UNIVERSITY OF RUHUNA

Faculty of Engineering

End-Semester 5 Examination in Engineering: October 2019

Module Number: CE5302 **Module Name: Highway Engineering Design**

[Three Hours]

[Answer all questions. Each question carries **TWELVE** marks]

All Standard Notations denote their regular meanings

Q1. Ruwanpura expressway a 4-lane dual carriageway is in the planning stages of the project in the present. This highway will be expressway with high-speed traffic connecting Rathnapura with the southern expressway. Difficult terrain has been identified as the most important factor in designing the location of the highway.

a) Identify 4 technical and 4 socio-economic factors, other than the terrain, which need to be considered in designing the location of the highway.

[4.0 Marks]

b) Office study is the first step in the 4-step highway location design. Explain the processes involved in the office study giving special reference to data sources and data analysis.

[2.0 Marks]

c) Sections of the proposed highway travel through the flood plain of the River Kalu. There are two options to go through the plains; build earth embankment or build a via-duct. Compare and contrast the two options available.

[4.0 Marks]

d) Although the proposed expressway will travel through the very beautiful landscape it will not be designed as a scenic route. Explain the difference between an expressway and a scenic route.

[2. 0 Marks]

Q2. Generally, a parabolic ground profile is used for the vertical curves. When designing a vertical crest curve for the proposed expressway stated in Q1, it is needed to connect two points located L distance apart and having elevations Z_s and Z_t via midpoint Z_m by a crest curve.

a) Name two types of curves, other than parabola, that can be used to design a vertical curve and state one advantage of a parabolic curve over them.

[1.0 Mark]

b) Derive the equation for the parabolic ground profile in the following form:

$$Z = ax^2 + bx + Z_s$$

where,

$$a = \frac{2}{L^2}(Z_t - 2Z_m + Z_s)$$

and

$$b = \frac{1}{L}(-Z_t + 4Z_m - 3Z_s)$$

[2.0 Marks]

c) A certain vertical curve in the proposed expressway is designed to connect two points located 700 m away and having elevations of 521.00 m and 524.50 mvia mid-point having an elevation of 528.875 m. Based on the data provided Determine:

i. The equation for the ground profile;
ii. Type of vertical curve;
iii. Initial (G_1) and terminal (G_2) gradients of the vertical curve;
iv. Elevation of the PVI of the curve;
v. Maximum elevation achieved by the curve; and
vi. Available site distance considering $h_1 = 1.050\ m$ and $h_2 = 0.310\ m$
vii. Safety against stopping considering approach speed of 85 km/h, a driver reaction time of 2 s and a maximum deceleration of 3 m/s^2.

[7.00 Marks]

d) For the curve stated in the Q2. c), explain how elevations of other points may be determined (**Note:** *No detail calculations needed*).

[2.0 Marks]

Q3. Section of the proposed expressway stated in Q1 and Q2 is passing through a hilly terrain where it is required to blast rocks to pass through a mountain. There are a variety of rock drilling machines available according to the cutting action of the drilling machine, they can be divided into two they are percussion drilling and rotary drilling machines.

a) With the help of neat sketches briefly, explain the working mechanism of the percussion drilling machines and rotary drilling machines.

[1.0 Mark]

b) During the construction of the expressway stated in Q1 and Q2, it was required to design a bench blast with a vertical bench height of 9 m and the inclined blast holes with a slope of 1:8 (1 horizontal: 8 verticals). ANFO (density 1250 kg/m^3) is to be used as the explosive. The bench is characterized by a ground factor of 35. Further, 100 mm diameter drills are available with an operator capable of maximum starting error of 5 cm and a hole deviation of 3%, determine the following:

i. Total sloped length of the drill hole including the under drilling
ii. Practical overburden (V) and practical hole spacing (E)
iii. Lengths of stemming (h_o), bottom charge (h_b) and column charge (h_p).
iv. Densities of the bottom charge (q_{bk}) and the column charge (q_{pk})
v. Total bottom charge and column charge per hole

[4.0 Marks]

d) Marshall mix design was carried out in the laboratory. Table Q3-1 shows the volumetric calculation information of the Marshall mix design, from the information, provided determine the following;

i. The bulk specific gravity of the combined aggregates,
ii. The effective specific gravity of the combined aggregates,
iii. The asphalt absorption,
iv. Effective asphalt binder content,
v. VMA,
vi. Air voids, and
vii. VFA of the given asphalt mixture.

[7.0 Marks]

Q4. a) Part of a rural two-lane dual carriageway highway is to be designed as a flexible pavement consisting of three layers they are, 4.0 inches of hot-mix asphalt (HMA) wearing surface, 11.5 inches Dense-graded crushed stone base, and 14 inches of crushed stone sub base (See Table Q4-1). M_2 and M_3 are equal to 0.9. Determine the overall structural number of the pavement.

[2.0 Marks]

b) Traffic data collected for the highway stated in Q4.a) is shown in the Table Q4-2 and the corresponding FHWA classification table is shown in Table Q4-3. If this highway is to be designed with a structural number of 5 for a design life of 20 years with a TSI value of 2.5. Determine the 18-kip ESAL (W_{18}) for the entire lifetime **provide your answer in Table Q4-6** found on the last page of this paper. You may use the ELAF factors shown in Table Q4-4 and Table Q4-5 and assume f_D.and f_L to be equal to 1.

[6.0 Marks]

c) If the effective subgrade resilient modulus is 15,000 lb/in², the reliability is 90%, the overall standard deviation is 0.5, the initial PSI is 4.7, and the TSI is 2.5, With calculation, show that this pavement design stated in Q4.a) is an over design for the traffic load given in Q4.b).

[2.0 Marks]

d) If the current design is implemented despite the fact it's an over design, determine the reliability of the pavement.

[2.0 Marks]

Q5. A certain section of the proposed highway (stated in Q1) is to be a 4 lane (2 lanes in one direction) dual carriageway road with a flexible pavement with three layers. It is proposed to use the AASHTO method for the design. Refere Table Q5-1 when necessary.

a) The variation of the subgrade soil resilient modulus with months is shown in Table Q5-1. Calculate the effective roadbed soil resilient modulus for the year.

[3.0 Marks]

b) Estimated total 18- kip equivalent single-axis load for one direction is $\widehat{W}_{18} = 4\ (\times 10^6$ ESAL) and it is estimated that 65% of the traffic will occupy the design lane. Determine the cumulative EASL (W_{18}) considering the directional factor f_D, lane distribution factor f_L

[2.0 Marks]

c) The top layer (Layer 1) is to be designed with a Reliability of 90%, an overall standard deviation of 0.40; and a present serviceability index loss of 1.5. If the layer coefficient $a_1 = 0.40$ determine the Structural number required of layer 1 and the layer thickness

[3.0 Marks]

d) Layer 2 has a structural number of 5.5, layer coefficient of 0.38, drainage modifying factor of 0.9. Layer 3 has a structural number of 8.0, layer coefficient of 0.3, drainage modifying factor of 0.85. Determine the layer thicknesses of layers 2 and 3.

[4.0 Marks]

Annex: Equations, Figures and Tables

Table Q3-1 Volumetric Calculation Information for Marshall Mix Design

Material	Measured specifigravity	Mixture composition	
		Weight of total mixture (%)	Weight of total aggregate (%)
Coarse aggregate	2.450	58.9	62
Crushed sand	2.560	17.1	18
Natural sand	2.680	17.1	18
Mineral filler	2.889	1.9	2
Asphalt binder	0.993	5.0	
Compacted mixture, bulk	2.224		
Uncompacted mixture, measured maximum	2.349		

Table Q4-1 Structural-Layer Coefficients

Pavement component	Coefficient
Wearing surface	
Sand-mix asphaltic concrete	0.35
Hot-mix asphaltic (HMA) concrete	0.44
Base	
Crushed stone	0.14
Dense-graded crushed stone	0.18
Soil cement	0.2
Emulsion/aggregate-bituminous	0.3
Portland cement/aggregate	0.4
Lime-pozzolan/aggregate	0.4
Hot-mix asphaltic (HMA) concrete	0.4
Subbase	
Crushed stone	0.11

Table Q4-2 Traffic Count Data According to FHWA Classification

FHWA Class Group	FHWA Vehicle Classification	Axle Load ($\times 10^3 lb$)		Annual Growth Rate (%)	AADT
2	Cars	Front	2.0	6.0	400
		Rear	2.0		
3	Pickup and vans	Front	8.0	4.0	300
		Rear	15.0		
4	Busses	Front	20.0	3.0	100
		Rear	30.0		
5	2 axle single unit	Front	16.0	5.0	250
		Rear	20.0		
6	3 axle single unit	Front	15.0	5.0	300
		Rear	30.0		

Table Q4-3 FHWA Vehicle Classification Scheme

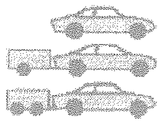
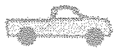
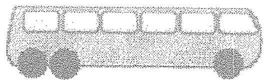
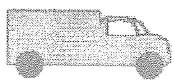
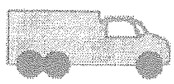
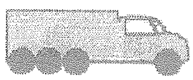
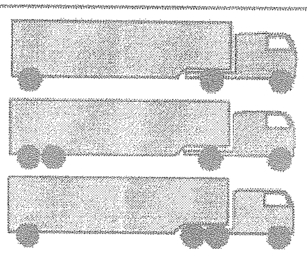
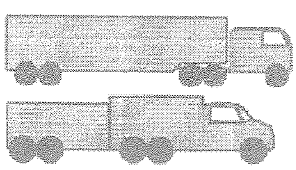
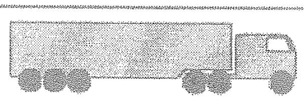
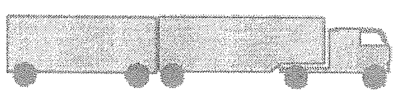
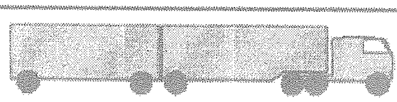
	CLASS GROUP		DESCRIPTION	NO. OF AXLES
	1		MOTORCYCLES	2
	2		ALL CARS CARS CARS W/ 1-AXLE TRAILER CARS W/ 2-AXLE TRAILER	2 3 4
	3		PICK-UPS & VANS 1 & 2 AXLE TRAILERS	2, 3, & 4
	4		BUSES	2 & 3
	5		2-AXLE, SINGLE UNIT	2
	6		3-AXLE, SINGLE UNIT	3
	7		4-AXLE, SINGLE UNIT	4
HEAVY TRUCKS	8		2-AXLE, TRACTOR, 1-AXLE TRAILER (2&1) 2-AXLE, TRACTOR, 2-AXLE TRAILER (2&2) 3-AXLE, TRACTOR, 1-AXLE TRAILER (3&1)	3 4 4
	9		3-AXLE, TRACTOR, 2-AXLE TRAILER (3&2) 3-AXLE, TRUCK W/ 2-AXLE TRAILER	5 5
	10		TRACTOR W/ SINGLE TRAILER	6 & 7
	11		5-AXLE MULTI-TRAILER	5
	12		6-AXLE MULTI-TRAILER	6
	13	ANY 7 OR MORE AXLE		7 or more
	14	NOT USED		
	15	UNKNOWN VEHICLE TYPE		

Table Q4-4Axle-Load Equivalency Factors for Rigid Pavements, Single Axles, and TSI = 2.5

Axle loads (kip)	Pavement Structural Number (SN)						
	1	2	3	4	5	6	7
2	0.0004	0.0004	0.0003	0.0002	0.0002	0.0002	0.0002
4	0.0029	0.0042	0.0035	0.0026	0.0021	0.0019	0.0018
6	0.0110	0.0174	0.0167	0.0128	0.0104	0.0094	0.0089
8	0.0319	0.0470	0.0507	0.0412	0.0343	0.0310	0.0295
10	0.0781	0.1022	0.1175	0.1023	0.0877	0.0802	0.0767
12	0.1682	0.1984	0.2288	0.2126	0.1891	0.1759	0.1695
14	0.3278	0.3583	0.3985	0.3882	0.3600	0.3420	0.3328
16	0.5908	0.6126	0.6464	0.6450	0.6229	0.6065	0.5976
18	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
20	1.6084	1.5686	1.4948	1.4739	1.5125	1.5539	1.5803
22	2.4798	2.3762	2.1749	2.0936	2.1819	2.2993	2.3811
24	3.6901	3.4915	3.0926	2.8932	3.0317	3.2661	3.4463
26	5.3276	4.9946	4.3096	3.9148	4.0896	4.4835	4.8192
28	7.4945	6.9780	5.8969	5.2081	5.3891	5.9816	6.5422
30	10.3074	9.5473	7.9355	6.8310	6.9707	7.7925	8.6565
32	13.8982	12.8220	10.5171	8.8495	8.8828	9.9526	11.2027
34	18.4149	16.9360	13.7447	11.3378	11.1813	12.5040	14.2223
36	24.0224	22.0389	17.7328	14.3787	13.9303	15.4956	17.7586
38	30.9035	28.2961	22.6086	18.0643	17.2020	18.9844	21.8589
40	39.2596	35.8900	28.5120	22.4956	21.0764	23.0355	26.5762
42	49.3111	45.0204	35.5962	27.7838	25.6419	27.7225	31.9699
44	61.2990	55.9054	44.0286	34.0497	30.9952	33.1277	38.1077
46	75.4849	68.7821	53.9912	41.4250	37.2415	39.3420	45.0656
48	92.1522	83.9070	65.6806	50.0520	44.4950	46.4651	52.9291
50	111.6065	101.5572	79.3096	60.0844	52.8788	54.6052	61.7929

Table Q4-5 Axle-Load Equivalency Factors for Rigid Pavements, Tandem Axles, and TSI = 2.5

Axle loads (kip)	Pavement Structural Number (SN)						
	1	2	3	4	5	6	7
2	0.0001	0.0001	0.0001	0.0000	0.0000	0.0000	0.0000
4	0.0005	0.0005	0.0004	0.0003	0.0003	0.0002	0.0002
6	0.0017	0.0021	0.0017	0.0012	0.0010	0.0009	0.0008
8	0.0040	0.0057	0.0048	0.0036	0.0029	0.0026	0.0024
10	0.0082	0.0127	0.0113	0.0085	0.0069	0.0062	0.0058
12	0.0152	0.0240	0.0230	0.0176	0.0143	0.0129	0.0122
14	0.0264	0.0409	0.0418	0.0329	0.0270	0.0243	0.0231
16	0.0439	0.0647	0.0698	0.0567	0.0472	0.0426	0.0406
18	0.0700	0.0971	0.1091	0.0917	0.0773	0.0703	0.0671
20	0.1075	0.1406	0.1617	0.1408	0.1206	0.1104	0.1055
22	0.1599	0.1980	0.2295	0.2067	0.1803	0.1663	0.1596
24	0.2313	0.2729	0.3147	0.2924	0.2601	0.2420	0.2331
26	0.3265	0.3695	0.4199	0.4006	0.3638	0.3418	0.3308
28	0.4509	0.4929	0.5482	0.5340	0.4952	0.4704	0.4578
30	0.6106	0.6484	0.7031	0.6953	0.6583	0.6328	0.6195
32	0.8126	0.8426	0.8892	0.8873	0.8569	0.8343	0.8220
34	1.0647	1.0824	1.1114	1.1129	1.0947	1.0800	1.0717
36	1.3755	1.3755	1.3755	1.3755	1.3755	1.3755	1.3755
38	1.7546	1.7308	1.6881	1.6789	1.7029	1.7263	1.7404
40	2.2124	2.1577	2.0562	2.0274	2.0805	2.1375	2.1737
42	2.7604	2.6665	2.4878	2.4258	2.5120	2.6146	2.6829
44	3.4111	3.2686	2.9916	2.8798	3.0013	3.1628	3.2754
46	4.1780	3.9763	3.5770	3.3955	3.5525	3.7871	3.9587
48	5.0758	4.8028	4.2540	3.9797	4.1703	4.4926	4.7405
50	6.1203	5.7623	5.0338	4.6401	4.8594	5.2843	5.6282

Table Q5-1 Roadbed Soil Modulus

Month	Roadbed Soil Modulus MR (psi)
Jan	22,000
Feb	20,000
Mar	18,000
Apr	10,500
May	9,000
June	6,000
July	6,000
Aug	9,500
Sep	9,500
Oct	15,000
Nov	18,000
Dec	21,000

Table Q5-2 Cumulative Percent Probabilities of Reliability

R	0	1	2	3	4	5	6	7	8	9	9.5	9.9
90	−1.282	−1.341	−1.405	−1.476	−1.555	−1.645	−1.751	−1.881	−2.054	−2.326	−2.576	−3.080
80	−0.842	−0.878	−0.915	−0.954	−0.994	−1.036	−1.080	−1.126	−1.175	−1.227	−1.253	−1.272
70	−0.524	−0.553	−0.583	−0.613	−0.643	−0.675	−0.706	−0.739	−0.772	−0.806	−0.824	−0.838
60	−0.253	−0.279	−0.305	−0.332	−0.358	−0.385	−0.412	−0.440	−0.468	−0.496	−0.510	−0.522
50	0	−0.025	−0.050	−0.075	−0.100	−0.125	−0.151	−0.176	−0.202	−0.228	−0.241	−0.251

Useful Equations with usual notations

$$h_p = H - (h_o + h_b)$$

$$L = 2d_s - \frac{200 \times (\sqrt{h_1} + \sqrt{h_2})^2}{|G_2 - G_1|} \quad for\ d_s > L$$

$$K = \frac{|G_2 - G_1|}{L}$$

$$GF = \frac{(1+r)^n - 1}{r}$$

$$V_{Max} = C \times d$$

$$U = 0.3 \times V_{Max}$$

$$H = (K + u) \times 1.03$$

$$F = 0.05 + 0.03 \times H$$

$$Equvalent\ Factor(EF) = \left(\frac{Axle\ Load}{8160}\right)^{4.5}$$

$$V = V_{Max} - F$$

$$E = 1.25 \times V$$

$$L = |G_2 - G_1| \times k$$

$$U_f = 1.18 \times 10^8 \times M_r^{-2.32}$$

$$L = \frac{|G_2 - G_1| d_s^2}{100 \times (\sqrt{2h_1} + \sqrt{2h_2})^2} \quad for\ d_s < L$$

$$P_{ba} = 100 \times \frac{G_{se} - G_{sb}}{G_{se} \times G_{sb}} \times G_b$$

$$P_{be} = P_b - \frac{P_{ba}}{100} P_s$$

$$P_a = \frac{G_{mm} - G_{mb}}{G_{mm}} \times 100$$

$$q_{bk} = \frac{3.14}{4} \times d^2 \times P$$

$$q_{pk} = 0.5 \times q_{bk}$$

$$Q_b = q_{bk} \times h_b$$

$$Q_p = q_{pk} \times h_p$$

$$Q_{tot} = Q_b + Q_p$$

$$q = Q_{tot} / (K \times V \times E)$$

$$D_1 \geq \frac{SN_1}{a_1}$$

$$D_2 \geq \frac{(SN_2 - SN_1^*)}{a_2 m_2}$$

$$D_3 \geq \frac{(SN_3 - SN_2^* - SN_1^*)}{a_3 m_3}$$

$$h_o = V_{Max}$$

$$h_b = 1.3 \times V_{Max}$$

$$W_{18} = f_D \times f_L \times \widehat{W}_{18}$$

$$D_n \geq (SN_n - SN_{n-1}^* \cdots - SN_1^*)/a_n m_n$$

$$G_{sb} = \frac{P_1 + P_2 + \cdots + P_n}{\frac{P_1}{G_1} + \frac{P_2}{G_2} + \cdots + \frac{P_n}{G_n}}$$

$$G_{se} = \frac{P_{mm} - P_b}{\frac{P_{mm}}{G_{mm}} - \frac{P_b}{G_b}}$$

$$VMA = 100 - \frac{G_{mb} \times P_s}{G_{sb}}$$

$$VFA = \frac{VMA - P_a}{VMA} \times 100$$

$$\log_{10}(W_{18}) = Z_R S_o + 9.36 \times [\log_{10}(SN + 1)] - 0.20 + \frac{\log_{10}[\Delta PSI/2.7]}{0.4 + [1094/(SN+1)^{5.19}]} + 2.32\log_{10}(M_R) - 8.07$$

Index Number________________________

Table Q4-6 ESAL Work Sheet

FHWA Class Group	FHWA Vehicle Classification	Axle Load ($\times 10^3 lb$)		ELAF	Truck Factor	Annual Growth Rate (%)	Growth Factor	Class AADT	Class ESAL ($\widehat{W}_{18}$)
2	Cars	Front	2.0			6.0		400	
		Rear	2.0						
3	Pickup and vans	Front	8.0			4.0		300	
		Rear	15.0						
4	Busses	Front	20.0			3.0		100	
		Rear	30.0						
5	2 axle single unit	Front	16.0			5.0		250	
		Rear	20.0						
6	3 axle single unit	Front	15.0			5.0		300	
		Rear	30.0						
								Total $\widehat{W}_{18}$	

W_{18} = ____________________

NOTE: Detach this and attach it to your answer script