Equations: Quiz 1

Theoretical Braking Distance

\[ f_{rb} = 0.01 \left( 1 + \frac{V}{147} \right) \]

\[ \text{Theoretical Braking Distance} = \frac{\gamma_b (V_f^2 - V_i^2)}{2g(\eta_b \mu + f_{rb} \pm G)} \]

**TRANSPORTATION**

**Stopping Sight Distance**

U.S. Customary Units Equation

\[ S = \frac{V^2}{30[(a/32.2) \pm G]} + 1.47Vt \]

(PRACTICAL SSD)

Metric Equation:

\[ S = \frac{V^2}{254[(a/9.81) \pm G]} + 0.278Vt, \]

where (as appropriate):

- \( S \) = stopping sight distance (ft or m),
- \( G \) = percent grade divided by 100,
- \( V \) = design speed (mph or km/h),
- \( a \) = deceleration rate (ft/s² or m/s²),
  \[ = 11.2 \text{ ft/s}^2 = 3.4 \text{ m/s}^2 \] and
- \( t \) = driver reaction time (s).

**Sight Distance Related to Curve Length**

a. Crest Vertical Curve (general equations):

\[ L = \frac{AS^2}{200(\sqrt{h_1} + \sqrt{h_2})^2} \quad \text{for } S \leq L \]

\[ L = 2S - \frac{200(\sqrt{h_1} + \sqrt{h_2})^2}{A} \quad \text{for } S > L \]

where

- \( L \) = length of vertical curve (ft or m),
- \( A \) = algebraic difference in grades (%),
- \( S \) = sight distance for stopping or passing, (ft or m),
- \( h_1 \) = height of drivers' eyes above the roadway surface (ft or m), and
- \( h_2 \) = height of object above the roadway surface (ft or m).
U.S. Customary Units:

When \( h_1 = 3.50 \) ft and \( h_2 = 2.0 \) ft,
\[
\begin{align*}
L &= \frac{AS^2}{2158} \\
L &= 25 - \frac{2158}{A} 
\end{align*}
\]
for \( S \leq L \)

for \( S > L \)

Metric Units:

When \( h_1 = 1.080 \) mm and \( h_2 = 600 \) mm,
\[
\begin{align*}
L &= \frac{AS^2}{658} \\
L &= 25 - \frac{658}{A} 
\end{align*}
\]
for \( S \leq L \)

for \( S > L \)

b. Sag Vertical Curve (based on standard headlight criteria):

U.S. Customary Units
\[
L = \frac{AS^2}{400 + 3.5S} \\
L = 25 - \frac{400 + 3.5A}{A} 
\]
for \( S \leq L \)

for \( S > L \)

Metric Units
\[
L = \frac{AS^2}{120 + 3.5S} \\
L = 25 - \frac{120 + 3.5A}{A} 
\]
for \( S \leq L \)

for \( S > L \)

c. Sag Vertical Curve (based on adequate sight distance under an overhead structure to see an object beyond a sag vertical curve)
\[
L = \frac{AS^2}{800} \left( C - \frac{h_1 + h_2}{2} \right) \\
L = 25 - \frac{800}{A} \left( C - \frac{h_1 + h_2}{2} \right) 
\]
where

where \( C = \) vertical clearance for overhead structure (underpass) located within 200 ft (60 m) of the midpoint of the curve (ft or m).

d. Sag Vertical Curve (based on riding comfort):

U.S. Customary Units
\[
L = \frac{AV^2}{46.5} \\
L = \frac{AV^2}{395} 
\]

where (as appropriate):

- \( L = \) length of vertical curve (ft or m),
- \( V = \) design speed (mph or km/hr), and
- \( A = \) algebraic difference in grades (%)

e. Horizontal curve (to see around obstruction):
\[
M = R \left[ 1 - \cos \left( \frac{28.65S}{R} \right) \right] 
\]
where

- \( R = \) radius (ft or m)
- \( M = \) middle ordinate (ft or m),
- \( S = \) stopping sight distance (ft or m).

Superelevation of Horizontal Curves

a. Highways:

U.S. Customary Units:
\[
\frac{e}{100} + f = \frac{V^2}{15R} 
\]

Metric Units:
\[
\frac{e}{100} + f = \frac{V^1}{127R} 
\]

where (as appropriate):

- \( e = \) superelevation (%),
- \( f = \) side-friction factor,
- \( V = \) vehicle speed (mph or km/hr), and
- \( R = \) radius of curve (ft or m).

b. Railroads:
\[
E = \frac{Gv^2}{gR} 
\]

where

- \( E = \) equilibrium elevation of outer rail (in.),
- \( G = \) effective gage (center-to-center of rails) (in.),
- \( v = \) train speed (ft/s),
- \( g = \) acceleration of gravity (ft/s²), and
- \( R = \) radius of curve (ft).

---

Table 2.4 Typical Values of Coefficients of Road Adhesion

<table>
<thead>
<tr>
<th>Pavement</th>
<th>Maximum</th>
<th>Slide</th>
</tr>
</thead>
<tbody>
<tr>
<td>Good, dry</td>
<td>1.00*</td>
<td>0.80</td>
</tr>
<tr>
<td>Good, wet</td>
<td>0.90</td>
<td>0.60</td>
</tr>
<tr>
<td>Poor, dry</td>
<td>0.80</td>
<td>0.55</td>
</tr>
<tr>
<td>Poor, wet</td>
<td>0.60</td>
<td>0.30</td>
</tr>
<tr>
<td>Packed snow or ice</td>
<td>0.25</td>
<td>0.10</td>
</tr>
</tbody>
</table>
Vertical Curve Offsets

\[ Y = \frac{A}{200L} x^2 \]

\[ A = |G_1 - G_2| \quad \text{*A is in percent form.} \]

\[ K = \frac{L}{A} \]

\[ x_{hl} = K \times |G_i| \]

Parabolic Equations

\[ y = ax^2 + bx + c \]

Where \( y \) = roadway elevation at distance \( x \) from the PVC.

\[ a = \frac{G_2 - G_1}{2L}; \quad b = G_1; \quad c = \text{ELEV}_{PVC} \]

*keep in mind that you must use either station/% or ft/decimal for \( x/G_i \).
<table>
<thead>
<tr>
<th>Design speed (mi/h)</th>
<th>Stopping sight distance (ft)</th>
<th>Rate of vertical curvature, $K^<em>$&lt;sup&gt;</em>&lt;/sup&gt;</th>
<th>Design speed (km/h)</th>
<th>Stopping sight distance (m)</th>
<th>Rate of vertical curvature, $K^<em>$&lt;sup&gt;</em>&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Calculated</td>
<td>Design</td>
<td></td>
<td>Calculated</td>
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<td>80</td>
<td>3.0</td>
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<td>20</td>
<td>20</td>
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<tr>
<td>20</td>
<td>115</td>
<td>6.1</td>
<td>7</td>
<td>30</td>
<td>20</td>
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<tr>
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<td>155</td>
<td>11.1</td>
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<tr>
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<td>200</td>
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<td>50</td>
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<tr>
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<td>29.0</td>
<td>29</td>
<td>60</td>
<td>65</td>
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<tr>
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<td>305</td>
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<td>44</td>
<td>70</td>
<td>85</td>
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<tr>
<td>45</td>
<td>360</td>
<td>60.1</td>
<td>61</td>
<td>80</td>
<td>105</td>
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<tr>
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<tr>
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<td>495</td>
<td>113.5</td>
<td>114</td>
<td>100</td>
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<tr>
<td>60</td>
<td>570</td>
<td>150.6</td>
<td>151</td>
<td>110</td>
<td>185</td>
</tr>
<tr>
<td>65</td>
<td>645</td>
<td>192.8</td>
<td>193</td>
<td>120</td>
<td>220</td>
</tr>
<tr>
<td>70</td>
<td>730</td>
<td>246.9</td>
<td>247</td>
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<td>250</td>
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<tr>
<td>75</td>
<td>820</td>
<td>311.6</td>
<td>312</td>
<td>140</td>
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<tr>
<td>80</td>
<td>910</td>
<td>383.7</td>
<td>384</td>
<td>150</td>
<td>320</td>
</tr>
</tbody>
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*Rate of vertical curvature, $K$, is the length of curve per percent algebraic difference in intersecting grades ($A$): $K = L/A$.


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Selection of ITE Rates/Equations, or Collection of Local Data

1. Compatible with ITE Land Use Code?
   - Yes
   - No

2. Size within Data Extremes?
   - Yes
   - No

3. Number of Data Points?
   - 1 or 2
   - 3-5
   - 6 +

4. Regression Equation?
   - A
   - No
   - Yes

If number of data points between 3 and 5, analysts are encouraged to collect local data, but can proceed to Step 4.

Selection of ITE Rates/Equations, or Collection of Local Data (cont.)

5. Standard Deviation 10 percent?
   - Yes
   - No

6. Data Cluster Okay?
   - Yes
   - No

Use Weighted Average Rate

Selection of ITE Rates/Equations, or Collection of Local Data (cont.)

7. 20 or More Data Points?

Yes

Use Regression Equation

No

8A. $R^2 \geq 0.75$? And Within Cluster?

8B. Std Dev $\geq 110\%$? And Within Cluster?

If 8A is yes & 8B is yes

Choose Line at Cluster

If 8A is yes & 8B is no

Use Regression Equation

If 8A is no & 8B is yes

Use Weighted Average Rate

If 8A is no & 8B is no

Collect Local Data

Figure 3.1


Selection of ITE Rates/Equations, or Collection of Local Data (cont.)