Chapter Twenty-five
HORIZONTAL ALIGNMENT

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Chapter Twenty-five
HORIZONTAL ALIGNMENT

25.1 GENERAL

The horizontal alignment of a highway facility will have a significant impact on vehicular operation and construction costs. Chapter Twenty-five presents the Department's criteria for those horizontal alignment elements that are typically applicable to projects administered by the Geometrics Unit within the Traffic Engineering Section. Chapter Nine of the Montana Road Design Manual presents considerably more information on horizontal alignment which may, occasionally, apply to a project administered by the Geometrics Unit. These include:

1. general controls for horizontal alignment (Section 9.1),
2. calculation of superelevation runoff lengths and tangent runout lengths (Sections 9.3.5 and 9.4.4),
3. use of reverse curves on mainline (Section 9.3.8),
4. use of broken-back curves on mainline (Section 9.3.9), and
5. horizontal alignment at bridges on mainline (Section 9.3.10).

As necessary, the designer should reference the Montana Road Design Manual for these horizontal alignment criteria.

25.2 HORIZONTAL CURVES

25.2.1 Definitions

1. Simple Curve. A curve that has a continuous arc of constant radius that achieves the necessary highway deflection without an entering or exiting transition.

2. Compound Curves. A series of two or more horizontal curves with deflections in the same direction immediately adjacent to each other.

3. Spiral Curve. A curvature arrangement used to transition between a tangent section and a simple curve that are consistent with the transitional characteristics of vehicular turning paths. When moving from the tangent to the simple curve, the sharpness of the spiral curve gradually increases from a radius of infinity to the radius of the simple curve.

4. Reverse Curves. Two simple curves with deflections in opposite directions that are joined by a common point or a relatively short tangent distance.

5. Broken-Back Curves. Two closely spaced horizontal curves with deflections in the same direction and a short intervening tangent.

25.2.2 Selection of Curve Type

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

1. Rural State Highways and High-Speed (V > 45 mph (70 km/h)) Urban Roadways. Based on the curve radii, the following will apply:

   a. R ≤ 3820 ft (1165 m) — use a spiral curve.
   b. R >3820 ft (1165 m) — use a simple curve.

   Compound curves are not allowed on these facilities, except in transitional areas.

2. Low-Speed (V ≤ 45 mph (70 km/h)) Urban Roadways/Non-State Highways. Typically, simple curves will be used on low-speed urban roadways and non-State highways. 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 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 (i.e., $R_1 \le 1.5\ R_2$, where R_1 is the flatter curve).

25.2.3 Calculation of Curve Radius

25.2.3.1 Basic Curve Equation

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

$$R = \frac{V^2}{15\,(e + f)}$$ US Customary (Equation 25.2-1)

$$R = \frac{V^2}{127\,(e + f)}$$ Metric (Equation 25.2-1)

where:

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

25.2.3.2 General Theory

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

1. Open-Roadway Conditions. The theoretical basis for horizontal curvature assuming open-roadway conditions includes:

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

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

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.

Open-roadway conditions apply to all rural facilities and to all high-speed urban facilities (i.e., where the design speed (V) > 45 mph (70 km/h)).

2. Low-Speed Urban Streets. The theoretical basis for horizontal curvature assuming low-speed urban street conditions includes:

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

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

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

   Low-speed urban streets are defined as streets within an urban or urbanized area where the design speed (V) ≤ 45 mph (70 km/h). Designers should check local design criteria for off-system facilities.

25.2.4 Minimum Radii

Figures 25.2A and 25.2B present the minimum radii (R_{min}) for open-roadway facilities and low-speed urban streets. To define R_{min}, a maximum superelevation rate (e_{max}) must be selected. R_{min} is based on Equation 25.2-1 rounded to the next highest 5 ft (5 m) increment. See Section 25.3 for MDT criteria for e_{max}.

25.2.5 Selection of Curve Radius

Where practical, the designer will select curve radii from among the radii listed in Figure 25.2C for mainline on open roadways. This will provide uniformity in project design. At individual curves, however, it may be necessary to select radii intermittent between those in the figure, rounded to the next highest 10 ft (5 m) increment. Curve radii on

US Customary				Metric			
Design Speed, V (mph)	e_{max}	f_{max}	Minimum Radii, R_{min} (ft)	Design Speed, V (km/h)	e_{max}	f_{max}	Minimum Radii, R_{min} (m)
20	8.0%	0.170	110	30	8.0%	0.17	30
25	8.0%	0.165	175	40	8.0%	0.17	55
30	8.0%	0.160	255	50	8.0%	0.16	85
35	8.0%	0.155	350	60	8.0%	0.15	125
40	8.0%	0.150	470	70	8.0%	0.14	180
45	8.0%	0.145	605	80	8.0%	0.14	230
50	8.0%	0.140	765	90	8.0%	0.13	305
55	8.0%	0.130	965	100	8.0%	0.12	395
60	8.0%	0.120	1205	110	8.0%	0.11	505
65	8.0%	0.110	1490	120	8.0%	0.09	670
70	8.0%	0.100	1825				
75	8.0%	0.090	2215				

MINIMUM RADII
(Open-Roadway Conditions)

Figure 25.2A

US Customary				Metric			
Design Speed, V (mph)	e_{max}	f_{max}	Minimum Radii, R_{min} (ft)	Design Speed, V (km/h)	e_{max}	f_{max}	Minimum Radii, R_{min} (m)
20	4.0%	0.300	80	30	4.0%	0.312	20
25	4.0%	0.252	145	40	4.0%	0.252	45
30	4.0%	0.221	230	50	4.0%	0.214	80
35	4.0%	0.197	345	60	4.0%	0.186	125
40	4.0%	0.178	490	70	4.0%	0.163	190
45	4.0%	0.163	670				

MINIMUM RADII
(Low-Speed Urban Streets V $\leq$ 45 mph (70 km/h))

Figure 25.2B

low-speed urban streets will be selected on a case-by-case basis. Figure 25.2D provides the relationship between (rounded) degree of curvature and radii for US Customary units.

Select curve radii from the following			
US Customary (ft)		Metric (m)	
23,000	1500	7000	450
11,500	1150	3500	350
7700	1000	2350	300
5700	800	1750	250
3800	700	1150	220
3000	600	900	190
2300	550	700	170
2000	520	600	160
1650	500	500	150

SELECTION OF CURVE RADII
(Open Roadways)

Figure 25.2C

Radius in Ft	Degree of Curvature	Radius in Ft	Degree of Curvature
22,920	0°15′	1433	4°00′
11,460	0°30′	1146	5°00′
7640	0°45′	955	6°00′
5730	1°00′	819	7°00′
3820	1°30′	716	8°00′
2865	2°00′	637	9°00′
2292	2°30′	573	10°00′
1910	3°00′	521	11°00′
1637	3°30′	478	12°00′

RELATIONSHIP BETWEEN DEGREE OF
CURVATURE AND RADIUS

Figure 25.2D

25.2.6 Maximum Deflection Without Curve

It may be appropriate to design a facility without a horizontal curve where small deflection angles (Δ) are present. As a guide, the designer may retain deflection angles of about 1° or less (urban) and 0.5° or less (rural) for the highway mainline. In these cases, the absence of a horizontal curve will not likely affect driver response or aesthetics.

For highway mainline at urban intersections, higher deflection angles may be acceptable based on an evaluation of the design speed, traffic volumes, functional class, existing/future signalization, etc.

25.2.7 Minimum Length of Curve

Short horizontal curves may provide the driver with the appearance of a kink in the alignment. To improve the aesthetics of the highway, the designer should lengthen short curves, if practical, even if not necessary for engineering reasons. The following guidance should be used to establish minimum curve lengths for deflection angles (Δ) of 5° or less:

1. Open Roadways. For open roadways, use the following criteria that results in the greatest curve length:

   a. the minimum radius that results in a normal crown cross slope;

   b. the length of curve in feet (meters) = 15V (3V), where V is the design speed in mph (km/h); or

   c. a 500 ft (150 m) length of curve for a 5° deflection. The designer should add 100 ft (30 m) for each 1° decrease in the central angle.

   If these criteria cannot be met, the designer should document this in the Alignment Review Report.

2. Low-Speed Urban. The minimum length of curves on low-speed urban streets will be determined on a case-by-case basis.

25.2.8 Computation

Section 25.6 presents the applicable mathematical details for the computation of horizontal curves.

25.3 SUPERELEVATION (Open-Roadway Conditions)

25.3.1 Definitions

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. Maximum Superelevation (e_{max}). The maximum rate of superelevation (e_{max}) is an overall superelevation control used on a specific facility. Its selection depends on several factors including overall climatic conditions, terrain conditions, type of facility and type of area (rural or urban).

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

    a. Tangent Runout (TR). 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., the outside lane(s) is level).

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

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

5. Superelevation Rollover. The algebraic difference (A) between the superelevated traveled way slope and shoulder slope on the outside of a horizontal curve.

6. Relative Longitudinal Slope. The difference between the centerline grade and the grade of the edge of traveled way.

7. Open Roadways. All rural facilities regardless of design speed and all urban facilities with a design speed greater than 45 mph (70 km/h).

8. Low-Speed Urban Streets. All streets within urbanized and small urban areas with a design speed of 45 mph (70 km/h) or less.

25.3.2 Maximum Superelevation Rate

The selection of a maximum rate of superelevation (e_{max}) depends upon several factors. These include urban/rural location, type of facility and prevalent climatic conditions within Montana. For open-roadway conditions, MDT has adopted the following for the selection of e_{max}:

1. Rural Facilities. An e_{max} = 8.0% is used on all rural facilities for all design speeds.

2. Urban Facilities (V > 45 mph (70 km/h)). An e_{max} = 8.0% is used on all urban facilities where the design speed (V) is greater than 45 mph (70 km/h).

25.3.3 Superelevation Rates

Based on the selection of e_{max} and the use of AASHTO Method 5 to distribute e and f, Figure 25.3A allows the designer to select the superelevation rate for combinations of curve radii (R) and design speed (V).

See Section 9.3 of the Montana Road Design Manual for the detailed methodology for calculating superelevation runoff and tangent runout lengths.

Note that superelevation rates are a controlling criteria. The designer must seek a design exception for any proposed rate which does not meet the criteria in Figure 25.3A. See Section 24.7 for Department procedures on design exceptions.

e	V = 30 mph	V = 35 mph	V = 40 mph
	R(ft)	R(ft)	R(ft)
NC	R ≥ 3290	R ≥ 4305	R ≥ 5460
2.0%	3290 > R ≥ 2405	4305 > R ≥ 3155	5460 > R ≥ 4010
3.0%	2405 > R ≥ 1520	3155 > R ≥ 2000	4010 > R ≥ 2545
4.0%	1520 > R ≥ 1065	2000 > R ≥ 1405	2545 > R ≥ 1800
5.0%	1065 > R ≥ 780	1405 > R ≥ 1035	1800 > R ≥ 1335
6.0%	780 > R ≥ 565	1035 > R ≥ 770	1335 > R ≥ 1000
7.0%	565 > R ≥ 415	770 > R ≥ 570	1000 > R ≥ 750
8.0%	415 > R ≥ 255	570 > R ≥ 350	750 > R ≥ 470
	R_{min} = 255 ft	R_{min} = 350 ft	R_{min} = 470 ft

e	V = 45 mph	V = 50 mph	V = 55 mph
	R(ft)	R(ft)	R(ft)
NC	R ≥ 6760	R ≥ 8195	R ≥ 9785
2.0%	6760 > R ≥ 4965	8195 > R ≥ 6025	9785 > R ≥ 7205
3.0%	4965 > R ≥ 3160	6025 > R ≥ 3840	7205 > R ≥ 4610
4.0%	3160 > R ≥ 2240	3840 > R ≥ 2735	4610 > R ≥ 3295
5.0%	2240 > R ≥ 1675	2735 > R ≥ 2050	3295 > R ≥ 2490
6.0%	1675 > R ≥ 1270	2050 > R ≥ 1570	2490 > R ≥ 1930
7.0%	1270 > R ≥ 960	1570 > R ≥ 1200	1930 > R ≥ 1495
8.0%	960 > R ≥ 605	1200 > R ≥ 765	1495 > R ≥ 965
	R_{min} = 605 ft	R_{min} = 765 ft	R_{min} = 965 ft

e	V = 60 mph	V = 65 mph	V = 70 mph
	R(ft)	R(ft)	R(ft)
NC	R ≥ 11,525	R ≥ 12,970	R ≥ 14,515
2.0%	11,525 > R ≥ 8495	12,970 > R ≥ 9585	14,515 > R ≥ 10,750
3.0%	8495 > R ≥ 5455	9585 > R ≥ 6190	10,750 > R ≥ 6980
4.0%	5455 > R ≥ 3920	6190 > R ≥ 4480	6980 > R ≥ 5085
5.0%	3920 > R ≥ 2980	4480 > R ≥ 3440	5085 > R ≥ 3940
6.0%	2980 > R ≥ 2335	3440 > R ≥ 2735	3940 > R ≥ 3170
7.0%	2335 > R ≥ 1835	2735 > R ≥ 2195	3170 > R ≥ 2595
8.0%	1835 > R ≥ 1205	2195 > R ≥ 1490	2595 > R ≥ 1825
	R_{min} = 1205 ft	R_{min} = 1490 ft	R_{min} = 1825 ft

e	V = 75 mph
	R(ft)
NC	R ≥ 16,160
2.0%	16,160 > R ≥ 12,000
3.0%	12,000 > R ≥ 7835
4.0%	7835 > R ≥ 5745
5.0%	5745 > R ≥ 4490
6.0%	4490 > R ≥ 3645
7.0%	3645 > R ≥ 3035
8.0%	3035 > R ≥ 2215
	R_{min} = 2215 ft

e_{max} = 8.0%

Key:

R = Radius of curve, ft
V = Design speed, mph
e = Superelevation rate, %
NC = Normal crown = 2.0%

Note: See Figure 25.2C for typical selection of curve radii.

RATE OF SUPERELEVATION
(Open Roadways) (US Customary)

Figure 25.3A

e	V = 40 km/h	V = 50 km/h	V = 60 km/h
	R(m)	R(m)	R(m)
NC	R ≥ 785	R ≥ 1095	R ≥ 1500
2.0%	785 > R ≥ 575	1095 > R ≥ 800	1500 > R ≥ 1100
3.0%	575 > R ≥ 360	800 > R ≥ 505	1100 > R ≥ 700
4.0%	360 > R ≥ 250	505 > R ≥ 355	700 > R ≥ 495
5.0%	250 > R ≥ 175	355 > R ≥ 260	495 > R ≥ 365
6.0%	175 > R ≥ 125	260 > R ≥ 190	365 > R ≥ 270
7.0%	125 > R ≥ 90	190 > R ≥ 140	270 > R ≥ 200
8.0%	90 > R ≥ 55	140 > R ≥ 85	200 > R ≥ 125
	R_{min} = 55 m	R_{min} = 85 m	R_{min} = 125 m

e	V = 70 km/h	V = 80 km/h	V = 90 km/h
	R(m)	R(m)	R(m)
NC	R ≥ 1980	R ≥ 2450	R ≥ 2975
2.0%	1980 > R ≥ 1455	2450 > R ≥ 1800	2975 > R ≥ 2195
3.0%	1455 > R ≥ 925	1800 > R ≥ 1150	2195 > R ≥ 1405
4.0%	925 > R ≥ 655	1150 > R ≥ 820	1405 > R ≥ 1010
5.0%	655 > R ≥ 490	820 > R ≥ 615	1010 > R ≥ 765
6.0%	490 > R ≥ 370	615 > R ≥ 475	765 > R ≥ 600
7.0%	370 > R ≥ 280	475 > R ≥ 360	600 > R ≥ 470
8.0%	280 > R ≥ 180	360 > R ≥ 230	470 > R ≥ 305
	R_{min} = 180 m	R_{min} = 230 m	R_{min} = 305 m

e	V = 100 km/h	V = 110 km/h	V = 120 km/h
	R(m)	R(m)	R(m)
NC	R ≥ 3640	R ≥ 4200	R ≥ 4915
2.0%	3640 > R ≥ 2685	4200 > R ≥ 3105	4915 > R ≥ 3650
3.0%	2685 > R ≥ 1730	3105 > R ≥ 2010	3650 > R ≥ 2385
4.0%	1730 > R ≥ 1245	2010 > R ≥ 1460	2385 > R ≥ 1745
5.0%	1245 > R ≥ 950	1460 > R ≥ 1125	1745 > R ≥ 1365
6.0%	950 > R ≥ 750	1125 > R ≥ 900	1365 > R ≥ 1105
7.0%	750 > R ≥ 595	900 > R ≥ 730	1105 > R ≥ 920
8.0%	595 > R ≥ 395	730 > R ≥ 505	920 > R ≥ 670
	R_{min} = 395 m	R_{min} = 505 m	R_{min} = 670 m

e_{max} = 8.0%

Key:

R = Radius of curve, m
V = Design speed, km/h
e = Superelevation rate, %
NC = Normal crown = 2.0%

Note: See Figure 25.2C for typical selection of curve radii.

RATE OF SUPERELEVATION
(Open Roadways) (Metric)

Figure 25.3A

25.3.4 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. Figure 25.3A indicates the threshold (or minimum) radius for a normal crown section at various design speeds. This threshold is based on a theoretical superelevation rate of +1.5%.

See Section 9.2 of the Montana Road Design Manual for the detailed methodology for calculating these minimum lengths.

25.4 SUPERELEVATION (Low-Speed Urban Streets)

25.4.1 General

Low-speed urban street conditions may be used for superelevating streets in small urban and urbanized areas where V ≤ 45 mph (70 km/h). On these facilities, providing superelevation at horizontal curves is frequently impractical because of roadside conditions and, in some cases, may result in undesirable operational conditions. The following lists some of the characteristics of low-speed urban streets that often complicate superelevation development:

1. Roadside Development/Intersections/Driveways. Built-up roadside development is common adjacent to low-speed urban streets. Matching superelevated curves with many driveways, intersections, sidewalks, etc., creates considerable complications. This may also require re-grading parking lots, lawns, etc., to compensate for the higher elevation of the high side of the superelevated curve.

2. Non-Uniform Travel Speeds. On low-speed urban streets, travel speeds are often non-uniform because of frequent signalization, stop signs, vehicular conflicts, etc. It is undesirable for traffic to stop on a superelevated curve, especially when snow or ice is present.

3. Limited Right-of-Way. Superelevating curves often results in more right-of-way impacts than would otherwise be necessary. Right-of-way is often restricted along low-speed urban streets.

4. Wide Pavement Areas. Many low-speed urban streets have wide pavement areas because of high traffic volumes in built-up areas, the absence of a median and the presence of parking lanes. In general, the wider the pavement area, the more complicated will be the development of superelevation.

5. Surface Drainage. Proper pavement drainage on low-speed urban streets can be difficult even on sections with a normal crown. Superelevation introduces another complicating factor.

As discussed in Section 9.2 of the Montana Road Design Manual, AASHTO Method 2 is used to distribute superelevation and side friction in determining superelevation rates for the design of horizontal curves on low-speed urban streets. In addition, relatively high side-friction factors are used. The practical impact is that superelevation is rarely warranted on these facilities.

The designer should not apply the superelevation criteria assuming low-speed urban street conditions to highway transitions between rural and urban areas, even if the design speed is V ≤ 45 mph (70 km/h). These areas should be designed assuming open-roadway conditions.

25.4.2 Superelevation

Based on the selection of e_{max} = 4.0% and the use of AASHTO Method 2 to distribute e and f, Figure 25.4A allows the designer to select the superelevation rate for combinations of curve radii (R) and design speed (V). Note that superelevation rates are a controlling criteria. The designer must seek a design exception for any proposed rate which does not meet the criteria in Figure 25.4A. See Section 24.7 for Department procedures on design exceptions.

25.4.3 Minimum Radii Without Superelevation

On low-speed urban streets, horizontal curves with sufficiently large radii do not require superelevation; i.e., the normal crown section can be maintained around a curve. The threshold exists where the theoretical superelevation equals -2.0%. Figure 25.4A indicates limiting radii for normal crown (NC).

US Customary				
e	V = 30 mph	V = 35 mph	V = 40 mph	V = 45 mph
	R(ft)	R(ft)	R(ft)	R(ft)
NC	R ≥ 299	R ≥ 462	R ≥ 676	R ≥ 945
2.0%	299 > R ≥ 249	462 > R ≥ 377	676 > R ≥ 539	945 > R ≥ 738
3.0%	249 > R ≥ 239	377 > R ≥ 360	539 > R ≥ 513	738 > R ≥ 700
4.0%	239 > R ≥ 230	360 > R ≥ 345	513 > R ≥ 490	700 > R ≥ 670
	R_{min} = 230 ft	R_{min} = 345 ft	R_{min} = 490 ft	R_{min} = 670 ft

Metric					
e	V = 30 km/h	V = 40 km/h	V = 50 km/h	V = 60 km/h	V = 70 km/h
	R(m)	R(m)	R(m)	R(m)	R(m)
NC	R ≥ 25	R ≥ 55	R ≥ 102	R ≥ 171	R ≥ 270
2.0%	25 > R ≥ 22	55 > R ≥ 47	102 > R ≥ 85	171 > R ≥ 138	270 > R ≥ 211
3.0%	22 > R ≥ 21	47 > R ≥ 46	85 > R ≥ 81	138 > R ≥ 132	211 > R ≥ 200
4.0%	21 > R ≥ 20	46 > R ≥ 45	81 > R ≥ 80	132 > R ≥ 125	200 > R ≥ 190
	R_{min} = 20 m	R_{min} = 45 m	R_{min} = 80 m	R_{min} = 125 m	R_{min} = 190 m

Key:

R = Radius of curve, ft
V = Design speed, mph
e = Superelevation rate, %
NC = Normal crown = 2.0%

e_{max} = 4.0%

RATE OF SUPERELEVATION
(Low-Speed Urban Streets)

Figure 25.4A

25.5 HORIZONTAL SIGHT DISTANCE

25.5.1 Sight Obstruction (Definition)

Sight obstructions on the inside of a horizontal curve are defined as obstacles that interfere with the line of sight on a continuous basis. These 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 designer must 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.

25.5.2 Middle Ordinate

The needed clearance on the inside of the horizontal curve is calculated as follows:

$$M = R\left(1 - \cos\left(\frac{90° \bullet S}{\pi \bullet R}\right)\right) \qquad \text{(Equation 25.5-1)}$$

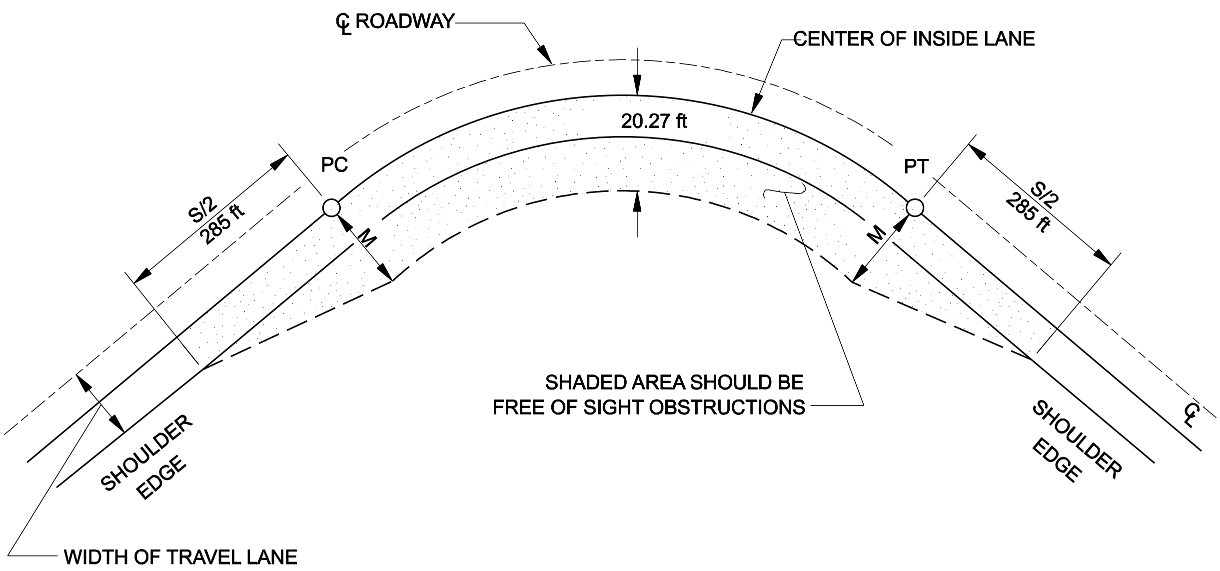
Where:

M	=	Middle ordinate, or distance from the center of the inside travel lane to the obstruction, ft (m)
R	=	Radius of curve, ft (m)
S	=	Stopping sight distance, ft (m)

Note: The expression $\left(\frac{90° \bullet S}{\pi \bullet R}\right)$ *is in degrees, not radians.*

At a minimum, SSD must be available throughout the horizontal curve. See Figure 24.5A for stopping sight distances.

The example in Figure 25.5A illustrates the determination of clearance requirements at a horizontal curve based on SSD.



<u>Example 25.5-1</u>

Given: Design Speed = 60 mph
R = 2000 ft

Problem: Determine the horizontal clearance requirements for the horizontal curve using the desirable SSD value.

Solution: Figure 24.5A yields a SSD = 570 ft. Using Equation 25.5-1 for horizontal clearance:

$$M = R\left(1 - \cos\left(\frac{90^\circ \bullet S}{\pi \bullet R}\right)\right)$$

$$M = 2000\left(1 - \cos\left(\frac{(90^\circ)(570\text{ ft})}{(\pi)(2000\text{ ft})}\right)\right) = 20.27\text{ ft}$$

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

SIGHT CLEARANCE REQUIREMENTS FOR HORIZONTAL CURVES
(Example Problem)

Figure 25.5A

25.5.3 Entering/Exiting Portions

The M values using Equation 25.5-1 apply between the PC and PT of the horizontal curve (or from the SC to the CS). In addition, some transition is needed on the entering and exiting portions of the curve. The designer should typically use the following steps:

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

Step 2: Locate the point that is a distance M measured laterally from the center of the inside travel lane at the PC or SC.

Step 3: Connect the two points located in Steps 1 and 2. The area between this line and the roadway should be clear of all continuous sight obstructions.

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

The example presented in Figure 25.5A illustrates the determination of clearance requirements entering and exiting from a simple curve.

25.5.4 Application

For application, the height of eye is 3.5 ft (1080 mm) and the height of object is 2 ft (600 mm). Both the eye and object are assumed to be in the center of the inside travel lane. In the elevation view, the line-of-sight intercept with the obstruction is at the midpoint of the sightline and 2.75 ft (840 mm) above the road surface.

25.5.5 Longitudinal Barriers

Longitudinal barriers (e.g., bridge rails, guardrail, CMB) can cause sight distance restrictions at horizontal curves, because barriers are placed relatively close to the traveled way (often 10 ft (3 m) or less) and because their height is greater than 2 ft (600 mm). The designer should check the line of sight over a barrier along a horizontal curve and attempt to locate the barrier so that it does not block the line of sight. The following should also be considered:

1. Superelevation. A superelevated roadway will elevate the driver eye and improve the line of sight over the barrier.

2. Vertical Curves. The line of sight over a barrier may be improved for a driver on a sag vertical curve and lessened on a crest vertical curve.

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

4. Object Height. Because of the typical heights of barriers, there may be many sites where the barrier blocks visibility to a 2 ft (600 mm) object, the typical height of vehicular taillights.

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 elevation of the driver eye, the elevation of the object (2 ft (600 mm) above the pavement surface) and the elevation of the barrier where the line of sight intercepts the barrier run. If the barrier does block the line of sight to a 2 ft (600 mm) object, the designer should consider relocating the barrier or revising the horizontal alignment.

25.6 COMPUTATION OF HORIZONTAL CURVES

25.6.1 Spiral Curves

Special Note: *The computation of the spiral curve is dependent on one of two publications:*

- Transition Curves for Highways, Public Roads Administration (Joseph Barnett); and
- Oregon Standard Highway Spiral, Oregon Department of Transportation.

The following presents typical figures for computing a spiral curve:

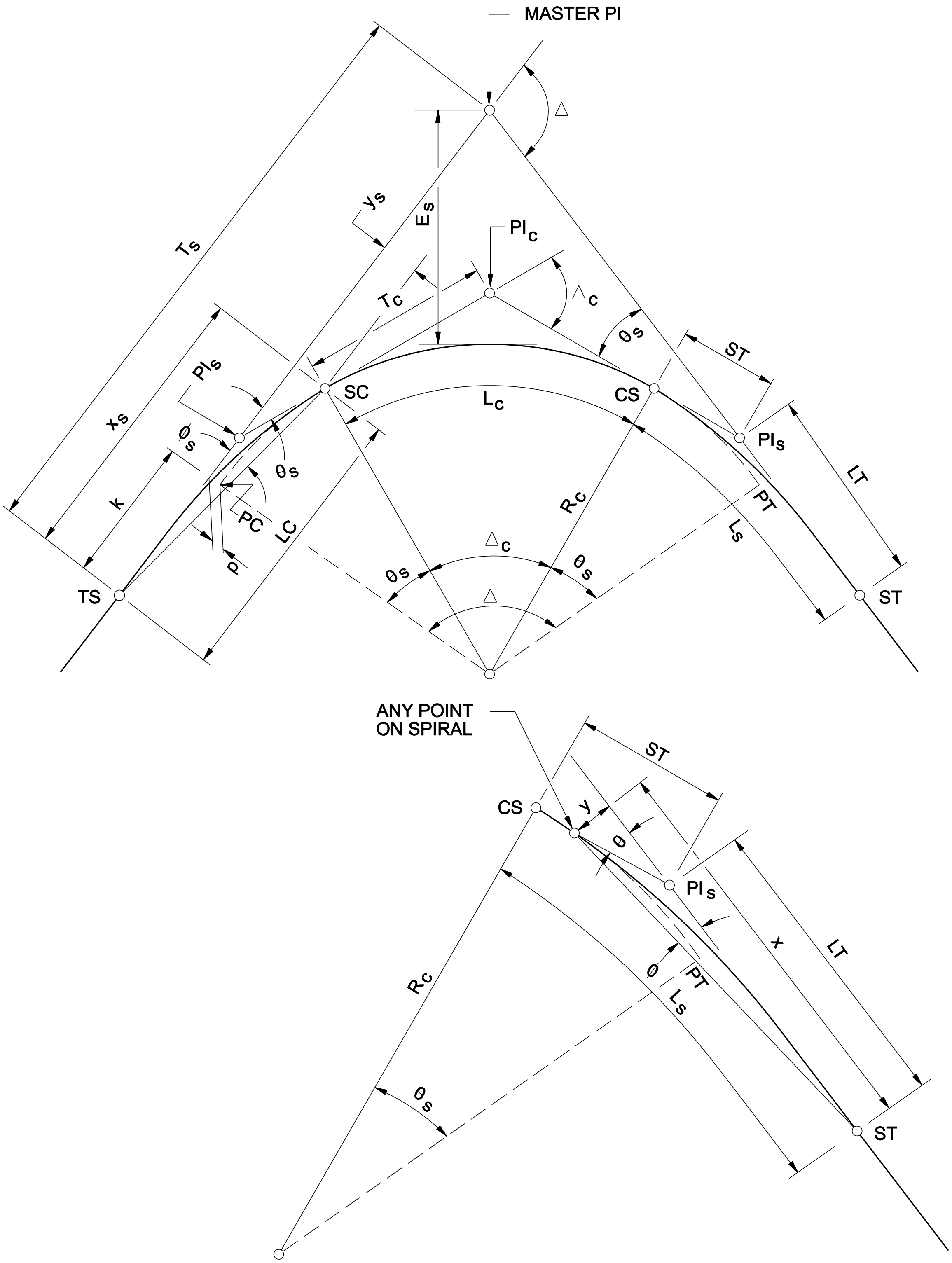
1. Figure 25.6A illustrates the key elements of a spiral curve.
2. Figure 25.6B presents definitions for the spiral curve nomenclature on Figure 25.6A.
3. Figure 25.6C presents equations for computing a spiral curve.

Typically, the known data will be the station of the Master PI, the deflection angle (Δ) and the radius of the circular curve (R_C) in feet (meters). The length of the spiral curve (L_S) is set equal to the length of the superelevation runoff; see Section 9.3 of the Montana Road Design Manual. Based on the values of Δ, L_S and R_C, θ_s can be calculated as indicated in Figure 25.6C, and the p and k values can be read from Table II in Transition Curves for Highways by Joseph Barnett. The tangent length (T_s), the external distance (E_S) and the remaining spiral curve data can be computed as described in Figure 25.6C. Example 25.6-1 illustrates the computation of a spiral curve.

The following steps are used to determine the locations of the TS, SC, CS and ST:

1. PI station – T_s = TS station
2. TS station + L_s = SC station
3. SC station + L_c = CS station
4. CS station + L_s = ST station

Figures 25.6A, 25.6B and 25.6C are consistent with the Barnett spiral publication. It is also acceptable to use the data from the Oregon Standard Highway Spiral to compute a spiral curve.



Note: See Figure 25.6B for definition of terms.

SPIRAL CURVE ELEMENTS

Figure 25.6A

SPIRAL TRANSITION CURVE NOMENCLATURE

Master PI = Point of intersection of the main tangents.

PC = Point at which the circular curve extended becomes parallel to the line from TS to the Master PI.

PT = Point at which the circular curve extended becomes parallel to the line from ST to the Master PI.

PI_c = Point of intersection of circular curve tangents.

PI_s = Point of intersection of the main tangent and tangent of circular curve.

TS = Tangent to spiral; common point of spiral and near transition.

SC = Spiral to curve; common point of spiral and circular curve of near transition.

CS = Curve to spiral; common point of circular curve and spiral of far transition.

ST = Spiral to tangent; common point of spiral and tangent of far transition.

R_c = Radius of the circular curve (SC to CS), ft (m).

L_s = Length of spiral, ft (m).

L_c = Length of circular curve, ft (m).

T_s = Tangent distance Master PI to TS or ST, ft (m).

T_c = Tangent distance from SC or CS to PI_c, ft (m).

E_s = External distance Master PI to midpoint of circular curve, ft (m).

LT = Long tangent of spiral only, ft (m).

ST = Short tangent of spiral only, ft (m).

LC = Long chord of spiral, ft (m).

p = Offset distance from the main tangent to the PC or PT of the circular curve produced, ft (m).

k = Distance from TS to point on main tangent opposite the PC of the circular curve produced, ft (m).

Δ = Total deflection angle between main tangents of the entire curve, degrees.

Δ_c = Deflection angle between tangents at the SC and the CS or the central angle of the circular curve, degrees.

θ_s = Central angle between the tangent of the complete curve and the tangent at the SC; i.e., the "spiral angle," degrees.

φ_s = Spiral deflection angle from tangents at TS to SC or from ST to SC, degrees.

$x_s y_x$ = Coordinates of SC from the TS or of CS from ST.

L = Length of spiral arc from the TS or ST to any point on the spiral, ft (m).

x,y = Coordinates to any point on the spiral from TS or ST.

φ = Spiral deflection angle from TS or ST to any point on spiral, degrees.

θ = The central angle of spiral arc L to any point on the spiral, degrees. θ equals θ_s when L equals L_s. Note that the θ referred to in Table II of Transition Curves for Highways is actually θ_s.

SPIRAL CURVE NOMENCLATURE

Figure 25.6B

CURVE FUNCTIONS

1. $\theta_s = (L_s / R_c)(90/\pi)$

2. $\Delta_c = \Delta - 2\theta_s$

3. $L_c = \dfrac{\Delta_c}{360} 2\pi R_c$

4. $T_s = (R_c + p)\tan(\Delta/2) + k$

5. $E_s = (R_c + p)(1/\cos(\Delta/2) - 1) + p = \left[\dfrac{(R_c + p)}{\cos(\Delta/2)} - (R_c + p)\right] + p$

6. p and k are obtained from Transition Curves for Highways by Barnett.

SPIRAL FUNCTIONS

Corrections for C in Formula: $\varphi = \dfrac{\theta}{3} - C$

θ_s in Degrees	15	20	25	30	35	40	45	50
C in Minutes	0.2	0.4	0.8	1.4	2.2	3.4	4.8	6.6

7. $\varphi \text{ (approx.)} = \dfrac{\theta}{3}, \text{ if } \theta_s < 15°00'$

8. $\varphi \text{ (approx.)} = \dfrac{\theta}{3} - C, \text{ if } \theta_s \geq 15°00'$

9. $\varphi = \dfrac{\varphi_s}{3}\left[\dfrac{L}{L_s}\right]^2$

10. Exact value of φ by coordinates:

$\tan\varphi = \dfrac{y}{x}$

11. $ST = \dfrac{y_s}{\sin\theta_s}$

12. $LT = x_s - \left(\dfrac{y_s}{\tan\theta_s}\right)$

13. $LC = \dfrac{x_s}{\cos\varphi_s}$

14. $x_s = LC\cos\varphi_s$

15. $y_s = LC\sin\varphi_s$

16. $\theta = \dfrac{L^2}{L_s^2}\theta_s$

17. $x = L\left(1 - \dfrac{\theta^2}{10} + \dfrac{\theta^4}{216} - \dfrac{\theta^6}{9360} + \dfrac{\theta^8}{685440}\right)^*$

18. $y = L\left(\dfrac{\theta}{3} - \dfrac{\theta^3}{42} + \dfrac{\theta^5}{1320} - \dfrac{\theta^7}{75600} + \dfrac{\theta^9}{6894720}\right)^*$

∗ θ is in radians for Equations 17 and 18 only.

Note: These equations are based on Transition Curves for Highways by Barnett.

SPIRAL CURVE FORMULAS

Figure 25.6C

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Example 25.6-1

Given: Rural Two-Lane State Highway
Design Speed = 60 mph
Δ = 15°00′00″ Right
(Master) PI Station = 243 + 18.72
R_c = 3000 ft

Problem: If warranted, determine the curve data for the spiral curve.

Solution: The following steps apply:

Step 1: From Section 25.2.2, a spiral curve is warranted on a rural State highway where $R \leq 3820$ ft. Therefore, use a spiral curve.

Step 2: The length of the spiral curve is set equal to the superelevation runoff (L_s) length. From Figure 9.3A of the Montana Road Design Manual, L_s = 135 ft for V = 60 mph and R_c = 3000 ft.

Step 3: From the equations in Figure 25.6C, calculate the curve functions as follows:

1. $\theta_s = (L_s/R_c)(90/\pi) = (135/3000)(90/\pi)$
   $\theta_s = 1.2892\ ...\ °$
   θ_s = 1°17′21″ (rounded value)

2. $\Delta_c = \Delta - 2\theta_s$ = (15°0′00″) – (2°34′42″)
   Δ_c = 12°25′18″ = 12.4217°

3. $L_c = \frac{\Delta_c}{360} 2\pi R_c = \frac{12.42}{360}(2\pi)(3000)$
   L_c = 650.3097 ft
   L_c = 650.31 ft (rounded value)

4.* $T_s = (R_c + p) \tan(\Delta/2) + k$

5.* $E_s = (R_c + p)(1/\cos(\Delta/2) - 1) + p$

* For Equations 4 and 5, obtain the values for p and k from Table II of Transition Curves for Highways:

$p = 0.001855$ $k = 0.49999$

Note that these values are for a unit spiral length. To obtain the actual values for p and k, multiply by L_s (135 ft):

$p = (0.001855)(135) = 0.2504$ ft
$k = (0.49999)(135) = 67.4987$ ft

Therefore:

$T_s = (3000 + 0.2504) \tan(15/2) + 67.4987$
$T_s = 462.4892$ ft
$T_s = 462.49$ ft (rounded value)

$E_s = (3000 + 0.2504)(1/\cos(15/2) - 1) + 0.2504$
$E_s = 26.1394$ ft
$E_s = 26.14$ ft (rounded value)

Step 4: Determine the Stations for TS, SC, CS and ST:

TS Station = PI Station – T_s = 243 + 18.72 – 462.49 = 238 + 56.23
SC Station = TS Station + L_s = 238 + 56.23 + 135 = 239 + 91.23
CS Station = SC Station + L_c = 239 + 91.23 + 650.31 = 246 + 41.54
ST Station = CS Station + L_s = 246 + 41.54 + 135 = 247 + 76.54

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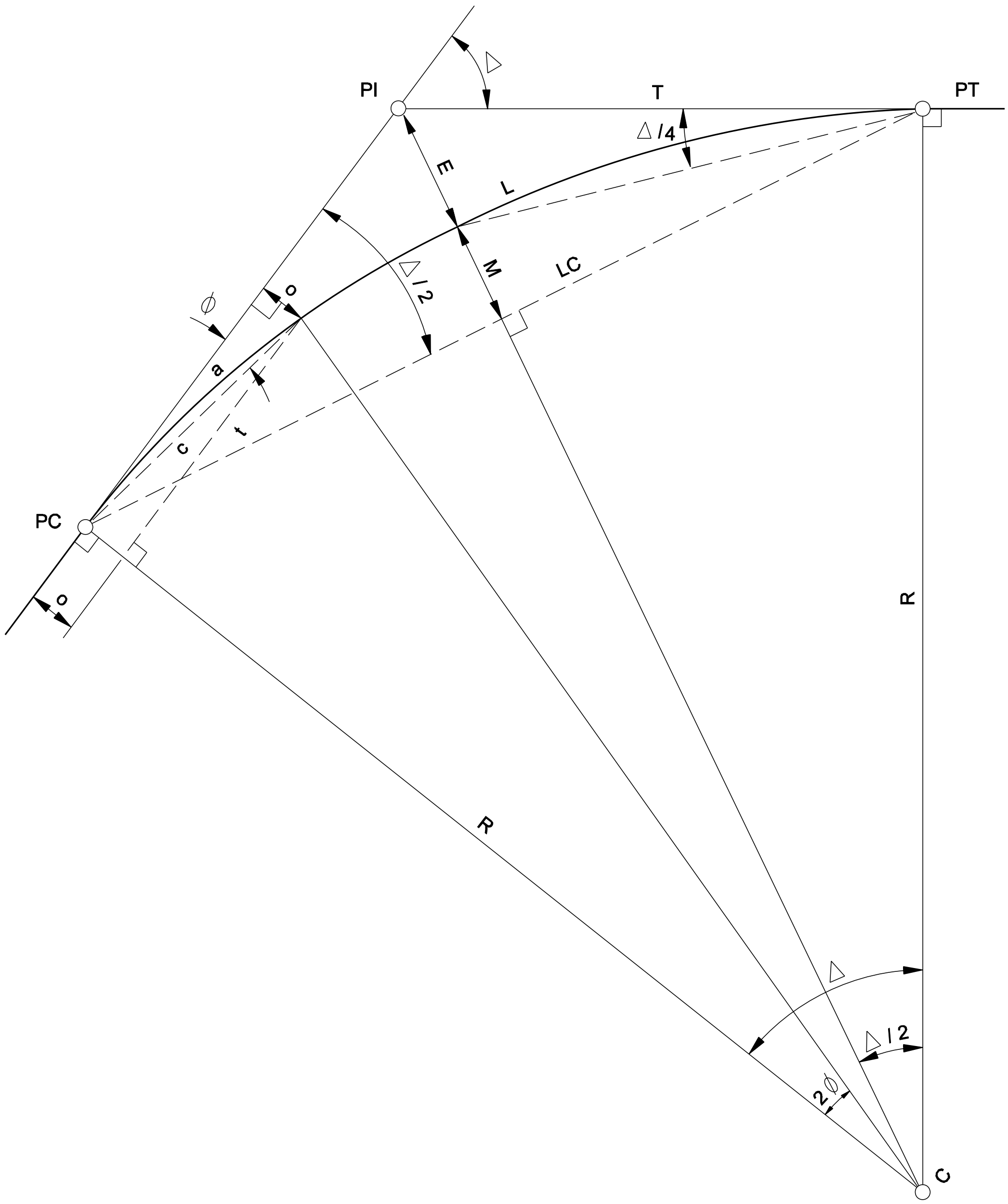
25.6.2 Simple Curves

The following presents typical figures for computing a simple curve:

1. Figure 25.6D illustrates the key elements of a simple curve.

2. Figure 25.6E presents definitions for the simple curve nomenclature on Figure 25.6D.

Typically, the known data will be the station of the PI, the deflection angle (Δ) and the radius of the simple curve (R). The remaining curve data must be computed. Example 25.6-2 illustrates a sample calculation.



SIMPLE CURVE ELEMENTS

Figure 25.6D

CURVE SYMBOLS

Δ	=	Deflection angle, degrees
T	=	Tangent distance, ft (m). T = distance from PC to PI or distance from PI to PT
L	=	Length of curve, ft (m). L = distance from PC to PT along curve
R	=	Radius of curvature, ft (m)
E	=	External distance (PI to mid-point of curve), ft (m)
C	=	Intersection of radii at center of circular arc
LC	=	Length of long chord (PC to PT), ft (m)
M	=	Middle ordinate (mid-point of arc to mid-point of long chord), ft (m)
a	=	Length of arc to any point on a curve, ft (m)
c	=	Length of chord from PC to any point on curve, ft (m)
φ	=	Deflection angle from tangent to any point on curve, degrees
t	=	Distance along tangent from PC to any point on curve, ft (m)
o	=	Tangent offset to any point on curve, ft (m)

CURVE FORMULA

$$T = R(\tan(\Delta/2)) = R\,\frac{\sin(\Delta/2)}{\cos(\Delta/2)}$$

$$L = \frac{\Delta}{360}\,2\pi R$$

$$E = \frac{R}{\cos(\Delta/2)} - R = T\,\tan(\Delta/4)$$

$$LC = 2R\,(\sin(\Delta/2)) = 2T\,(\cos\,\Delta/2)$$

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

$$a = \frac{(200\varphi)(2\pi R)}{100(360)} = \frac{(\varphi)(\pi R)}{90}$$

$$c = 2R\left(\sin\frac{(100)(360a)}{(200)(2\pi R)}\right) = 2R\left(\sin\frac{90a}{\pi R}\right)$$

$$\varphi = \frac{90a}{(\varphi)(\pi R)}$$

$$\cos\varphi = (R - o)/2R$$

$$t = R\,\sin 2\varphi = (c)\cos\varphi$$

$$o = (c)\sin\varphi$$

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

$$o = R - (R\cos 2\varphi)$$

$$o = R\,(1 - \cos 2\varphi)$$

$$\pi = 3.141592654$$

CIRCULAR CURVE ABBREVIATIONS

PC	=	Point of Curvature (Beginning of Curve)
PT	=	Point of Tangency (End of Curve)
PI	=	Point of Intersection of Tangents
PRC	=	Point of Reverse Curvature
PCC	=	Point of Compound Curvature

LOCATING THE PC AND PT

Station PC = Station PI – T
Station PT = Station PC + L

Stations are in 100 feet. For example, Sta 13+54.86 means 1354.86 feet from Sta 0+00.

SIMPLE CURVE NOMENCLATURE/FORMULAS

Figure 25.6E

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Example 25.6-2

Given: $\Delta = 7°00'00''$
R = 5700 ft
PI Station = 154 + 56.42

Problem: According to Section 25.2.2, use a simple curve when the radius is greater than 3820 ft. Assuming the use of a simple curve, determine the curve data.

Solution: Use the equations from Figure 25.6E as follows:

1. $T = R (\tan (\Delta/2)) = 5700 (\tan (7/2))$
   T = 348.6269 ft
   T = 348.63 ft (rounded value)

2. $$L = \frac{\Delta}{360} 2\pi r = \frac{7}{360}(2\pi)(5700)$$
   L = 696.38637 ft
   L = 696.39 ft (rounded value)

3. $$E = \frac{R}{\cos(\Delta/2)} - R = \frac{5700}{\cos(7/2)} - 5700$$
   E = 10.6515 ft
   E = 10.65 ft (rounded value)

4. $LC = 2R (\sin (\Delta/2)) = (2)(5700)(\sin 7/2))$
   LC = 695.95335 ft
   LC = 695.95 ft (rounded value)

5. $M = R(1 - \cos (\Delta/2)) = 5700 (1 - \cos (7/2))$
   M = 10.6316 ft
   M = 10.63 ft (rounded value)

6. Stations are as follows:

   Station PC = Station PI – T = 154 + 56.42 – 348.63 = 151 + 07.79
   Station PT = Station PC + L = 151 + 07.79 + 695.95 = 158 + 03.74

* * * * * * * * * *

25.6.3 Compound Curves

Figure 25.6F illustrates the key elements of a symmetrical, 3-centered compound curve. It also presents the equations to compute the curve elements assuming that the following are known:

1. Δ, the deflection angle;

2. p, the offset between the interior curve (extended) to a point where it becomes parallel with the tangent line;

3. R_1, the radius of the flatter entering and exiting curve; and

4. R_2, the radius of the sharper, interior curve.

Example 25.6-3 illustrates a sample computation for a 3-centered, symmetrical compound curve.

25.6.4 Rounding of Curve Data

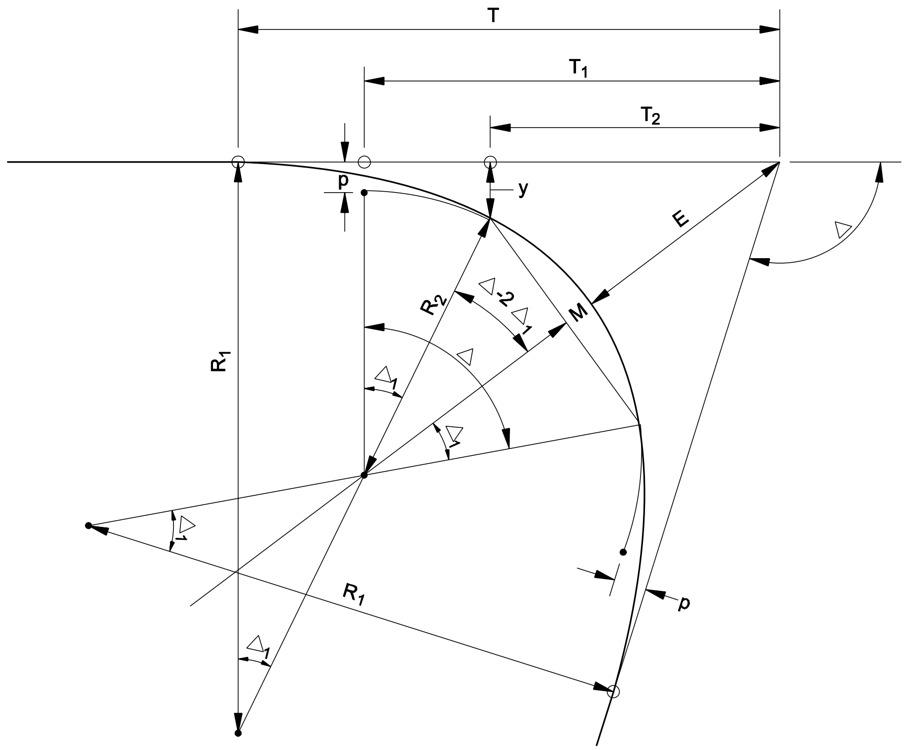
25.6.4.1 New Horizontal Curve

The following summarizes Department practices for presenting data for a new horizontal curve on the roadway plans:

1. Deflection Angle. These should be recorded in degrees rounded to the nearest second of a degree.

2. Linear Distances. These should be recorded in feet (meters) rounded to the nearest one hundredth of a foot (meter) (i.e., two decimal places).

3. Curve Radii. Normally, curve radii will be selected from those in Figure 25.2C. Where rounding is necessary, radii should be recorded in feet (meters) rounded to the 5 ft (5 m) increment.



CURVE FORMULA

1. $T_1 = (R_2 + p)\tan\frac{\Delta}{2}$

2. $\Delta_1 = \cos^{-1}\left[\frac{R_1 - R_2 - p}{R_1 - R_2}\right]$

3. $T = T_1 + (R_1 - R_2)\sin\Delta_1$

4. $T_2 = T_1 - R_2 \sin\Delta_1$

5. $E = \frac{R_2 + p}{\cos(\Delta/2)} - R_2$

6. $M = R_2 - [R_2 \cos(\Delta/2 - \Delta_1)]$

7. $y = (R_2 + p) - R_2 \cos\Delta_1$

Note: "p" is the offset location between the interior curve (extended) to a point where it becomes parallel with the tangent line. See Figure 25.6E for other circular curve nomenclature.

COMPOUND CURVE ELEMENTS/FORMULAS

Figure 25.6F

* * * * * * * * * *

Example 25.6-3

Given: $\Delta = 40°$
$R_1 = 600$ ft
$R_2 = 250$ ft
$p = 5$ ft

Problem: Determine the curve data for the compound curve.

Solution: Use the equations from Figure 25.6F as follows:

1. $T_1 = (R_2 + p) \tan(\Delta/2) = (250 + 5) \tan(40/2)$
$T_1 = 92.81$ ft

2. $$\Delta_1 = \cos^{-1}\left[\frac{R_1 - R_2 - p}{R_1 - R_2}\right] = \cos^{-1}\left[\frac{600 - 250 - 5}{600 - 250}\right]$$
$\Delta_1 = 9.6963°$
$\Delta_1 = 9°41'47''$ (rounded value)

3. $T = T_1 + (R_1 - R_2)\sin\Delta_1 = 92.81 + (600 - 250)\sin(9.6963°)$
$T = 151.7591$ ft
$T = 151.76$ ft (rounded value)

4. $T_2 = T_1 - R_2 \sin\Delta_1 = 92.81 - (250)\sin(9.6963°)$
$T_2 = 50.7036$ ft
$T_2 = 50.70$ ft (rounded value)

5. $$E = \frac{R_2 + p}{\cos(\Delta/2)} - R_2 = \frac{250 + 5}{\cos(40/2)} - 250$$
$E = 21.3653$ ft
$E = 21.37$ ft (rounded value)

6. $$M = R_2 - [R_2 \cos(\Delta/2 - \Delta_1)] = 250 - \left(250 \cos\left(\frac{40}{2} - 9.6963\right)\right)$$
$M = 4.0316$ ft
$M = 4.03$ ft (rounded value)

7. $y = (R_2 + p) - R_2 \cos \Delta_1 = (250 + 5) - (250)\cos(9.6963°)$
$y = 8.5714$ ft
$y = 8.57$ ft (rounded value)

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When using computer-generated curve data, the designer must consider the implications of rounding off the data according to the above criteria. To ensure mathematical consistency, the following procedure should be used when defining the horizontal alignment in Geopak:

Given: Horizontal alignment defined with PI coordinates from survey data or design.

Input:

1. Store given PI coordinates.

2. Inverse PI coordinates to produce distance and bearing between PIs.

3. Round distance to two places (0.01). Round bearings to nearest second (01″).

4. a. Define the horizontal alignment by traversing PI to PI using the rounded distance and bearing.

   b. Set station preference to two places (0.01).

   c. Set distance preference to four places (0.0001).

Output:

5. a. Rounded bearings to nearest second (to be shown on plans).

   b. Rounded control point stations to two places (to be shown on plans).

   c. Adjusted control point coordinates to four places (to be shown on coordinate table).

   d. Curve data to four places that must be rounded to two places before placing on plans. Round T, L and E by hand computations using the rounded Δ and R as shown on the plans. Minor adjustments to the control point stations may be necessary to reflect the rounded curve data.

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Example 25.6-4

Given: GEOPAK SPIRAL CURVE DATA OUTPUT

Note: GEOPAK spiral curve nomenclature does not match exactly the nomenclature in Figures 25.6A through 25.6C.

PISCS	CG2	N30,530.4772	E30,526.8770	STA 202+63.64
Total Tangent	=	803.7278		
Total Length	=	1,582.7160		
Total Delta	=	26E13N01.00O (LT)		
Back Tangent	=	N 72E51N14.00O E		
Ahead Tangent	=	N 46E38N13.00O E		

Spiral Back (Spiral CG2B) Type 1 Spiral Element

Angle	=	2°00′19.27″ (LT)	P	=	0.6125	BK	=	N 72°51′14.00″ E
LS	=	210.0000	K	=	104.9957	AH	=	N 70°56′54.73″ E
R	=	3,000.0000	LT	=	140.0090	Defl	=	0°40′06.40″
YS	=	2.4498	ST	=	70.0082			
XS	=	209.9743	LC	=	209.9886			
A	=	793.7254						

Spiral Coordinates

Point	North	East	Station
TS	30,293.5306	29,758.8700	194+59.91
PI	30,334.8066	29,892.6564	195+99.92
SC	30,357.7739	29,958.7900	196+69.91
CC	33,191.7378	28,974.5904	

Circular Section Curve Data

Curve CG2

P.I. Station	=	202+58.66	N30,550.9219	E30,514.9518
Delta	=	22°12′22.46″ (LT)		
Tangent	=	588.7462		
Length	=	1,162.7160		

Radius	=	3,000.0000		
External	=	57.2246		
Long Chord	=	1,155.4524		
Mid. Ord.	=	56.1535		
P.C. Station		196+69.91	N30,357.7739	E29,958.7900
P.T. Station		208+32.63	N30,939.9406	E30,956.8642
C.C.			N33,191.7378	E28,974.5904
Back	=	N 70°50′54.73″ E		
Ahead	=	N 48°38′32.27″ E		
Chord Bearing	=	N 59°44′43.50″ E		Circular Section

Spiral Ahead (Spiral CG2A) Type 2 Spiral Element

Angle	=	2°00′19.27″ (LT)	P	=	0.6125	BK	=	N 48°38′32.27″ E
LS	=	210.0000	K	=	104.9957	AH	=	N 46°38′13.00″ E
R	=	3,000.0000	LT	=	140.0090	Defl	=	0°40′06.40″
YS	=	2.4498	ST	=	70.0082			
XS	=	209.9743	LC	=	209.9886			
A	=	793.7254						

Spiral Coordinates

Point	North	East	Station
CS	30,939.9406	30,956.8642	208+32.63
PI	30,986.1991	30,009.4123	209+02.64
ST	31,082.3319	30,111.2013	210+42.63
CC	33,191.7378	28,974.5904	

Problem: Recompute curve data manually to produce rounded values to be shown on the plans.

Solution: Hold Geopak values for PI Station, Δ, R_C and L_S.

$$\theta_s = \frac{90 \cdot 210}{\pi \cdot 3000} = 2°00'19''$$

Δ_c = 26°13′01″ – (2) 2°00′19″ = 22°12′23″ → 22.2064°

$$L_c = \frac{22.2064°}{360} 2\,\pi\,3000 = 1162.72 \text{ ft}$$

$T_s = (R_c + p) \tan \Delta/2 + k$

Use p and k found in Barnett’s (p = 0.6127, k = 104.9958)

$$T_s = (3000 + 0.6127)\tan\frac{26.2169}{2} + 104.9958 = 803.73\text{ ft}$$

202+63.64 – 803.73	=	194+59.91	TS
		+210	
		196+69.91	SC
		+1162.72	
		208+32.63	CS
		+210	
		210+42.63	ST

Note: GEOPAK currently does not have the capability to round curve data and at the same time produce coordinates to four places. Therefore, coordinates listed in the coordinate table for PC, PT, TS, SC, CS, ST will differ slightly from coordinates computed using the rounded curve data shown on the plans.

25.6.4.2 Existing Horizontal Curves

For existing US Customary horizontal curves, the Department's rounding practices for presentation on the roadway plans are:

1. Deflection Angle. These should be recorded in degrees rounded to the nearest second of a degree.
2. Linear Distances. These should be recorded in feet (meters) rounded to the nearest one hundredth of a foot (meter) (i.e., two decimal places).
3. Curve Radii. Rounding will be determined by the Project Scope of Work as follows:

   a. Overlay and Widening. Where an existing horizontal curve will be retained in the project, the designer will calculate the US Customary radius from the known radius and round to three decimal places. The T and L distances are then calculated based on the US Customary radius and rounded to the nearest 0.01 of a foot; see Example 25.6-5.

   b. Reconstruction. Where the alignment for a reconstruction project will approximate the existing alignment, normally the curve radii will be selected from those in Figure 25.2C. Where this is not practical, the radii of the reconstructed curve may be rounded to the nearest 5 ft. The T and

L distances are then calculated based on the US Customary radius and rounded to the nearest 0.01 of a foot; see Example 25.6-6.

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Example 25.6-5 (Metric to US Customary)

Given: An existing horizontal curve has the following data in metric units:

PI Sta = 92+09.86
Δ = 12°30′
R = 1150.00 m
T = 125.95 m
L = 250.89 m

Problem: For an overlay and widening project and assuming the curve will be retained as is, determine the proper US Customary dimensions for the horizontal curve.

Solution: The US Customary data are:

PI Sta = 302+16.08
Δ = 12°30′
R = 3772.97′ (D=0°39′31″)
T = 413.22′
L = 823.13′

Example 25.6-6 (Metric to US Customary)

Given: An existing horizontal curve has the following data in metric units:

PI Sta = 92+25.86
Δ = 12°30′
R = 1400 m
T = 153.32 m
L = 305.43 m

Problem: For a reconstruction project and assuming the curve will be reconstructed, determine the proper US Customary dimensions for the horizontal curve.

Solution: The US Customary data are:

PI Sta = 302+68.57
Δ = 12°30′
R = 4595′ (D=0°48′07″)
T = 503.23′
L = 1002.47′

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For existing metric horizontal curves, the Department's rounding practices for presentation on the roadway plans are:

1. Deflection Angle. These should be recorded in degrees rounded to the nearest second of a degree.

2. Linear Distances. These should be recorded in feet (meters) rounded to the nearest one hundredth of a foot (meter) (i.e., two decimal places).

3. Curve Radii. Rounding will be determined by the Project Scope of Work as follows:

   a. Overlay and Widening. Where an existing horizontal curve will be retained in the project, the designer will calculate the metric radius from the known radius and round to three decimal places. The T and L distances are then calculated based on the metric radius and rounded to the nearest 0.01 of a meter; see Example 25.6-7.

   b. Reconstruction. Where the alignment for a reconstruction project will approximate the existing alignment, normally the curve radii will be selected from those in Figure 25.2C. Where this is not practical, the radii of the reconstructed curve may be rounded to the nearest 5 m. The T and L distances are then calculated based on the metric radius and rounded to the nearest 0.01 of a meter; see Example 25.6-8.

* * * * * * * * * *

Example 25.6-7 (US Customary to Metric)

Given: An existing horizontal curve has the following data in US Customary units:

PI Sta = 302+68.57
Δ = 12°30′

R = 4583.66′ (D=1°15′)
T = 501.99′
L = 1000.00′

Problem: For an overlay and widening project and assuming the curve will be retained as is, determine the proper metric dimensions for the horizontal curve.

Solution: The metric data are:

PI Sta = 92+25.86
Δ = 12°30′
R = 1397.010 m
T = 153.00 m
L = 304.78 m

Example 25.6-8 (US Customary to Metric)

Given: An existing horizontal curve has the following data in US Customary units:

PI Sta = 302+68.57
Δ = 12°30′
R = 4583.66′ (D=1°15′)
T = 501.99′
L = 1000.00′

Problem: For a reconstruction project and assuming the curve will be reconstructed, determine the proper metric dimensions for the horizontal curve.

Solution: The metric data are:

PI Sta = 92+25.86
Δ = 12°30′
R = 1400 m
T = 153.32 m
L = 305.43 m

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25.6.5 Stationing and Bearings

The following will apply to projects where control points are used to establish horizontal alignment:

1. Rounding. All stationing will be rounded to the nearest hundredth of a foot (meter) (i.e., two decimal places). All bearings will be rounded to the nearest second of a degree. When rounding computer-generated bearings, the designer must ensure that the rounded numbers for the bearings are mathematically consistent.

2. Coordinates. The designer will prepare a table of coordinates for the linear and level data sheet. The table will illustrate the coordinate values for all control points for either the staked centerline or control traverse survey and for the projected centerline. The control points will include the project beginning and ending points; the PC, PI and PT for simple curves; the TS, SC, (Master) PI, CS and ST for spiral curves; and all equations. All coordinates must be computed to at least five decimals and rounded in the table to the nearest four decimals.

For projects that are using the as-built plans as the basis of horizontal alignment (typically overlay projects), the designer will soft convert the as-built stationing to US Customary. Retain the degree of accuracy shown on the as-built plans. Also, when existing right-of-way (R/W) plans are used to describe additional R/W acquisition, the designer will ensure that the accuracy of the stationing and bearings matches that of the old R/W plans.

For projects with a new survey (typically reconstruction or major widening projects), new US Customary stationing should be used.

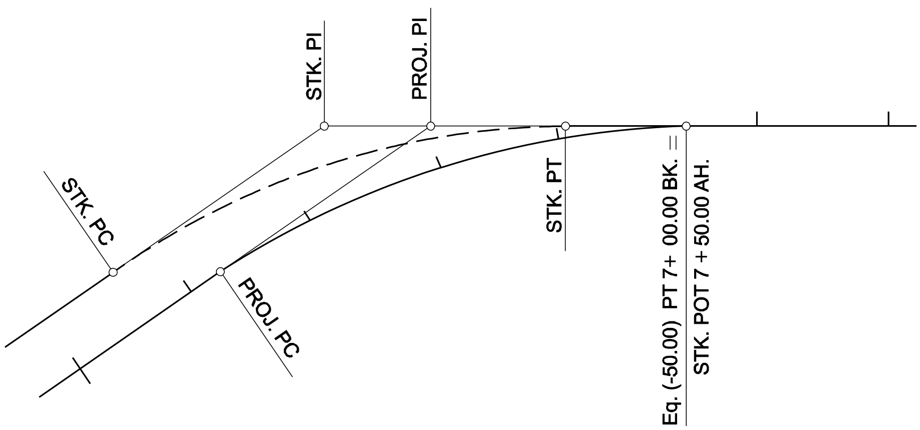
25.6.6 Equations

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

1. Purpose. An equation is used to equate two station numbers — one that is correct when measuring on the line back of the equation and one that is correct when measuring on the line ahead of the equation. Equations should be used where stationing is not continuous throughout a project.

2. Locations. Equations should be computed where design lines become coincident with staked lines. This situation is illustrated in Figure 25.6G.

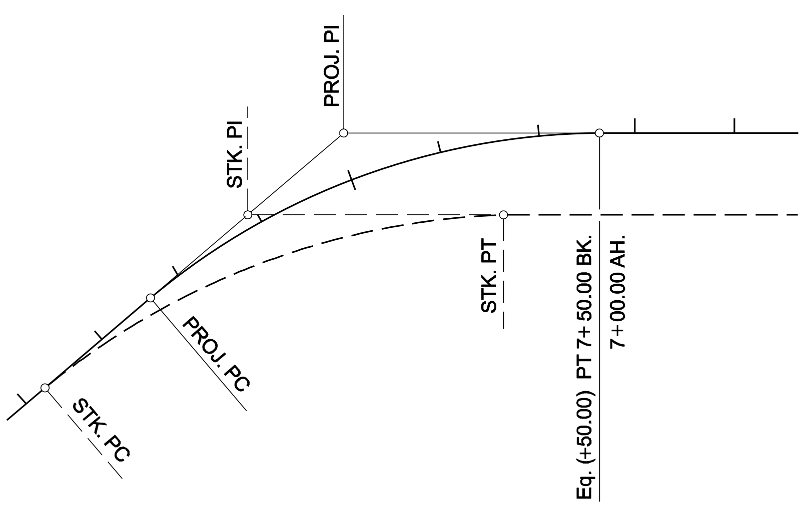
Equations also should be computed in certain cases where design lines become parallel with staked lines. If the design line remains parallel with the staked line for a considerable distance through numerous cross sections, it is more convenient to compute an equation than to re-station the cross sections. An example of such an equation is illustrated in Figure 25.6H.



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

EQUATION WHERE DESIGN LINE BECOMES COINCIDENT

Figure 25.6G



EQUATION WHERE DESIGN LINE BECOMES PARALLEL WITH STAKED LINE

Figure 25.6H