MONTANA DEPARTMENT OF TRANSPORTATION

ROAD DESIGN MANUAL

Chapter 3

Horizontal Alignment

January 2026

Contents

CHAPTER 3 HORIZONTAL ALIGNMENT 3-1

3.1 DESIGN PRINCIPLES AND APPROACH 3-1

3.1.1 Coordination with Other Design Elements.................................... 3-1

3.1.2 Horizontal Alignment Considerations 3-2

3.2 HORIZONTAL CURVES...3-4

3.2.1 Selection of Curve Type.. 3-4

3.2.2 Calculation of Curve Radii 3-5

3.2.3 Minimum Radii.. 3-6

3.2.4 Maximum Deflection without a Curve.. 3-7

3.2.5 Length of Curve 3-7

3.3 SUPERELEVATION 3-8

3.3.1 Maximum Superelevation Rate 3-9

3.3.2 Superelevation Rates.. 3-9

3.3.3 Minimum Radii without Superelevation 3-13

3.3.4 Transition Length 3-13

3.3.4.1 Application of Transition Length.................................. 3-14

3.3.5 Axis of Rotation 3-16

3.3.5.1 Roadways without a Median.. 3-16

3.3.5.2 Roadways with Medians.. 3-18

3.3.6 Shoulder Superelevation 3-20

3.3.7 Reverse Curves 3-20

3.3.8 Broken-Back Curves... 3-23

3.3.9 Compound Curves.. 3-23

3.3.10 Bridges 3-23

3.4 STATION EQUATIONS..3-24

3.5 REFERENCES...3-25

Chapter 3

Horizontal Alignment

The horizontal alignment of a roadway, as well as the vertical alignment and cross section, has an impact on the safety and operational performance for all road users, as well as construction and maintenance costs. This chapter presents the basic design principles and approach for designing horizontal alignment elements, including a discussion of the different types of horizontal curves and methods of achieving superelevation. The *Montana Department of Transportation Baseline Criteria Practitioner's Guide (1)* provides specific horizontal alignment standards relative to a roadway's functional classification. Example calculations and detailed definitions associated with this chapter can be found in Appendix K.

3.1 DESIGN PRINCIPLES AND APPROACH

The use of horizontal curves in roadway design should contribute to the overall safety of the roadway and enhance the aesthetic appearance of the roadway for road users. The design team should adhere to general design principles and limiting criteria discussed in the context of the five types of horizontal curves in the following sections.

3.1.1 Coordination with Other Design Elements

The horizontal alignment chosen should reflect design consistency, encourage appropriate driver behavior, and consider trade-offs relative to other engineering design parameters.

The horizontal alignment works in conjunction with other design elements, such as the vertical alignment and cross section elements, to achieve the best possible design for the roadway. The horizontal alignment should provide a design consistent with driver expectation, avoiding abrupt, unexpected changes or sharp curves following long tangents. The alignment should be as directional as practical, using the smallest practical deflection (Δ) angles and longest practical curve lengths, while still generally conforming to the natural topography and remaining consistent with other existing physical and economic constraints. Where possible, it is best to avoid abrupt alignment reversals or "S" curves by providing a sufficient length of tangent roadway between reversing curves. The horizontal alignment should also be consistent with roadway conditions beyond the project extents to meet driver expectation.

***NCHRP Report 785* provides additional details on the relationship between various design elements and performance measures *(2)*.**

Consideration of the above principles should also be consistent with vertical design elements. Best practice is to avoid a horizontal alignment which constrains the vertical design or creates areas of excess cut and/or fill. The vertical and horizontal design should be harmonious rather than allowing one to directly dictate the other. Vertical alignment and coordination between vertical and horizontal design is discussed in Chapter 4, Section 4.1.3.

The design of the horizontal alignment should be coordinated with features outside of the roadway itself. These may include environmentally sensitive or culturally significant areas adjacent to the project, existing infrastructure, and intersections. Coordination with these elements should consider all of the above mentioned items related to consistency and vertical design. Additional guidance on basic horizontal design controls and coordination with other design elements can be found in Chapter 2, Section 2.9.1.

Chapter 1, Section 1.2 provides additional information on applying a performance-based design approach.

The *MDT Baseline Criteria Practitioner's Guide (1)* provides the design team with design criteria for the horizontal design elements. The criteria provide a starting point for the design team to make a thoughtful evaluation of the project needs in consideration of the specific context. Design decisions may result in reasonable exceptions to the design criteria in order to meet the overall project purpose. A performance-based design framework can provide tools for making these decisions, context specific design, scope specific criteria, and design exceptions can help document these design choices.

3.1.2 Horizontal Alignment Considerations

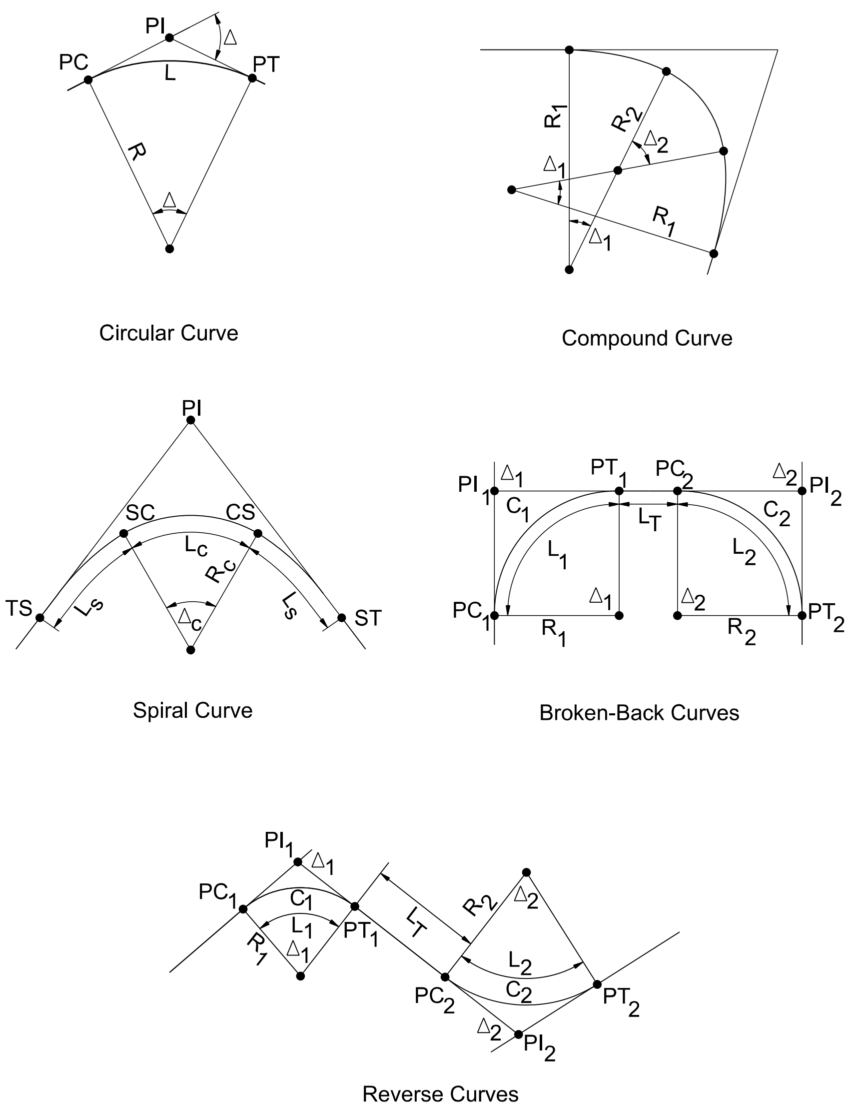
There are five types of horizontal curves that can be used to satisfy the horizontal constraints and considerations discussed above. The five types of horizontal curves are described below and illustrated in Exhibit 3-1.

1. **Circular curves** are continuous arcs of constant radii that achieve the necessary roadway deflection without an entering or exiting transition. Circular curves are also referred to as simple curves.
2. **Compound curves** are a series of two or more adjacent horizontal curves with deflections in the same direction and different radii.
3. **Spiral curves** are curvature arrangements that gradually increase from the tangent section (radius of infinity) to the radius of the circular curve or vice versa. These types of curves are more consistent with the transitional characteristics of vehicular turning paths used to transition between a tangent section and a circular curve.
4. **Broken-back curves** are two closely-spaced horizontal curves, of the same or different radii, with deflections in the same direction and a short tangent between the curves.
5. **Reverse curves** are two circular curves with deflections in opposite directions joined at a common point or by a relatively short tangent.

Within the five types of horizontal curves, the following reference points are used:

- Point of Curvature (PC)
- Point of Intersection (PI)
- Point of Tangency (PT)
- Length of Curve (L)
- Spiral to Curve (SC)
- Curve to Spiral (CS)
- Tangent to Spiral (TS)
- Spiral to Tangent (ST)
- Radius of Curve (R)

Exhibit 3-1
Schematic of Horizontal Alignment Curves



An important consideration in horizontal alignment design is its effect on the cross section. In particular, the use of normal crown sections on tangents and superelevation on horizontal curves requires considering the axis of rotation for transitioning to and from the superelevated sections. Axis of rotation about the centerline profile is the preferred rotation method for all rural or urban roadways without a median. Axis of rotation methods, and design considerations for each, are discussed in Section 3.3.5.

If the project extents include a bridge section, it is important to consider the bridge approach and structure as a unique part of the horizontal alignment. In general, it is undesirable to locate a bridge and its approach slabs on a horizontal curve of any type. Additional guidance and considerations for horizontal curves near bridges is provided in Section 3.3.10.

Sight obstructions on the inside of a horizontal curve are defined as obstacles which interfere with the line of sight on a continuous basis. These may include walls, cut slopes, wooded areas, buildings, and high farm crops. In general, point obstacles such as traffic signs and utility poles are not considered sight obstructions on the inside of horizontal curves. The design team should examine each curve individually to determine whether it is necessary to remove an obstruction or to adjust the horizontal alignment to obtain the required sight distance. Chapter 2, Section 2.8.1.1 provides additional information for determining horizontal sight distance requirements.

Refer to Chapter 2, Section 2.2.1 for detailed functional classification descriptions of rural and urban roadways.

Throughout this chapter, the following general categories are used to describe standards and parameters for horizontal curves and superelevation for different types of roadways:

1. **Rural Conditions.** All rural (outside the boundaries of urban areas) roadways and urban roadways where the design speed (V) > 45mph.
2. **Urban Conditions.** All roadways within the boundaries of an urban area where the design speed (V) ≤ 45mph.

3.2 HORIZONTAL CURVES

Once the constraints and parameters of the horizontal alignment have been established, the design team can begin the process of selecting the appropriate curve type and radius as discussed below. This section also discusses the use of minimum radii, maximum deflection without curve, and minimum length of curve for use in unique design situations. Basic equations for designing horizontal curves are provided in this chapter. Detailed calculation examples are provided in Appendix K.

It may not be feasible to meet some criteria for rural roadways in mountainous terrain. For these situations, the use of reverse curves, compound curves, and/or circular curves with 7-percent or greater superelevation may help the design team match the existing terrain.

3.2.1 Selection of Curve Type

The following presents MDT practice for the selection of the type of horizontal curve based on the type of roadway:

1. **Rural Conditions**. Based on the superelevation rate (*e*) criteria for the horizontal curve (Section 3.3.2), the following will apply:
    a. Superelevation < 7%: Use a circular curve.
    b. Superelevation ≥ 7%: Use a spiral curve.

Compound curves are typically not allowed on these roadways, except in transitional areas. For example, a larger radius circular curve approaching a smaller radius circular curve and then leaving the smaller radius circular curve with a larger radius circular curve may be appropriate to match existing topography.

2. **Urban Conditions.** Typically, circular curves will be used on roadways in urban conditions. In urban areas, if necessary, it is acceptable to use compound curves on the mainline to:
   a. Avoid obstructions,
   b. Avoid right-of-way problems, and/or
   c. Fit the existing topography.

Where used, compound curves on the mainline should be designed such that the radius of the flatter curve is no more than 1.5 times the radius of the sharper curve ($R_1 \le 1.5R_2$, where R_1 is the flatter curve).

3.2.2 Calculation of Curve Radii

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 circular curve is:

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

Equation 3.2-1

Where:

R = radius of curve, feet (ft)

e = superelevation rate, decimal

f = side-friction factor, decimal (from Exhibit 3-2)

V = design speed, miles per hour (mph)

Establishing horizontal curvature criteria requires a selection of various factors in the basic curve equation (Equation 3.2-1). These include the selection of maximum side-friction factors (*f*) and the distribution method between side friction and superelevation. For roadway mainlines, the theoretical basis will be one of the following:

1. **Rural Conditions.** The theoretical basis for horizontal curvature assuming rural conditions includes:
   a. Relatively low maximum side-friction factors (that is, a relatively small level of driver discomfort); and
   b. Use of American Association of State Highway and Transportation Officials (AASHTO) Method 5 to distribute side friction and superelevation *(3)*.

   AASHTO Method 5 distributes side friction and superelevation such that each element is used simultaneously to offset the outward pull of the vehicle traveling around the curve.

2. **Urban Conditions.** The theoretical basis for horizontal curvature assuming urban conditions includes:
   a. Relatively high maximum side-friction factors to reflect a higher level of driver acceptance of discomfort; and

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

Check local design criteria for off-system roadways.

AASHTO Method 2 distributes side friction and superelevation such that side friction alone is used, up to the maximum side friction factor (f_{max}), to offset the outward pull of the vehicle traveling around the curve. Only then is superelevation introduced.

3.2.3 Minimum Radii

The minimum radius of curvature is determined assuming the maximum rate of superelevation (e_{max}) and the maximum side friction factor (f_{max}), while still maintaining a level of driver comfort and a margin of safety against skidding or vehicle rollover. Once the minimum radius is determined for a given design speed, the ranges of appropriate radii for curves with less than the maximum superelevation rate can be determined for the given design speed.

Exhibits 3-2 and 3-3 present the minimum radii (R_{min}) for rural and urban roadways. To define R_{min}, a maximum superelevation rate must be selected. See Section 3.3.1 for MDT criteria for e_{max}.

Exhibit 3-2 Minimum Radii for Rural Conditions

Design Speed, *V* (mph)	e_{max} (percent)	f_{max}	Minimum Radii, R_{min} (ft)
20	8.0%	0.27	80
25	8.0%	0.23	140
30	8.0%	0.20	220
35	8.0%	0.18	320
40	8.0%	0.16	450
45	8.0%	0.15	590
50	8.0%	0.14	760
55	8.0%	0.13	960
60	8.0%	0.12	1200
65	8.0%	0.11	1480
70	8.0%	0.10	1810
75	8.0%	0.09	2210
80	8.0%	0.08	2670

Note: R_{min} is based on Equation 3.2-1 rounded up to the nearest 10-foot increment. R_{min} is typically measured at the center of gravity of vehicles in the inside most lane.

Exhibit 3-3
Minimum Radii for Urban Conditions

Design Speed, *V* (mph)	e_{max}	f_{max}	Minimum Radii, R_{min} (ft)
20	4.0%	0.27	86
25	4.0%	0.23	154
30	4.0%	0.20	250
35	4.0%	0.18	371
40	4.0%	0.16	533
45	4.0%	0.15	711

Note: R_{min} is based on Equation 3.2-1 rounded to the nearest 1-foot increment. R_{min} is typically measured at the center of gravity of vehicles in the inside most lane.

Horizontal curve radii larger than design minimums should be used where feasible.

When selecting a curve radius, the design team should again consider the desired performance of the roadway and the existing and future constraints. The values provided in Exhibits 3-2 and 3-3 are design minimums, but a larger radius should be selected if it better fits the topography and constraints of an area. If a smaller radius, and therefore a lower design speed, is appropriate to fit the topography and constraints of the area, the design team shall document the deviation as appropriate. See Chapter 2, Section 2.9 for MDT procedures on design exceptions. Also, if the design speed for the horizontal curve is lower than the posted speed, the design team should coordinate with the Traffic and Safety Bureau. Appropriate warning signage for the curve may be required according to the latest *MUTCD* guidance (*4*).

3.2.4 Maximum Deflection without a Curve

It may be appropriate to design a roadway without a horizontal curve where small deflection angles (Δ) are present. As a guide, the design team may retain deflection angles of about 1 degree or less in urban areas and 0.5 degrees or less in rural areas. In these cases, the absence of a horizontal curve will not likely affect driver response or aesthetics.

For urban intersections, deflection angles greater than 1 degree without a horizontal curve may be acceptable based on an evaluation of the design speed, traffic volumes, functional class, and existing/future signalization. A design exception for the minimum radius criterion may be necessary for use of a deflection angle. See Chapter 2, Section 2.9 and the *Baseline Criteria Practitioner's Guide (1)* for MDT procedures on documenting design deviations.

3.2.5 Length of Curve

The design team should document the curve design approach and constraints in the Alignment and Grade Review Report.

Short horizontal curves may provide the driver with the less desirable aesthetic appearance of a kink in the alignment. Short curves with long spirals, maximum super-elevated curves and minimum radius curves are not preferred and should be avoided to the extent practical. Minimum radius curves at the end of long tangents should be avoided. Providing curves with the smallest central angle and the longest corresponding curve length practical for the physical conditions is the preferred design approach.

Establishing the curve length is an iterative process. The following guidance are not supported by theoretical derivation but provide useful baseline curve length criteria.

1. **Rural Conditions.**
   a. The length of curve in feet = 15*V*, where *V* is the design speed in mph.
   b. For deflection angles (Δ) of 5 degrees or less, a 500-foot length of curve for a 5-degree deflection, add 100 feet for each 1-degree decrease in the central angle.
2. **Urban Conditions.** The length of curves in urban conditions will be determined on a case-by-case basis.

3.3 SUPERELEVATION

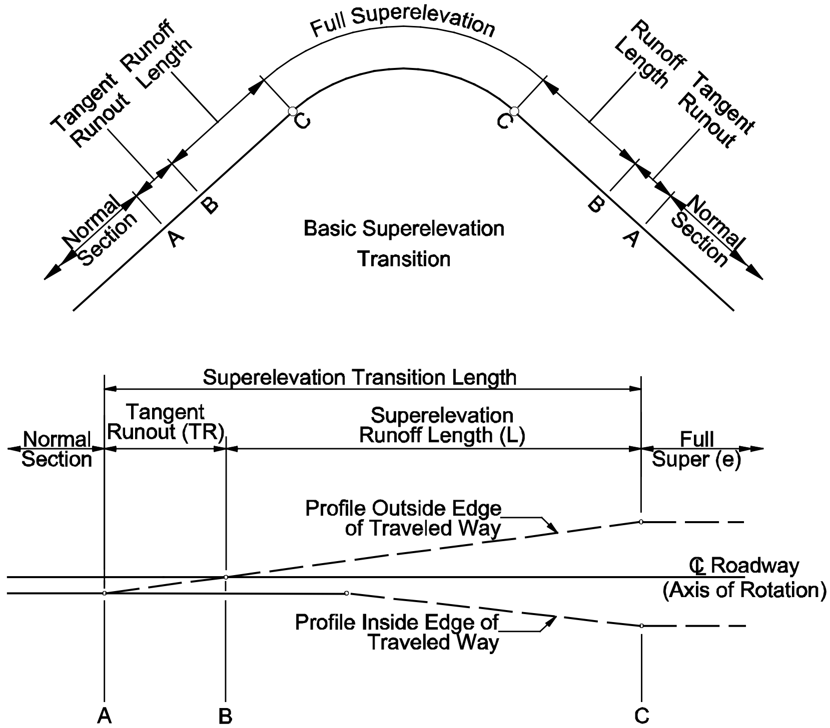
It may not always be practical or desirable to provide superelevation, particularly on low-speed urban roadways.

Another element of horizontal design is the cross slope of the roadway and how it influences the horizontal curve design. As used in this section, the terms below are defined as follows:

1. **Superelevation**. The amount of cross slope or "bank" provided on a horizontal curve to help counterbalance the outward pull of a vehicle traversing the curve.
2. **Transition Length**. The superelevation transition length is the distance required to transition the roadway from a normal crown (*NC*) section to a full superelevation. Superelevation transition length is the sum of the tangent runout (*TR*) and superelevation runoff (*L*) distances:
   a. **Tangent Runout (*TR*)**. Tangent runout is the distance needed to transition the roadway from a normal crown section to a point where the adverse cross slope of the outside lane or lanes is removed (i.e., where the outside lane(s) is level).
   b. **Superelevation Runoff (*L*)**. Superelevation runoff is the distance needed to transition the cross slope from the end of the tangent runout to a section that is sloped at the design superelevation rate.
3. **Axis of Rotation**. The superelevation axis of rotation is the line about which the pavement is rotated to superelevate the roadway. This line will maintain the normal roadway profile through the curve.

Exhibit 3-4 provides an illustration of these terms in both plan and profile views.

Exhibit 3-4
Superelevation Terms



The following discusses MDT practice for the application of superelevation to each curve type on both rural and urban roadways.

3.3.1 Maximum Superelevation Rate

The selection of a maximum rate of superelevation (e_{max}) depends upon several factors; these include urban/rural location, type of roadway, and prevalent climatic conditions. MDT has adopted the following criteria for the selection of e_{max}:

1. **Rural Conditions.** An e_{max} = 8% is used for paved rural conditions.
2. **Urban Conditions.** When used, an e_{max} = 4% is appropriate for urban conditions.

3.3.2 Superelevation Rates

Based on the selection of e_{max} and the roadway type (rural or urban), the following criteria will be used to determine the superelevation rate for combinations of curve radii (*R*) and design speed (*V*) and to select the minimum length of transition.

Exhibits 3-5 and 3-6 apply to two-lane, two-way roadways and multilane roadways (three to four lanes), respectively, in rural conditions where e_{max} = 8%. Under rural conditions distribution of *e* and *f* over a range of curves is based on AASHTO Method 5 *(3)*. Exhibit 3-7 applies to roadways in urban conditions, where

e_{max} = 4%. Under urban conditions, distribution of *e* and *f* over a range of curves is based on AASHTO Method 2 *(3)*.

Exhibit 3-5 Rate of Superelevation and Minimum Length of Transition (Two-Lane, Two-Way Roadways in Rural Conditions)

e	V = 30 mph			V = 35 mph			V = 40 mph		
	R(ft)	Trans. Length		R(ft)	Trans. Length		R(ft)	Trans. Length	
		L(ft)	TR(ft)		L(ft)	TR(ft)		L(ft)	TR(ft)
NC	R ≥ 3240	0	0	R ≥ 4260	0	0	R ≥ 5410	0	0
2.0%	3240 > R ≥ 2370	36	36	4260 > R ≥ 3120	40	40	5410 > R ≥ 3970	42	42
3.0%	2370 > R ≥ 1480	54	36	3120 > R ≥ 1960	60	40	3970 > R ≥ 2510	63	42
4.0%	1480 > R ≥ 1030	72	36	1960 > R ≥ 1370	80	40	2510 > R ≥ 1770	84	42
5.0%	1030 > R ≥ 730	90	36	1370 > R ≥ 1000	100	40	1770 > R ≥ 1310	105	42
6.0%	730 > R ≥ 510	108	36	1000 > R ≥ 720	120	40	1310 > R ≥ 970	126	42
7.0%	510 > R ≥ 360	126	36	720 > R ≥ 520	140	40	970 > R ≥ 720	147	42
8.0%	360 > R ≥ 220	144	36	520 > R ≥ 320	160	40	720 > R ≥ 450	168	42
	R_{min} = 220 ft			R_{min} = 320 ft			R_{min} = 450 ft		

e	V = 45 mph			V = 50 mph			V = 55 mph		
	R(ft)	Trans. Length		R(ft)	Trans. Length		R(ft)	Trans. Length	
		L(ft)	TR(ft)		L(ft)	TR(ft)		L(ft)	TR(ft)
NC	R ≥ 6710	0	0	R ≥ 8150	0	0	R ≥ 9720	0	0
2.0%	6710 > R ≥ 4930	44	44	8150 > R ≥ 5990	48	48	9720 > R ≥ 7150	52	52
3.0%	4930 > R ≥ 3130	66	44	5990 > R ≥ 3820	72	48	7150 > R ≥ 4580	78	52
4.0%	3130 > R ≥ 2220	88	44	3820 > R ≥ 2720	96	48	4580 > R ≥ 3270	104	52
5.0%	2220 > R ≥ 1650	110	44	2720 > R ≥ 2040	120	48	3270 > R ≥ 2470	130	52
6.0%	1650 > R ≥ 1250	132	44	2040 > R ≥ 1560	144	48	2470 > R ≥ 1920	156	52
7.0%	1250 > R ≥ 940	154	44	1560 > R ≥ 1190	168	48	1920 > R ≥ 1480	182	52
8.0%	940 > R ≥ 590	176	44	1190 > R ≥ 760	192	48	1480 > R ≥ 960	208	52
	R_{min} = 590 ft			R_{min} = 760 ft			R_{min} = 960 ft		

e	V = 60 mph			V = 70 mph			V = 80 mph		
	R(ft)	Trans. Length		R(ft)	Trans. Length		R(ft)	Trans. Length	
		L(ft)	TR(ft)		L(ft)	TR(ft)		L(ft)	TR(ft)
NC	R ≥ 11,500	0	0	R ≥ 14,500	0	0	R ≥ 17,800	0	0
2.0%	11,500 > R ≥ 8440	54	54	14,500 > R ≥ 10,700	60	60	17,800 > R ≥ 13,300	70	70
3.0%	8440 > R ≥ 5420	81	54	10,700 > R ≥ 6930	90	60	13,300 > R ≥ 8700	105	70
4.0%	5420 > R ≥ 3890	108	54	6930 > R ≥ 5050	120	60	8700 > R ≥ 6420	140	70
5.0%	3890 > R ≥ 2960	135	54	5050 > R ≥ 3910	150	60	6420 > R ≥ 5050	175	70
6.0%	2960 > R ≥ 2320	162	54	3910 > R ≥ 3150	180	60	5050 > R ≥ 4140	210	70
7.0%	2320 > R ≥ 1820	189	54	3150 > R ≥ 2580	210	60	4140 > R ≥ 3480	245	70
8.0%	1820 > R ≥ 1200	216	54	2580 > R ≥ 1810	240	60	3480 > R ≥ 2670	280	70
	R_{min} = 1200 ft			R_{min} = 1810 ft			R_{min} = 2670 ft		

Key:

e_{max} = 8.0%
Lane width = 12 ft (L & TR values for other lane widths can be determined using Equations 3.3-1 & 3.3-2, respectively)
R = Radius of curve, ft
V = Design speed, mph
e = Superelevation rate, %
L = Minimum length of superelevation runoff (from adverse slope removed to full super), ft
TR = Tangent runout from NC to adverse slope removed, ft
NC = Normal crown = 2.0%

Exhibit 3-6 Rate of Superelevation and Minimum Length of Transition (Multilane Roadways in Rural Conditions) (Three- to Four-Lane Roadways)*

e	V = 30 mph			V = 35 mph			V = 40 mph		
	R(ft)	Trans. Length		R(ft)	Trans. Length		R(ft)	Trans. Length	
		L(ft)	TR(ft)		L(ft)	TR(ft)		L(ft)	TR(ft)
NC	R ≥ 3240	0	0	R ≥ 4260	0	0	R ≥ 5410	0	0
2.0%	3240 > R ≥ 2370	56	56	4260 > R ≥ 3120	58	58	5410 > R ≥ 3970	62	62
3.0%	2370 > R ≥ 1480	84	56	3120 > R ≥ 1960	87	58	3970 > R ≥ 2510	93	62
4.0%	1480 > R ≥ 1030	112	56	1960 > R ≥ 1370	116	58	2510 > R ≥ 1770	124	62
5.0%	1030 > R ≥ 730	140	56	1370 > R ≥ 1000	145	58	1770 > R ≥ 1310	155	62
6.0%	730 > R ≥ 510	168	56	1000 > R ≥ 720	174	58	1310 > R ≥ 970	186	62
7.0%	510 > R ≥ 360	196	56	720 > R ≥ 520	203	58	970 > R ≥ 720	217	62
8.0%	360 > R ≥ 220	224	56	520 > R ≥ 320	232	58	720 > R ≥ 450	248	62
	R_{min} = 220 ft			R_{min} = 320 ft			R_{min} = 450 ft		

e	V = 45 mph			V = 50 mph			V = 55 mph		
	R(ft)	Trans. Length		R(ft)	Trans. Length		R(ft)	Trans. Length	
		L(ft)	TR(ft)		L(ft)	TR(ft)		L(ft)	TR(ft)
NC	R ≥ 6710	0	0	R ≥ 8150	0	0	R ≥ 9720	0	0
2.0%	6710 > R ≥ 4930	68	68	8150 > R ≥ 5990	72	72	9720 > R ≥ 7150	78	78
3.0%	4930 > R ≥ 3130	102	68	5990 > R ≥ 3820	108	72	7150 > R ≥ 4580	117	78
4.0%	3130 > R ≥ 2220	136	68	3820 > R ≥ 2720	144	72	4580 > R ≥ 3270	156	78
5.0%	2220 > R ≥ 1650	170	68	2720 > R ≥ 2040	180	72	3270 > R ≥ 2470	195	78
6.0%	1650 > R ≥ 1250	204	68	2040 > R ≥ 1560	216	72	2470 > R ≥ 1920	234	78
7.0%	1250 > R ≥ 940	238	68	1560 > R ≥ 1190	252	72	1920 > R ≥ 1480	273	78
8.0%	940 > R ≥ 590	272	68	1190 > R ≥ 760	288	72	1480 > R ≥ 960	312	78
	R_{min} = 590 ft			R_{min} = 760 ft			R_{min} = 960 ft		

e	V = 60 mph			V = 70 mph			V = 80 mph		
	R(ft)	Trans. Length		R(ft)	Trans. Length		R(ft)	Trans. Length	
		L(ft)	TR(ft)		L(ft)	TR(ft)		L(ft)	TR(ft)
NC	R ≥ 11,500	0	0	R ≥ 14,500	0	0	R ≥ 17,800	0	0
2.0%	11,500 > R ≥ 8440	80	80	14,500 > R ≥ 10,700	90	90	17,800 > R ≥ 13,300	104	104
3.0%	8440 > R ≥ 5420	120	80	10,700 > R ≥ 6930	135	90	13,300 > R ≥ 8700	156	104
4.0%	5420 > R ≥ 3890	160	80	6930 > R ≥ 5050	180	90	8700 > R ≥ 6420	208	104
5.0%	3890 > R ≥ 2960	200	80	5050 > R ≥ 3910	225	90	6420 > R ≥ 5050	260	104
6.0%	2960 > R ≥ 2320	240	80	3910 > R ≥ 3150	270	90	5050 > R ≥ 4140	312	104
7.0%	2320 > R ≥ 1820	280	80	3150 > R ≥ 2580	315	90	4140 > R ≥ 3480	364	104
8.0%	1820 > R ≥ 1200	320	80	2580 > R ≥ 1810	360	90	3480 > R ≥ 2670	416	104
	R_{min} = 1200 ft			R_{min} = 1810 ft			R_{min} = 2670 ft		

Key:

e_{max} = 8.0%
Lane width = 12 ft (L & TR values for other lane widths can be determined using Equations 3.3-1 & 3.3-2, respectively)
R = Radius of curve, ft
V = Design speed, mph
e = Superelevation rate, %
L = Minimum length of superelevation runoff (from adverse slope removed to full super), ft
TR = Tangent runout from NC to adverse slope removed, ft
NC = Normal crown = 2.0%

*For more than four lanes use Equation 3.3-3

Exhibit 3-7 Rate of Superelevation and Minimum Length of Transition (Urban Conditions)

e	V = 20 mph					V = 25 mph				
	R(ft)	Trans. Length (Two-Lane)		Trans. Length (Multilane)*		R(ft)	Trans. Length (Two-Lane)		Trans. Length (Multilane)*	
		L(ft)	TR(ft)	L(ft)	TR(ft)		L(ft)	TR(ft)	L(ft)	TR(ft)
NC	R ≥ 107	0	0	0	0	R ≥ 198	0	0	0	0
2.0%	107 > R ≥ 92	32	32	50	50	198 > R ≥ 167	34	34	52	52
3.0%	92 > R ≥ 89	48	32	75	50	167 > R ≥ 160	51	34	78	52
4.0%	89 > R ≥ 86	64	32	100	50	160 > R ≥ 154	68	34	104	52
	Rmin = 86 ft					R_{min} = 154 ft				

e	V = 30 mph					V = 35 mph				
	R(ft)	Trans. Length (Two-Lane)		Trans. Length (Multilane)*		R(ft)	Trans. Length (Two-Lane)		Trans. Length (Multilane)*	
		L(ft)	TR(ft)	L(ft)	TR(ft)		L(ft)	TR(ft)	L(ft)	TR(ft)
NC	R ≥ 333	0	0	0	0	R ≥ 510	0	0	0	0
2.0%	333 > R ≥ 273	36	36	56	56	510 > R ≥ 408	40	40	58	58
3.0%	273 > R ≥ 261	54	36	84	56	408 > R ≥ 389	60	40	87	58
4.0%	261 > R ≥ 250	72	36	112	56	389 > R ≥ 371	80	40	116	58
	R_{min} = 250 ft					R_{min} = 371 ft				

e	V = 40 mph					V = 45 mph				
	R(ft)	Trans. Length (Two-Lane)		Trans. Length (Multilane)*		R(ft)	Trans. Length (Two-Lane)		Trans. Length (Multilane)*	
		L(ft)	TR(ft)	L(ft)	TR(ft)		L(ft)	TR(ft)	L(ft)	TR(ft)
NC	R ≥ 762	0	0	0	0	R ≥ 1039	0	0	0	0
2.0%	762 > R ≥ 593	42	42	62	62	1039 > R ≥ 794	44	44	68	68
3.0%	593 > R ≥ 561	63	42	93	62	794 > R ≥ 750	66	44	102	68
4.0%	561 > R ≥ 533	84	42	124	62	750 > R ≥ 711	88	44	136	68
	R_{min} = 533 ft					R_{min} = 711 ft				

Key:

e_{max} = 4.0%

Lane width = 12 ft (L & TR values for other lane widths can be determined using Equations 3.3-1 & 3.3-2, respectively)

R = Radius of curve, ft
V = Design speed, mph
e = Superelevation rate, %
L = Minimum length of superelevation runoff (from adverse slope removed to full super), ft
TR = Tangent runout from NC to adverse slope removed, ft
NC = Normal crown = 2.0%

*For three- to four-lane roadways. If more than four lanes use Equation 3.3-3

3.3.3 Minimum Radii without Superelevation

A horizontal curve with a sufficiently large radius does not require superelevation, and the normal crown (*NC*) used on tangent sections can be maintained throughout the curve for both rural and urban roadways. Exhibits 3-5 and 3-6 indicate the threshold (or minimum) radius for a normal crown section at various design speeds for rural conditions. Exhibit 3-7 indicates the threshold (or minimum) radius for a normal crown section at various design speeds for urban conditions. The transition length values shown in Exhibits 3-5 through 3-7 are calculated based on Equations 3.3-1 through 3.3-3 and rounded for design. Equations 3.3-1 through 3.3-3 can be used to calculate values for conditions other than those presented in Exhibits 3-5 through 3-7.

3.3.4 Transition Length

The following outlines MDT procedure for determining the superelevation transition length for different types of roadways under both rural and urban conditions.

Two-Lane, Two-Way Roadways in Rural Conditions. To calculate the superelevation transition length, the superelevation runoff (*L*) and tangent runout (*TR*) must first be calculated. Exhibit 3-5 presents the superelevation runoff lengths for two-lane, two-way roadways in rural conditions for various combinations of curve radii, design speed, and superelevation rate. The superelevation runoff can be calculated from Equation 3.3-1 for a two-lane roadway.

$$L = e \times W \times RS$$

Equation 3.3-1

where:

L = Superelevation runoff length for a two-lane roadway, feet

W = Width of travel lane, feet

RS = Reciprocal of relative longitudinal slope between the roadway centerline and outside edge of traveled way (see Exhibit 3-8)

e = Superelevation rate, decimal

Exhibit 3-5 presents the tangent runout distances based on a 2-percent normal crown for two-lane, two-way roadways in rural conditions. For roadways having a normal crown other than 2-percent, use Equation 3.3-2 to compute the tangent runout distance:

$$TR = \frac{S_{NORMAL}}{e/L} = \frac{(S_{NORMAL})(L)}{e}$$

Equation 3.3-2

where:

TR = Tangent runout distance for a two-lane roadway, feet

S_{NORMAL} = Travel lane cross slope on tangent (typically 0.02), decimal

e = Design superelevation rate (that is, full superelevation for horizontal curve), decimal

L = Superelevation runoff length for a two-lane roadway, feet

**Exhibit 3-8
Maximum Relative
Longitudinal Slopes for
Two-Lane Roadways**

Design Speed (mph)	RS	Maximum Relative Longitudinal Slope, G(%)*
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
70	250	0.40
80	286	0.35

*G(%) = 1/RS x 100

Multilane Roadways in Rural Conditions. Exhibit 3-6 summarizes the superelevation runoff and tangent runout distances for three- to four-lane roadways in rural conditions for various combinations of curve radii, design speed, and superelevation rate. For rotation of three- to four-lane roadways, the superelevation runoff length will be 1.5 times that for two-lane roadways and can be calculated from Equation 3.3-3. For rotation of roadways with more than four lanes, the superelevation runoff length will be 2.0 times that for two-lane roadways.

Equation 3.3-3

$$L = C \times L_{\text{Two-lane roadways}}$$

C = 1.5, for three- to four-lane roadways
C = 2.0, for roadways with more than four lanes

The tangent runout for multilane roadways in rural conditions is calculated from Equation 3.3-2. This will ensure that the relative longitudinal gradient of the tangent runout equals that of the superelevation runoff.

Urban Conditions. Exhibit 3-7 summarizes the superelevation runoff and tangent runout with various combinations of superelevation rates and design speed in urban conditions. For two-lane roadways and multilane roadways in urban conditions the superelevation runoff and tangent runout can also be calculated from the equations used for rural conditions.

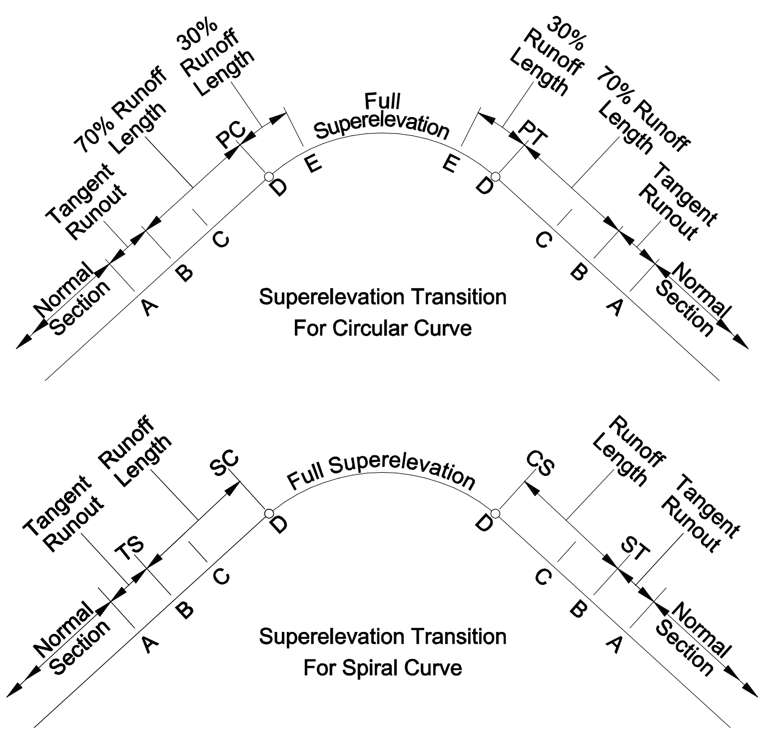
3.3.4.1 Application of Transition Length

Once the superelevation runoff and tangent runout have been calculated or determined from Exhibits 3-5 through 3-7, the design team needs to determine how to fit the length in the horizontal and vertical planes. Exhibit 3-9 illustrates the application of the transition length in the plan view for both rural and urban roadways. See Section 3.3.5 for illustrations in the profile and cross section views. The following will apply:

1. **Spiral Curves.** The tangent runout (*TR*) will be placed on the tangent sections immediately before and after the spiral sections of the horizontal curve. The superelevation runoff (*L*) length at the beginning of the curve will begin at the point of tangent to spiral (*TS*) and end at the point of spiral to circular curve (*SC*). The application of *L* to the end of the curve will be from the curve to spiral (*CS*) to the spiral to tangent (*ST*). This means the length of the spiral curves are set equal to the superelevation runoff length.
2. **Circular Curves.** Typically, 70 percent of the superelevation runoff length will be placed on the tangent and 30 percent on the curve. For resurfacing and widening projects, it is acceptable to match the existing distribution of the superelevation runoff between the tangent and curve sections, even if 100 percent of the runoff length is on the tangent.

Exhibit 3-9
Application of Transition Length (Plan View)

Note: See Section 3.3.5 for profile and cross section views (Points A, B, C, D, and E) of superelevation development. Point C is the first (or last) point at which the cross section has a uniform slope



3.3.5 Axis of Rotation

The design team should prepare profiles along the roadway edges, top back of curb, and/or ditch flow lines to confirm ponding will not be an issue.

Superelevation axis of rotation should typically be about the centerline profile (Method A below) for all rural or urban roadways, except for those roadways with a median more than 10 feet wide. One of AASHTO Cases I to III should be applied, as described below, for roadways with a median more than 10 feet wide. Drainage should be carefully considered in the application of superelevation and the determination of axis of rotation. When one side of the roadway drops, this may lead to ponding along the inside of the curve. Additionally, blockages in ditch flow can occur, particularly if one side of the roadway is raised above centerline.

3.3.5.1 Roadways without a Median

Method A, axis of rotation about the centerline profile, is the preferred rotation method for all rural or urban roadways without a median.

Rural or urban roadways without a median should typically be rotated according to Method A; these include roadways with no median, flush medians, or raised medians 10 feet wide or less (see Case I in Section 3.3.5.2). Method A rotates the traveled way about the centerline profile of the traveled way. The centerline profile remains fixed while the inside-edge profile is dropped below the centerline and the outside-edge profile is raised above the centerline, thus creating the least amount of distortion to the edge of the roadway. This is the most widely used and adaptable method according to AASHTO. See Exhibits 3-10 and 3-11 for illustrations of Method A rotation for circular curves and spiral curves, respectively.

Methods B through D are described further in Appendix G. Use of any of these methods should be documented in the Alignment and Grade Review Report.

Method B, rotation about the inside-edge profile, was MDT's previously preferred axis of rotation method, but should now only be applied in special or unique circumstances. Method C, rotation about the outside-edge profile, and Method D, straight cross slope rotated about the outside-edge profile, are additional axis of rotation methods that are also only to be applied in special or unique circumstances.

In urban conditions, the axis of rotation is typically about the centerline of the traveled way (Method A). This means, for example, if on-street parking is present on only one side, the axis of rotation will not be in the center of the roadway section. Urban conditions may also present special cases because of the presence of two-way left-turn lanes, turning lanes at intersections, and other unique circumstances. For these situations, where superelevated, the axis of rotation should be determined on a case-by-case basis.

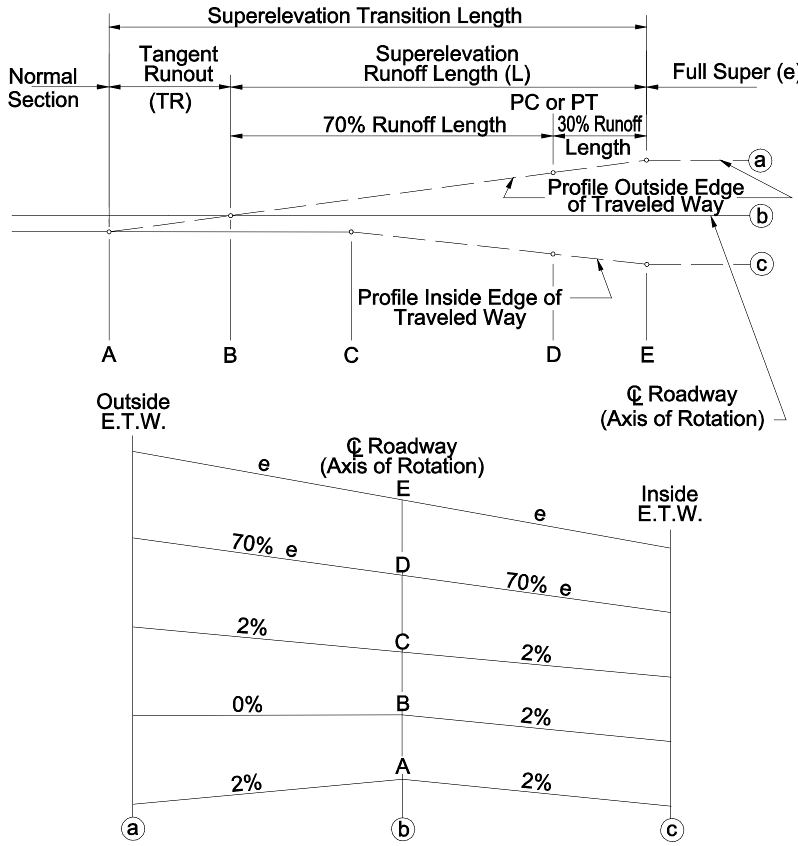
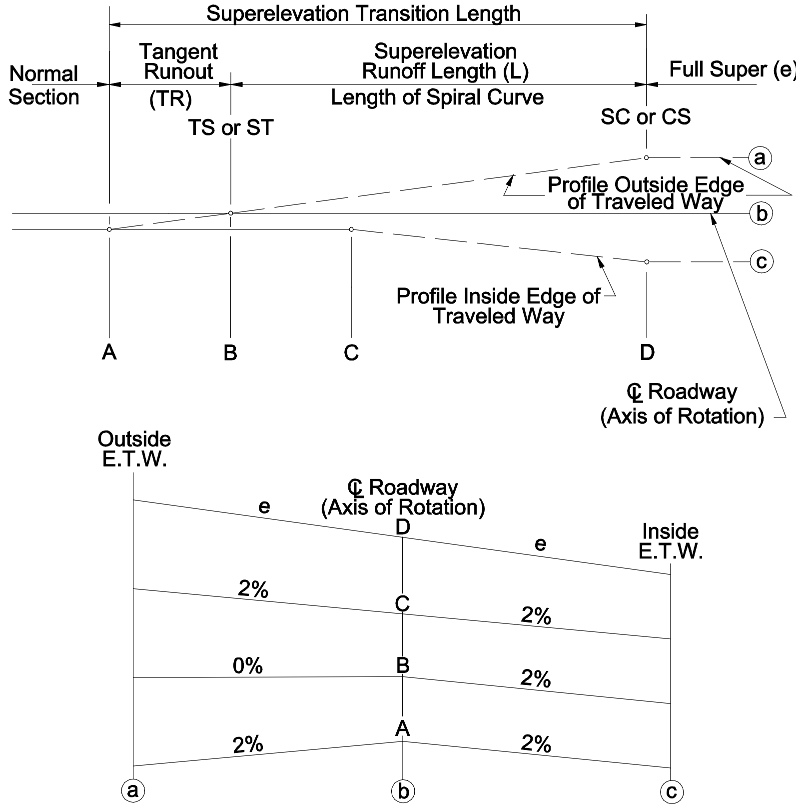


Exhibit 3-10
Axis of Rotation about Centerline Profile (Method A, Circular Curve)

Note: See Exhibit 3-9 for Plan View Illustration

**Exhibit 3-11
Axis of Rotation about Centerline Profile (Method A, Spiral Curve)**

Note: See Exhibit 3-9 for Plan View Illustration



3.3.5.2 Roadways with Medians

Exceptions to the location of the superelevation axis of rotation for roadways with medians may be necessary, particularly under urban conditions.

Rural or urban roadways with medians should typically be rotated according to AASHTO Cases I to III as described below:

- **Case I – Narrow Medians (≤ 10 feet wide):** The whole of the traveled way, including the median, is rotated as a plane section about the centerline profile, similar to Method A described above. Use of Case I should be limited to narrow medians less than 10 feet wide (may be applied with medians up to 15 feet wide if appropriate given the context) and moderate superelevation rates to avoid substantial differences in elevation of the extreme edges of the traveled way arising from the median tilt.
- **Case II – Medians >10 feet to 76 feet wide:** The median is held in a horizontal plane, and the two traveled ways are rotated separately about the median-edge of pavement. By holding the median edges level, the difference in elevation between the extreme edges of the traveled way can be limited to that needed to superelevate the roadway. See Exhibits 3-12 and 3-13 for illustrations of Case II rotation for circular curves and spiral curves, respectively.
- **Case III – Wide Medians (> 76 feet wide):** The two traveled ways are treated independently, with each typically being rotated about its respective centerline profile. The differences in elevation of the extreme edges of the traveled way are minimized by a compensating slope across the median.

Exhibit 3-12
Axis of Rotation about Median-Edge of Pavement (AASHTO Case II, Circular Curve)

Note: See Exhibit 3-9 for Plan View Illustration

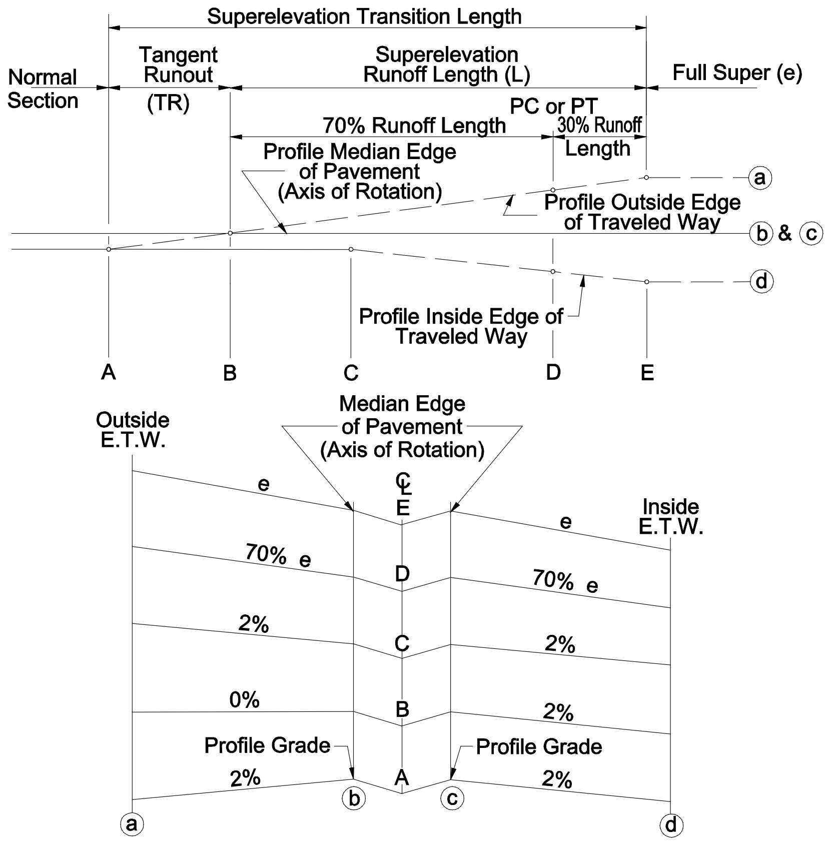
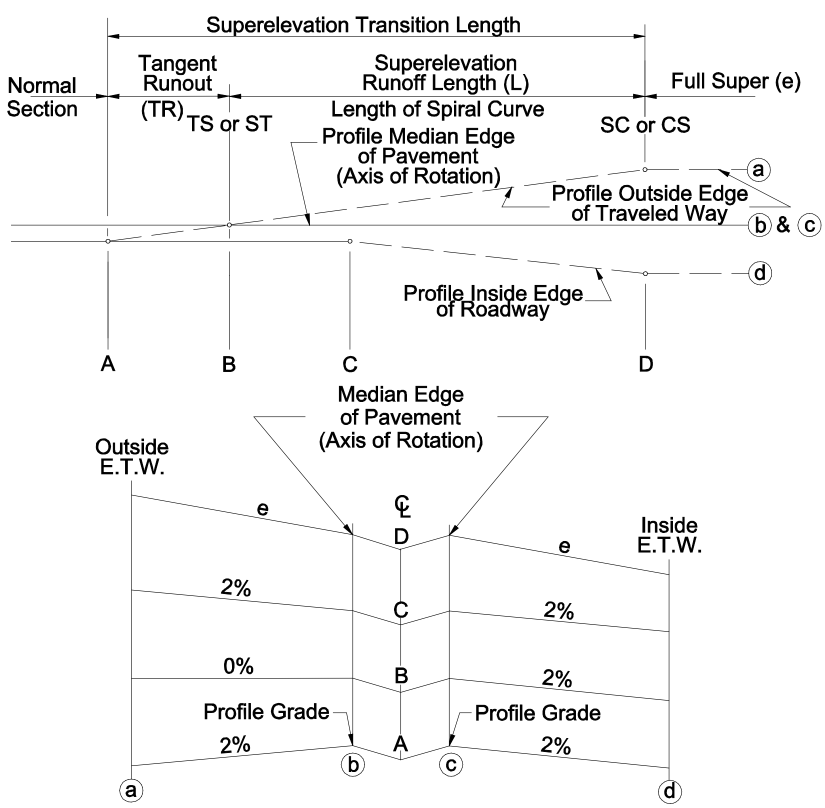


Exhibit 3-13
Axis of Rotation about Median-Edge of Pavement (AASHTO Case II, Spiral Curve)

Note: See Exhibit 3-9 for Plan View illustration



3.3.6 Shoulder Superelevation

The typical application for shoulder superelevation is to rotate the shoulder concurrently with the adjacent travel lane; that is, the shoulder and travel lane remain in a plane section throughout the superelevated curve. This applies to superelevated sections on both rural and urban roadways.

This allowance may be necessary to meet roadside development constraints.

An allowance for the high side is to slope the shoulder such that the algebraic difference between the shoulder and adjacent travel lane does not exceed 8 percent (referred to as superelevation rollover). This rollover also applies to lanes which diverge from the mainline, such as ramps, and intersecting roadways.

For the low side, the portion of the subgrade from a point below the finished shoulder to the subgrade shoulder point is designed using a 2-percent slope, regardless of the superelevation of the traveled way. See the typical section figures in Chapter 5, Section 5.6 for illustrations.

3.3.7 Reverse Curves

Reverse curves are two closely spaced horizontal curves with deflections in opposite directions. When feasible, a normal crown tangent section of roadway should be provided between the curves. However, if superelevation transition requirements cannot be met to achieve a normal crown section for at least twice the tangent runout (*TR*) distance between the two curves, the roadway should be continuously rotated in a plane about the defined axis of rotation (typically the centerline profile). The relative longitudinal slope should remain consistent throughout the reverse curves if a continuously rotated plane is used.

The design team should adhere to the applicable superelevation transition lengths, where practical, for each curve. The minimum distance between the PT and PC of reverse circular curves should be the sum of 70-percent of the required runoff length for each of the two curves where practical.

If the minimum distance between the PT and PC cannot be achieved, the design team should document the specific application of the runoff length in the Alignment and Grade Review Report.

Exhibit 3-14 provides a schematic illustration of a transition to a normal crown section between circular reverse curves. The transition is the same between reverse spiral curves except the superelevation runoff lengths occur entirely on the spirals between the two curves (CS1 to ST1 and TS2 to SC2). Exhibit 3-15 provides a schematic illustration of a continuously rotating plane through circular reverse curves. The transition is the same between reverse spiral curves except the superelevation runoff lengths are applied to the spirals and tangent between the two curves (CS1 to SC2). See Appendix K for examples of the application and calculation of reverse curves.

Exhibit 3-14
Superelevation of Reverse Curves - Transition to Normal Crown between Curves

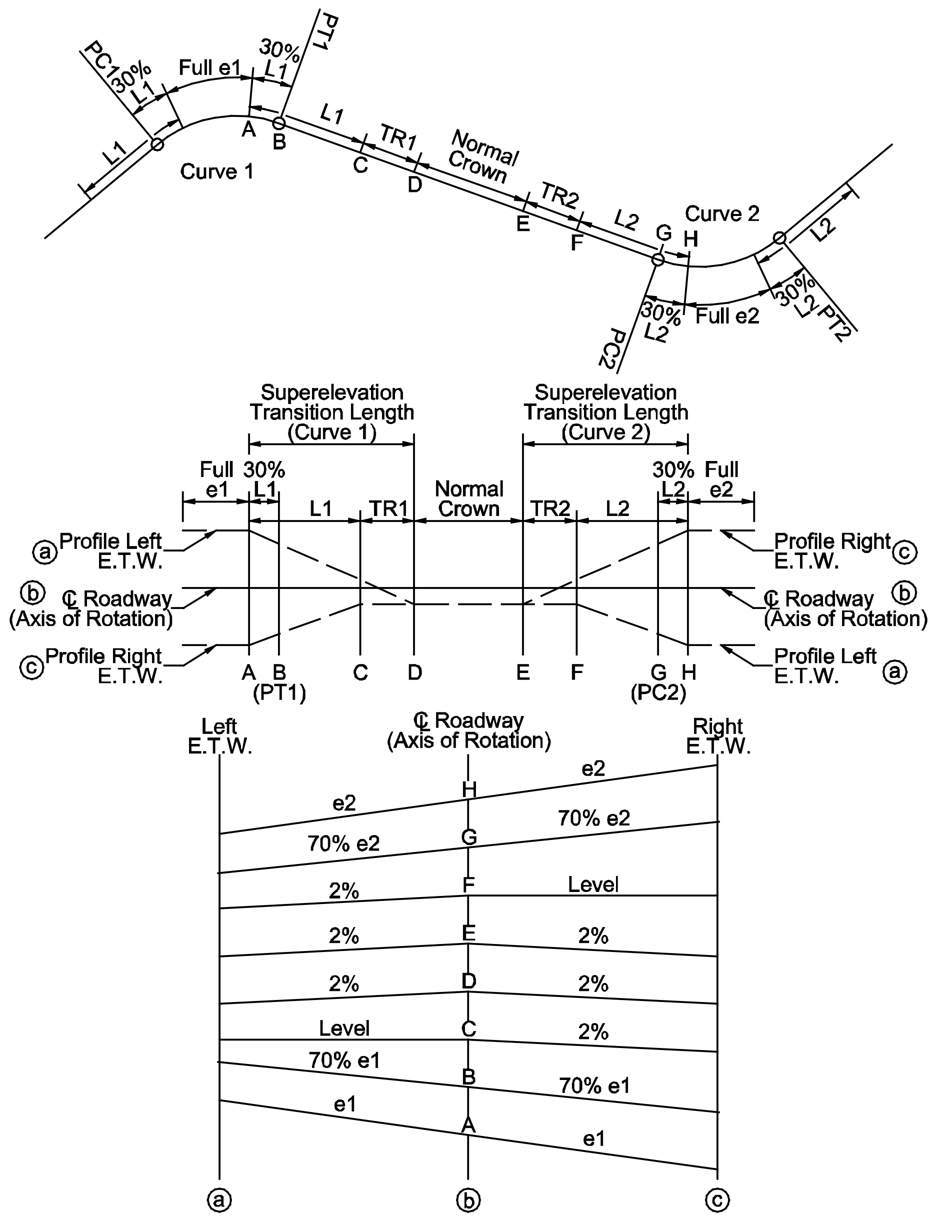
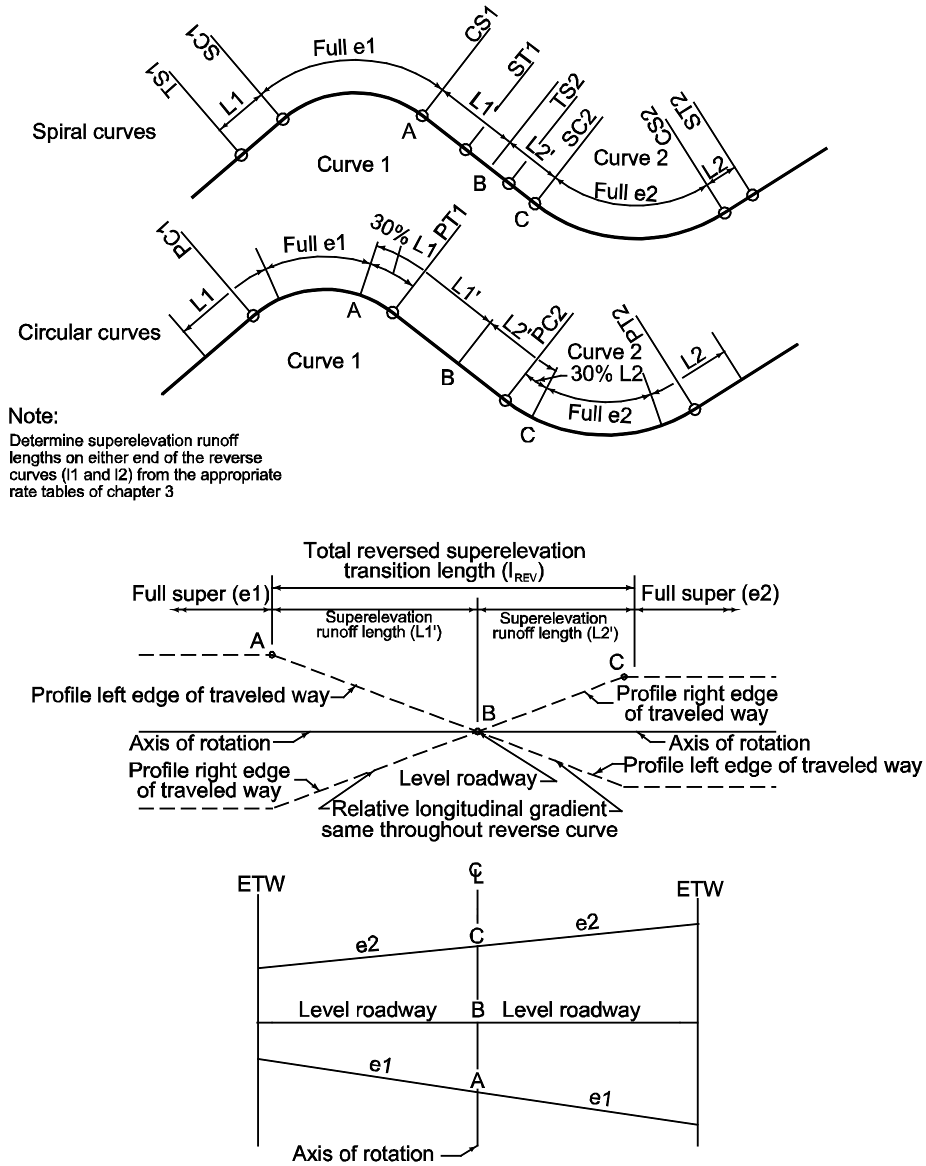


**Exhibit 3-15
Superelevation of Reverse Curves - Continuously Rotating Plane**



3.3.8 Broken-Back Curves

Avoid the use of broken-back curves where practical.

Broken-back curves are two closely spaced horizontal curves with deflections in the same direction and a short, intervening tangent. Where broken-back curves are used, the following will apply:

1. **Normal Crown Section.** The design team should not attempt to achieve a normal tangent section between broken-back curves unless the superelevation transition requirements can be met for both curves and at least 200 feet of normal crown section can be achieved.
2. **Superelevated Section.** If 200 feet of normal crown section cannot be achieved, the design team should provide a transitional curve-to-curve spiral, compound curve, or tangent connection to accommodate the gradual change between superelevation rates. This section should transition down from the first curve and back up to the second curve such that the rate of superelevation transition matches the standard value and a constant, lesser superelevation is maintained for at least 200 feet between the curves.

See Appendix K for examples of the application and calculation of broken-back curves.

3.3.9 Compound Curves

Compound curves are undesirable on Rural State Highways and High-Speed Urban Roadways except in transitional areas.

Compound curves are a series of two or more horizontal curves with deflections in the same direction immediately adjacent to each other. Compound curves are most commonly used for transitioning low-speed roadways at intersections (for example, ramps, slip lanes), but can also be used on the mainline of low-speed urban roadways, particularly as a practical design alternative to spiral transitions. The design team should avoid a curve radius misleading the motorist's expectation of the sharpness of another curve radius within the compound curve. Therefore, compound curves on the mainline should be designed such that the radius of the flatter curve is no more than 1.5 times the radius of the sharper curve ($R_1 \leq 1.5R_2$, where R_1 is the flatter curve). Superelevation transition lengths can be applied to the approaching and leaving curves in the same manner as applied to single curves. See Appendix K for examples of the application and calculation of compound curves.

3.3.10 Bridges

From the perspective of the roadway user, a bridge is an integral part of the roadway system and, ideally, horizontal curves and their transitions will be located irrespective of their impact on bridges. However, safety considerations and practical factors in bridge design and bridge construction warrant consideration in the location of horizontal curves at bridges. The following presents, in order from the most desirable to the least desirable, the application of horizontal curves to bridges:

1. The most desirable treatment is to locate the bridge and its approach slabs on a tangent section and sloped at the typical cross slope; that is, no portion of the curve or its superelevation development is on the bridge or bridge approach slabs.

For #2, transitions are completed off of the bridge prior to Section D (spiral curve) and Section E (circular curve) in Exhibit 3-9.

2. If a bridge is located within a horizontal curve, transitions should not be located on the bridge or its approach slabs. This includes both superelevation transitions and spiral transitions. This will result in a uniform cross slope (the design superelevation rate) and a constant rate of curvature throughout the length of the bridge and bridge approach slabs.

For #3, transitions are completed off of the bridge prior to Section C (for both spiral and circular curves) in Exhibit 3-9.

3. If the superelevation transition is located on the bridge or its approach slabs, the design team should place on the roadway approach that portion of the superelevation development, which transitions the roadway cross section from its normal crown to a point where the roadway slopes uniformly, that is, there is no break in the cross slope on the bridge deck. This will avoid the need to warp the crown on the bridge or the bridge approach slabs.

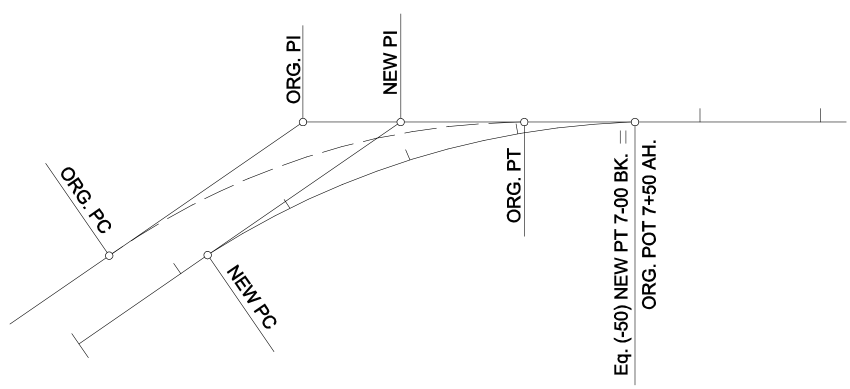
3.4 STATION EQUATIONS

The following will apply to the use of equations in project stationing:

If back station > ahead station, equation is (+). If back station < ahead station, equation is (-).

1. **Purpose**. An equation is used to equate two station numbers: one that is correct when measuring on the line before the equation, and one that is correct when measuring on the line after the equation. Equations should be used where stationing is not continuous throughout a project. Station equations should be avoided where possible on new roadway alignments.
2. **Locations.** Equations should be computed where the new design line become coincident with the original design line. This situation is illustrated in Exhibit 3-16.

Exhibit 3-16
New Design Line Becomes Coincident With Original Design Line



The design team should refer to Chapter 12 – Plan Preparation for details on indicating station equations throughout the road plans. It should be noted that (−) equations will not result in duplicate stationing, but (+) equations may result in duplicate stationing. The design team should attempt to avoid duplicate stationing when possible and be aware of the problems that can occur with duplicate stationing. For large (+) alignment changes, it may be necessary to add a large (−) equation at the point of divergence so that stationing is not duplicated.

3.5 REFERENCES

1. Montana Department of Transportation (MDT). *Baseline Criteria Practitioner's Guide*. MDT, Helena, MT, 2021.
2. Ray, B., E. Ferguson, J. Knudsen, and R. J. Porter. *NCHRP Report 785: Performance-Based Analysis of Geometric Design of Highways and Streets.* Transportation Research Board of the National Academies, Washington, D.C., 2014.
3. American Association of State Highway and Transportation Officials. *A Policy on Geometric Design of Highways and Streets*. AASHTO, Washington, D.C., 2011.
4. FHWA. *Manual on Uniform Traffic Control Devices (MUTCD)*. FHWA, Washington, D.C., 2023.