## 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: $\dfrac{front\ brake\ \ force}{rear\ brake\ \ force}$

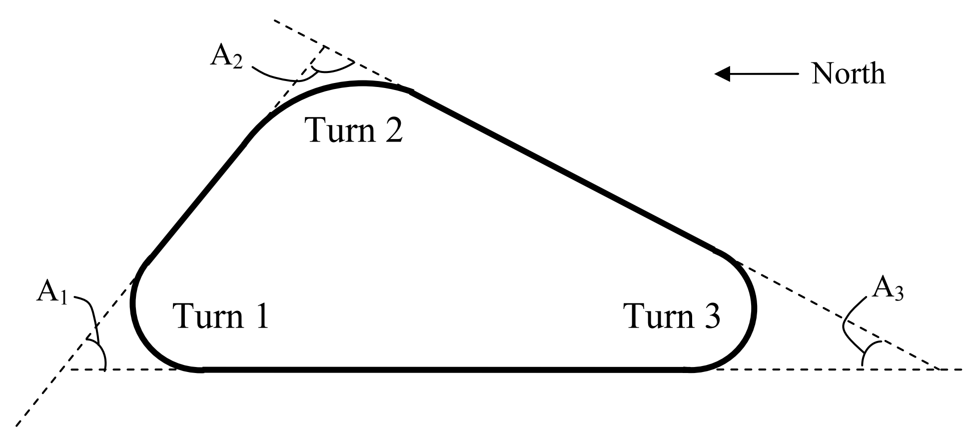
You need to know what it is and how it's typically expressed for full credit.

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 (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 horizontal curve 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.



CEE 320 Example Midterm Question Answers

| 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 <u>NOT</u> 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.

<u>Turn 1</u>

Find curve radius

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

Find design speed

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

<u>Turn 2</u>

Find curve radius

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

Find design speed

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

<u>Turn 3</u>

Find curve radius

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

Find design speed

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

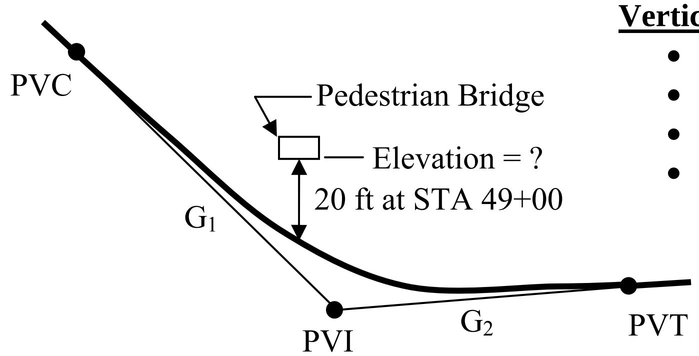
Design Speed = the lowest of the three rounded down to the nearest mph = 38 mph

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

## Question 3 (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 4 (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).