CEE 320 Example Problems

Short Answers

Based on the short reading, *Environmental Justice & Transportation: A Citizen's Handbook*, to what does the term "environmental justice" refer?

It refers to the equality or equitable distribution of benefits and costs from a transportation or other engineering project. When undertaking a project one must consider its effects (intended or not) on all citizen groups and demographics to ensure than it does not unjustly benefit or burden any specific group or groups.

Anything that gets at the "fairness" or "equitable distribution of benefits" concept gets full credit

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.

Anything to this effect gets full credit.

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 (2 points)

$$d = \frac{V_1^2 - V_2^2}{2a} = \frac{(60 \times 1.47)^2 - (30 \times 1.47)^2}{2(11.2)} = 260.5 \quad ft$$ (3 points)

Problem 2

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
- The design PCC slab thickness for a 50-year pavement life using the WSDOT table provided at the end of this exam.

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):

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

Now, determine the pavement design using the WSDOT table. Enter in the “doweled joints, HMA base material” section, choose “< 25 million ESALs” and read across to the “Reliability = 85%” column. You should get 0.79 ft (9.5 inches).

Problem 3

Shirley Muldowney, a five-time world champion top fuel dragster, set a personal best speed of 327.66 mph in 2003 in Chicago. Information about this run:

- Dragster weight = 2150 lbs (with driver)
- Coefficient of drag = 0.12
- Frontal area = 12 ft^2
- Air density = 0.0020 $slugs/ft^3$
- Grade = 0% (flat)

At the very end of this quarter-mile run, assume Shirley is at top speed (327.66 mph) in her dragster and at constant velocity (no acceleration). What engine generated tractive effort is required to maintain this top speed?

This problem is really asking you to solve the F = ma equation for the unknown “F”.

The basic equation is:

$F_e = \gamma_m ma + R_a + R_{rl} + R_g$ ← since the ground is flat, R_g = 0 and you are given a = 0.

Therefore, the equation simplifies to:

$F_e = R_a + R_{rl}$ ← In other words, the question is asking, "what is the force needed to just match the aerodynamic and rolling resistances?"

Aerodynamic resistance

$$R_a = \frac{\rho}{2} C_D A_f V^2 = \frac{0.0020}{2}(0.12)(12)(327.66 \times 1.47)^2 = 334.1 \ lb$$

Rolling resistance

$$f_{rl} = 0.01\left(1 + \frac{V}{147}\right) = 0.01\left(1 + \frac{327.66 \times 1.47}{147}\right) = 0.0428$$

$$R_{rl} = f_{rl} W = 0.0428(2{,}150) = 91.9 \ lb$$

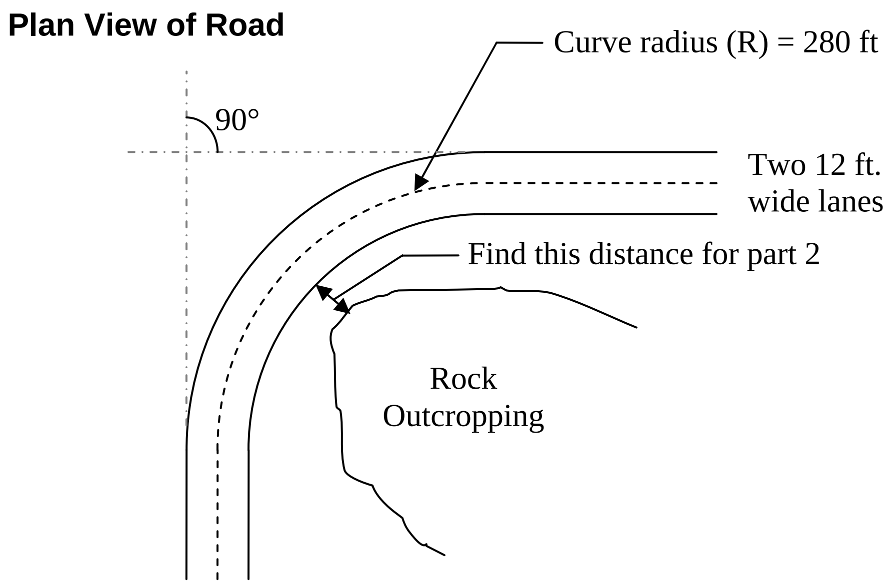
Now, solve for F_e:

$$F_e = R_a + R_{rl} = 334.1 + 91.9 = 426.0 \ lb$$

Problem 4

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?



<u>Part 1</u>

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.

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

<u>Part 2</u>

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)

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

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

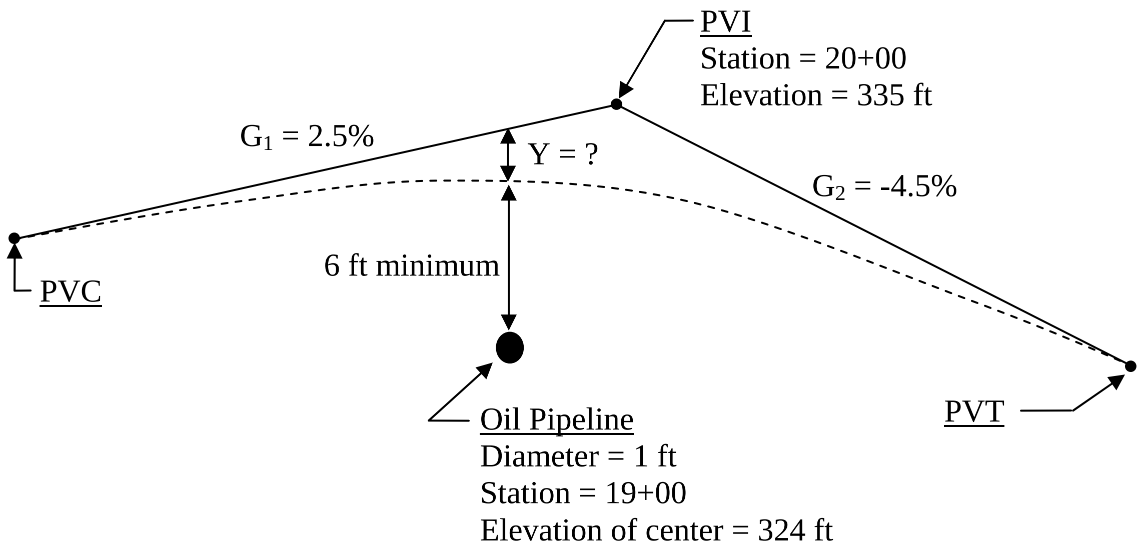
Distance = 28.02 ft – 6 ft = 22.02 ft.

Problem 5

You are designing the vertical alignment of an east-west portion of SR 528 through Marysville. An equal tangent crest vertical curve must go over an existing north-south Olympic oil pipeline. According to safety regulations, the top of the pipeline must be at least 6 ft below the centerline roadway surface. Known grades, stationing and elevations are given in the drawing below. Design the curve for the highest possible design speed without violating the pipeline's 6 ft cover requirement.

Report the longest possible curve length, and the associated design speed rounded down to the nearest 5 mph (be careful with units in your calculations!).

Profile View



There are two principal ways you can solve this problem. Either one is fine, although the first way is shorter and perhaps less prone to math errors.

Method 1: Determine L using vertical curve offsets

$A = |G_1 - G_2| = |2.5 - -4.5| = 7$

At station 19+00, the elevation of the roadway must be at least:

Elevation of pipeline (324 ft) + half the diameter of the pipe (0.5 ft) + 6 ft = 330.5 ft

Also realize that the PVI is at the half-way point on the vertical curve, or L/2. This makes station 19+00 = PVI station – 100 ft. OR… L/2 – 100.

Use the offset equation: $Y = \frac{A}{200L}x^2$

Note that the offset is the elevation of G_1 at station 19+00 minus the roadway elevation and that the elevation of G_1 at station 19+00 is the PVI elevation – 100(G_1):

$$Y = 335 - 100(0.025) - 330.5 = 2 \quad ft$$

$$Y = \frac{A}{200L}x^2 = 2 = \frac{7}{200L}\left(\frac{L}{2} - 100\right)^2$$

$$2 = \frac{0.035}{L}\left(0.25L^2 - 100L + 10{,}000\right) \Rightarrow 57.14L = \left(0.25L^2 - 100L + 10{,}000\right)$$

$0 = 0.25L^2 - 157.14L \_ 10{,}000$ ← solve quadratic and get L = 556.7 or 71.9 ft.

Since 71.9 ft is too short (the curve would not even extend to station 19+00 and it would also not be the LONGEST curve one could design), choose L = 556.7 ft.

Method 2: Determine L using the equation for a vertical curve
(working in stations and percent grade)
At PVC, y = c. Therefore, c = 335 (elevation of PVI) – L/2(G_1) = 335 – 1.25L
At PVC, b = G_1 = 2.5

Anywhere, $a = \dfrac{G_2 - G_1}{2L} = \dfrac{-4.5-2.5}{2L} = \dfrac{-7}{2L} = \dfrac{-3.5}{L}$

The point on the curve you know is right above the pipline: station 19+00, elevation 330.5 ft (see method 1 for a determination of the elevation). The station (19+00) is actually L/2 – 1.

Use the point and the equation for the curve to solve for L:

$$y = ax^2 + bx + c \;\Rightarrow\; 330.5 = \frac{-3.5}{L}\left(\frac{L}{2}-1\right)^2 + 2.5\left(\frac{L}{2}-1\right) + 335 - 1.25L$$

$$330.5 = \frac{-3.5}{L}\left(\frac{L^2}{4} - L + 1\right) + 1.25L - 2.5 + 335 - 1.25L$$

$$0 = \frac{-3.5}{L}\left(0.25L^2 - L + 1\right) + 2$$

$$0 = -3.5\left(0.25L^2 - L + 1\right) + 2L$$

$0 = -0.875L^2 + 5.5L - 3.5$ ← solve quadratic and get L = 5.567 or 0.719 stations

Since 0.719 stations is too short (the curve would not even extend to station 19+00 and it would also not be the LONGEST curve one could design), choose L = 5.567 stations or 556.7 ft.

Determine the design speed

Using the K-value and Table 3.2 in the textbook:

$$K = \frac{L}{A} = \frac{556.7}{7} = 79.5$$

From Table 3.2, the minimum K-value for a 45 mph design speed is 61, while the minimum K-value for a 50 mph design speed is 84. Since we have a K-value of 79.5 to work with, this is greater than 61, but less than 84. Therefore, the maximum design speed is 45 mph.

You could also just begin choosing random design speeds from Table 3.2 and then calculate the elevation of the resulting curve at station 19+00. Once you find the speed where the elevation is too low, you know you have exceeded the design speed. If you did it this way, you got most credit but the curve length you found would not be the "longest possible".

WSDOT Rigid Pavement Slab Thicknesses Design Table for New or Reconstructed Pavements

(English Version)

Design Period ESALs	Slab Thickness[1] (feet)		
	Reliability = 75%	Reliability = 85%	Reliability = 95%
Undoweled Joints, Crushed Stone Base Material			
< 5 million	0.74	0.79	0.85
5 - 10 million	0.82	0.87	0.95

10 - 15 million	0.89	0.94	1.02
Undoweled Joints, HMA Base Material			
< 5 million	0.71	0.75	0.84
5 - 10 million	0.80	0.85	0.94
10 - 25 million	0.94	0.98	1.08
Doweled Joints, Crushed Stone Base Material			
< 25 million	0.85	0.90	0.98
25 - 50 million	0.95	1.00	1.02
> 50 million	1.02	1.07	1.16
Doweled Joints, HMA Base Material			
< 25 million	0.75	0.79	0.87
25 - 50 million	0.84	0.90	0.97
> 50 million	0.90	0.95	1.03

1. Based on the 1993 AASHTO *Guide for Design of Pavement Structures* for rigid pavements with the following inputs:

ΔPSI = 1.5	E_c = 26,700 MPa (4,000,000 psi)	Modulus of subgrade reaction (k):
S_0 = 0.40	S'_c = 4,480 kPa (650 psi)	k = 54 MPa/m (200 pci) for stone base
C_d = 1.0	J = 3.4 for undoweled pavement	k = 108 MPa/m (400 pci) for HMA base
	J = 2.7 for doweled pavement	assumes unyielding subgrade conditions

To solve a quadratic equation (in case you forgot)

Where: $ax^2 + bx + c = 0$ The solution is: $x = \dfrac{-b \pm \sqrt{b^2 - 4ac}}{2a}$