Short Answers

Which US President was most responsible for the development of the US Interstate System?

**Eisenhower**

What metric is used to calculate intersection Level of Service?

**Estimated average delay per vehicle**

Why is automobile traffic typically ignored when calculating pavement structural design?

*Individual automobiles constitute very low LEFs, on the order of 0.001 or less. Therefore, ignoring them does not appreciably change the overall ESAL estimate for a pavement.*

A vehicle slows from 60 mph down to 30 mph on a flat grade. Using the standard AASHTO recommended deceleration rate, what is the braking distance over which this occurs?

\[
d = \frac{V_f^2 - V_i^2}{2a} = \frac{0 \times 1.47^2 - 60 \times 1.47^2}{2 \times 11.2} = 260.5 \text{ ft}
\]
Problems
A 2-lane (12 ft wide lanes) combined horizontal and crest vertical curve is reportedly designed for 35 mph. Both curves begin at point A and end at point B.

Given the data below, is this section of roadway adequately designed for 35 mph? Show appropriate calculations to support your conclusion.

**Horizontal Curve Data**
- Curve length = 390 ft
- 60° angle as shown
- 4% superelevation
- \(M_s = 25\) ft (perpendicular distance from centerline of inside lane to nearest obstruction)

**Vertical Curve Data**
- Curve length = 390 ft
- \(G_1 = 6\%\)
- \(G_2 = -3.5\%\)

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**Horizontal Curve**
Check superelevation and radius:

\[
L = \frac{\pi}{180} R\Delta 
\Rightarrow R = \frac{180L}{\pi\Delta} = \frac{180 \cdot 90}{\pi \cdot 0} = 372 \text{ ft}
\]

From this, \(R_v = R - 6 = 366\) ft

From The horizontal curve handout with a superelevation of 4%, 35 mph gives \(R_v = 371\) ft, therefore the curve is NOT adequate for 35 mph (but almost).

Check stopping sight distance (SSD):

\[
SSD = \frac{\pi R_v}{90} \left[ \cos^{-1}\left( \frac{R_v - M_s}{R_v} \right) \right]
\]

\[
SSD = \frac{\pi \cdot 372 - 6}{90} \left[ \cos^{-1}\left( \frac{372 - 6 - 25}{372 - 6} \right) \right] = 272 \text{ ft}
\]

From Table 3.1, 35 mph required SSD = 250 ft, therefore the curve is adequate for 35 mph.

**Vertical Curve**

\[
K = \frac{L}{A} = \frac{390}{6 - (3.5)} = \frac{390}{9.5} = 41
\]

From Table 3.2, \(K = 29\) is required for 35 mph. 41 > 29, therefore the curve is adequate for 35 mph.

**Overall, the curve is NOT adequate for 35 mph.**
A new pavement must be built for the I-5 off-ramp to the Metro bus facility just south of N 175 St. in Shoreline. Assume all buses at the facility are 60 ft Flyer hybrid diesel-electric buses. They are always empty (one driver only) when they drive across the off-ramp and enter the facility. Metro logs show an average of 400 buses per day use the off-ramp with no expected growth rate. The off-ramp pavement is to be doweled rigid (portland cement concrete – PCC) pavement using a hot mix asphalt (HMA) base and 85% reliability.

Report the following:
- The number of ESALs for a single bus
- Total number of ESALs over 50 years

<table>
<thead>
<tr>
<th>Condition</th>
<th>Weight when bus is empty</th>
</tr>
</thead>
<tbody>
<tr>
<td>Front axle</td>
<td>13,300 lb</td>
</tr>
<tr>
<td>Middle axle</td>
<td>18,200 lb</td>
</tr>
<tr>
<td>Rear axle</td>
<td>12,200 lb</td>
</tr>
</tbody>
</table>

First, calculate the number of ESALs per bus:

\[
\left(\frac{13,300}{18,000}\right)^4 + \left(\frac{18,200}{18,000}\right)^4 + \left(\frac{12,200}{18,000}\right)^4 = 0.298 + 1.045 + 0.211 = 1.554 \text{ ESALs per bus}
\]

Now find the total number of ESALs in 50 years (assuming no growth rate):

\[
Total = 1.554 \frac{ESALs}{bus} \times 400 \frac{busses}{day} \times 365 \frac{days}{year} \times 50 \text{ years} = 11.34 \text{ million ESALs}
\]
The road up Mt. Baker is being redesigned to accommodate a 35 mph design speed. Part of this road has an existing curve with a 280 ft radius and zero superelevation. Answer the following 2 questions about the redesign of this curve:

1. If the existing curve radius is kept unchanged, what superelevation is required for the curve to accommodate a 35 mph design speed (use $f_s = 0.23$).
2. How far back from the edge of the road must the rock outcropping be to allow adequate sight distance for a 35 mph design speed?

**Plan View of Road**

**Part 1**
Use the equation for $R_v$ and solve for $e$. First, notice that with two lanes, each 12 ft wide, $R_v$ is 6 ft less than $R$ ⇒ $R_v = 274$ ft.

\[
R_v = \frac{V^2}{g \left( \frac{f_s}{v^2} + e \right)} \quad \Rightarrow \quad e = \frac{V^2}{gR_v} - f_s = \frac{47 \times 1.47^3}{2.2 \times 274} - 0.23 = 0.07 \text{ or } 7%
\]

**Part 2**
You need to first determine the 35 mph design stopping sight distance (SSD). Then use this in equation 3.42 from the textbook to determine $M_s$.

SSD for 35 mph from Table 3.1 in the book = 250 ft. (calculated value of 246.2 is okay too)

\[
M_s = R_v \left( 1 - \cos \left( \frac{90 \times SSD}{\pi R_v} \right) \right) = 274 \left( 1 - \cos \left( \frac{90 \times 250}{\pi \times 274} \right) \right) = 28.02 \text{ ft}
\]

But, $M_s$ is actually the distance from the sight obstruction to the center of the inside lane. So, you need to subtract 6 ft (half the inside lane width) to get the distance from the edge of the road to the obstruction.

Distance = 28.02 ft – 6 ft = 22.02 ft.
Refer to the intersection diagram below and determine the Level of Service for the westbound approach of this pre-timed signal. You will need to determine the signal timing, including the cycle time and effective green time for the approach.

Assume the following:
- Saturation flow rate per lane = 1800 veh/h
- Start-up lost time/phase: 2 sec
- Clearance lost time/phase = 2 sec

\[ \mu = 1800 \]

\[ NB_{thru} = 575, \ EB_{all} = 340, \ WB_{all} = 425, \ NB_{rt} = 25 \]

\[ LT_{NS} = 2 + 2 = 4 \]
\[ LT_{EW} = 2 + 2 = 4 \]
\[ LT_{tot} = LT_{NS} + LT_{EW} + LT_{EW} = 12 \]
\[
\nu S_1 = \frac{600}{\mu} = 0.3333 \quad \nu S_2 = \frac{340}{\mu} = 0.1889 \quad \nu S_3 = \frac{425}{\mu} = 0.2361
\]
\[
\nu S_{\text{sum}} = 0.2361 + 0.1889 + 0.2361 = 0.7583
\]

\[X_e = 0.95\]

\[
C_{\text{min}} = \frac{LT_{\text{tot}} X_e}{X_e - \nu S_{\text{sum}}} = \frac{12 \times 0.95}{0.95 - 0.7583} = 59.5 \text{ so } C_{\text{min}} = 60
\]

\[X_e = \frac{\nu S_{\text{sum}} C_{\text{min}}}{C_{\text{min}} - LT_{\text{tot}}} = 0.948\]

\[g_3 = \nu S_3 \left(\frac{C_{\text{min}}}{X_e}\right) = 14.9\]

\[c = 1800 \left(\frac{g_3}{C}\right) = 447\]

\[X = \frac{425}{447} = 0.95\]

\[d_1 = \frac{0.5 \times C \times (1 - \frac{g_3}{C})^2}{1 - \left(X \times \frac{g_3}{C}\right)} = 22.19\]

\[T = 0.25, \ \kappa = 0.5, \ I = 1.0\]

\[d_2 = 900T \left[ (X - 1) + \sqrt{(X - 1)^2 + \frac{8kIX}{cT}} \right] = 31.89\]

\[d_3 = 0\]

\[PF = 1\]

\[d = d_1PF + d_2 + d_3 = 54.07 \text{ which is LOSD (Table 7.4)}\]