Bridge Design Details 2.1 February 2025

Bridge Layout

This section describes vertical and horizontal curve information used to establish the control points and primary geometric characteristics of a structure.

Bridge Design Details 2.2 February 2025

Vertical Curves

A vertical curve is used to change the profile of a highway to provide a smooth transition between two sloped grades. The design of a vertical curve is dependent on the intended design speed for the roadway, required drainage, slope, friction, sight distance, and acceptable rate of change.

It is recommended that the vertical curves extend beyond the bridge length, where possible, to minimize the design, drainage issues, and construction complexity of the bridge structure.

There are two types of vertical curves, sag curves and crest curves.

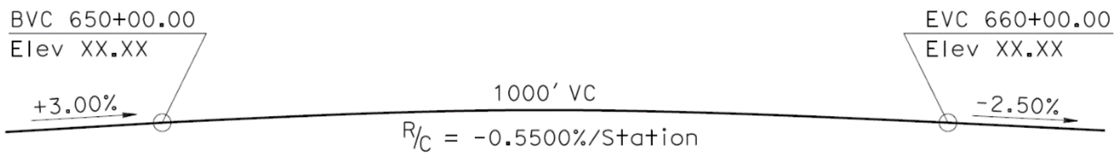
Vertical curve data is shown with a PROFILE GRADE detail on the GENERAL PLAN sheet. Vertical curve data includes:

- Begin Vertical Curve (BVC) station
- End Vertical Curve (EVC) station
- Point of Reversing Vertical Curve (PRVC) station
- Profile Grade approaching the vertical curve (G_1%)
- Profile Grade departing the vertical curve (G_2%)
- Length of curve (L) feet
- Rate of Change ($^R/_C$ %) per station

Bridge Design Details 2.3 June 2025

Rate of Change of Vertical Curves

EXAMPLE:



PROFILE GRADE

NO SCALE

$$R/C = \frac{-2.50 - (+3.00)}{10} = \frac{-5.50}{10} = -0.5500\%/\text{Station}$$

Figure 2.3.1 Vertical Curve Profile Grade

Normally, the Rate of Change is given on the PROFILE GRADE and shown on the GENERAL PLAN sheet above the ELEVATION view, where:

R/C = Rate of Change of Grade per Station (% Station)

(Carry this value to four significant figures to maintain accuracy)

The Rate of Change Formula is:

$$R/C = \frac{\text{Grade at EVC} - \text{Grade at BVC}}{\text{Length of vertical curve}} = \frac{G_2 - G_1}{L}$$

G_1 = Grade at first point on curve (%)

G_2 = Grade at last point on curve (%)

+G = ascending grade

-G = descending grade

L = Length of vertical curve in stations

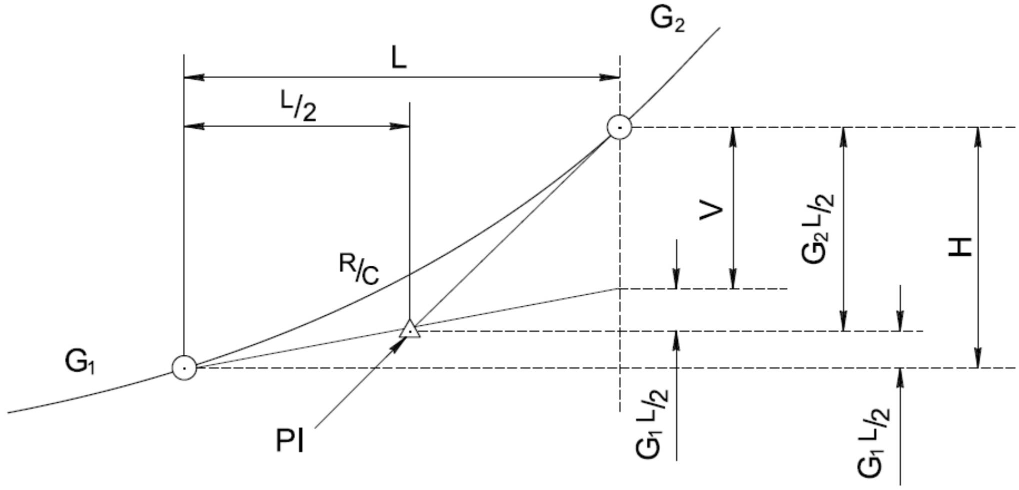


Figure 2A.A.1 Vertical Curve Formula

Rate of Change per Station Method Equations:

(1) $$R/C = \frac{G_2 - G_1}{L}$$

(2) $$V = \frac{L(G_2 - G_1)}{2}$$

(3) $$H = \frac{L(G_2 + G_1)}{2}$$

From these equations, or a combination of these, any point on a vertical curve can be determined.

V = Tangent offset from the first point to the second (feet)

H = Difference in elevation from BVC to EVC (feet)

PI = Projected intersection of the approaching and departing grades

+(V or H) measured upward

-(V or H) measured downward

Bridge Design Details 2B June 2025

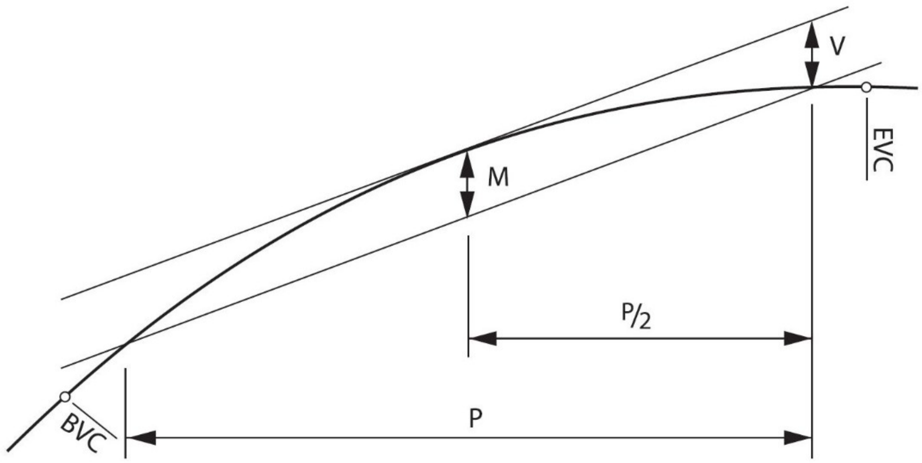


Figure 2A.B.1 Middle Ordinate Formula

Combining equations (1) and (2) given in 2A – Vertical Curve Formula – Attachment A, the Middle Ordinate is derived, and equation (4) is as follows:

(4) $$V = \frac{\left(R/C\right)\left(L\right)^2}{2}$$

For Length = $P/2$, then: $V = \frac{\left(R/C\right)\left(P/2\right)^2}{2}$

Using the figure and equation above, set M equal to V to get the following:

$$V = \frac{\left(R/C\right)\left(P/2\right)^2}{2} = M$$

Then simplify to get: $M = \frac{\left(R/C\right)P^2}{8}$

(P) measured horizontally

(M) measured vertically

Bridge Design Details 2C June 2025

High Point and Low Point Formula

$$\ell = \frac{G_1}{\left(R/C\right)}$$

ℓ - Length at high point or low point.

The elevation at any point along a curve is given by the following equation:

$$\text{Ø} = G_1 + \left(R/C\right)(\ell)$$

$$\ell = \frac{-G_1}{\left(R/C\right)}$$

Examples:

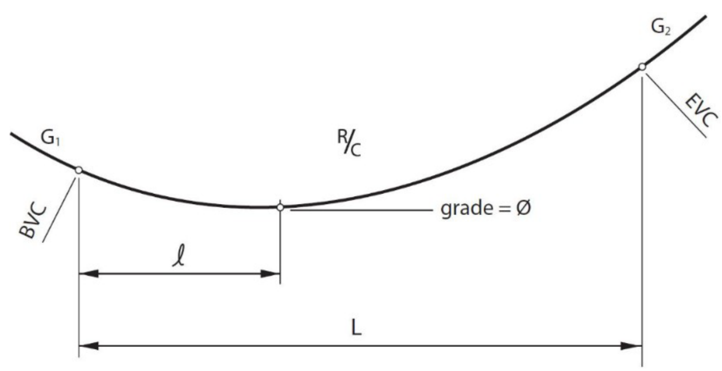


Figure 2A.C.1 Low Point (Sag Curve)

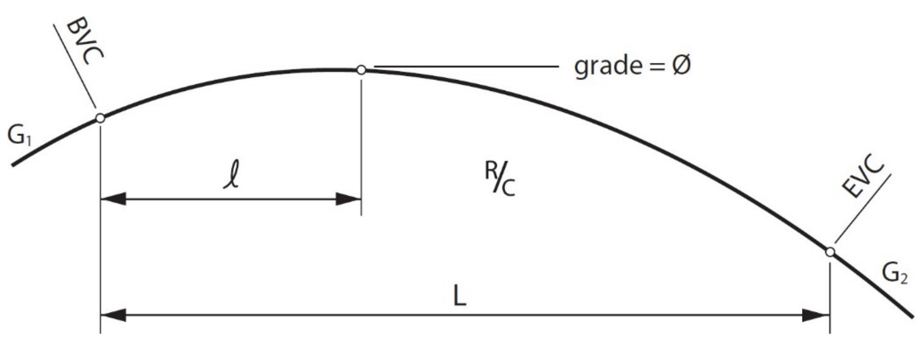


Figure 2A.C.2 High Point (Crest Curve)

Bridge Design Details 2D June 2025

To find the elevation at any given station on a vertical curve, use data given on the PROFILE GRADE and the following equation:

$$(5) \qquad (Elev\_PG)_D = (Elev\_BVC) + (D \text{ x } G_1) + \frac{D^2 \text{ x } \left(R/C\right)}{2}$$

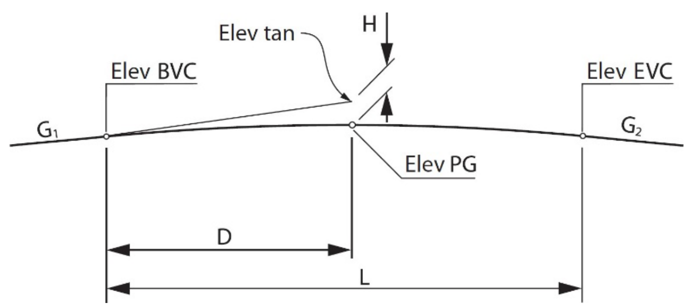


Figure 2A.D.1 Vertical Curve Definition

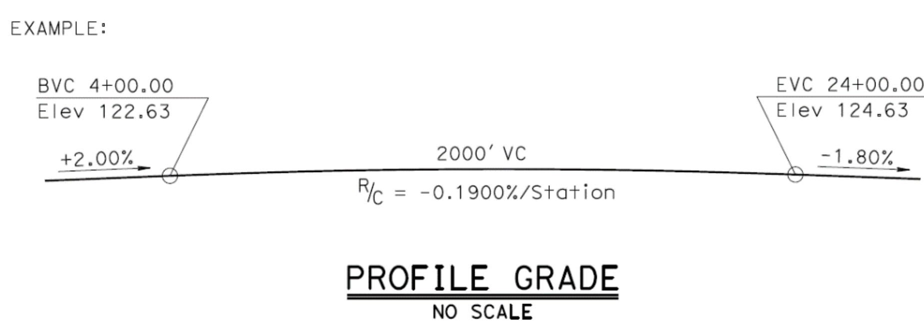
Where:

D = Distance from BVC to a point in stations

$$(6) \qquad (Elev\_tan) = (Elev\_BVC) + (D \text{ x } G_1))$$

H = Rise from Profile Grade to (Elev_tan): $H = \dfrac{D^2 \times R/C}{2}$

Example:



Find: Elevation at Station 12+60.00

Thus: Elev PG(12+60.00) $= 122.63 + (8.60)(2.00) + \dfrac{(8.60)^2(-0.19)}{2}$

$= 122.63 + 17.20 - 7.03$

$= 132.80$

Figure 2A.D.2 Vertical Curve Example Calculations

Example:

The "Brownell" method for calculating elevations at given stations along a vertical curve.

Given:

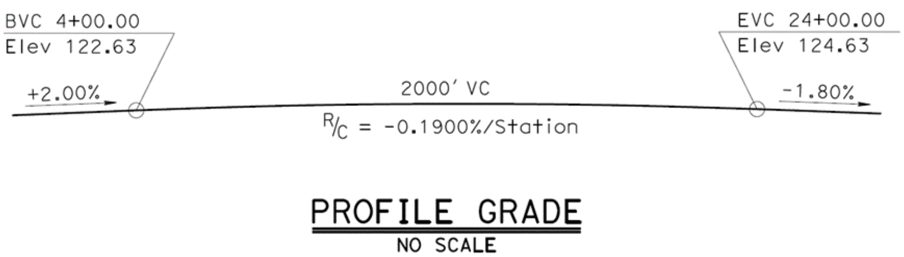


Figure 2A.D.3 Vertical Curve "Brownell" Example Calculations

Find elevations at: Abutment 1 at 11+50.00

Bent 2 at 12+60.00

Abutment 3 at 13+70.00

Station	R/C (% / Station)	G (Grade at Station)
BVC 4+00.00	-0.1900	+2.00
11+50.00 Abut 1	-0.1900	+0.5750
12+60.00 Bent 2	-0.1900	+0.3660
13+70.00 Abut 3	-0.1900	+0.1570
EVC 24+00.00	-0.1900	-1.80

Distance	L (Length - Stations)	R/C × L (Change in Grade)	L × Avg G (Change in Elevation)
BVC 4+00.00 to Abut 1	7.50	-1.4250	+9.6562
Abutment 1 to Bent 2	1.10	-0.2090	+0.5175
Bent 2 to Abut 3	1.10	-0.2090	+0.2876
Abutment 3 to EVC 24+00.00	10.30	-1.9570	-8.4614

Station	Elevation
4+00.00 BVC	122.63
11+50.00 Abut 1	**132.29**
12+60.00 Bent 2	**132.80**
13+70.00 Abut 3	**133.09**
24+00.00 EVC (Calculated)	124.63
24+00.00 EVC (Given)	124.63

Bridge Design Details 2.4 June 2025

Horizontal Curves

Roadway Designers use simple arcs for the design of roadway horizontal curves. The horizontal curve length is the distance between two tangent lengths that provides a safe sight distance for traffic moving at a specified design speed.

It is recommended that horizontal curves extend beyond the bridge length, if possible, to minimize the design and construction complexity of the bridge structure. Horizontal curve data includes:

- Beginning of Curve (BC) station
- End of Curve (EC) station
- Point on Curve (POC) station
- Point of Intersection (PI) station
- Bearings of Tangents (Brg)
- Radius (R) feet
- Central Angle (∆) degrees
- Tangent Distance (T) feet
- Length of Curve (L) feet
- Point of Compound Curve (PCC) station
- Point of Reverse Curve (PRC) station

If the tangents coming in or out of the horizontal curves are not tangential to the radius, you may need to label angle points and identify subtangent bearings.

Examples:

Coming into curve…

Angle Point @ (BC or PRC):

Back Subtangent Brg = NXX°XX'XX"W, Forward Subtangent Bearing = NXX°XX'XX"W

Coming out of curve…

Angle Point @ (EC or PRC):

Curve Subtangent Bearing = N XX°XX'XX" W

Bridge Design Details 2E June 2025

Horizontal Curve Equations

BC = Beginning of Curve

EC = End of Curve

PC = Point of Curvature

PT = Point of Tangency

d = Deflection Angle for point on curve

Δ = Delta or Central Angle

ℓ = Length along Curve (BC to POC)

L = Length of Curve = $\dfrac{2\pi R}{360^\circ}\Delta$

LC = Long Chord = $2R\left(1 - \sin\dfrac{\Delta}{2}\right)$

M = Middle Ordinate = $R\left(1 - \cos\dfrac{\Delta}{2}\right)$

PI = Point of Intersection

POC = Point on Curve

R = Radius

T = Tangent Distance = $R\tan\dfrac{\Delta}{2}$

Ex = External = $\left(\dfrac{R}{\cos\dfrac{\Delta}{2}} - R\right)$

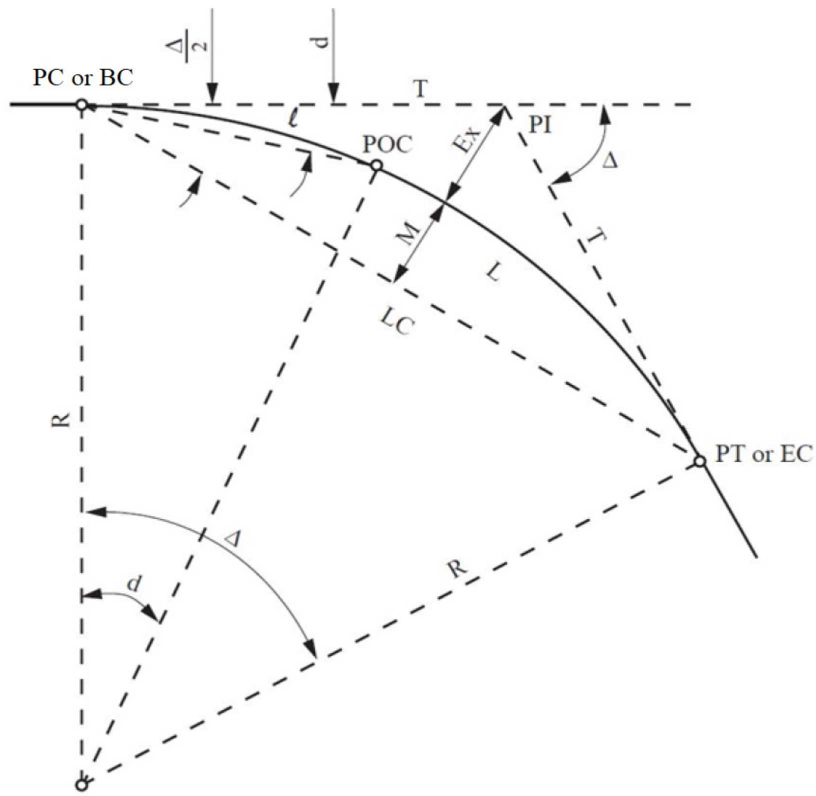


Figure 2A.E.1 Horizontal Curve Functions

All Curve Data may be obtained with two of the following curve parameters:

- Delta (Δ)
- Radius
- Tangent
- Length
- External

Example:

Given Length and Radius, solve for Delta Δ.

$$T = R \ \tan\frac{\Delta}{2} \qquad L=\frac{2\pi R}{360^\circ}\Delta$$

$$\tan\frac{\Delta}{2} = \frac{T}{R} \Rightarrow \Delta = 2\tan^{-1}\left(\frac{T}{R}\right), \ \Delta \text{ in degrees}$$

$$\Delta \text{ in degrees} = \frac{L \text{ x } 57.2958}{R}$$

Example:

Given Radius and Delta Δ, solve for L.

$$L = \frac{2\pi R\Delta}{360^\circ} \text{ or } L = R \ \text{func}\,\Delta \Rightarrow \frac{L}{2\pi R} = \frac{\Delta}{360^\circ} \Rightarrow L = \frac{2\pi R}{360^\circ}\Delta \qquad \text{where } \Delta \text{ is in degrees}$$

$$d = \frac{\Delta d}{2} \text{ where } \frac{\Delta d}{360} = \frac{\ell}{2\pi R} \Rightarrow d = \frac{180\ell}{2\pi R} \quad (\text{in degrees})$$

$$Ex = \frac{R}{\cos\frac{\Delta}{2}} - R \Rightarrow R\left(\frac{1}{\cos\frac{\Delta}{2}} - 1\right)$$

$$M = R - R \ \cos\frac{\Delta}{2} \Rightarrow R\left(1 - \cos\frac{\Delta}{2}\right)$$

Bridge Design Details 2F June 2025

Tangent Offset for Circular Curves

Radius	Distance from EC or BC (Along Tangents)												
	50'	**100'**	**150'**	**200'**	**250'**	**300'**	**400'**	**500'**	**600'**	**700'**	**800'**	**900'**	**1,000'**
20,000'	0.06	0.25	0.56	1.00	1.56	2.25	4.00	6.25	9.00	12.25	16.01	20.26	25.02
15,000'	0.08	0.33	0.75	1.33	2.08	3.00	5.33	8.34	12.01	16.34	21.35	27.02	33.37
10,000'	0.13	0.50	1.13	2.00	3.13	4.50	8.00	12.51	18.02	24.53	32.05	40.58	50.13
9,000'	0.14	0.56	1.25	2.22	3.47	5.00	8.89	13.90	20.02	27.26	35.62	45.11	55.73
8,000'	0.16	0.63	1.41	2.50	3.91	5.63	10.01	15.64	22.53	30.68	40.10	50.79	62.75
7,000'	0.18	0.71	1.61	2.86	4.47	6.43	11.44	17.88	25.76	35.09	45.87	58.10	71.80
6,000'	0.21	0.83	1.88	3.33	5.21	7.51	13.35	20.87	30.08	40.97	53.57	67.88	83.92
5,000'	0.25	1.00	2.25	4.00	6.25	9.01	16.03	25.06	36.13	49.24	64.42	81.67	101.02
4,500'	0.28	1.11	2.50	4.45	6.95	10.01	17.81	27.86	40.18	54.78	71.68	90.92	112.52
4,000'	0.31	1.25	2.81	5.00	7.82	11.27	20.05	31.37	45.26	61.73	80.82	102.57	127.02
3,500'	0.36	1.43	3.22	5.72	8.94	12.88	22.93	35.90	51.81	70.71	92.66	117.69	145.90
3,000'	0.42	1.67	3.75	6.67	10.44	15.04	26.79	41.96	60.61	82.81	108.63	138.18	171.57
2,500'	0.50	2.00	4.50	8.01	12.53	18.07	32.20	50.51	73.07	100.00	131.46	167.62	208.71
2,000'	0.63	2.50	5.63	10.03	15.69	22.63	40.41	63.51	92.12	126.50	166.97	213.94	267.95
1,800'	0.70	2.78	6.26	11.15	17.45	25.18	45.01	70.84	102.94	141.69	187.55	241.15	303.34
1,700'	0.74	2.94	6.63	11.81	18.48	26.68	47.73	75.19	109.40	150.81	200.00	257.78	325.23

Table 2A.F.1 Distance from Beginning or End of Curve Along Tangents

Radius	Distance from EC or BC (Along Tangents)												
	50'	100'	150'	200'	250'	300'	400'	500'	600'	700'	800'	900'	1,000'
1,600'	0.78	3.12	7.05	12.55	19.65	28.38	50.81	80.13	116.76	161.25	214.36	277.12	351.00
1,500'	0.83	3.34	7.52	13.39	20.98	30.31	54.32	85.79	125.23	173.35	231.14	300.00	
1,400'	0.89	3.58	8.06	14.36	22.50	32.52	58.36	92.33	135.09	187.56	251.09	327.61	
1,300'	0.96	3.85	8.68	15.48	24.27	35.09	63.07	100.00	146.74	204.56	275.31		
1,250'	1.00	4.01	9.03	16.10	25.26	36.53	65.73	104.36	153.41	214.38	289.53		
1,200'	1.04	4.17	9.41	16.78	26.33	38.11	68.63	109.13	160.77	225.32	305.57		
1,100'	1.14	4.56	10.28	18.34	28.79	41.70	75.31	120.20	178.05	251.47			
1,000'	1.25	5.01	11.31	20.20	31.75	46.06	83.49	133.96	200.00	285.86			
900'	1.39	5.57	12.59	22.50	35.42	51.47	93.77						
800'	1.56	6.28	14.19	25.40	40.07	58.38	107.18						
750'	1.67	6.70	15.15	27.16	42.89	62.61							
700'	1.79	7.18	16.26	29.18	46.17	67.54							
650'	1.93	7.74	17.54	31.53	50.00	73.37							
600'	2.09	8.39	19.05	34.32	54.56	80.39							
550'	2.28	9.17	20.85	37.65	60.10								
500'	2.51	10.10	23.03	41.74	66.99								
450'	2.79	11.25	25.74	46.89									
400'	3.14	12.70	29.19	53.59									
300'	4.20	17.16	67.71										
200'	6.35	26.80	67.71										
100'	13.40												

Table 2A.F.1 Distance from Beginning or End of Curve Along Tangents (continued)

Derivation of Table

Given: Radius and X, Find: Offset Y

(1) $R \sin\Delta = X \Rightarrow \sin\Delta = \dfrac{X}{R}$

(2) $Y = R - R\cos\Delta = R(1 - \cos\Delta)$

Given: Y and X, Find: Radius

(1) $\tan\dfrac{\Delta}{2} = \dfrac{Y}{X}$

(2) $R = \dfrac{X}{\sin\Delta}$

Note:

For approximate results, the following simpler formula can be used.

(The error is $\leq 1\%$ when $X \leq 0.2R$)

$$\left(Y = \frac{X^2}{2R}\right)$$

Example:

Given Radius = 900'.

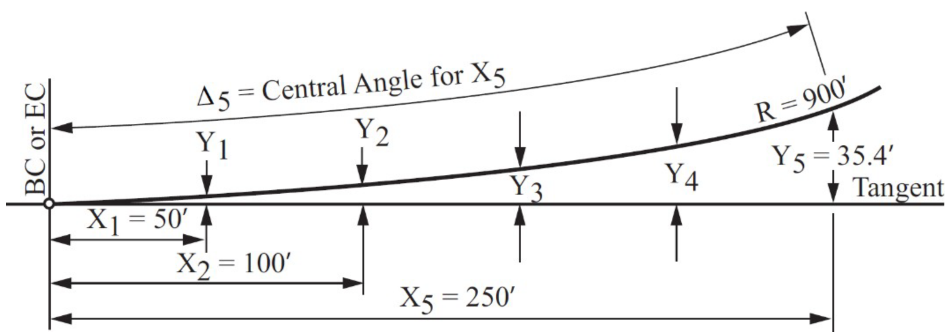
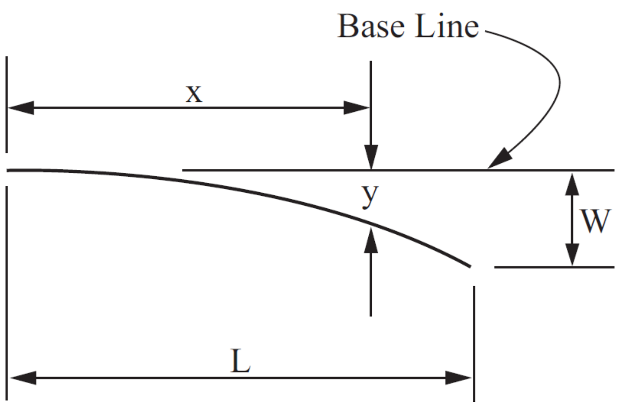


Figure 2A.F.1 Example of Distances along Tangent from Curve

Bridge Design Details 2G June 2025

Parabolic Curve Flares



$$y = \frac{Wx^2}{L^2}$$

x = distance along base line in feet

y = offset from base line in feet

L = length of flare in feet

W = maximum offset in feet*

Width to Length Ratio = 1:5

Flare Length	x=10	x=15	x=20	x=25
25	0.80	1.80	3.20	**5.00***

Flare Length	x=10	x=20	x=30	x=40	x=50
50	0.40	1.60	3.60	6.40	**10.00***

Width to Length Ratio = 1:10

Flare Length	x=10	x=20	x=30	x=40	x=50
50	0.20	0.80	1.80	3.20	**5.00***

Flare Length	x=10	x=20	x=30	x=40	x=50	x=60	x=70	x=80	x=90	x=100
100	0.10	0.40	0.90	1.60	2.50	3.60	4.90	6.40	8.10	**10.00***

Width to Length Ratio = 1:15

Flare Length	x=10	x=20	x=30	x=40	x=45
45'	0.15	0.59	1.33	2.37	**3.00***

Flare Length	x=10	x=20	x=30	x=40	x=50	x=60	x=70	x=75
75'	0.09	0.36	0.80	1.42	2.22	3.20	4.36	**5.00***

Flare Length	x=10	x=20	x=30	x=40	x=50	x=60	x=70	x=80	x=90
90'	0.07	0.30	0.67	1.19	1.85	2.67	3.63	4.74	**6.00***

Flare Length	x=10	x=20	x=30	x=40	x=50	x=60	x=70	x=80	x=90	x=100	x=110	x=120
120'	0.06	0.22	0.50	0.89	1.39	2.00	2.72	3.56	4.50	5.56	6.72	**8.00***

Table 2A.G.1 Offset "y" in Feet for Given Distance "x"

Bridge Design Details 2.5 February 2025

Horizontal Alignment

A horizontal alignment is provided in the Bridge Site Submittal from the District and is given as a stationed layout line for highways, off-ramps, walls, or other structures. All horizontal alignments are laid out by stations, which are given as 100-foot increments along the layout line. For smaller structures, the station line may be given as 20-foot increments along the layout line (e.g., +20, +40, +60, etc.). Whole stations shall not include “plus stations” (e.g., 10+00). For three-digit whole stations, it is acceptable to drop the first two digits and fully label every 500 feet (e.g., 100, 1, 2, 3, 4, 105, etc.).

Stations

Locations along a station line are generally shown to the nearest hundredth of a foot and without the station abbreviation (Sta).

Example: 12+56.00 "A” LINE

Bearings

The bearing direction for tangent lines follows the direction of increasing stationing and the north arrow.

Offsets

Any location within the same plane of a given horizontal alignment can be found using a station-offset from a specific alignment. Offsets are distances, left or right, from any given station line to the location of a specific point.

Example: P_1 is offset 2.00 feet left of station 12+10.00.

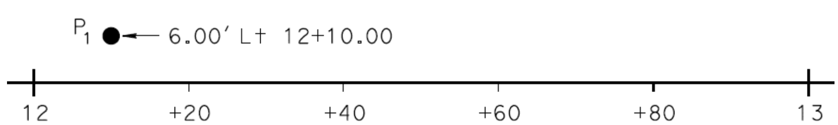


Figure 2.5.1 Point Offset Location

It is common practice to either begin the retaining wall layout lines at 10+00.00 or to match the beginning station to the corresponding mainline alignment.

Example: Beginning of wall is 6.00 feet left of station; 12+08.00 "A" Line.

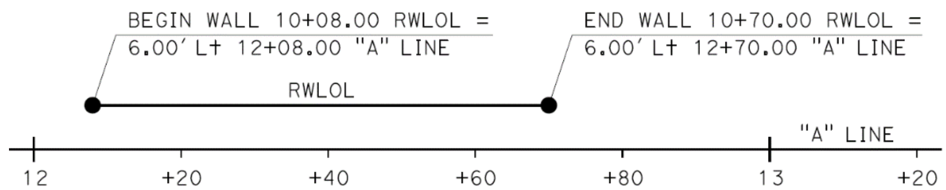


Figure 2.5.2 Retaining Wall Offset Locations

To prevent errors between Structure and Roadway Plans, avoid re-stationing through the design process. If the District provides an alignment that starts at 10+00.00 for a retaining wall, use that as a starting point for layout. Any subsequent changes the Design Branch makes to locate the wall based on actual topography and profile would add or subtract from that initial stationing without affecting downstream stationing (e.g., If the beginning of walls is moved 2 feet, the new beginning station would become 10+02.00 or in opposite direction 9+98.00).

Alignment Labels

Alignment labels shall always follow this layout...

<Descriptor><Station Numbers><Alignment Name>

Potential Descriptors could include BEGIN, END, BC, EC, or PI.

Examples:

Correct: 16+25.00 “A” LINE
EC 15+06.00 “B” LINE
BEGIN BC 10+00.00 “A1” LINE

Incorrect: POT 16+25.00 “A” LINE
“B” 15+06.00 EC
BC “A1” 10+00 BEGIN LINE

Also, do not include POT and POC at intersection of alignments.

Examples:

Correct: 14+45.00 “B” LINE =
20+25.00 “C” LINE

Incorrect: POC 14+45.00 “B” LINE=
POT 20+25.00 “C” LINE

“B1” 1651+80.23 POT =
“C” 30+63.24 POC

Standard abbreviation for ELEVATION is Elev (without period should be used), and the term “Sta” shall not be used for alignment callouts.

Examples:

Incorrect: EB Sta 1652.74±
Elev. 284.45±

Sta 10+00.00 “A” LINE =
40’ Lt Sta 85+50.00 “ROUTE” LINE

Bridge Design Details 2H June 2025

Bridge Design Details 2H June 2025

Develop Horizontal Alignment Stations

Examples:

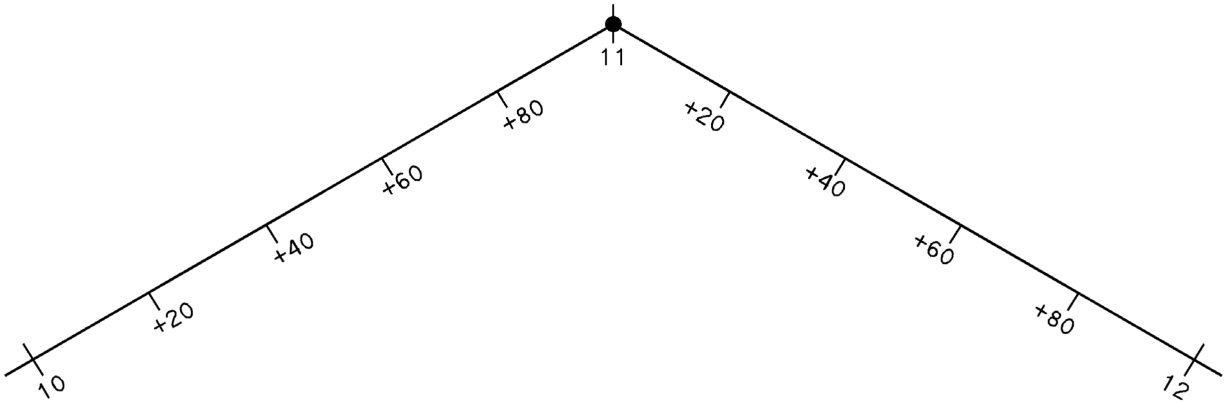


Figure 2A.H.1 Alignment Stationing without Horizontal Curve

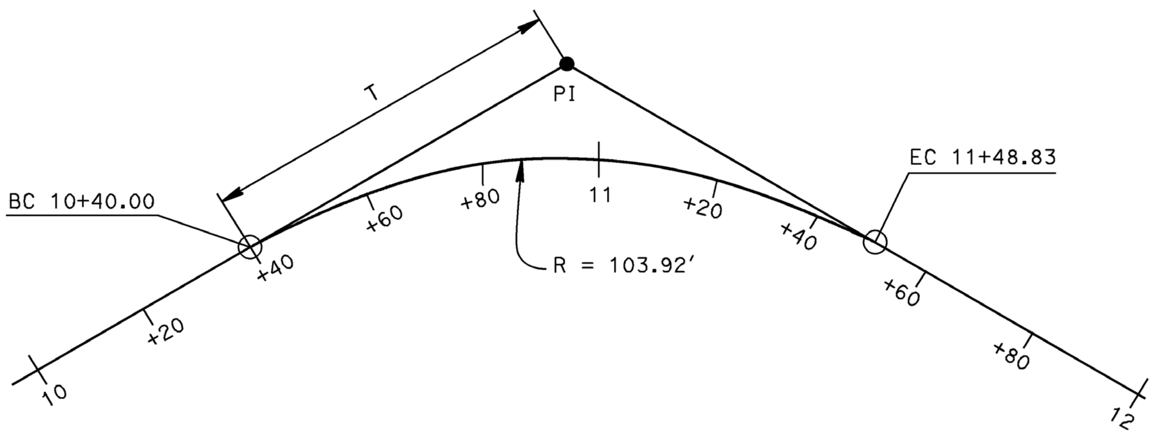


Figure 2A.H.2 Revised Alignment Stationing with Horizontal Curve

Caltrans

Curve Data Tables

Standard detailing cells for CURVE DATA tables have been setup for use. All cells can be modified based on number of radii shown on sheet.

If you have a single alignment with a single radius, you do not have to label Radius with number (e.g., R#). If you have a single alignment with more than one radius use:

CURVE DATA

R_1 =	XXXX.XX′	R_2 =	XXXX.XX′
Δ =	XX°XX′XX″	Δ =	XX°XX′XX″
T =	XXXX.XX′	T =	XXXX.XX′
L =	XXXX.XX′	L =	XXXX.XX′

If you have multiple alignments shown, all radii should be labeled:

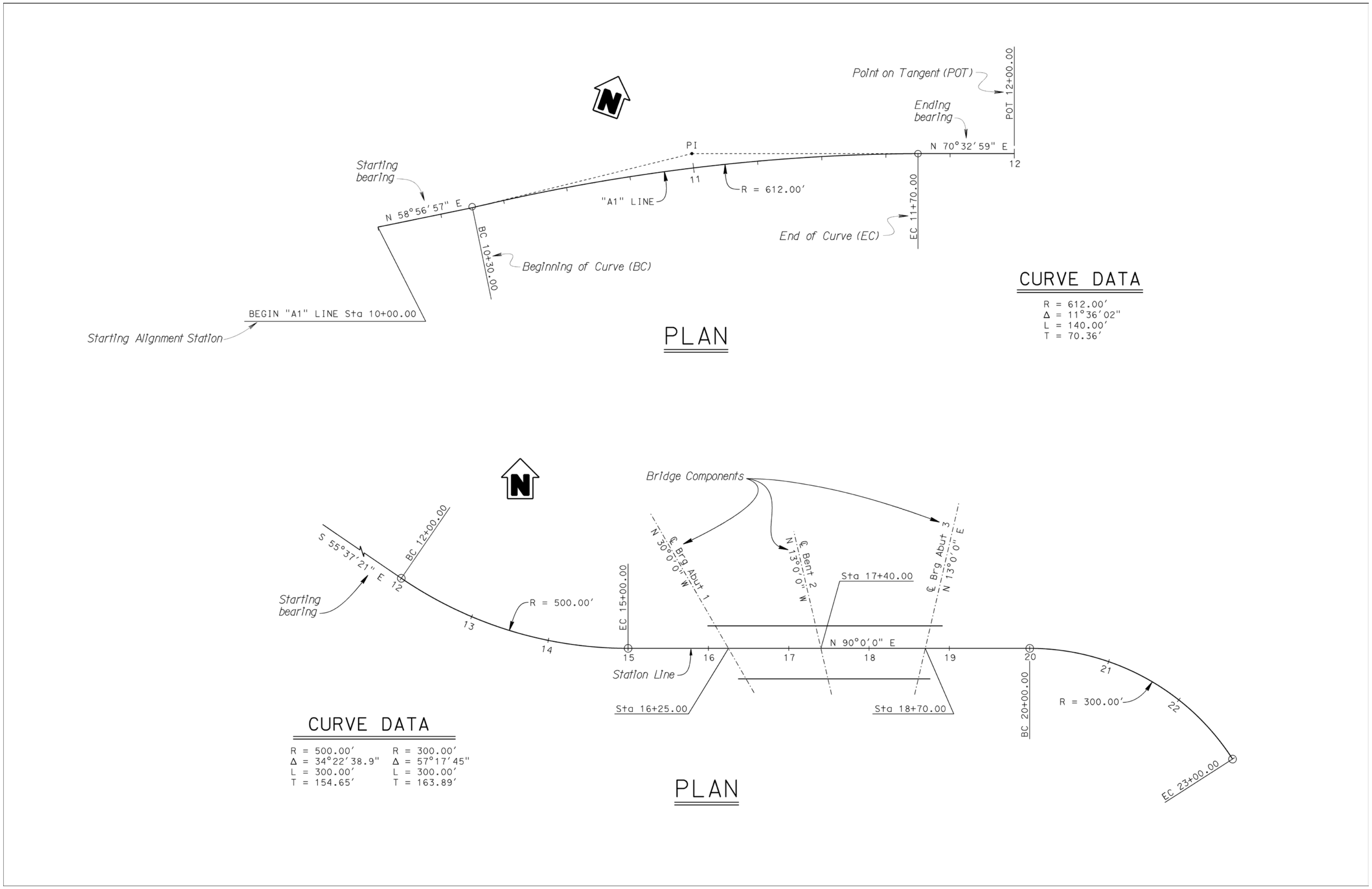
CURVE DATA

"X1" LINE		"X2" LINE	
R =	XXXX.XX′	R =	XXXX.XX′
Δ =	XX°XX′XX″	Δ =	XX°XX′XX″
T =	XXXX.XX′	T =	XXXX.XX′
L =	XXXX.XX′	L =	XXXX.XX′

Foundation Plans should use the following:

CURVE DATA				
No.	R	Δ	T	L
1	----.--′	--°--′--″	----.--′	----.--′
2	----.--′	--°--′--″	----.--′	----.--′
3	----.--′	--°--′--″	----.--′	----.--′

Figure 2A.I.1 Horizontal Alignment Examples



Fgure 2A.J.1 Projecting Parallel Horizontal Alignment Example