National Examinations – May 2017

16-Civ-A6, Highway Design, Construction and Maintenance

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, not given but required, can be assumed.

3. This is a **"CLOSED BOOK"** examination. Candidates may use one of two calculators, the Casio or Sharp approved models.

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

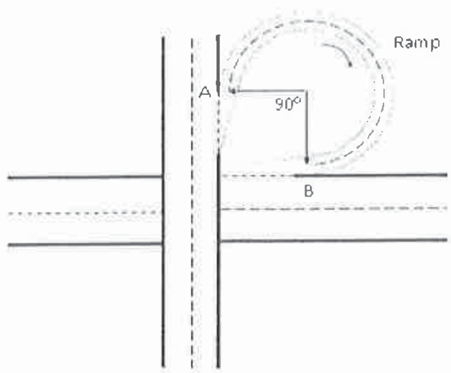
5. All questions are of equal value.

6. For non-numerical questions, clarity and organization of the answer are important.

Marking Scheme

1. (a) 8 marks; (b) 8 marks; (c) 4 marks
2. (a) 8 marks; (b) 8 marks; (c) 4 marks
3. (a) 15 marks; (b) 5 marks
4. (a) 15 marks; (b) 5 marks
5. (a) 8 marks; (b) 8 marks; (c) 4 marks
6. (a) 15 marks; (b) 5 marks
7. (a) 10 marks; (b) 10 marks

1. You are asked to design a ramp of an interchange connecting two freeways as shown in the following figure. The ramp has two lanes and each lane has a lane width of 3.6 m. The elevation difference between point A (overpass) and point B is 5 m. A simple curve is to be used with a design speed of 30 km/h and a superelevation of 0.08 on this ramp.
   a) What is the minimum radius required for this ramp (measured from the center line of the two lanes)?
   b) If the minimum radius calculated in (a) is used, what distance must be cleared from the inside edge of the ramp to provide adequate stopping sight distance?
   c) If the minimum radius calculated in (a) is used and the stationing of the Point of Tangent (PT) is 90 + 00, determine the stationing of the Point of Curve (PC).



2. You are asked to design a horizontal curve for a two-lane two-way highway with a design speed of 80 km/h. The curve is located on 2% grade (Note that the inside lane is up grade) at a Point of Intersection with a central angle of 30°. The highway has 3.6-m lanes. Local guidelines dictate a maximum superelevation of 8%. A preliminary design has suggested a radius of 240 m for this curve.
   a) Verify that the recommended radius is safe for vehicles to negotiate the curve at the design speed.
   b) Due to expensive excavation, it is determined that a maximum of 6 meters can be cleared from the roads centerline, what speed limit should be imposed at this location?
   c) If the stationing of the Point of Intersection (PI) is 100 + 00, determine the stationing of the Point of Tangent (PT).

3. A vehicle was traveling at 80 km/h on a parabolic crest vertical curve section on a rural highway. A stalled vehicle was spotted on the same curve section and the drive immediately took action to stop the vehicle. Unfortunately he struck the stalled vehicle at a speed of 5 km/h. An after-accident investigation reveals that the curve connects a +3% grade to the -3% grade, and has a length of 270 m. The design speed of this highway is 80km/h. The vehicle has an eye height of 1.08 m and the stalled vehicle has a height of 1.10 m. A series of test runs show that the coefficient of friction is 0.32.
   a) The driver later claimed that there was not enough sight distance available at this section. Would you agree with him?
   b) What could be the other factors that had contributed to the accident?

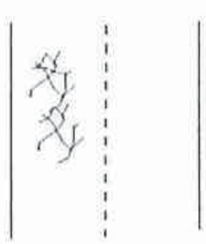
4. You are asked to design a flexible pavement structure for a new two-lane, two-way highway. The following information and design requirements are made available to you:

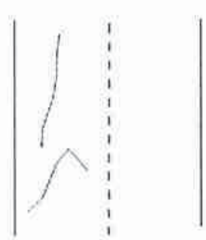
- The pavement should last for 15 years with a minimum PSI of 2.5 at a probability of 70% or higher. The initial PSI is 4.5 and overall standard deviation is 0.40.
- Several in-situ modulus tests show that the subgrade has an effective soil resilient modulus of 4000psi.
- The traffic on this highway is composed entirely of trucks with a daily volume of 120 trucks per lane for the first year. The predicted traffic growth rate is 5.0%. Each truck has one 18-kip single axle and one 30 kip tandem axle.
- The paving materials that are economically available for this highway includes hot-mix asphalt concrete, soil-cement and crushed stone.
- ASSHTO pavement design method was designated as the official design method.

The proposed pavement structure consists of a 4-in. hot-mix asphalt concrete wearing surface, a 6-in. Soil-cement base, and a 10-in. crushed stone subbase.

a) Determine whether or not the design is appropriate - neither over-designed nor under-designed. Make sure to justify your conclusion.
b) Explain how various environmental factors are considered in AASHTO pavement design method?

5. Briefly Answer the Following Questions:
   a) Engineer A was asked to design a RIGID pavement structure as an alternative to a FLEXIBLE pavement structure prepared by his fellow Engineer B. AASHTO design method were used for designing both rigid and flexible pavements. Engineer A decided to use some data from Engineer B's design, including the cumulative ESAL's. Is it acceptable for Engineer A to do so? Why or why not?
   b) During a pavement design process using AASHTO method, an engineer noticed that the LEF value of a 40-kip tandem axle load for SN=5 is higher than for SN=4. He/she then concluded that the axle load may cause a higher damage to a pavement with a higher SN than to a pavement with a lower SN. Do you think his/her inference logic is right? Why or why not?
   c) The sketches below illustrate two common types of pavement surface distresses or damages, what are the most likely causes for each of the damages?





6. A flexible pavement has been designed with a 4-in. hot-mix asphalt concrete wearing surface and a 12-in. soil cement base (no subbase). The following data have been used in the design:

- The annual daily volume in the first year is expected to be 300 trucks per lane. Each truck has two 16-kip single axles.
- The overall standard deviation is 0.40, the drainage coefficients are set as 1.0 and the subgrade resilient modulus is 5000 psi.
- Terminal PSI = 2.0 and initial PSI = 4.5.

a) If the truck volume will increase at an annual rate of 5% during the first 5 years and will then remain the same for the rest years, how long will the pavement last at the level of confidence of 90%?

b) Give three examples on how pavement quality and performance can be measured?

[You can use either Design Equation or Design Chart]

7. a). A vertical curve is designed to provide safe stopping sight distance. The PVC of the curve is at station 1+ 234.000 with elevation of 1100 m while the PVI is at station 1+ 324.000 (elevation 1100 m). The elevation at PVT is 1102.00 m. Based on the AASHTO design standard, is the curve adequate for a design speed of 100 km/h? Why or why not?

b). You are asked to locate a directional sign near the exit of a freeway ramp. How far should the directional sign be placed ahead of the exit of the freeway ramp? The following information is available for your analysis:

- The freeway has a posted speed of 120 km/h and the posted ramp speed is 30 km/h;
- Past research experiments indicated that most drivers can read a traffic sign within his or her area of vision at a distance of 50 meters when traveling at a speed of 120 km/h, and need 1 second to complete their reading and 1 second to decide and react (i.e., press brake to slow down if they want to exit);
- The highway section is on a 2% downgrade with a coefficient of road adhesion of 0.60 and a coefficient of friction of 0.28.

Equations

Geometric Design

$SSD = V_0^2/[2g(f+G)] + V_0\, t_{pr}$

$d = (V_0^2 - V_t^2)/[2g(f+G)] + V_0\, t_{pr}$

Horizontal:

$R_v = V^2/[g\,(f_s + e)]$

$T = R \tan(\Delta/2)$; $L = \pi\, \Delta R / 180$; $M = R - R\cos(\Delta/2)$; $E = R / \cos(\Delta/2) - R$

$\Delta_s = 2 \cos^{-1} (1 - M_s/R_v)$

$M_s = R_v - R_v \cos[(90\ SSD)/(\pi R_v)]$

Vertical:

$y = (G_2 - G_1)/(2L)\ x^2 + G_1 x$; $Y = A x^2 / (200L)$

$S = L/2 + 100(\sqrt{H_1} + \sqrt{H_2})^2/A$ **or** $L = 2S - 200(\sqrt{H_1} + \sqrt{H_2})^2/A$ (S≥L)

$S = \sqrt{\dfrac{200L}{A}}(\sqrt{H_1} + \sqrt{H_2})$ **or** $L = \dfrac{A\,S^2}{200(\sqrt{H_1 + H_2})^2}$ (S<L)

$S = \dfrac{A\,L + 200H}{2A - 200\tan\beta}$ **or** $L = 2S - 200(H + S\tan\beta)/A$ (S≥L)

$S = \dfrac{100L\tan\beta + \sqrt{(100L\tan\beta)^2 + 200ALH}}{A}$ **or** $L = \dfrac{A\,S^2}{200(H + S\tan\beta)}$ (S<L)

$L_m = K\,A$ where $K = SSD^2 / 658$

$L_m = K\,A$ where $K = SSD^2 / (120 + 3.5\ SSD)$

Pavement Design (Flexible)

Traffic Growth Factor (TGF) = $[(1+r)^n - 1]/r$ where r = growth rate

Design ESAL's = TGF * Present Daily ESAL * 365

$SN = a_1 D_1 + a_2 D_2 M_2 + a_3 D_3 M_3$

$$\log_{10}(W_{18}) = Z_R \times S_o + 9.36 \times \log_{10}(SN+1) - 0.20 + \frac{\log_{10}\left(\dfrac{\Delta PSI}{4.2 - 1.5}\right)}{0.40 + \dfrac{1094}{(SN+1)^{5.19}}} + 2.32 \times \log_{10}(M_R) - 8.07$$

Tables

1) Coefficient of friction and coefficient of side friction

Initial Vehicle Speed (km/h)	Coefficient of Friction (f)	Coefficient of Side Friction (f_s)
30	0.40	0.17
40	0.38	0.17
50	0.35	0.16
60	0.33	0.15
70	0.31	0.14
80	0.30	0.14
90	0.30	0.13
100	0.29	0.12
110	0.28	0.11
120	0.28	0.09

2) Z-statistics table

Table 4.5 Cumulative Percent Probabilities of Reliability, R, of the S
Corresponding Z_R

R	0	1	2	3	4	5	6
90	−1.282	−1.341	−1.405	−1.476	−1.555	−1.645	−1.751
80	−0.842	−0.878	−0.915	−0.954	−0.994	−1.036	−1.080

3) Structural layer coefficients

Pavement component	Coefficient
Wearing surface	
Sand-mix asphaltic concrete	0.35
Hot-mix asphaltic concrete	0.44
Base	
Crushed stone	0.14
Dense-graded crushed stone	0.18
Soil cement	0.20
Emulsion/aggregate-bituminous	0.30
Portland cement/aggregate	0.40
Lime-pozzolan/aggregate	0.40
Hot-mix asphaltic concrete	0.40
Subbase	
Crushed stone	0.11

4) LEF

Table 4.2 Axle-Load Equivalency Factors for Flexible Pavements, Single A

Axle load (kips)	Pavement structural numbe			
	1	2	3	
2	0.0004	0.0004	0.0003	0.
4	0.003	0.004	0.004	0.
6	0.011	0.017	0.017	0.
8	0.032	0.047	0.051	0.
10	0.078	0.102	0.118	0.
12	0.168	0.198	0.229	0.
14	0.328	0.358	0.399	0.
16	0.591	0.613	0.646	0.
18	1.00	1.00	1.00	1.
20	1.61	1.57	1.49	1.
22	2.48	2.38	2.17	2.
24	3.69	3.49	3.09	2.
26	5.33	4.99	4.31	3.
28	7.49	6.98	5.90	5.
30	10.3	9.5	7.9	6.

Table 4.4 Axle Load Equivalency Factors for Flexible Pavements, Tandem Axles, and TSI = 2.5

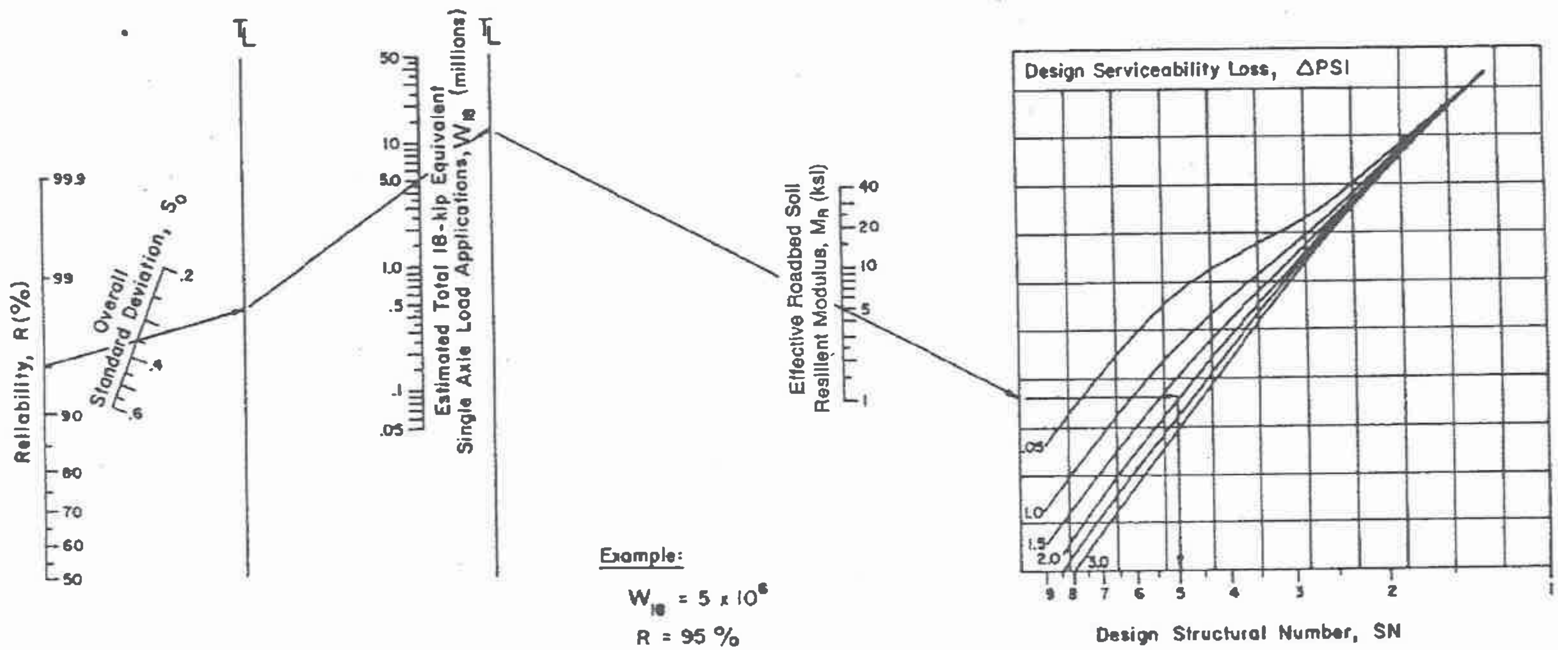
Axle load (kips)	Pavement structural number (SN)					
	1	2	3	4	5	6
2	0.0001	0.0001	0.0001	0.0000	0.0000	0.0000
4	0.0005	0.0005	0.0004	0.0003	0.0003	0.0002
6	0.002	0.002	0.002	0.001	0.001	0.001
8	0.004	0.006	0.005	0.004	0.003	0.003
10	0.008	0.013	0.011	0.009	0.007	0.006
12	0.015	0.024	0.023	0.018	0.014	0.013
14	0.026	0.041	0.042	0.033	0.027	0.024
16	0.044	0.065	0.070	0.057	0.047	0.043
18	0.070	0.097	0.109	0.092	0.077	0.070
20	0.107	0.141	0.162	0.141	0.121	0.110
22	0.160	0.198	0.229	0.207	0.180	0.166
24	0.231	0.273	0.315	0.292	0.260	0.242
26	0.327	0.370	0.420	0.401	0.364	0.342
28	0.451	0.493	0.548	0.534	0.495	0.470
30	0.611	0.648	0.703	0.695	0.658	0.633
32	0.813	0.843	0.889	0.887	0.857	0.834
34	1.06	1.08	1.11	1.11	1.09	1.08
36	1.38	1.38	1.38	1.38	1.38	1.38
38	1.75	1.73	1.69	1.68	1.70	1.73
40	2.21	2.16	2.06	2.03	2.08	2.14
42	2.76	2.67	2.49	2.43	2.51	2.61
44	3.41	3.27	2.99	2.88	3.00	3.16
46	4.18	3.98	3.58	3.40	3.55	3.79
48	5.08	4.80	4.25	3.98	4.17	4.49
50	6.12	5.76	5.03	4.64	4.86	5.28
52	7.33	6.87	5.93	5.38	5.63	6.17
54	8.72	8.14	6.95	6.22	6.47	7.15
56	10.3	9.6	8.1	7.2	7.4	8.2
58	12.1	11.3	9.4	8.2	8.4	9.4
60	14.2	13.1	10.9	9.4	9.6	10.7
62	16.5	15.3	12.6	10.7	10.8	12.1
64	19.1	17.6	14.5	12.2	12.2	13.7
66	22.1	20.3	16.6	13.8	13.7	15.4
68	25.3	23.3	18.9	15.6	15.4	17.2
70	29.0	26.6	21.5	17.6	17.2	19.2
72	33.0	30.3	24.4	19.8	19.2	21.3
74	37.5	34.4	27.6	22.2	21.3	23.6
76	42.5	38.9	31.1	24.8	23.7	26.1
78	48.0	43.9	35.0	27.8	26.2	28.8
80	54.0	49.4	39.2	30.9	29.0	31.7
82	60.6	55.4	43.9	34.4	32.0	34.8
84	67.8	61.9	49.0	38.2	35.3	38.1
86	75.7	69.1	54.5	42.3	38.8	41.7
88	84.3	76.9	60.6	46.8	42.6	45.6
90	93.7	85.4	67.1	51.7	46.8	49.7

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

Design Equation and Chart for Flexible Pavement

NOMOGRAPH SOLVES:

$$\log_{10} W_{18} = Z_R{*}S_o + 9.36{*}\log_{10}(SN+1) - 0.20 + \frac{\log_{10}\left[\frac{\Delta PSI}{4.2 - 1.5}\right]}{0.40 + \frac{1094}{(SN+1)^{5.19}}} + 2.32{*}\log_{10}M_R - 8.07$$



Example:

$W_{18} = 5 \times 10^6$

$R = 95\ \%$

$S_o = 0.35$

$M_R = 5000$ psi

$\Delta PSI = 1.9$

Solution: SN = 5.0