UNIVERSITY OF RUHUNA

Faculty of Engineering

End-Semester 5 Examination in Engineering: July 2017

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. There is a proposal to build a railway line between Kurunegala and Dambulla. This line will be a high-speed double track link. People living in the area have shown their dislike for this project by having a continues hunger strike. Assuming that you are appointed as the project manager of the road link design and build team answer the following questions.

a) Name three steps that can be taken to deal with protesting public as a professional.

[3.0 Marks]

b) Explain the four steps involved in the route location and giving brief description on the activities involved in each of the phases.

[5.0 Marks]

c) Section of the intended route goes through a very steep ascent and followed by a decent. Explain how this section of the route can be designed.

[2.0 Marks]

d) At Dambulla, A large railway station is to be located in the urban area. Name four factors that should be considered when locating the transportation facility in an urban area.

[2.0 Marks]

Q2. When designing vertical geometry for the railway line stated in stated in Q1, AASHTO guidelines was recommended by the lead consultant. When going through AASHTO guidelines "a constant rate of change in the gradient (K given in units of %/m)" is recommended.

a) If a constant "K (%/m)" rate of change in the gradient is to be achieved, prove that that vertical curve needs to be a parabola.

[2.0 Marks]

b) At a certain location along the proposed new highway, there are two successive gradients of +0.2% and +0.6%. What is the type of (parabola) vertical curve that should be placed here. (*No detail calculations are needed*).

[1.00 Mark]

c) If a K value of 950 (m/%) was selected, calculate the length of curve stated in Q2(b).

[2.0 Marks]

d) Design engineer has selected a curve length of 600 m for the curve stated in Q2(b). If the elevation of the starting point of the vertical curve is 121.500 m AMSL and the chain-age is 30+200 m, calculate the following:

i. Elevation of point of intersection;
ii. Elevation of the midpoint of the curve;
iii. Maximum elevation achieved by the curve;
iv. Chain-age at the end of the curve; and
v. Copy the Table Q2-1 and fill it considering 50m proper stations.

[7.0 Marks]

Q3. A six-lane undivided multi-lane highway is located in the suburbs of a highly congested metropolitan area. It is observed that the total demand volume of the multilane-highway is 10,656 veh/hr and 98% of the road users are daily commuters and residents in the vicinity. Consider the vertical alignment information of a 0.375 mi segment is given in Figure Q3-1, other relevant data given bellow and Tables Q3-1 to Q3-13 to answer the following questions.

Lane width	= 10 ft	Posted speed limit	= 60 mi/hr
Lateral clearance	= 4 ft	Vehicle composition	= Trucks 13%
Peak Hour Factor	=0.9		R.V 3%
Access point density	=10 pt/mi		
Directional split	= 50/50		

a) Define what is meant by "Highway Capacity".

[1.00 Mark]

b) List 4 factors which directly influence on highway capacity of a road segment.

[2.0 Marks]

c) Determine the level of service of the 0.375 mi segment of the above road.

[5.0 Marks]

d) It is proposed to upgrade this multi-lane highway (Stated above) to a freeway in order to increase the mobility. Accordingly, it is planned to include a 2 ft wide centre median maintaining same lateral clearance in both sides. Moreover, above addition does not change the lane width and number of lanes. The vertical alignment along the 0.375 mi is going to be excavate to maintain a level terrain. If the free-flow speed of the proposed freeway is 70 mi/hr and planned to maintain LOS B, determine the range of the demand volume that could be allowed in the basic freeway segment.

[4.0 Marks]

Q4. a) i. Identify two reasons for the trend of discouraging the cutback bitumen in the world

ii. What is emulsified asphalt? State three types of emulsions available in the highway industry.

[2.0 Marks]

b) Pelmadulla - Embilipitiya highway is made of a flexible pavement. This flexible pavement is constructed with 5 inches of hot-mix asphalt (HMA) wearing surface, 9 inches of emulsion/aggregate-bituminous base, and 10 inches of crushed stone subbase.

The subgrade has a soil resilient modulus of 10,000 lb/in², and M_2 and M_3 are equal to 1.0 and 0.9 respectively for the materials in the pavement structure. The overall standard deviation is 0.5, the initial PSI is 4.5, and the TSI is 2.5.

Due to Hambantota port, there is an increased vehicular traffic in this stretch. The daily traffic has 1080 20-kip single axles, 400 24-kip single axles, and 680 40-kip tandem axles. You may use the Tables Q4-1 to Q4-5 to answer the following questions.

i. Determine the overall structural number of the pavement.
ii. Determine the equivalency factors for the three types of vehicles stated. (hint: consider linear interpolation)
iii. Determine the total daily 18-kip ESAL.
iv. How many years would this pavement last under present traffic conditions (how long before its PSI drops below a TSI of 2.5) if it is needed to be 90% confident that the estimate was not too high. [10.0 Marks]

Q5. A six-lane highway (3 lanes in one direction) is to be designed as a dual carriage way road with flexible pavement with three layers. It is recommended to use AASHTO 1993 guideline for the design.

Variation of the roadbed soil modulus with respect to months are shown in Table Q5-1, The road section is predicted to have 65/35 directional distribution. The data to design the pavement is as follows.

- **Layer 1**
  Reliability $R = 95\%$; Overall standard deviation $S_0 = 0.40$;total 18- kip equivalent single axis load for entire road $\widehat{W}_{18} = 3.13\ (\times 10^6$ ESAL); Design present serviceability index loss $\Delta\ PSI = 1.5$ and Layer coefficient $a_1 = 0.5$
- **Layer 2**
  Layer coefficient $a_2 = 0.5$; Drainage modifying factor $m_2 = 0.9$; and SN $= 3.5$.
- **Layer 3**
  Layer coefficient $a_3 = 0.08$, Drainage modifying factor $m_2 = 0.85$ and SN $= 7.5$

a) Calculate the effective roadbed soil resilient modulus for the year. You may use the scale given in Figure Q5-1 or use the appropriate equation.

[3.0 Marks]

b) Determine the cumulative EASL (W_{18}) considering the directional factor f_D, lane distribution factor f_L given in Table Q5-2.

[2.0 Marks]

c) Determine the structural number needed for layer 1, using the nomograph given in Figure Q5-2 or by appropriate equation. (**If you using the nomograph method attach the nomograph to your answer sheet**).

[2.0 Marks]

d) Calculate the depths of layer 1, 2 and 3.

[5.0 Marks]

Equations, Figures and Tables

Table Q2-1 Setting out table for Vertical curve

Point		Chainage	Horizontal Length (m)	Elevation (m)
T1				
P1				
P_{Max}				
T2				

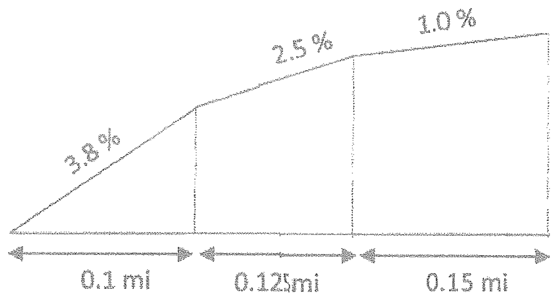


Figure Q3-1 Vertical alignment of 0.375 mi segment

Table Q3-1 Limits to select FFS in Multilane Highways

42.5 mi//h ≤ FFS ≤ 47.5 mi/h: use FFS = 45 mi/h
47.5 mi//h ≤ FFS ≤ 52.5 mi/h: use FFS = 50 mi/h
52.5 mi//h ≤ FFS ≤ 57.5 mi/h: use FFS = 55 mi/h
57.5 mi//h ≤ FFS ≤ 62.5 mi/h: use FFS = 60 mi/h

Table Q3-2 Definitions of grade conditions

Type of Grade	Condition
Extended freeway segments in general terrain	Grades are ≤ 2% and ≤ 0.25mi long Grades between2% and 3% are ≤0.5mi long
Specific Upgrade	Grades between 2% and 3% and longer than 0.5mi or 3% or greater and longer than 0.25mi
Composite Grade	Segments of freeway consist of two or more consecutive upgrades with different slopes *Average Method:* grades in subsections are less than 4% or less or total length of the composite grade is less than 4000ft *Graphical Method:* if any single portion of grades exceed 4% or if the toal length of grade exceeds 1200m

Table Q3-3 Equation describing Speed-Flow curves in Basic Freeway Segments

FFS (mi/h)	Breakpoint (pc/h/ln)	Flow Rate Range	
		≥0 ≤ Breakpoint	>Breakpoint ≤ Capacity
75	1,000	75	$75 - 0.00001107\,(v_p - 1{,}000)^2$
70	1,200	70	$70 - 0.00001160\,(v_p - 1{,}200)^2$
65	1,400	65	$65 - 0.00001418\,(v_p - 1{,}400)^2$
60	1,600	60	$60 - 0.00001816\,(v_p - 1{,}600)^2$
55	1,800	55	$55 - 0.00002469\,(v_p - 1{,}800)^2$

Notes: FFS = free-flow speed, v_p = demand flow rate (pc/h/ln) under equivalent base conditions.
Maximum flow rate for the equations is capacity: 2,400 pc/h/ln for 70- and 75-mph FFS; 2,350 pc/h/ln for 65-mph FFS; 2,300 pc/h/ln for 60-mph FFS; and 2,250 pc/h/ln for 55-mph FFS.

Table Q3-4 LOS on Basic Freeway Segments

LOS	Density (pc/mi/ln)
A	≤11
B	>11–18
C	>18–26
D	>26–35
E	>35–45
F	Demand exceeds capacity >45

Table Q3-5 Equations for Speed-Flow curves in Multilane Highways

FFS (mi/h)	For $v_p \le 1{,}400$ pc/h/ln, S (mi/h)	For $v_p > 1{,}400$ pc/h/ln, S (mi/h)
60	60	$60 - \left[5.00 \times \left(\frac{v_p - 1400}{800}\right)^{1.31}\right]$
55	55	$55 - \left[3.78 \times \left(\frac{v_p - 1400}{700}\right)^{1.31}\right]$
50	50	$50 - \left[3.49 \times \left(\frac{v_p - 1400}{600}\right)^{1.31}\right]$
45	45	$45 - \left[2.78 \times \left(\frac{v_p - 1400}{500}\right)^{1.31}\right]$

Table Q3-6 Adjustment to FFS for average lane width for Multilane Highways

Lane Width (ft)	Reduction in FFS, f_{LW} (mi/h)
≥12	0.0
>10–11	1.9
≥11–12	6.6

Table Q3-7 LOS of Multilane Highways

LOS	FFS (mi/h)	Density (pc/mi/ln)
A	All	>0–11
B	All	>11–18
C	All	>18–26
D	All	>26–35
E	60	>35–40
	55	>35–41
	50	>35–43
	45	>35–45
F	Demand Exceeds Capacity	
	60	>40
	55	>41
	50	>43
	45	>45

Table Q3-8 Adjustment to FFS for Lateral Clearance for Multilane Highways

Four-Lane Highways		Six-Lane Highways	
TLC (ft)	Reduction in FFS (mi/h)	TLC (ft)	Reduction in FFS (mi/h)
12	0.0	12	0.0
10	0.4	10	0.4
8	0.9	8	0.9
6	1.3	6	1.3
4	1.8	4	1.7
2	3.6	2	2.8
0	5.4	0	3.9

Note: Interpolation to the nearest 0.1 is recommended.

Table Q3-9 Adjustment to FFS for Median Type for Multilane Highways

Median Type	Reduction in FFS, f_M (mi/h)
Undivided	1.6
TWLTL	0.0
Divided	0.0

Table Q3-10 PCE for heavy vehicles in General Terrain Segments

Access-Point Density (access points/mi)	Reduction in FFS, f_A (mi/h)
0	0.0
10	2.5
20	5.0
30	7.5
≥40	10.0

Note: Interpolation to the nearest 0.1 is recommended.

Table Q3-11 PCE for heavy vehicles in General Terrain Segments

Vehicle	PCE by Type of Terrain: Level	Rolling	Mountainous
Trucks and buses, E_T	1.5	2.5	4.5
RVs, E_R	1.2	2.0	4.0

Table Q3-12 PCE for Trucks(E_T) on Upgrades

Percent Upgrade	Length (mi)	Proportion of Trucks and Buses: 2%	4%	5%	6%	8%	10%	15%	20%	25%
≤2	All	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
>2 – 3	0.00 – 0.25	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
	>0.25 – 0.50	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
	>0.50 – 0.75	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
	>0.75 – 1.00	2.0	2.0	2.0	2.0	1.5	1.5	1.5	1.5	1.5
	>1.00 – 1.50	2.5	2.5	2.5	2.5	2.0	2.0	2.0	2.0	2.0
	>1.50	3.0	3.0	2.5	2.5	2.0	2.0	2.0	2.0	2.0
>3 – 4	0.00 – 0.25	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
	>0.25 – 0.50	2.0	2.0	2.0	2.0	2.0	2.0	1.5	1.5	1.5
	>0.50 – 0.75	2.5	2.5	2.0	2.0	2.0	2.0	2.0	2.0	2.0
	>0.75 – 1.00	3.0	3.0	2.5	2.5	2.5	2.5	2.0	2.0	2.0
	>1.00 – 1.50	3.5	3.5	3.0	3.0	3.0	3.0	2.5	2.5	2.5
	>1.50	4.0	3.5	3.0	3.0	3.0	3.0	2.5	2.5	2.5
>4 – 5	0.00 – 0.25	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
	>0.25 – 0.50	3.0	2.5	2.5	2.5	2.0	2.0	2.0	2.0	2.0
	>0.50 – 0.75	3.5	3.0	3.0	3.0	2.5	2.5	2.5	2.5	2.5
	>0.75 – 1.00	4.0	3.5	3.5	3.5	3.0	3.0	3.0	3.0	3.0
	>1.00	5.0	4.0	4.0	4.0	3.5	3.5	3.0	3.0	3.0
>5 – 6	0.00 – 0.25	2.0	2.0	1.5	1.5	1.5	1.5	1.5	1.5	1.5
	>0.25 – 0.30	4.0	3.0	2.5	2.5	2.0	2.0	2.0	2.0	2.0
	>0.30 – 0.50	4.5	4.0	3.5	3.0	2.5	2.5	2.5	2.5	2.5
	>0.50 – 0.75	5.0	4.5	4.0	3.5	3.0	3.0	3.0	3.0	3.0
	>0.75 – 1.00	5.5	5.0	4.5	4.0	3.0	3.0	3.0	3.0	3.0
	>1.00	6.0	5.0	5.0	4.5	3.5	3.5	3.5	3.5	3.5
>6	0.00 – 0.25	4.0	3.0	2.5	2.5	2.5	2.5	2.0	2.0	1.0
	>0.25 – 0.30	4.5	4.0	3.5	3.5	3.5	3.0	2.5	2.5	2.5
	>0.30 – 0.50	5.0	4.5	4.0	4.0	3.5	3.0	2.5	2.5	2.5
	>0.50 – 0.75	5.5	5.0	4.5	4.5	4.0	3.5	3.0	3.0	3.0
	>0.75 – 1.00	6.0	5.5	5.0	5.0	4.5	4.0	3.5	3.5	3.5
	>1.00	7.0	6.0	5.5	5.5	5.0	4.5	4.0	4.0	4.0

Note: Interpolation for percentage of trucks and buses is recommended to the nearest 0.1.

Table Q3-13 PCE for RVs (E_{RV}) on Upgrades

Percent Upgrade	Length (mi)	Proportion of RVs: 2%	4%	5%	6%	8%	10%	15%	20%	25%
≤2	All	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
>2 – 3	0.00 – 0.50	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
	>0.50	3.0	1.5	1.5	1.5	1.5	1.5	1.2	1.2	1.2
>3 – 4	0.00 – 0.25	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
	>0.25 – 0.50	2.5	2.5	2.0	2.0	2.0	2.0	1.5	1.5	1.5
	>0.50	3.0	2.5	2.5	2.5	2.0	2.0	2.0	1.5	1.5
>4 – 5	0.00 – 0.25	2.5	2.0	2.0	2.0	1.5	1.5	1.5	1.5	1.5
	>0.25 – 0.50	4.0	3.0	3.0	3.0	2.5	2.5	2.0	2.0	2.0
	> 0.50	4.5	3.5	3.0	3.0	3.0	2.5	2.5	2.0	2.0
>5	0.00 – 0.25	4.0	3.0	2.5	2.5	2.5	2.0	2.0	2.0	1.5
	>0.25 – 0.50	6.0	4.0	4.0	3.5	3.0	3.0	2.5	2.5	2.0
	>0.50	6.0	4.5	4.0	4.0	3.5	3.0	3.0	2.5	2.0

Note: Interpolation for percentage of RVs is recommended to the nearest 0.1.

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 Cumulative Percent Probabilities of Reliability, R, of the Standard Normal Distribution, and Corresponding Z_R

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

Example: To be 55% confident that the pavement will remain at or above its TSI, a Z_R value of -0.125 would be obtained

Table Q4-3 Axle-Load Equivalency Factors for Flexible Pavements, Single Axles, and TSI = 2.5

Axle load (kips)	Pavement structural number (SN)					
	1	2	3	4	5	6
2	0.0004	0.0004	0.0003	0.0002	0.0002	0.0002
4	0.003	0.004	0.004	0.003	0.002	0.002
6	0.011	0.017	0.017	0.013	0.010	0.009
8	0.032	0.047	0.051	0.041	0.034	0.031
10	0.078	0.102	0.118	0.102	0.088	0.080
12	0.168	0.198	0.229	0.213	0.189	0.176
14	0.328	0.358	0.399	0.388	0.360	0.342
16	0.591	0.613	0.646	0.645	0.623	0.606
18	1.00	1.00	1.00	1.00	1.00	1.00
20	1.61	1.57	1.49	1.47	1.51	1.55
22	2.48	2.38	2.17	2.09	2.18	2.30
24	3.69	3.49	3.09	2.89	3.03	3.27
26	5.33	4.99	4.31	3.91	4.09	4.48
28	7.49	6.98	5.90	5.21	5.39	5.98
30	10.3	9.5	7.9	6.8	7.0	7.8
32	13.9	12.8	10.5	8.8	8.9	10.0
34	18.4	16.9	13.7	11.3	11.2	12.5
36	24.0	22.0	17.7	14.4	13.9	15.5
38	30.9	28.3	22.6	18.1	17.2	19.0
40	39.3	35.9	28.5	22.5	21.1	23.0
42	49.3	45.0	35.6	27.8	25.6	27.7
44	61.3	55.9	44.0	34.0	31.0	33.1
46	75.5	68.8	54.0	41.4	37.2	39.3
48	92.2	83.9	65.7	50.1	44.5	46.5
50	112.0	102.0	79.0	60.0	53.0	55.0

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

Table Q4-4 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.

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

Axle load (kips)	Pavement structural number (SN)					
	1	2	3	4	5	6
2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
4	0.0002	0.0002	0.0002	0.0001	0.0001	0.0001
6	0.0006	0.0007	0.0005	0.0004	0.0003	0.0003
8	0.001	0.002	0.001	0.001	0.001	0.001
10	0.003	0.004	0.003	0.002	0.002	0.002
12	0.005	0.007	0.006	0.004	0.003	0.003
14	0.008	0.012	0.010	0.008	0.006	0.006
16	0.012	0.019	0.018	0.013	0.011	0.010
18	0.018	0.029	0.028	0.021	0.017	0.016
20	0.027	0.042	0.042	0.032	0.027	0.024
22	0.038	0.058	0.060	0.048	0.040	0.036
24	0.053	0.078	0.084	0.068	0.057	0.051
26	0.072	0.103	0.114	0.095	0.080	0.072
28	0.098	0.133	0.151	0.128	0.109	0.099
30	0.129	0.169	0.195	0.170	0.145	0.133
32	0.169	0.213	0.247	0.220	0.191	0.175
34	0.219	0.266	0.308	0.281	0.246	0.228
36	0.279	0.329	0.379	0.352	0.313	0.292
38	0.352	0.403	0.461	0.436	0.393	0.368
40	0.439	0.491	0.554	0.533	0.487	0.459
42	0.543	0.594	0.661	0.644	0.597	0.567
44	0.666	0.714	0.781	0.769	0.723	0.692
46	0.811	0.854	0.918	0.911	0.868	0.838
48	0.979	1.015	1.072	1.069	1.033	1.005
50	1.17	1.20	1.24	1.25	1.22	1.20
52	1.40	1.41	1.44	1.44	1.43	1.41
54	1.66	1.66	1.66	1.66	1.66	1.66
56	1.95	1.93	1.90	1.90	1.91	1.93
58	2.29	2.25	2.17	2.16	2.20	2.24
60	2.67	2.60	2.48	2.44	2.51	2.58
62	3.09	3.00	2.82	2.76	2.85	2.95
64	3.57	3.44	3.19	3.10	3.22	3.36
66	4.11	3.94	3.61	3.47	3.62	3.81
68	4.71	4.49	4.06	3.88	4.05	4.30
70	5.38	5.11	4.57	4.32	4.52	4.84
72	6.12	5.79	5.13	4.80	5.03	5.41
74	6.93	6.54	5.74	5.32	5.57	6.04
76	7.84	7.37	6.41	5.88	6.15	6.71
78	8.83	8.28	7.14	6.49	6.78	7.43
80	9.92	9.28	7.95	7.15	7.45	8.21
82	11.1	10.4	8.8	7.9	8.2	9.0
84	12.4	11.6	9.8	8.6	8.9	9.9
86	13.8	12.9	10.8	9.5	9.8	10.9
88	15.4	14.3	11.9	10.4	10.6	11.9
90	17.1	15.8	13.2	11.3	11.6	12.9

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

Table Q5-1 Roadbed Soil Modulus

Month	Roadbed Soil Modulus MR (psi)
Jan	22,000
Feb	23,000
Mar	20,000
Apr	18,500
May	10,000
June	5,000
July	5,000
Aug	5,000
Sep	9,500
Oct	10,000
Nov	15,000
Dec	20,000

Table Q5-2: Recommended values for Lane Distribution Factor

Number of Lanes in each direction	Lane Distribution Factor f_L
1	1.00
2	0.80-1.00
3	0.60-0.80
4	0.50-0.75

*For this exam purposes use the minimum value of the corresponding factor range

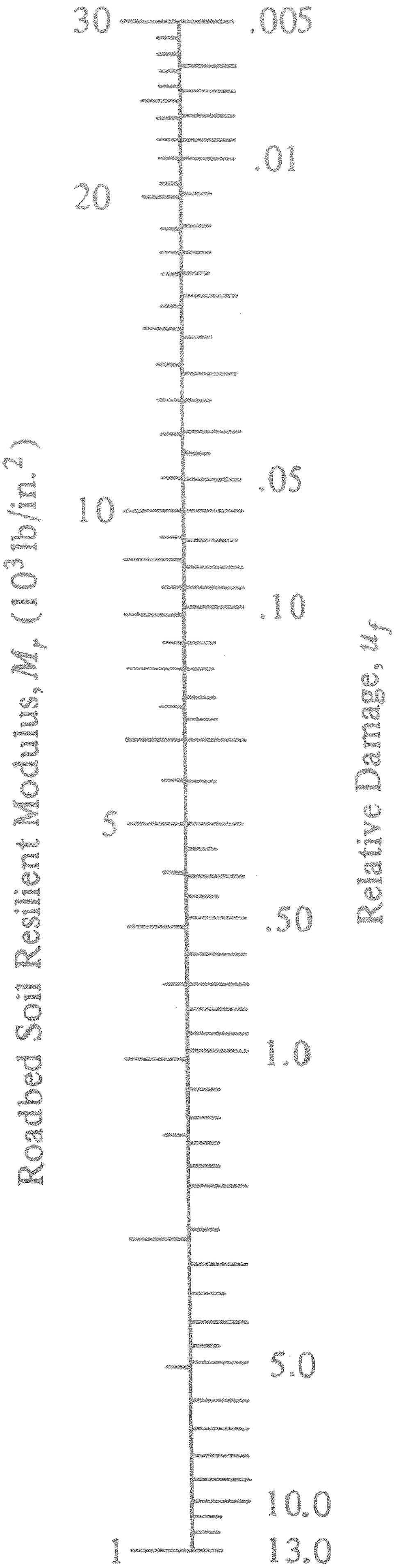


Figure Q5-1 Roadbed resilient modulus and relative damage

Equations to be used in the calculations

$h_p = H - (h_o + h_b)$

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

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

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

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

$Q_b = q_{bk} \times h_b$

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

$Q_p = q_{pk} \times h_p$

$V_{Max} = C \times d$

$Q_{tot} = Q_b + Q_p$

$U = 0.3 \times V_{Max}$

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

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

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

$F = 0.05 + 0.03 \times H$

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

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

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

$V = V_{Max} - F$

$h_o = V_{Max}$

$E = 1.25 \times V$

$h_b = 1.3 \times V_{Max}$

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

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

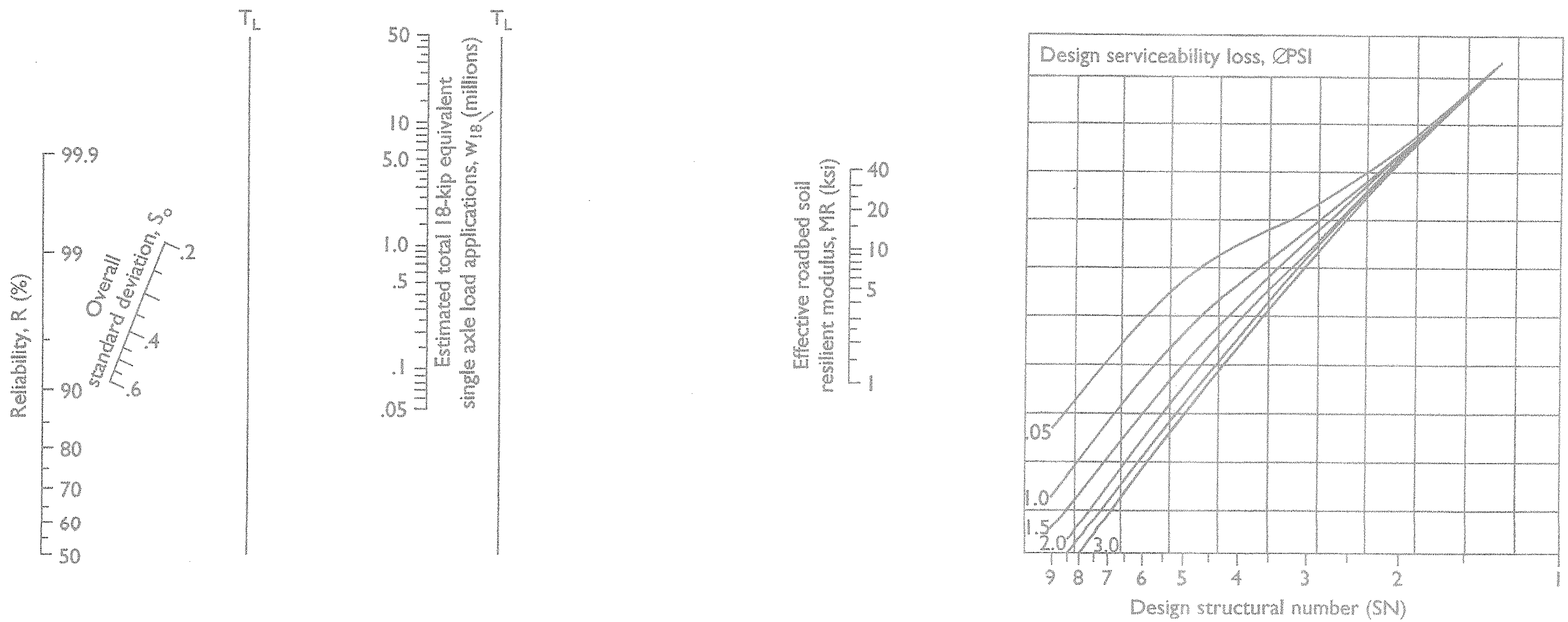
$U_f = 1.18 \times 10^8 \times M_r{}^{-2.32}$

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

$$\log W_{18} = Z_R S_o + 9.36 \log(SN + 1) - 0.2 + \frac{\log[\Delta PSI/(4.2 - 1.5)]}{0.4 + 1094/(SN + 1)^{5.19}} + 2.32 \log M_R - 8.07$$

Explanation on imperial units

- mi= Miles= 1.609 km
- lb/in^2=Pounds per square inch=psi
- kip =A kip is a US customary unit of force. It equals 1000 pounds-force, used
- 1 kip = 4448.2216 N = 4.4482216 kN



AASHTO flexible pavement design nomograph.

Source: From *Guide for the Design of Pavement Structures*; 1991, by the American Association of State Highway Transportation Officials, Washington, DC. Used by permission.

Figure Q5-2 Nomograph of flexible pavement design

$$FFS = BFFS - f_{LW} - f_{LC} - f_M - f_A$$

where

$BFFS$ = base FFS for multilane highway segment (mi/h);

FFS = FFS of basic freeway segment (mi/h);

f_{LW} = adjustment for lane width, from Exhibit 14-8 (mi/h);

f_{LC} = adjustment for TLC, from Exhibit 14-9 (mi/h);

f_M = adjustment for median type, from Exhibit 14-10 (mi/h); and

f_A = adjustment for access-point density, from Exhibit 14-11 (mi/h).

$$v_p = \frac{V}{PHF \times N \times f_{HV} \times f_p}$$

where

v_p = demand flow rate under equivalent base conditions (pc/h/ln);

V = demand volume under prevailing conditions (veh/h);

PHF = peak hour factor;

N = number of lanes (one direction);

f_{HV} = adjustment factor for presence of heavy vehicles in traffic stream, from Equation 14-4; and

f_p = adjustment factor for atypical driver populations.

$$f_{HV} = \frac{1}{1 + P_T(E_T - 1) + P_R(E_R - 1)}$$

where

f_{HV} = heavy-vehicle adjustment factor,

P_T = proportion of trucks and buses in traffic stream,

P_R = proportion of RVs in traffic stream,

E_T = passenger-car equivalent (PCE) of one truck or bus in traffic stream, and

E_R = PCE of one RV in traffic stream.