CEE 320 2nd Midterm Examination (50 minutes)

- Please write your name on this cover.
- Please write you last name on all other exam pages

- You are allowed to use one 8.5 by 11 sheet of notes..
- There are 6 questions worth a total of 200 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 to unstaple pages, I have a stapler to restaple them at the end of the examination.

Name (first, last): ____

True or False (1 point)

A straight section of road has a sag vertical curve of length 500 ft. Another flat section of road has a horizontal curve of length 500 ft. If one were to measure each curve along the centerline of the road ON THE ACTUAL ROAD SURFACE (rather than use stationing), which measurement would be longer?

vertical

In situations where the stopping sight distance (SSD) is greater than the vertical curve length, is the listed curve length in the design tables (Table 3.2 and 3.3 in your text) more than or less than the actual required vertical curve length based on actual geometry?

Circle one: More than actual curve length

Less than actual curve length

Are the following statements **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.

True

In horizontal curve design, R_v is measured to the center of the vehicle's travelled path.

True

The critical lane group has the highest traffic intensity.

True

Short Answer (5 points each)

Calculate the number of equivalent single axle loads for an empty double axle delivery truck with a front axle weight of 10,000 pounds and a rear axle weight of 5,000 pounds.

$$\left(\frac{10{,}000}{18{,}000}\right)^4 + \left(\frac{5{,}000}{18{,}000}\right)^4 = 0.101 ESALs\ per\ bus$$

At least how many feet away from an obstacle must a driver start to brake (on a level grade) in order to stop before hitting the object if the vehicle is travelling 62 mph?

How many additional feet away from the obstacle must the driver start to brake if the driver is travelling along a 6% downgrade? Assume the driver is initially travelling at 62 miles per hour.

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.

Given G = 6% = 0.06 and g = 32.2 ft/s^2

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

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

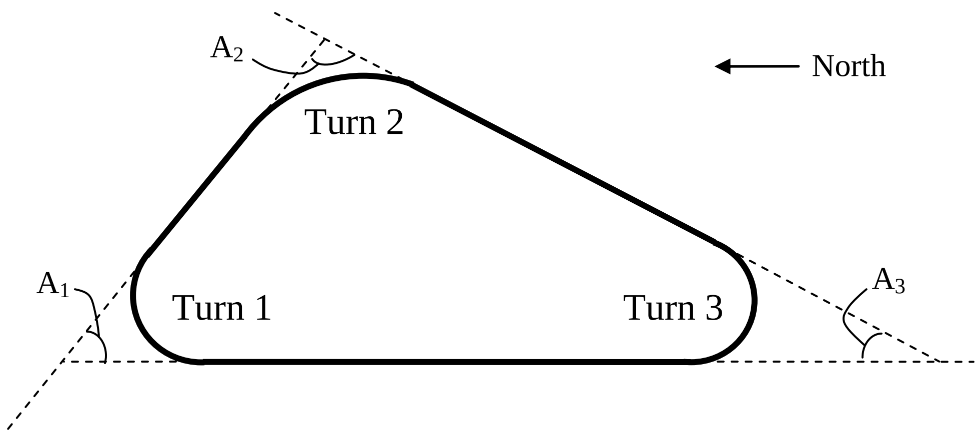
If a 6% downgrade is considered, the distance is 76.95 ft longer than the distance calculated for (1).

What is the lane group capacity if the saturation flow rate is 1800 vehicles per hour, the lane groups effective green time is 25 seconds, and the cycle length is 75 seconds?

=1800*25/75=600 veh/hour

Question 1 (25 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.



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

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

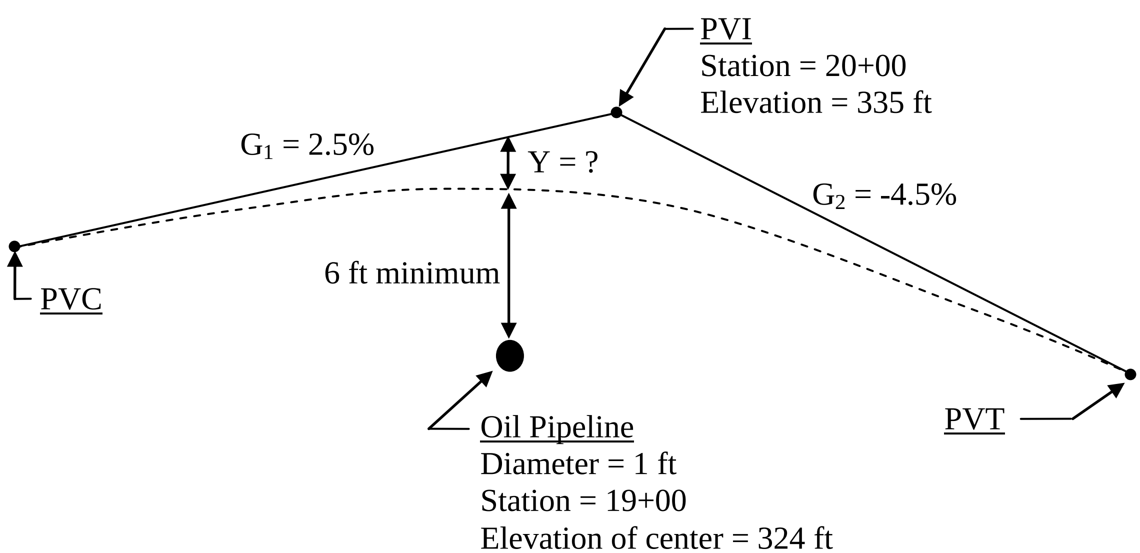
Design Speed = the lowest of the three rounded down to the nearest mph = 38 mph

Question 2 (20 points)

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.

<u>Method 2: Determine L using the equation for a vertical curve</u>
(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, $a = \frac{G_2 - G_1}{2L} = \frac{-4.5 - 2.5}{2L} = \frac{-7}{2L} = \frac{-3.5}{L}$

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.

<u>Determine the design speed (extra credit), full points were given if you got this far</u>

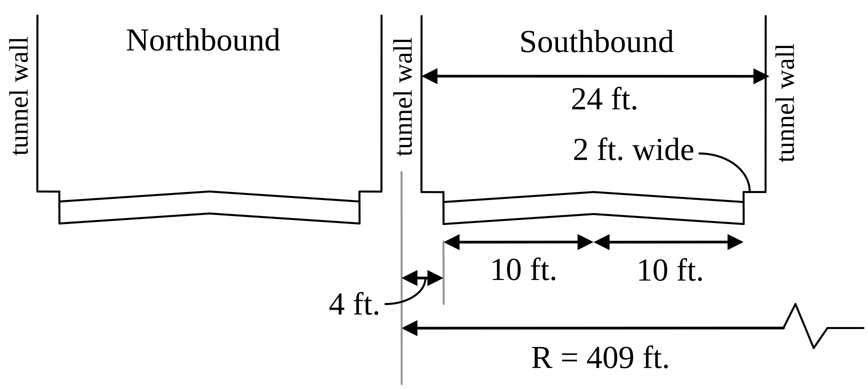
K=L/A so K=79.5

Adequate SSD for 45 mph requires K of 61, and for 50 mph requires K of 84, so maximum design speed is 45 mph.

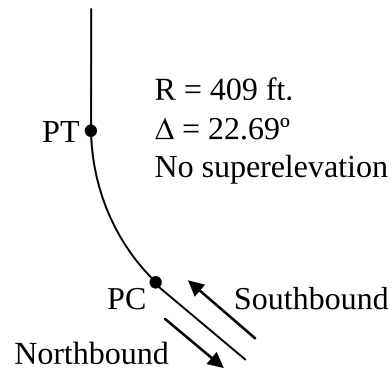
Question 3: (20 points)

At milepost 32.44, Aurora Avenue (SR 99) enters the Battery Street Tunnel in the southbound direction. There is a horizontal curve entering this tunnel with the dimensions shown below. Determine the design speed for this tunnel to the nearest 5 mph increment based on this horizontal curve (remember to round down). The southbound direction has two lanes of travel.

Cross Section View



Plan View



You need to check both the horizontal curve SSD and the superelevation.
I realize you can get the right answer even if you ignore superelevation but doing so does not represent good engineering practice. You really have to look at it.

First, check SSD
M_s = ½ inside lane + distance to wall = 5 + 2 = 7
R_v = 409 – 4 – 10 – 5 = 390 ft

$$SSD = \frac{\pi R_v}{90}\left[\cos^{-1}\left(\frac{R_v - M_s}{R_v}\right)\right] = \frac{\pi(390)}{90}\left[\cos^{-1}\left(\frac{390-7}{390}\right)\right] = 148 \ \ ft$$

For full credit, you need to check superelevation for 20 mph:

$$R_v = \frac{V^2}{g(f_s + e)} = \frac{(20 \times 1.47)^2}{32.2(0.27+0)} = 99.42 \ \ ft$$

If fs= 0.27, you only need 99.42 ft but your actual R_v is 390 ft so the curve is okay for 20 mph in terms of superelevation (or lack of superelevation). The limiting factor is SSD and the design speed is 20 mph.

$$148 = \frac{V_1^2}{2(11.2)} + V(2.5),$$
$$V = 33$$

Other values of fs were accepted if assumptions stated.

Question 4 (10 points)

A signal is being retimed so that its associated intersection will operate at 80% capacity. Assume a lost time of 4 seconds per phase. The intersection operates in 2 phases:

- Phase 1: eastbound and westbound traffic go at the same time.
- Phase 2: northbound and southbound traffic go at the same time.

The calculated saturation flow and measure flows are shown below.

Phase	Lane Group	Saturation Flow	Measured Flow
1	Eastbound	1000 veh/hr	100 veh/hr
	Westbound	1000 veh/hr	200 veh/hr
2	Northbound	1800 veh/hr	600 veh/hr
	Southbound	1600 veh/hr	600 veh/hr

Report the following:

1. The critical lane group for phase 1 and phase 2.
2. The minimum necessary cycle length (rounded up to the nearest 5 seconds).
3. The optimal cycle length using Webster's practical C_{opt} equation (rounded up to the nearest 5 seconds).

Critical Lane Groups

These are simply the lane groups in each phase with the highest v/s ratios

Critical lane groups are **westbound** and **southbound**

C_{min}

$$C_{\min} = \frac{8 \times 0.80}{0.80 - \left(\frac{200}{1000} + \frac{600}{1600}\right)} = 28 \ s$$

Or C_{min} = 30 seconds (rounded up to the nearest 5 seconds)

C_{opt}

$$C_{opt} = \frac{1.5(8) + 5}{1 - \left(\frac{200}{1000} + \frac{600}{1600}\right)} = 40 \ s$$

Or C_{opt} = 40 seconds (rounded up to the nearest 5 seconds)