National Examinations – Dec 2015

98-Civ-B7 Highway Engineering

3 Hour Duration

NOTES

1. If doubt exists as to the interpretation of any question, the candidate is urged to submit with the answer paper a clear statement of any assumptions made.

2. Any data required, but not given, can be assumed.

3. This is an **"OPEN BOOK"** examination. Any non-communicating calculator is permitted.

4. A total of **five** solutions is required. Only the first five as they appear in your answer book will be marked.

5. All questions are of equal value.

Grading Scheme:

Question 1: (20) marks

Question 2: (20) marks

Question 3: (20) marks

Question 4: (20) marks

Question 5: (20) marks

Question 6: (20) marks

Question 7: (20) marks

Question 8: (20) marks

Q1

A) A current roadway has a design speed of 100 km/hr, a coefficient of friction of 0.1, and carries drivers with perception-reaction times of 2.5 seconds. The drivers use cars that allows their eyes to be 1 meter above the road. Because of ample roadkill in the area, the road has been designed for carcasses that are 0.5 meters in height. All curves along that road have been designed accordingly.

The local government, seeing the potential of tourism in the area and the boost to the local economy, wants to increase the speed limit to 110 km/hr to attract summer drivers. Residents along the route claim that this is a horrible idea, as a particular curve called "Dead Man's Hill" would earn its name because of sight distance problems. "Dead Man's Hill" is a crest curve that is roughly 600 meters in length. It starts with a grade of +1.0% and ends with (-1.0)%. There has never been an accident on "Dead Man's Hill" as of yet, but residents truly believe one will come about in the near future.

A local politician who knows little to nothing about engineering (but thinks he does) states that the 600-meter length is a long distance and more than sufficient to handle the transition of eager big-city drivers. Still, the residents push back, saying that 600 meters is not nearly the distance required for the speed. The politician begins a lengthy campaign to "Bring Tourism to Town", saying that the residents are trying to stop "progress". As an engineer, determine if these residents are indeed making a valid point or if they are simply trying to stop progress?

1. $K = \dfrac{S^2}{200\left(\sqrt{h_1} + \sqrt{h_2}\right)^2}$ $\boxed{S < L}$

$K = \dfrac{2S}{A} - \left[\dfrac{200\left(\sqrt{h_1} + \sqrt{h_2}\right)^2}{A^2}\right]$ $\boxed{S > L}$

B) A given curve was very poorly designed. The two-lane road used has a lower-than-average coefficient of friction (0.05), no superelevation to speak of, and 4-meter lanes. 900 kg vehicles tend to go around this curve and are stylistically top heavy. County engineers have warned that this curve cannot be traversed as safely as other curves in the area, but politicians want to keep the speed up to boost tourism in the area. The curves have a radius of 500 m and a design speed of 80 km/hr. Because the vehicles using the curve are top heavy, they have a tendency to roll over if too much side force is exerted on them (the local kids often race around the curve at night to get the thrill of "two-wheeling"). As an engineer, you need to prove that this curve is infeasible before an accident occurs. How can you show this?

Q2) Superelevation Problem

Complete the superelevation design for a roadway with the following coordinate geometry information:

Point	Northing	Easting	Station/ Radius
BOP	765.978	765.978	0+000
1	1000.000	1000.000	R=509.296
2	1000.000	1500.000	R=408.105
EOP	1200.000	1700.000	

Assume the following:

Road Class:	Urban Collector Undivided 80
Number of Lanes	4 (two in each direction)
Lane Width:	3.5 m each
e_{max}	0.04 m/m (see Table 2.1.2.5)(next Page)
Normal Cross Slope	0.02 m/m

No Spiral
Roadway Rotation about centreline of pavement

Required:

a) Curve #1: station values and cross slope information for NC, RC, PC, FS, PT
b) Curve #2: station values and cross slope information for NC, RC, PC, FS, PT

Table 2.1.2.5 Superelevation and Minimum Spiral Parameters, e_{max} = 0.04 m/m

Design Speed (km/h)	40			50			60			70			80			90			100		
Radius (m)	e	A 2 lane	A 4 lane	e	A 2 lane	A 4 lane	e	A 2 lane	A 4 lane	e	A 2 lane	A 4 lane	e	A 2 lane	A 4 lane	e	A 2 lane	A 4 lane	e	A 2 lane	A 4 lane
7000	NC			NC			NC			NC			NC			NC			NC		
5000	NC			NC			NC			NC			NC			NC			NC		
4000	NC			NC			NC			NC			NC			NC			NC		
3000	NC			NC			NC			NC			NC			NC			RC	410	410
2000	NC			NC			NC			NC			RC	300	300	RC	315	315	RC	335	335
1500	NC			NC			NC			RC	240	240	RC	260	260	RC	275	275	0.022	290	290
1200	NC			NC			NC			RC	215	215	RC	230	230	0.021	245	245	0.026	250	260
1000	NC			NC			RC	180	180	RC	200	200	0.020	210	210	0.025	225	225	0.030	235	235
900	NC			NC			RC	175	175	RC	190	190	0.021	200	200	0.027	210	210	0.032	225	225
800	NC			NC			RC	165	165	RC	180	180	0.023	190	190	0.029	200	200	0.034	210	210
700	NC			RC	140	140	RC	150	150	0.020	165	165	0.026	175	175	0.032	185	185	0.036	200	200
600	NC			RC	130	130	RC	140	140	0.023	155	155	0.029	165	165	0.035	175	175	0.039	190	190
500	NC			RC	120	120	0.021	130	130	0.026	140	140	0.033	150	150	0.038	160	160	0.040	190	190
400	RC	95	95	RC	105	105	0.025	115	115	0.031	125	125	0.037	135	135	0.040	160	160	0.040	190	190
350	RC	90	90	0.020	100	100	0.027	110	110	0.033	120	120	0.039	135	135	0.040	160	160	min R = 490		
300	RC	80	80	0.023	90	90	0.031	100	100	0.036	110	110	0.040	135	135	min R = 380					
250	RC	75	75	0.026	85	85	0.034	90	90	0.038	110	110	0.040	135	135						
220	RC	70	70	0.029	80	80	0.036	90	90	0.039	110	110	min R = 280								
200	0.021	65	65	0.031	75	75	0.038	90	90	0.040	110	110									
180	0.023	65	65	0.033	70	70	0.039	90	90	0.040	110	110									
160	0.025	60	60	0.035	70	70	0.040	90	90	min R = 200											
140	0.028	55	55	0.037	70	70	0.040	90	90												
120	0.031	50	55	0.039	70	70	min R = 150														
100	0.034	50	50	0.040	70	70															
90	0.036	50	50	0.040	70	70															
80	0.038	50	50	min R = 100																	
70	0.040	50	50																		
60	0.040	50	50																		
	0.040	50	50																		
	min R = 60																				

$e_{max} = 0.04$

Notes:

- e is superelevation
- A is spiral parameter in metres
- NC is normal cross section
- RC is remove adverse crown and superelevate at normal rate
- Spiral length, L = A2 / Radius
- Spiral parameters are minimum and higher values may be used
- For 6 lane pavement: above the dashed line use 4 lane values
- below the dashed line, use 4 lane values x 1.15
- A divided road having a median less than 3 m wide may be treated as a single pavement

Q3) Vertical Curve Problem

You have been assigned a street reconstruction project. The existing profile of the street consists of a 80 m sag vertical curve consisting of a -5% grade line intersecting an 8% grade line at station 0+150 (elevation 26.50). There is an existing catchbasin located at station 0+139 with a grate elevation of 27.74. The catchbasin is not on the low point on the curve and this has created a flooding problem on the street

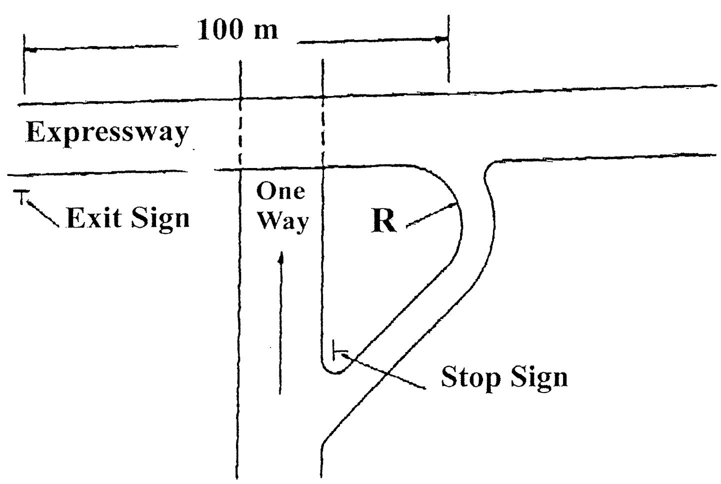
If the catchbasin cannot be moved horizontally, but can be adjusted vertically up or down, what can be done to the roadway's vertical geometry to ensure that the catchbasin is at the low point on the curve ? Assume that -5% grade line is fixed but everything else is flexible. The new vertical curve must be symmetrical.

Using your assumption, what is the new grate elevation of the adjusted catchbasin ?

Q4) An elevated freeway goes through an urban area, and crosses a local street as shown the following figure. The ramp is on a 2% grade and all vehicles leaving the freeway should stop at the intersection with the local street before merging. Determine the **minimum** radius and length required for the ramp for following conditions:

Maximum speed on freeway	=	100 km/hr
Distance between the sign and exit ramp	=	100 m
Coefficient of friction	=	0.2
Perception-reaction time	=	2.5 sec
Maximum superelevation	=	0.08
Highway grade	=	0%
Letter height of road sign	=	100 mm

Assume that the driver can read a road sign within his/her area vision at a distance of 15 m for each 25 mm of letter height, and the driver sees the stop sign immediately on ramp entering the ramp.

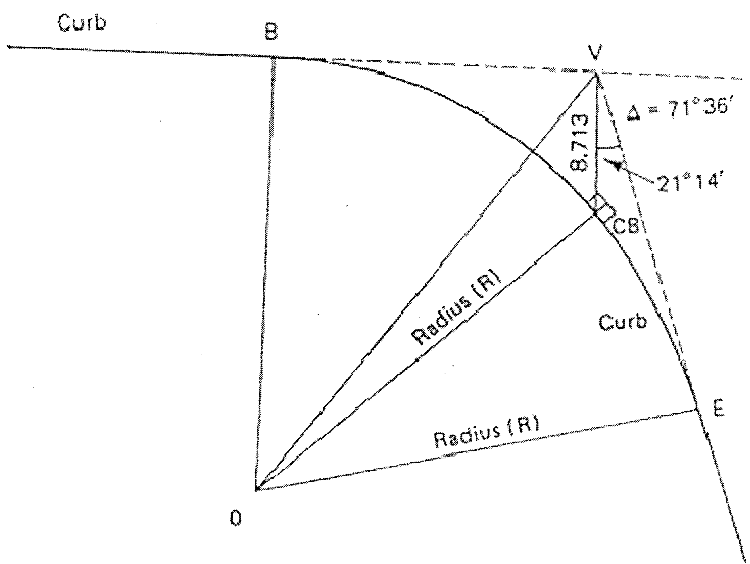


Q5) A) Given:

Tangent 1, 0+000 to 0+525, Bearing = S 33° 30′ E
Tangent 2, 0+525 to 0+770, Bearing = S 49° 00′ E
Tangent 3, 0+770 to 1+350, Bearing = S 14° 30′ W

The tangents are to be connected by simple curves, each with radius 200m. Determine the stations of the BCs and the ECs along the final route

B) Two street curb lines intersect with $\Delta = 71°36'$. A curb radius must be selected so that an existing catch basin (CB) will abut the future curb. The curb-side of the catch basin centerline is located from point V: V to CB = 8.713 m and angle E, V, CB = 21°14'. Compute the **radius** which will permit the curb to abut the existing catch basin. **(Show all your calculations)**



Q6) <u>AASHTO Design Method</u>

Six-lane rural TransCanada (interstate) highway has a truck count of 578 per day (including two axle, four tire panel and pickup trucks) and an annual growth rate of 4%. The HMA will be laid on cement treated base course, and a sand-gravel subbase. The quality of drainage is considered fair because water can be removed from the subbase within a week. However, due to large amount of precipitation, more than 25% of the time the pavement will be exposed to moisture levels approaching saturation. The materials properties are summarized below: effective roadbed soil resilient modulus = 5500 psi, resilient modulus of subbase = 15000 psi, unconfined compressive strength of cement-treated base at 7 days = 500 psi and resilient modulus of HMA = 430,000 psi. <u>Use the minimum thickness for HMA</u> (see the following Table) determine the thickness of the **base and subbase courses required.** The analysis period = 20 years. (Use R= 99%, Standard Deviation = 0.35 , and □PSI = 2.0)

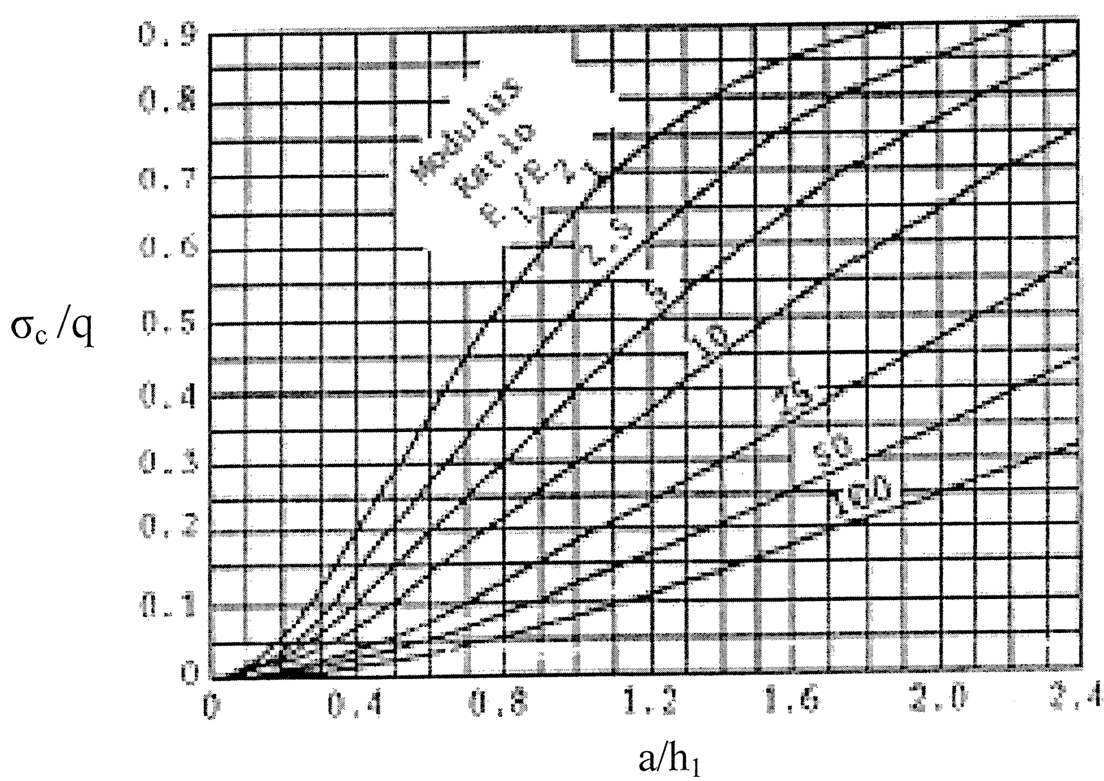
Traffic ESAL	**Min.Thickness for HMA (inches)**
less than 50,000	1
50,001- 150,000	2
150,001- 500,000	2.5
500,001- 2,000,000	3
2,000,001 - 7,000,000	3.5
Greaterthan 7,000,001	4

Q7

Your firm has been contracted to design a road that will provide occasional access (once a month) to a vehicle with a maximum single axle load of 22,600 lbs (11,300 lbs per tire) with 100 psi tire pressure (**q**). Site investigations indicate that the existing subgrade is a clayey soil that will have a modulus as low as 5000 psi during the wet part of the year. Under these conditions, laboratory tests have determined that the subgrade cannot tolerate vertical stresses greater than 15 psi without incurring high permanent deformation (rutting). You are to consider one of two possible designs:

- Crushed rock (ER = 50,000 psi) with a thin bituminous seal coat surface to make the pavement impermeable. The cost of the crushed rock is $5.00 per ton (unit weight = 120 lb/ft3) and the cost of the seal coat may be considered to be negligible for your analysis.
- Asphalt concrete (EAC = 250,000 psi) at a cost of $32.00 per ton (unit weight = 145 lb/ft3).

Determine which of these two options would be the most economical **(ton = 2000 lb)**



Q8

A) A bituminous mix design using the Marshall Mix Design Method was carried out and the following results as shown in Table 3 and 3.a were obtained. Determine the percentage air voids, percentage Voids in the Mineral Aggregate (VMA), percent bitumen absorbed and percent bitumen effective.

Table 3

Aggregate	Bulk Specific Gravity	Effective Specific Gravity	Apparent Specific Gravity	Percent by weight of aggregate blend
Coarse	2.370	2.390	2.410	55%
Sand	2.390	2.410	2.440	15%
Fines	2.390	2.410	2.440	30%
Mineral Filler	2.600	2.620	2.630	0%

Table 3a

Marshall Data	Value
Mass of Compacted Surface Dry Soaked Sample	1375.0
Mass of Compacted Sample in Water	745.0
Asphalt Content by mass of mix	3.75%
Specific Gravity of Asphalt	1.010

B) There are a number of methods for classifying and grading asphalt cements that are currently used in Canada. Currently these include viscosity-graded asphalts (e.g. AC10), penetration graded asphalts (e.g. PG 64-22). Discuss the tests required by each methodology used to arrive at a classification for an asphalt cement. Discuss the meaning of the letters and numbers that make up the classification label. Discuss the advantages and disadvantages of each in the context of building asphalt cement concrete pavements in Canada.