# CEE 320 Midterm Examination (50 minutes)

- Please write your name on this cover.
- Please write you last name on all other exam pages
- This examination is open-book, open-note.
- There are 5 questions worth a total of 100 points.
- Each question lists the point value for that question.
- Please work quietly and respect other people's space.
- Carefully read each question and ensure that you answer what is asked.
- If you need additional workspace, use the back of the page or the blank page included at the end of the examination.
- If you need to unstaple pages, I have a stapler to restaple them at the end of the examination.

## ANSWER KEY

Name (first, last): _____

## Question 1: Short Answers (3 points each)

Regarding a vehicle's braking system, to what does the term "brake force ratio (BFR)" refer?

BRF is the ratio of the distribution of braking forces by the vehicle's braking system between front and rear brakes to achieve maximum braking force.

It is expressed as: $\frac{front\ brake\ \ force}{rear\ brake\ \ force}$

You need to know what it is and how it's typically expressed for full credit.

Answer one of the following questions:

Based on the short reading, *Reconsidering the Gas Tax: Paying for What You Get*, is the author in favor of or opposed to the gas tax?

In favor of the gas tax. He generally argues that it is a somewhat equitable user tax.

Based on the short reading, *The Road To Hell is Unpaved*, what example does the author use to describe how bad roads hurt the poor?

The author uses the price of a bottle of Coca-Cola at various locations as you move away from big cities.

Based on the short reading, *Environmental Justice and Transportation: A Citizen's Handbook*, provide a definition for Environmental Justice.

Environmental justice is about fairless toward the disadvantaged and often addresses the exclusion of racial and ethnic minorities from decision making.

Based on the short reading, *Must a Bridge Be Beautiful Too?*, was the Golden Gate Bridge designed to be a work of art, or was it primarily designed for function and economy?.

The Golden Gate Bridge was designed primarily for function and economy, not aesthetics, although it is now lauded as one of the world's signature spans.

c) Is the following statement **true** or false?
The primary source of rolling resistance for a typical vehicle driving on paved roadway is the deformation of the tire as it passes over the roadway surface.

d) Is the following statement **true** or false?
Sag vertical curve design differs from crest vertical curve design in the sense that sight distance on a sag vertical curve is governed by nighttime conditions.

e)Which of the following factors does NOT affect a vehicle's coefficient of side friction?

(1) vehicle speed
(2) pavement texture
(3) tire condition
**(4) vehicle weight**

## Question 2 (10 points)

A garbage truck has axle weights shown in the table below. Using the 4th power thumbrule, estimate how much more damage a full garbage truck does to the pavement than an empty one. Express this quantity as a multiple of the empty truck damage. For instance, "the full truck causes XX times more damage than the empty one".

| Condition | Front Axle Weight | Rear Axle Weight |
|---|---|---|
| Empty (no garbage) | 6,000 lb | 10,000 lb |
| Full of garbage | 8,000 lb | 23,000 lb |

Picture from Heil Environmental Industries, Ltd. (www.heilco.com)

Empty

$$\left(\frac{6{,}000}{18{,}000}\right)^4 + \left(\frac{10{,}000}{18{,}000}\right)^4 = 0.0625 + 0.09526 = 0.107606 \ \ ESALs$$

Full

$$\left(\frac{8{,}000}{18{,}000}\right)^4 + \left(\frac{23{,}000}{18{,}000}\right)^4 = 0.039018 + 2.665762 = 2.70478 \ \ ESALs$$

Multiple

$$\frac{2.70478}{0.107606} = 25.13607$$

The full truck causes 25.13 times more damage than the empty truck

Question 3 (15 points)

A truck is climbing up a 6% grade towards Manastash Summit on Interstate 82 just outside of Ellensburg. It is just able to maintain a **constant speed** of 55 mph as it ascends the 6% grade. Given the following, what is the engine generated tractive effort?

- Truck weight = 105,500 lbs
- Coefficient of drag = 1.00
- Frontal area = 70 $ft^2$
- Air density = 0.0020 slugs/$ft^3$
- Interstate 82 grade = 6%

Remember, at a constant velocity, acceleration = 0.

This problem essentially asks you to calculate the three basic resistances (aerodynamic, rolling and grade) and then, knowing acceleration = 0, add them up to find the force. If you look at Figure 2.6 in your text you will see that the engine generated tractive effort is the controlling force once you get out of the first couple of gears.

Aerodynamic resistance

$$R_a = \frac{\rho}{2} C_D A_f V^2 = \frac{0.0020}{2}(1.00)(70)(55 \times 1.47)^2 = 457.5706 \ lb$$

Rolling resistance

$$f_{rl} = 0.01\left(1 + \frac{V}{147}\right) = 0.01\left(1 + \frac{55 \times 1.47}{147}\right) = 0.0155$$

$$R_{rl} = f_{rl} W = 0.0155(105{,}500) = 1{,}635.25 \ lb$$

Grade resistance

$$R_g = WG = 105{,}500(0.06) = 6{,}330.0 \ lb$$

Find the engine generated tractive effort

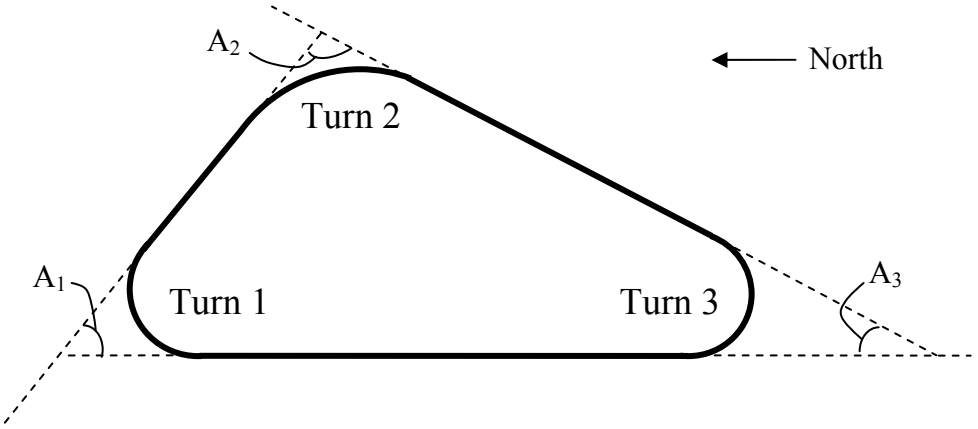
$F_e - \sum R = \gamma_m ma$ However, a = 0 since velocity is constant. Therefore,

$$F_e = \sum R = 457.5706 + 1{,}635.25 + 6{,}330.0 = 8{,}422.820575 \ lb$$

## Question 4 (15 points)

The Pocono Raceway in Pennsylvania consists of three turns as diagramed below. Turn data are given in the table below. Using standard design assumptions, what is the design speed (**to the nearest mph**) for the Pocono Raceway based on <u>horizontal curve</u> geometry only (you must perform calculations for all 3 curves to get full credit). Note that this is

the design speed for a typical automobile and not for a race car. Assume $R_v = R$ and the coefficient of side friction = 0.155 in all cases and for all speeds.




| Turn Number | Curve Length | Superelevation | Angle[2] |
|---|---|---|---|
| 1 | 800 ft | 10.5% | $A_1$ = 60 degrees |
| 2 | 750 ft | 14.1 % | $A_2$ = 90 degrees |
| 3 | 675 ft | 24.9 % | $A_3$ = 30 degrees |

Note 2: Angles measured are as indicated in the picture and are NOT Δ (delta).

You need to first calculate the radius for each turn and then use the basic superelevation equation to determine the velocity. Do this for all three turns. The lowest of the three calculated velocities would be the controlling design speed and would, therefore, be the design speed of the entire race track.

Recognize that the central angle of the curve (Δ) is equal to 180 minus the angle given in the table.

Also, you need to convert the velocity you obtain from ft/second to mph, which involved dividing by 1.47.

Turn 1

Find curve radius

$$L = \frac{\pi}{180} R\Delta \quad \Rightarrow \quad R = \frac{180L}{\pi\Delta} = \frac{180(800)}{\pi(180-60)} = 381.97 \;\; ft = R_v$$

Find design speed

$$R_V = \frac{V^2}{g(f_s + e)} \;\Rightarrow\; V = \frac{\sqrt{R_v g(f_s + e)}}{1.47} = \frac{\sqrt{(381.97)(32.2)(0.155+0.105)}}{1.47} = 38.5 \;\; mph$$

Turn 2

Find curve radius

$$L = \frac{\pi}{180} R\Delta \quad \Rightarrow \quad R = \frac{180L}{\pi\Delta} = \frac{180(750)}{\pi(180-90)} = 477.46 \;\; ft = R_v$$

Find design speed

$$R_V = \frac{V^2}{g(f_s + e)} \Rightarrow V = \frac{\sqrt{R_v g(f_s + e)}}{1.47} = \frac{\sqrt{(477.46)(32.2)(0.155 + 0.141)}}{1.47} = 45.9 \ mph$$

Turn 3
Find curve radius

$$L = \frac{\pi}{180} R\Delta \quad \Rightarrow \quad R = \frac{180L}{\pi\Delta} = \frac{180(675)}{\pi(180 - 30)} = 257.83 \ \ ft = R_v$$

Find design speed

$$R_V = \frac{V^2}{g(f_s + e)} \Rightarrow V = \frac{\sqrt{R_v g(f_s + e)}}{1.47} = \frac{\sqrt{(257.83)(32.2)(0.155 + 0.249)}}{1.47} = 39.4 \ mph$$

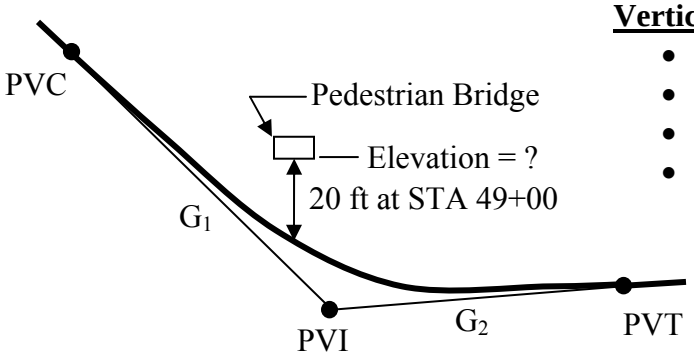
Design Speed = the lowest of the three rounded down to the nearest mph = 38 mph

If you rounded up to 39 mph, you also got full credit.

## Question 5 (30 points)

Design a 40 mph equal tangent sag vertical curve to connect the two grades as shown in the drawing. A pedestrian walk-bridge must be built over station 49+00. The bottom of the bridge must be 20 ft above the centerline surface of the roadway to allow for proper vehicle clearance under the bridge.

Report the curve length and the elevation of the pedestrian bridge bottom.




**Vertical Curve Data**

- PVI station = 50+00
- PVI elevation = 123 ft
- $G_1$ = -6.5%
- $G_2$ = 2%

Strategy
Design a standard 40 mph sag vertical curve using K values. Find the length of the curve and calculate PVC station. PVC elevation comes from knowing $G_1$, curve length and PVI elevation.

Once the curve is designed, you need to find the elevation at station 49+00. To do this you will need to express the curve as a parabola and then solve for a specific location (bridge). Then add 20 ft and you have the bridge height.

Calculations

$K_{sag}$ from Table 3.3 for 40 mph is 64.

$$L = KA = 64(|-6.5-2|) = 544 \quad ft$$

$$PVC = PVI - \frac{L}{2} = 5000 - \frac{544}{2} = STA\ 47 + 28.00$$

$$elev_{PVC} = elev_{PVI} - \frac{L}{2}(G_1) = 123 - \frac{544}{2}(-0.065) = 140.68 \quad ft$$

Now, determine the equation for the parabola.

$$y = ax^2 + bx + c$$

$$\text{At the PVC: } x = 0 \quad \text{and} \quad Y = c = 140.68 \quad ft$$

$$\text{At the PVC: } x = 0 \quad \text{and} \quad \frac{dY}{dx} = b = G_1 = -6.5$$

$$\text{Anywhere: } \frac{d^2Y}{dx^2} = 2a = \frac{G_2 - G_1}{L} \Rightarrow a = \frac{G_2 - G_1}{2L} = \frac{2 - -6.5}{2(5.44)} = 0.7813$$

Therefore,

$y = 0.7813x^2 - 6.5x + 140.68$

with x in stations and y in feet

Find the pedestrian bridge bottom elevation at STA 49+00 (this is 4900 - 4728 = 1.72 stations along the curve). First find the elevation of the roadway at this point and then add 20 ft to get the bridge elevation.

$$elev_{road} = 0.7813(1.72)^2 - 6.5(1.72) + 140.68 = 131.81 \quad ft$$

$$elev_{bridge} = elev_{road} + 20 = 131.81 + 20 = 151.81 \quad ft$$

## Question 6 (10 points)

1. A truck exits Southbound I-5 via the Dearborn Street off-ramp. Assume that the traffic light at the end of the ramp is in red when the truck is approaching at 62 mph. Please use the practical stopping distance formula to calculate:

(1) At least how many feet away must the driver start to brake in order to stop before the stop line if grade impact is ignored? [4 points]
(2) If a 6% downgrade is considered, how many feet longer is the distance than that calculated for (1)? [6 points]

Solution:

(1) Given: $V_1 = 62$ mph, $V_2 = 0$ mph, and $a = 11.2$ ft/s$^2$

$$d_1 = \frac{V_1^2 - V_2^2}{2a} = \frac{(62 \times 5280 / 3600)^2}{2 \times 11.2} = 369.15 \text{ ft}$$

The driver must start to brake at least 369.15 ft ahead of the stop line.

(2) Given $G = 6\% = 0.06$ and $g = 32.2$ ft/s$^2$

$$d_2 = \frac{V_1^2 - V_2^2}{2a - 2gG} = \frac{(62 \times 5280 / 3600)^2}{2 \times 11.2 - 2 \times 32.2 \times 0.06} = 446.10 \text{ ft}$$

$$\Delta d = d_2 - d_1 = 446.10 - 369.15 = 76.95 \text{ ft}$$

If a 6% downgrade is considered, the distance is 76.95 ft longer than the distance calculated for (1).