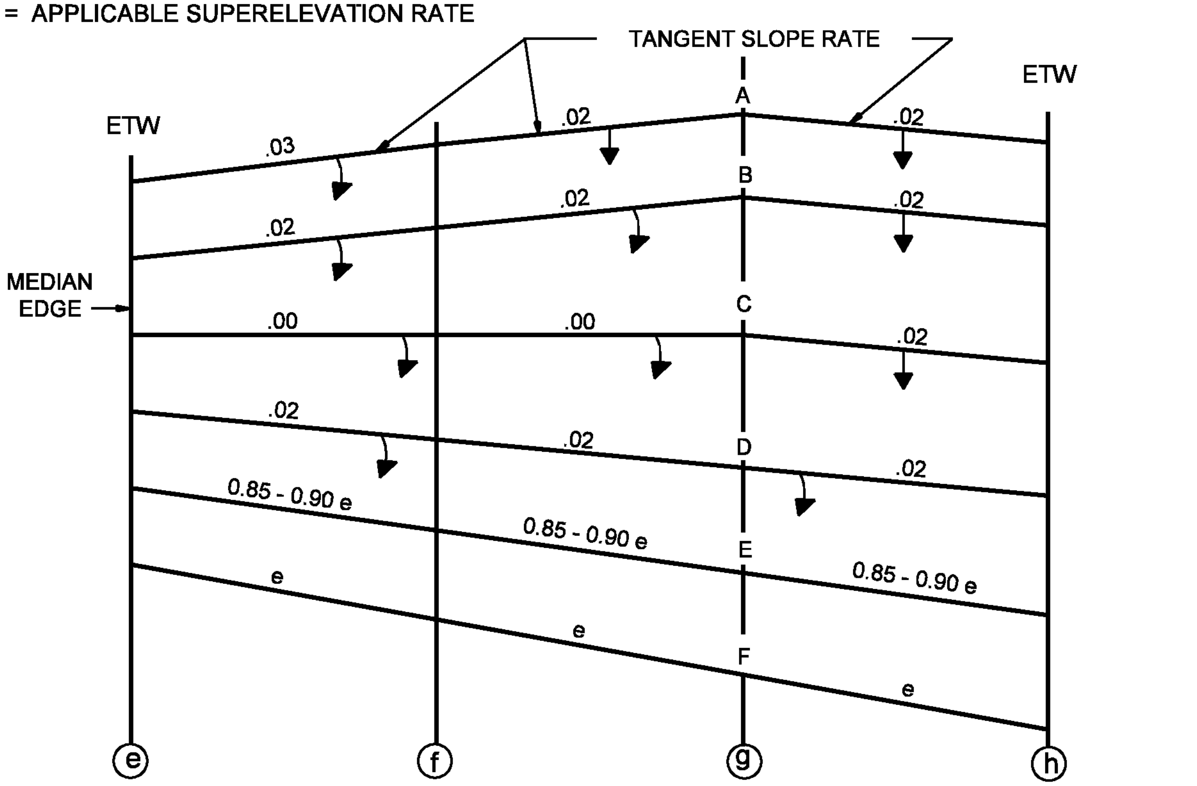
SUPERELEVATION DEVELOPMENT
(Six-Lane (or more) Divided)
(Four-Lane Divided with Future Additional Lanes)

Figure 43-3J



INSIDE ROADWAY

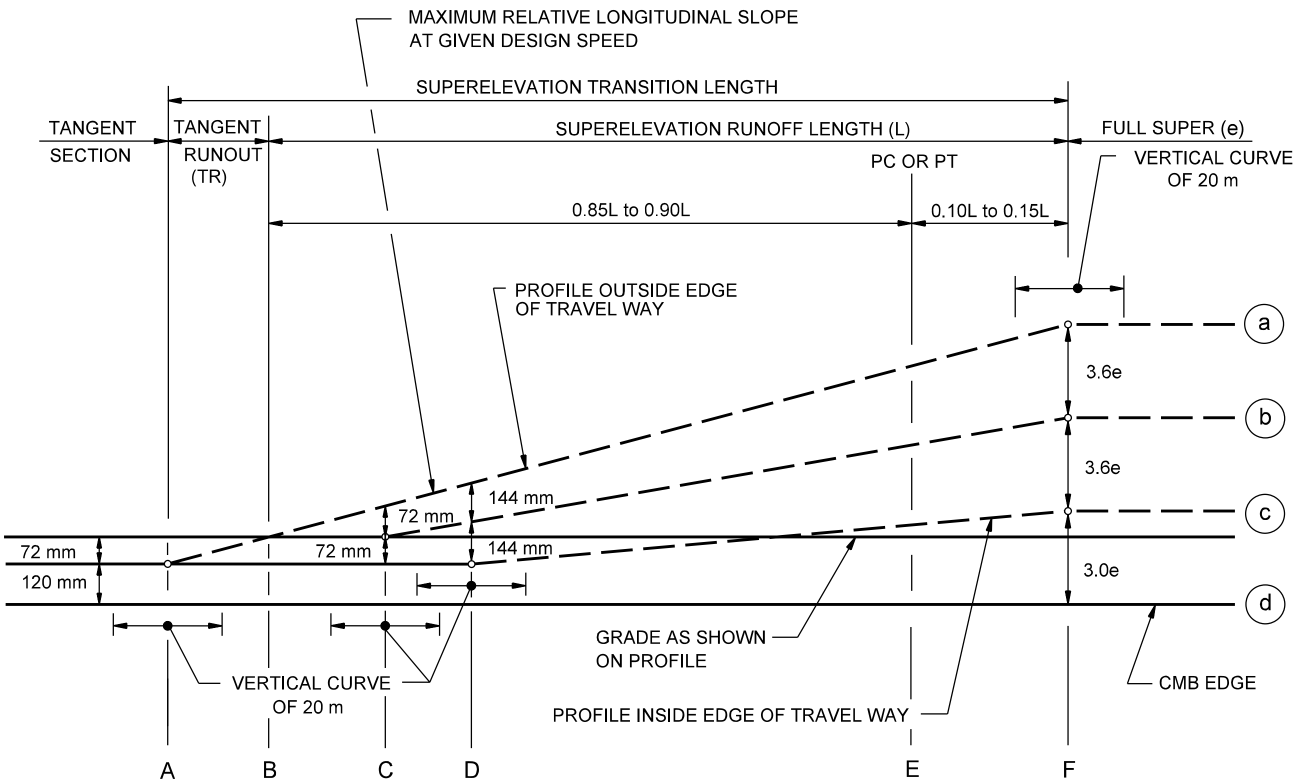
NOTES:
1. AXES OF ROTATION ABOUT TWO MEDIAN EDGES
2. e = APPLICABLE SUPERELEVATION RATE



INSIDE ROADWAY

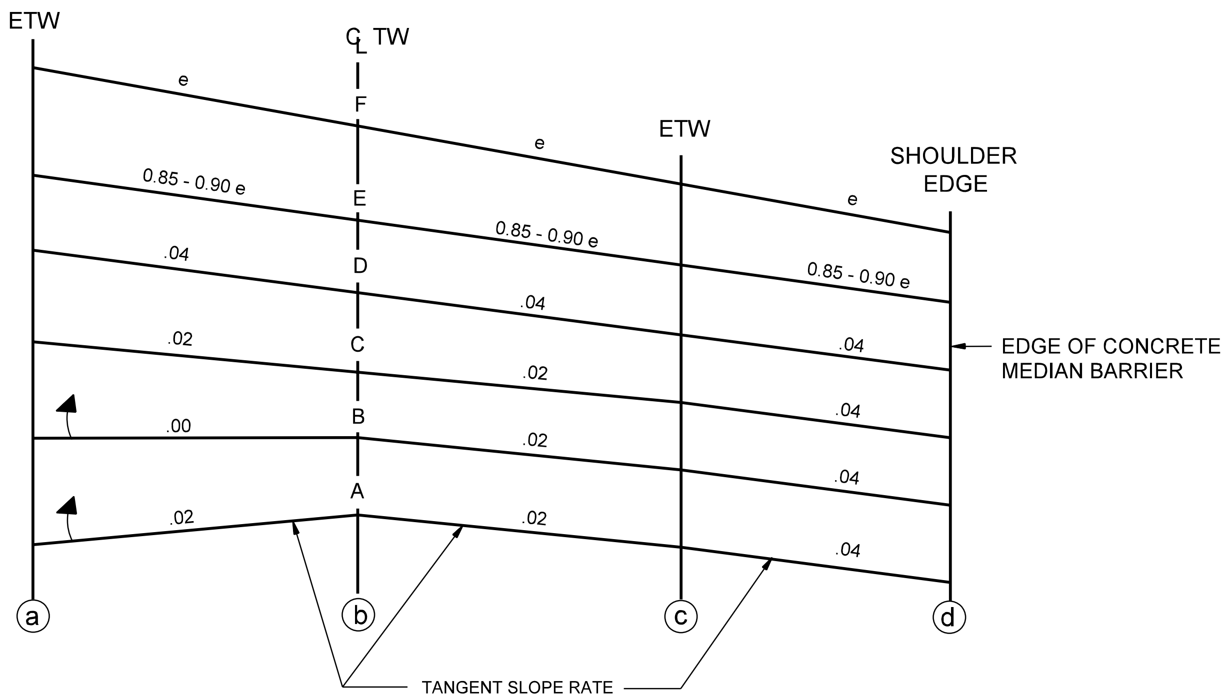
SUPERELEVATION DEVELOPMENT
(Six-Lane (or more) Divided)
(Four-Lane Divided with Future Additional Lanes)

Figure 43-3J
(Continued)



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

Design Speed (km/h)	Superelevation Rate, *e*	Minimum Superelevation Runoff, L_2 (m)
30	.02	10
	.03	15
	.04	19
	.05	24
	.06	29
40	.02	10
	.03	15
	.04	21
	.05	26
	.06	31
50	.02	11
	.03	16
	.04	22
	.05	27
	.06	.2
60	.02	12
	.03	18
	.04	24
	.05	30
	.06	36
70	.02	13
	.03	19
	.04	26
	.05	33
	.06	39

Note: For a superelevation rate between two shown in the table, use a straight-line interpolation to calculate the superelevation runoff length.

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

Figure 43-3L

Paved Shld. Width, *w* (m)	High-Side-Shoulder Cross Slope	Low-Side-Shoulder Cross Slope
$0.6 \le w \le 12$	*e*	*e*
$w > 1.2$	*e* for 0.6 m Closest to Travel Lane, then **	*e* for 0.6 m 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 SLOPE
SUPERELEVATED SECTION, WITH UNDERDRAINS

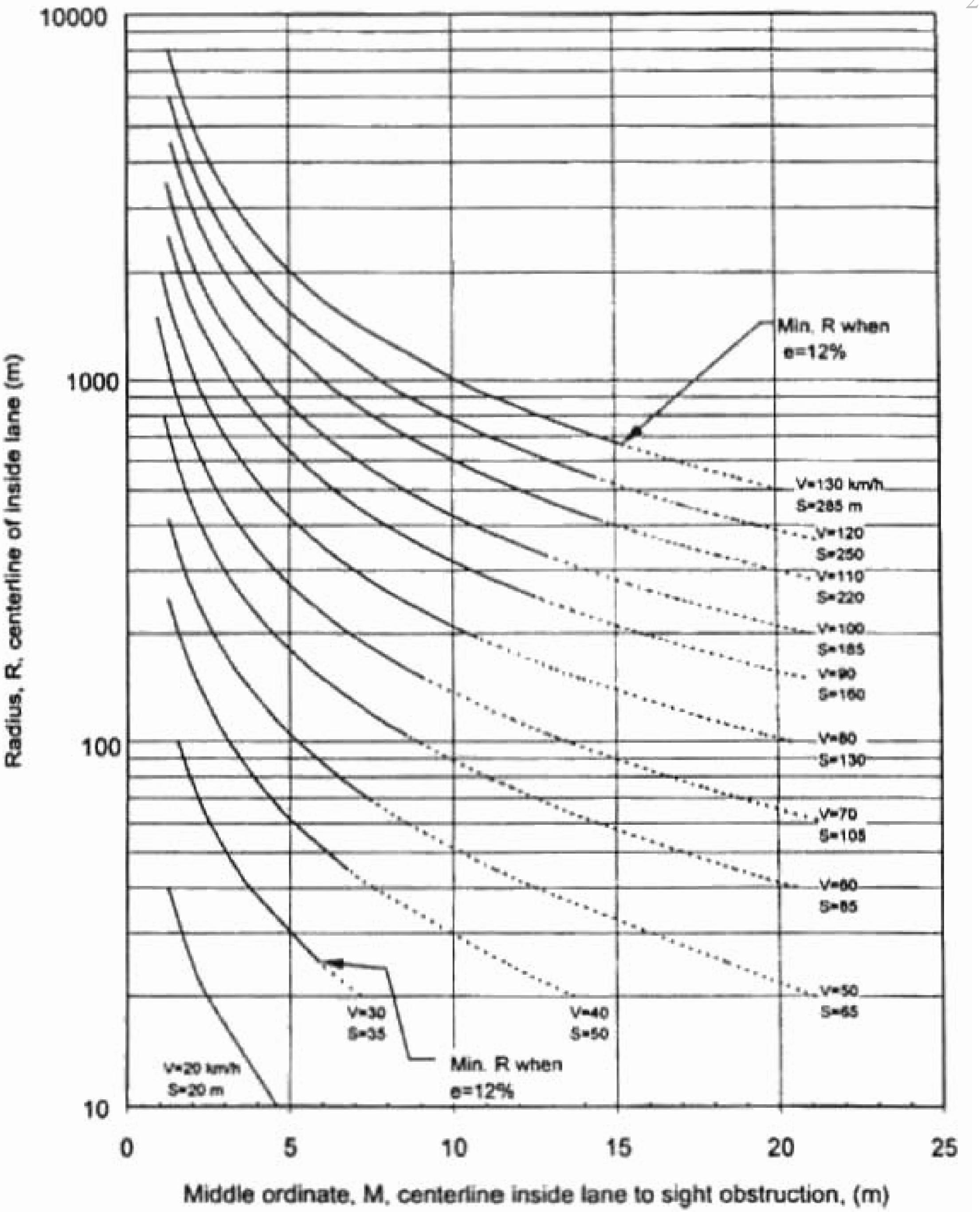
Figure 43-3M

Paved Shld. Width, *w* (m)	High-Side-Shoulder Cross Slope	Low-Side-Shoulder Cross Slope
$0 \le w \le 0.6$	*e*	*e*
$0.6 < w \le 1.2$	*e*	*e*
$w > 1.2$	**	***

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

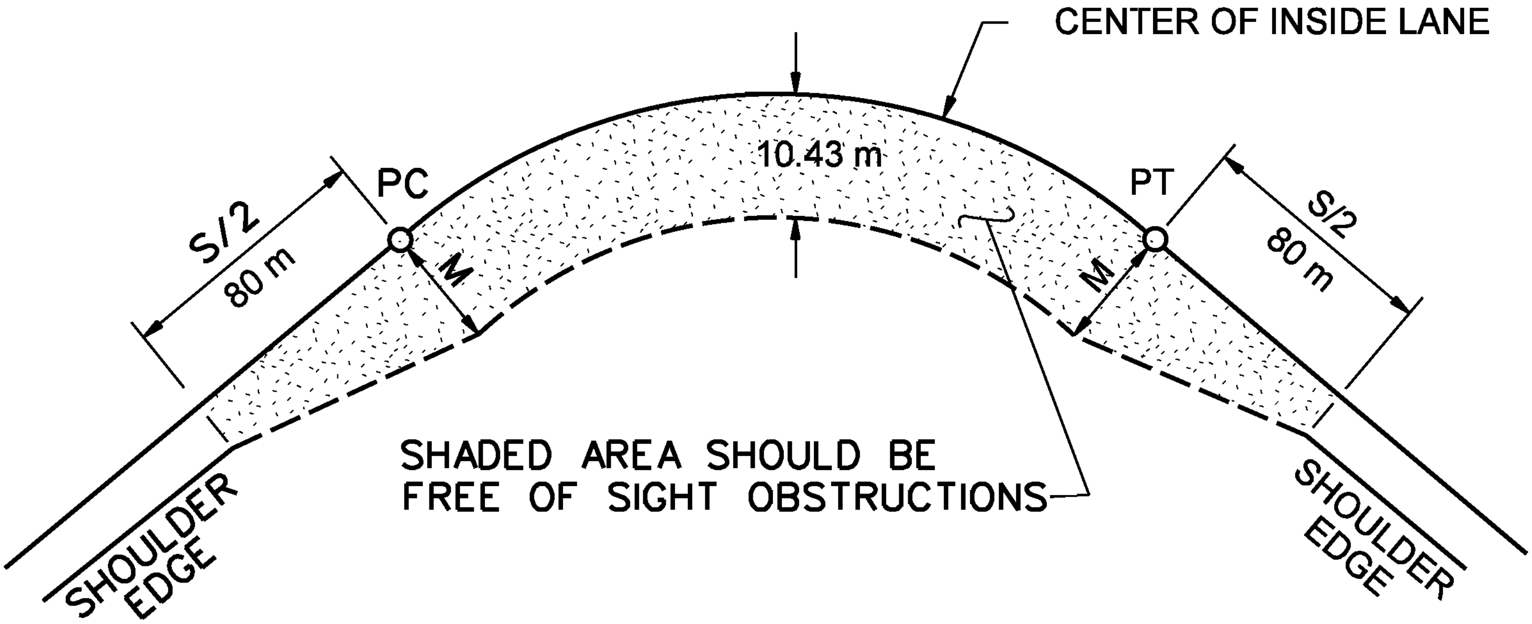
PAVED-SHOULDER CROSS SLOPE
SUPERELEVATED SECTION, WITHOUT UNDERDRAINS

Figure 43-3N



SIGHT DISTANCE AT HORIZONTAL CURVES

Figure 43-4A



<u>Example 43-4.1</u>

Given: Design Speed = 90 km/h, R = 305 m

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

Solution: The cve should be designed to accommodate the minimum SSD values. Figure 42-1A m. Using the equation for horizontal clearance (L > S):

M = R {1 - cos [(28.65 S) / R]}

M = 305 {1-cos [(28.65) (160) / 305]} = 10.43 m

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

SIGHT CLEARANCE REQUIREMENTS FOR HORIZONTAL CURVES

Figure 43-4C

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 Curve Stationing

MATHEMATICAL DETAILS FOR HORIZONTAL CURVE

Figure 43-6A

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

1. $\sin\alpha = \frac{a}{c}$

2. $\cos\alpha = \frac{b}{c}$

3. $\tan\alpha = \frac{a}{b}$

4. $csc\,\alpha = \frac{1}{\sin\alpha} = \frac{c}{a}$

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

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

7. $vers\,\alpha = 1 - \cos\alpha$

8. $covers\,\alpha = 1 - \sin\alpha$

9. $exsec\,\alpha = \sec\alpha - 1$

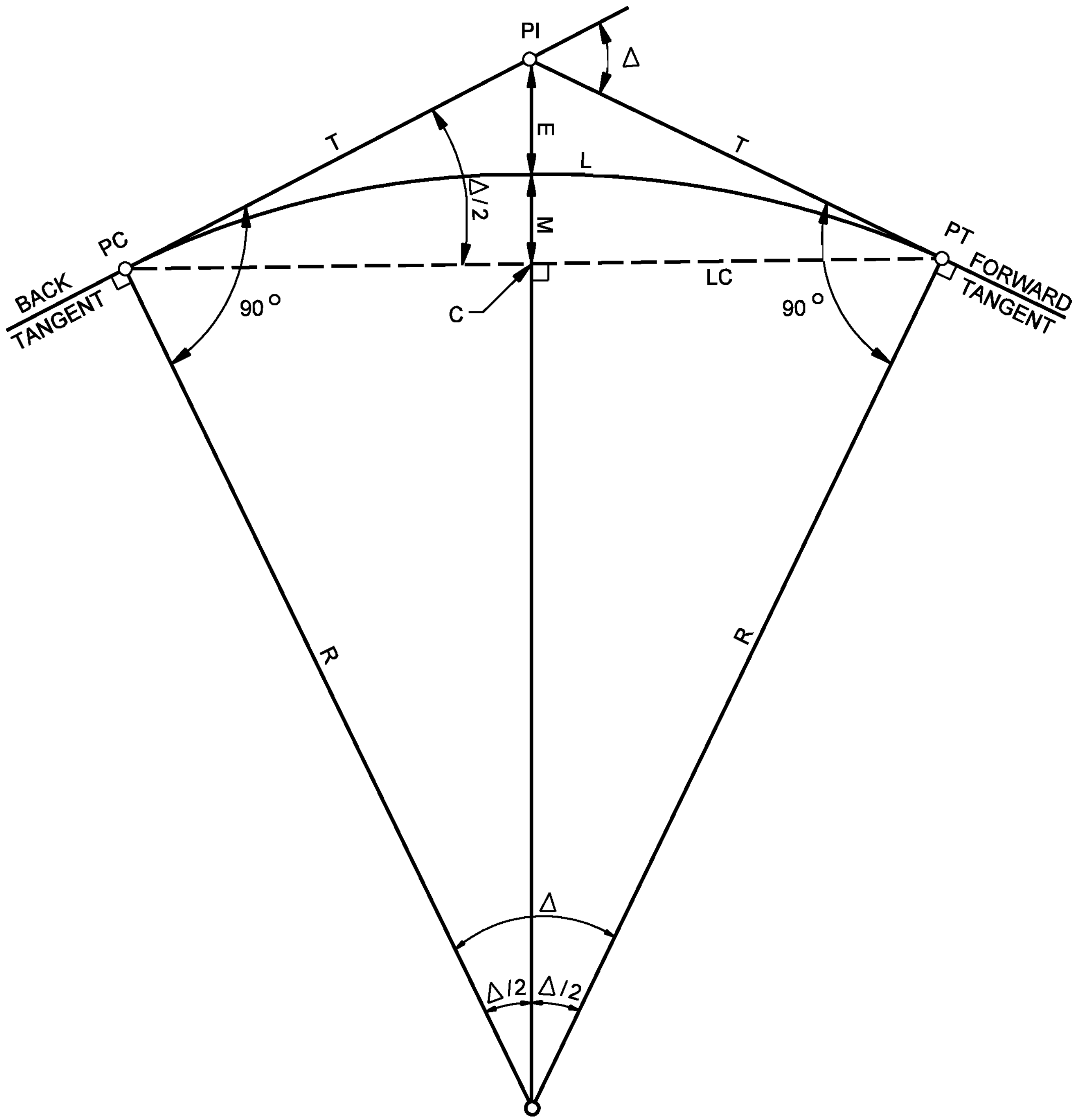
10. $coexsec\,\alpha = \csc\alpha - 1$

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

12. $\alpha + \beta = 90°$

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

BASIC TRIGONOMETRIC FUNCTIONS
Figure 43-6B



SIMPLE CURVE COMPUTATION

Figure 43-6C

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) (m)

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

R = Radius of curve (m)

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

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

C = midpoint of long Chord

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

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
Station of PT = Sta. of PC + L

1 station = 1 km. For example, Sta. 1+354.86 is 1354.86 m from Sta. 0+000.00.

HORIZONTAL-CURVE ABBREVIATIONS, SYMBOLS, AND FORMULAS

Figure 43-6D

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. = (2 + 077.72) - (1 + 964.78) = 112.94 m
T = PI Sta. - PC Sta. = (2 + 025.36) - (1 + 964.78) = 60.58 m

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

$$R = \frac{T}{\tan(\Delta/2)} = \frac{60.58}{\tan 19.17°} = \frac{60.58}{0.34765} = 174.26\,m$$

E = T tan (Δ/4) = (60.58)(tan 9.585) = (60.58)(0.16887) = 10.23 m
M = R (1 - cos Δ/2) = (174.26)(1 - cos 19.17) = (174.26)(0.05545) = 9.66 m

SIMPLE-CURVE COMPUTATION EXAMPLE

Figure 43-6E

STATIONING

1. The station at the first PI is 0 + 188.53.

2. The station at the first PC = 0 + 188.53 - 68.29 = 0 + 120.24.

3. The station at the first PT = 120.24 + 133.72 = 0 + 253.96.

4. The station at the second PC = 253.96 + (255.72 - 68.29 - 75.55) = 0 + 365.84.

5. The station at the second PI = 0 + 365.84 + 75.55 = 0 + 441.39.

6. The station at the second PT = 365.84 + 146.13 = 0 + 511.97.

7. The station at the third PC = 511.97 + (286.23 - 75.55 - 79.69) = 0 + 642.96.

8. The station at the third PI = 642.96 + 79.69 = 0 + 722.65.

9. The station at the third PT = 642.96 + 152.46 = 0 + 795.42.

10. The station at the final PT = 795.42 + (206.68 - 79.69) = 0 + 922.41.

11. Check: (188.53 + 255.72 + 286.23 + 206.68) – (2 x 68.29 + 2 x 75.55 + 2 x 79.69 -133.72 – 146.13 – 152.46) = 0 + 922.41.

SIMPLE-CURVE STATIONING

Figure 43-6F