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?

AASHTO recommended deceleration rate = 11.2 ft/sec^2

$$d = \frac{V_1^2 - V_2^2}{2a} = \frac{(60 \times 1.47)^2 - (30 \times 1.47)^2}{2(11.2)} = 260.5 \ \ ft$$

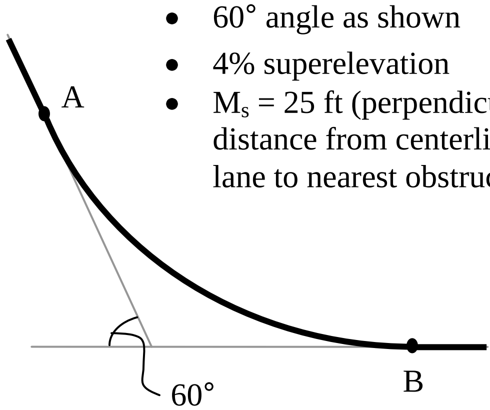
Problems

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.

<u>Horizontal Curve Data</u>

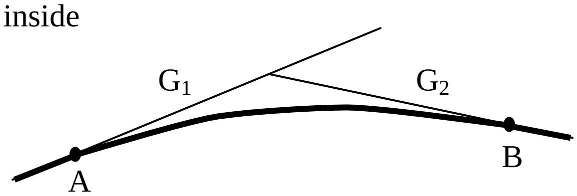
- Curve length = 390 ft
- 60° angle as shown
- 4% superelevation
- M_s = 25 ft (perpendicular distance from centerline of inside lane to nearest obstruction)



Plan View

<u>Vertical Curve Data</u>

- Curve length = 390 ft
- G_1 = 6%
- G_2 = -3.5%



Profile View

<u>Horizontal Curve</u>
Check superelevation and radius:

$$L = \frac{\pi}{180} R\Delta \quad \Rightarrow \quad R = \frac{180L}{\pi\Delta} = \frac{180(390)}{\pi(60)} = 372 \ \ ft$$

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):

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

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

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

<u>Vertical Curve</u>

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

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

Condition	Weight when bus is empty
Front axle	13,300 lb
Middle axle	18,200 lb
Rear axle	12,200 lb

photo by Ned Ahrens (from Metro website)

First, calculate the number of ESALs per bus:

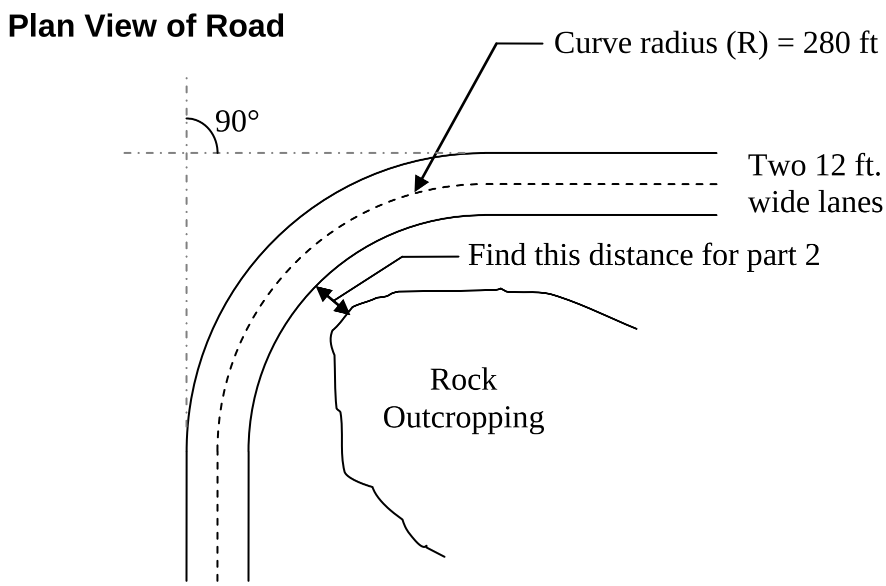
$$\left(\frac{13{,}300}{18{,}000}\right)^4 + \left(\frac{18{,}200}{18{,}000}\right)^4 + \left(\frac{12{,}200}{18{,}000}\right)^4 = 0.298 + 1.045 + 0.211 = 1.554 \ \ ESALs\ per\ bus$$

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

$$Total = 1.554\frac{ESALs}{bus} \times 400\frac{busses}{day} \times 365\frac{days}{year} \times 50 \ \ years = 11.34 \ \ million\ ESALs$$

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?



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 $\Rightarrow R_v = 274$ ft.

$$R_v = \frac{V^2}{g(f_s + e)} \quad \Rightarrow \quad e = \frac{V^2}{gR_v} - f_s = \frac{(35 \times 1.47)^2}{(32.2)(274)} - 0.23 = 0.07 \;\; or\; 7\%$$

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.

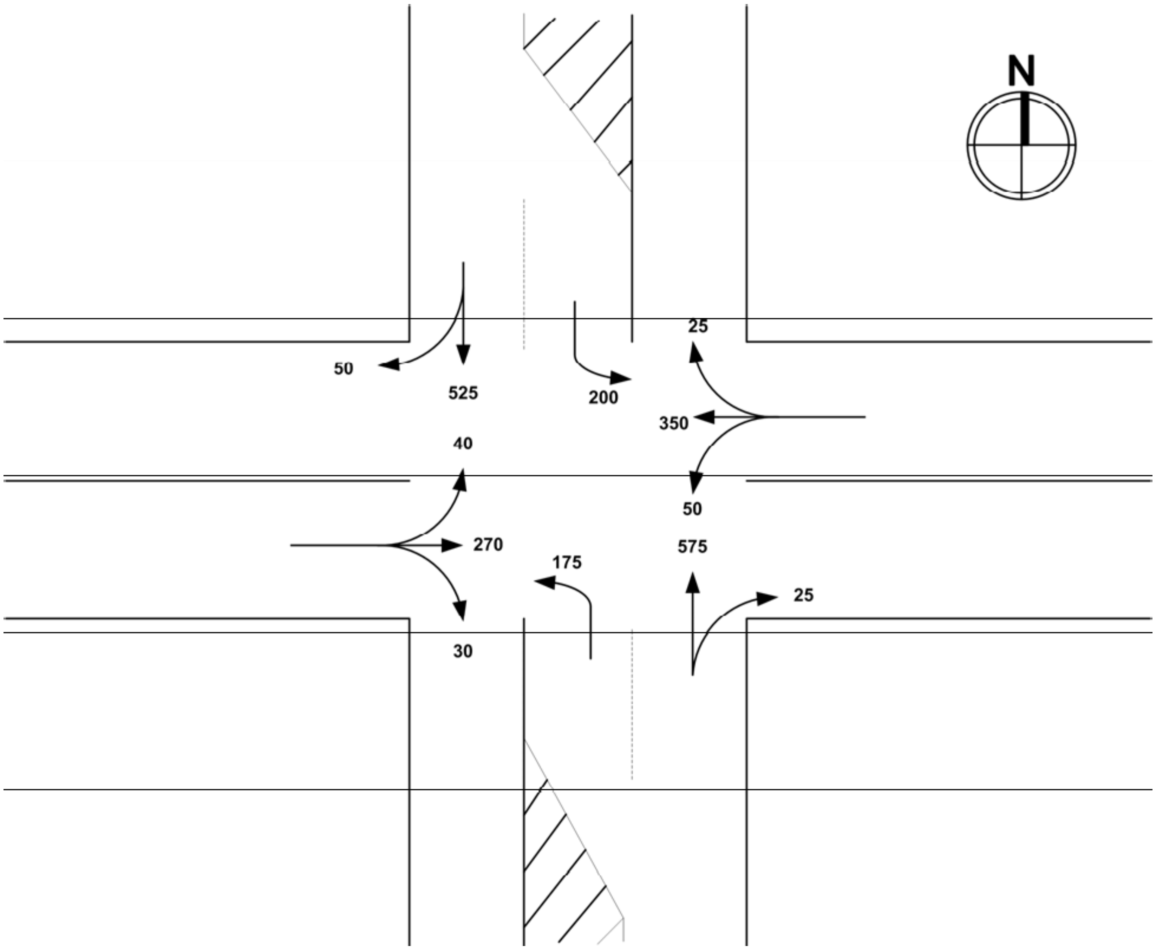
SSD for 35 mph from Table 3.1 in the book = 250 ft. (calculated value of 246.2 is okay too)

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

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

μ=1800

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

$LT_{NS}=2+2=4$
$LT_{EW}=2+2=4$
$LT_{tot}=LT_{NS}+LT_{EW}+LT_{EW}=12$

$$vs_1 = \frac{600}{\mu} = 0.3333 \; vs_2 = \frac{340}{\mu} = 0.1889 \; vs_3 = \frac{425}{\mu} = 0.2361$$

$$vs_{sum} = 0.2361 + 0.1889 + 0.2361 = 0.7583$$

X_c=0.95

$$C_{\min} = \frac{LT_{tot} X_c}{X_c - vs_{sum}} = \frac{12 \times 0.95}{0.95 - 0.7583} = 59.5$$ so C_{min}=60

$$X_c = \frac{vs_{sum} C_{\min}}{C_{\min} - LT_{tot}}$$ =0.948

$$g_3 = vs_3 \left(\frac{C_{\min}}{X_c} \right)$$ =14.9

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

$$X = \frac{425}{447} = 0.95$$

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

T=.25, k=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

$d = d_1 PF + d_2 + d_3$=54.07 which is LOSD (Table 7.4)