UNIVERSITY OF TORONTO
FACULTY OF APPLIED SCIENCE AND ENGINEERING

FINAL EXAMINATION, APRIL 2001

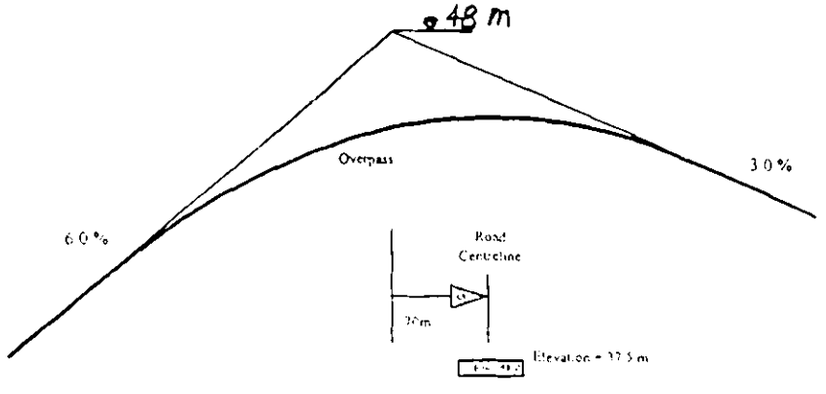
Second Year – Program: Civil Engineering
CIV231S – TRANSPORT 1: DESIGN

Exam type: D
Examiner: A. Shalaby

Problem	Marks
1	25
2	20
3	20
4	20
5	15
Total	100

1. A horizontal curve of a level four-lane two-way undivided highway is to be designed for a maximum speed of 80 km/h. Each lane is 3.5-m wide. The superelevation of 6% is attained by rotating the road section (which has an initial normal crown of 2%) around its inner edge along a spiral transition curve such that the change in centripetal acceleration should not exceed 0.3 $m/sec^2/sec$ and the slope of the outer edge should be no steeper than 1/200. The coefficient of side friction is 0.14.
   a. Determine the minimum radius for this horizontal curve.
   b. Calculate the spiral parameter and explain what it means.
   c. Draw a schematic showing how the superelevation is attained, and draw a cross section of the road at 10 and 50 m from TS.
   d. After the highway has been constructed, some construction work (involving heavy machinery that may obstruct vision) has to be done about 10 metres from the centreline of the highway, on the side of the curve centre. What do you propose to do?

2. An existing intersection is to be replaced by an E-W overpass. The PVI of the vertical curve is 70 m west of the centreline of the existing N-S road. The clearance between the vertical curve and the existing road surface should be exactly 6.3 m.
   a. Determine the minimum length of the vertical curve.
   b What should be the maximum allowable speed on the vertical curve? (assume f = 0.3)
   c. What is the horizontal distance required to effect a 1% change in slope?
   d. Determine the horizontal location and elevation of the curve's highest point.



3 A Portland Cement Concrete (PCC) slab has a modulus of elasticity of 4.2 million psi and a poisson ratio of 0.25. The pavement's radius of relative stiffness is 39.72 and the modulus of subgrade reaction is 150 pci.

a. Determine the slab thickness (use the revised Westergaard equations).
b. Calculate the stress and deflection if a tire load of 10 kilo-lb (with an associated tire pressure of 90 psi) is placed on the corner of the slab.

The pavement was designed for a 20-year life to carry traffic composed entirely of tractor semi-trailer trucks with one 16-kip single axle, one 20-kip single axle and one 35-kip tandem axle. The pavement has a concrete modulus of rupture of 800 psi, a load transfer coefficient of 3, an initial PSI of 4.5 and a terminal serviceability index of 2.5. A z-statistic of -1.645 and an overall standard deviation of 0.45 were used along with a drainage coefficient of 1. The highway has four northbound lanes and was conservatively designed.

c. How many tractor semi-trailer trucks, per day, were assumed to be travelling in the northbound direction?

4. a. Describe briefly the Rational method used for estimation of runoff quantities.
b. Define the passing sight distance and describe two of its uses.
c. What are the four main performance categories used for pavement evaluation? Describe briefly two of them.
d. What are the two methods used for rehabilitation programming? Mention the difference between them.
e. List the four phases followed to select a highway location.
f. List three functions of spiral curves.
g. What is the main difference between flexible and rigid pavements with respect to vertical load transfer?

5. A pavement stretch was monitored for several years and the Pavement Condition Rating (PCR) was determined and recorded as shown in the table below:

Age	0	1	2	3	4	5	6	7	8
PCR	100	99	99	98	98	96	95	93	89

a. Calibrate a pavement performance prediction model of the form $PCR = a + b\,(Age)^2$
b. When would this pavement be due for resurfacing, if the allowable terminal PCR value is 70?
c. What is the expected value of the PCR in 20 years, if no rehabilitation is done?

Table 4.7 Axle-Load Equivalency Factors for Rigid Pavements, Single Axles, and TSI = 2.5

Axle Load (kips)	Slab Thickness, D (inches)								
	6	7	8	9	10	11	12	13	14
2	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002
4	0.003	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002
6	0.012	0.011	0.010	0.010	0.010	0.010	0.010	0.010	0.010
8	0.039	0.035	0.033	0.032	0.032	0.032	0.032	0.032	0.032
10	0.097	0.089	0.084	0.082	0.081	0.080	0.080	0.080	0.080
12	0.203	0.189	0.181	0.176	0.175	0.174	0.174	0.174	0.173
14	0.376	0.360	0.347	0.341	0.338	0.337	0.336	0.336	0.336
16	0.634	0.623	0.610	0.604	0.601	0.599	0.599	0.599	0.598
18	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
20	1.51	1.52	1.55	1.57	1.58	1.58	1.59	1.59	1.59
22	2.21	2.20	2.28	2.34	2.38	2.40	2.41	2.41	2.41
24	3.16	3.10	3.22	3.36	3.45	3.50	3.53	3.54	3.55
26	4.41	4.26	4.42	4.67	4.85	4.95	5.01	5.04	5.05
28	6.05	5.76	5.92	6.29	6.61	6.81	6.92	6.98	7.01
30	8.16	7.67	7.79	8.28	8.79	9.14	9.35	9.46	9.52
32	10.8	10.1	10.1	10.7	11.4	12.0	12.3	12.6	12.7
34	14.1	13.0	12.9	13.6	14.6	15.4	16.0	16.4	16.5
36	18.2	16.7	16.4	17.1	18.3	19.5	20.4	21.0	21.3
38	23.1	21.1	20.6	21.3	22.7	24.3	25.6	26.4	27.0
40	29.1	26.5	25.7	26.3	27.9	29.9	31.6	32.9	33.7
42	36.2	32.9	31.7	32.2	34.0	36.3	38.7	40.4	41.6
44	44.6	40.4	38.8	39.2	41.0	43.8	46.7	49.1	50.8
46	54.5	49.3	47.1	47.3	49.2	52.3	55.9	59.0	61.4
48	66.1	59.7	56.9	56.8	58.7	62.1	66.3	70.3	73.4
50	79.4	71.7	68.2	67.8	69.6	73.3	78.1	83.0	87.1

Source: "AASHTO Guide for Design of Pavement Structures," The American Association of State Highway and Transportation Officials, Washington, DC, copyright 1993. Used by permission.

Table 4.11 Proportion of Directional W_{18} Assumed to Be in the Design Lane

Number of Directional Lanes	Proportion of Directional W_{18} in the Design Lane (PDL)
1	1.00
2	0.80–1.00
3	0.60–0.80
4	0.50–0.75

Table 4.8 Axle-Load Equivalency Factors for Rigid Pavements, Tandem Axles, and TSI = 2.5

Axle Load (kips)	Slab Thickness, D (inches)								
	6	7	8	9	10	11	12	13	14
2	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
4	0.0006	0.0006	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005
6	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002
8	0.007	0.006	0.006	0.005	0.005	0.005	0.005	0.005	0.005
10	0.015	0.014	0.013	0.013	0.012	0.012	0.012	0.012	0.012
12	0.031	0.028	0.026	0.026	0.025	0.025	0.025	0.025	0.025
14	0.057	0.052	0.049	0.048	0.047	0.047	0.047	0.047	0.047
16	0.097	0.089	0.084	0.087	0.081	0.081	0.080	0.080	0.080
18	0.155	0.143	0.136	0.133	0.132	0.131	0.131	0.131	0.131
20	0.234	0.220	0.211	0.206	0.204	0.203	0.203	0.203	0.203
22	0.340	0.325	0.313	0.308	0.305	0.304	0.303	0.303	0.303
24	0.475	0.462	0.450	0.444	0.441	0.440	0.439	0.439	0.439
26	0.644	0.637	0.627	0.622	0.620	0.619	0.618	0.618	0.618
28	0.855	0.854	0.852	0.850	0.850	0.850	0.849	0.849	0.849
30	1.11	1.12	1.13	1.14	1.14	1.14	1.14	1.14	1.14
32	1.43	1.44	1.47	1.49	1.50	1.51	1.51	1.51	1.51
34	1.82	1.82	1.87	1.92	1.95	1.96	1.97	1.97	1.97
36	2.29	2.27	2.35	2.43	2.48	2.51	2.52	2.52	2.53
38	2.85	2.80	2.91	3.03	3.12	3.16	3.18	3.20	3.20
40	3.52	3.42	3.55	3.74	3.87	3.94	3.98	4.00	4.01
42	4.32	4.16	4.30	4.55	4.74	4.86	4.91	4.95	4.96
44	5.26	5.01	5.16	5.48	5.75	5.92	6.01	6.06	6.09
46	6.36	6.01	6.14	6.53	6.90	7.14	7.28	7.36	7.40
48	7.64	7.16	7.27	7.73	8.21	8.55	8.75	8.86	8.92
50	9.11	8.50	8.55	9.07	9.68	10.14	10.42	10.58	10.66
52	10.8	10.0	10.0	10.6	11.3	11.9	12.3	12.5	12.7
54	12.8	11.8	11.7	12.3	13.2	13.9	14.5	14.6	14.9
56	15.0	13.8	13.6	14.2	15.2	16.2	16.8	17.3	17.5
58	17.5	16.0	15.7	16.3	17.5	18.6	19.5	20.1	20.4
60	20.3	18.5	18.1	18.7	20.0	21.4	22.5	23.2	23.6
63	23.5	21.4	20.8	21.4	22.8	24.4	25.7	26.7	27.3
64	27.0	24.6	23.8	24.4	25.8	27.7	29.3	30.5	31.3
66	31.0	28.1	27.1	27.6	29.2	31.3	33.2	34.7	35.7
68	35.4	32.1	30.9	31.3	32.9	35.2	37.5	39.3	40.5
70	40.3	36.5	35.0	35.3	37.0	39.5	42.1	44.3	45.9
72	45.7	41.4	39.6	39.8	41.5	44.2	47.2	49.8	51.7
74	51.7	46.7	44.6	44.7	46.4	49.3	52.7	55.7	58.0
76	58.3	52.6	50.2	50.1	51.8	54.9	58.6	62.1	64.8
78	65.5	59.1	56.3	56.1	57.7	60.9	65.0	69.0	72.3
80	73.4	66.2	62.9	62.5	64.2	67.5	71.9	76.4	80.2
82	82.0	73.9	70.2	69.6	71.2	74.7	79.4	84.4	88.8
84	91.4	82.4	78.1	77.3	78.9	82.4	87.4	93.0	98.1
86	102.0	92.0	87.0	86.0	87.0	91.0	96.0	102.0	108.0
88	113.0	102.0	96.0	95.0	96.0	100.0	105.0	112.0	119.0
90	125.0	112.0	106.0	105.0	106.0	110.0	115.0	123.0	130.0

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