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

See Section 3.4.2.3 Critical Lengths of Grade for Design in the AASHTO Green Book and reference Figure 3-1.

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 (G₁ or G₂).* 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*.

**Truck Climbing Lanes**

See Design Guidance – Truck Climbing Lanes.

**Vertical Clearance**

See EI C9 – Vertical Clearance.

**3-2.03 Pavement Design**

See 8-2.01 Design Types in *Pavement Design* for vertical alignment design considerations.
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
   - \( E = \frac{AL}{800} \) = external offset from the vertical curve to PVI at \( L \) / 2 (feet)

2. **Elevation Calculations** (Known: \( E_{PVI}, G_1, G_2, L, St_{PVI} \))

   **A. PVC information:**
   
   \[ St_{PVC} = St_{PVI} - \frac{L}{200} \]
   
   \[ E_{PVC} = E_{PVI} - \frac{G_1L}{200} \]

   **B. PVT information:**
   
   \[ St_{PVT} = St_{PVI} + \frac{L}{200} \]
   
   \[ E_{PVT} = E_{PVI} + \frac{G_2L}{200} \]

   **C. PVC to PVI:**
   
   \[ Y = \frac{G_1X}{100} - CX^2 + E_{PVC} \]
   
   \[ C = \frac{A}{200(L)} \]

   **D. PVI to PVT:**
   
   \[ Y = \frac{G_2(L - X)}{100} - C(L - X)^2 + E_{PVT} \]
   
   \[ C = \frac{A}{200(L)} \]

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

   \[ D = \frac{LG_1}{(G_1 - G_2)} \]

   where: \( D, L, G_1, G_2 \) are defined above.

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**TYPICAL VERTICAL CURVE**

Figure 3-2