

3. VERTICAL DESIGN

Practices and Procedures

3-1 SIGHT DISTANCE

3-1.01 Stopping Sight Distance

See EI C8 - Stopping Sight Distance and Design Guidance – Sag Vertical Curves.

3-2 VERTICAL ALIGNMENT

3-2.01 Grades

Minimum and Maximum Grades

See EI C5 – Maximum Gradient.

Critical Length of Grade - Updated 12/15/2021

See Design Guidance – Critical Length of Grade and Climbing Lanes and Section 3.4.2.3 Critical Lengths of Grade for Design in the *AASHTO Green Book*, along with [Figure 3-1](#) below.

3-2.02 Vertical Curves

Definitions

Vertical Curve. Vertical curves have the shape of a parabola and are used to produce a gradual change between tangent grades.

Point of Vertical Intersection (PVI). The PVI is the point where the extension of two tangent grades intersect.

Point of Vertical Curvature (PVC). The PVC is the point at which the tangent grade ends and the vertical curve begins.

Point of Vertical Tangency (PVT). The PVT is the point at which the vertical curve ends and the tangent grade begins.

Grade Slopes (G_1 or G_2). The grade slope is the rate of slope between two adjacent PVI's expressed as a percent. The numerical value for percent is the vertical rise or fall in feet for each 100 feet of horizontal distance. Upgrades in the direction of stationing are identified as plus (+). Downgrades are identified as minus (-).

Algebraic Difference (A). The value of A is the algebraic difference in percent between two tangent grades.

Length of Vertical Curve (L). L is the horizontal distance in feet from the PVC to the PVT.

See [Figure 3-2](#) for a diagram and equations for a typical vertical curve.

Curve Types

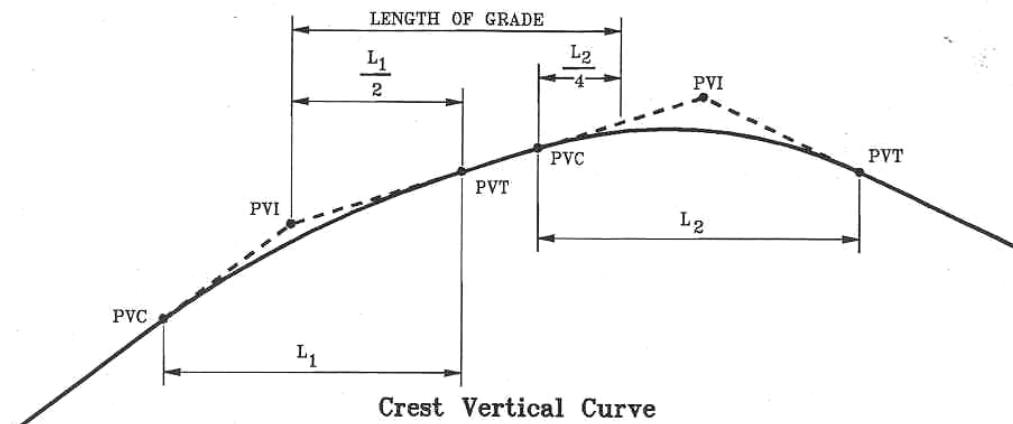
See Section 3.4.6 Vertical Curves in the *AASHTO Green Book*.

Climbing Lanes - Updated 12/15/2021

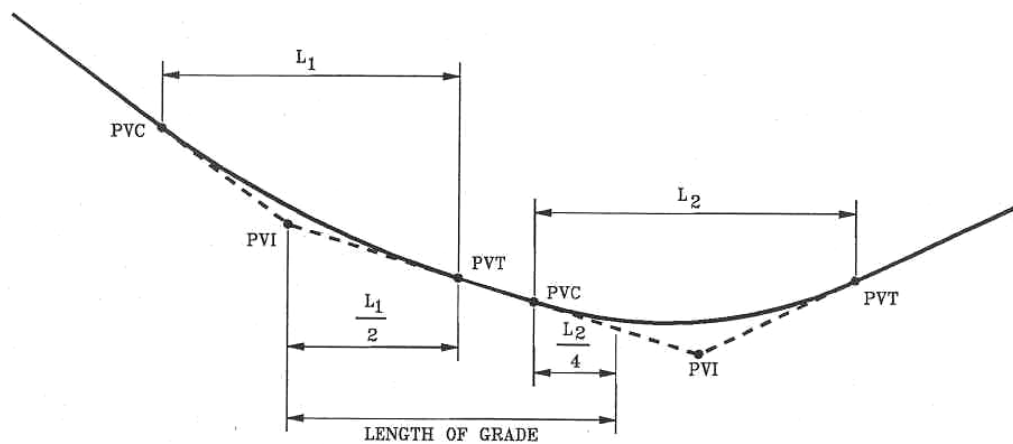
See Design Guidance – Critical Length of Grade and Climbing Lanes, along with Section 3.4.3.1 Climbing Lanes for Two-Lane Highways in the AASHTO Green Book.

Vertical Clearance

See EI C9 – Vertical Clearance.



Crest Vertical Curve



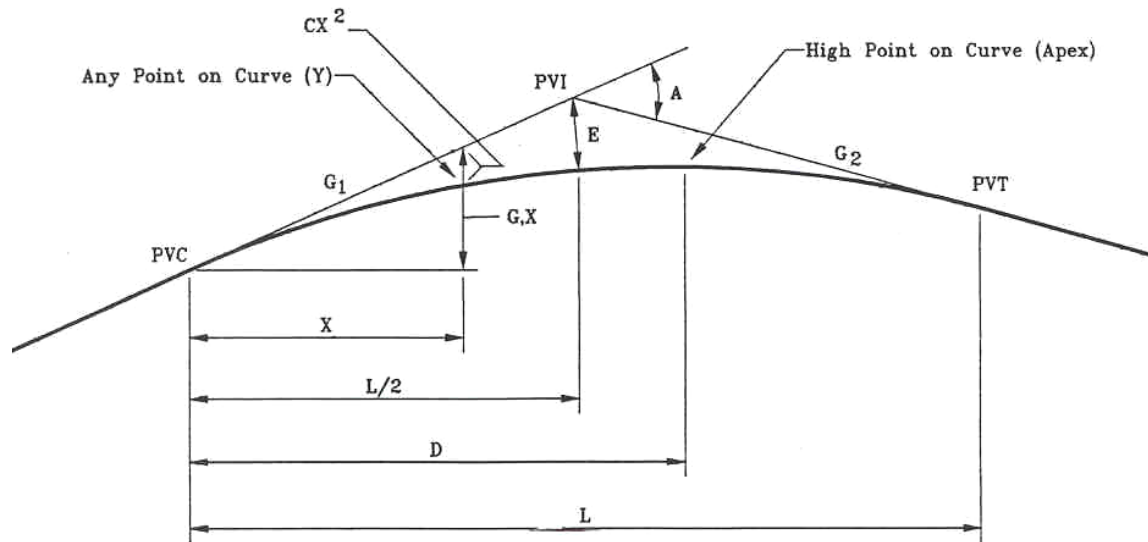
Sag Vertical Curve

Notes:

1. For vertical curves where the two grades are in the same direction, 50% of the curve length will be part of the length of grade.
2. For vertical curves where the two grades are in opposite directions, 25% of the curve length will be part of the length of grade.

MEASUREMENT FOR CRITICAL LENGTH OF GRADE

Figure 3-1



1. Legend

- X = horizontal distance from PVC to any point on curve (feet)
 Y = elevation above sea level of finished grade at any point on curve (feet)
 L = horizontal length of curve from PVC to PVT (feet)
 D = distance from PVC to high point on crests or low point of sags
 G_1, G_2 = the percent grades of the two tangents (%). "Upgrades" in the direction of stationing are denoted "positive" (+) ; "Downgrades" in the direction of stationing are denoted as "negative" (-) .

$A = G_2 - G_1$ = algebraic difference in grades

$E = AL / 800$ = external offset from the vertical curve to PVI at $L / 2$ (feet)

2. Elevation Calculations (Known: $El_{PVI}, G_1, G_2, L, Sta_{PVI}$)

A. PVC information:

$$Sta_{PVC} = Sta_{PVI} - L / 200$$

$$El_{PVC} = El_{PVI} - G_1 L / 200$$

C. PVC to PVI:

$$Y = (G_1 X / 100) - CX^2 + El_{PVC}$$

$$C = A / 200(L)$$

B. PVT information:

$$Sta_{PVT} = Sta_{PVI} + L / 200$$

$$El_{PVT} = El_{PVI} + G_2 L / 200$$

D. PVI to PVT:

$$Y = [G_2 (L - X) / 100] - C(L - X)^2 + El_{PVT}$$

$$C = A / 200(L)$$

3. Distance (D) to High Point (Crests) or Low Point (Sags).

$$D = LG_1 / (G_1 - G_2) \quad \text{where: } D, L, G_1, G_2 \text{ are defined above.}$$

TYPICAL VERTICAL CURVE

Figure 3- 2