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Universiti Tun Hussein Onn Malaysia

UNIVERSITI TUN HUSSEIN ONN MALAYSIA

FINAL EXAMINATION
SEMESTER II
SESSION 2023/2024

COURSE NAME	:	PAVEMENT ENGINEERING
COURSE CODE	:	BFT 40203
PROGRAMME CODE	:	BFF
EXAMINATION DATE	:	JULY 2024
DURATION	:	3 HOURS
INSTRUCTIONS	:	1. ANSWER ALL QUESTIONS 2. THIS FINAL EXAMINATION IS CONDUCTED VIA ☐ Open book ☒ Closed book 3. STUDENTS ARE **PROHIBITED** TO CONSULT THEIR OWN MATERIAL OR ANY EXTERNAL RESOURCES DURING THE EXAMINATION CONDUCTED VIA CLOSED BOOK

THIS QUESTION PAPER CONSISTS OF **NINETEEN (19)** PAGES

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Q1 (a) Elaborate on Equivalent axle load factor (EALF)

(4 marks)

(b) Briefly explain the design factors that considered in the American Association of State Highway and Transportation Officials (AASHTO) Procedure.

(6 marks)

(c) The equivalent standard axle load applied for the design lane of the urban highway is 5.0×10^6 for 20 years. Design a suitable flexible pavement using AASHTO procedure if the pi = 4.2, pt = 2.2 and the drainage quality is good. Given:

Reliability level, R = 95%
Standard deviation, SO = 0.35
Pavement exposed to moisture = 20% of the time
CBR value: subgrade = 7%, base = 70% and subbase = 20%
Elastic modulus of asphalt mixture, MR1 =450,000 psi

Refer to **Table APPENDIX A.1** and **Figure APPENDIX A.1** to **Figure APPENDIX A.5** four your calculation.

(15 marks)

Q2 (a) Discuss the function of reinforcement bar in Continuous Reinforcement Concrete Pavement (CRCP).

(3 marks)

(b) The presence of water in cracks and transverse joints in rigid pavement is caused by a part of build-up of loose material under the cross-traffic load on approach and leave slabs. Using a suitable diagram, propose and explain how to reduce this phenomenon.

(7 marks)

(c) **Figure Q2.1** shows the concrete block section of rigid pavement. Given that the temperature differential of 10°C. By assuming the $\alpha t = 9 \times 10^{-6}$ mm/mm/°C and elastic concrete modulus (E) = 2×10^7 kPa, Poisson ratio = 0.15, stress coefficient of C_x=1.0 and C_y=0.55, thickness of the slab is 0.025 m, determine the following:

(i) Curling stress in x direction at point A and point B of the infinite slab.

(6 marks)

(ii) Maximum stress and deflection if there are an interior loading 45 kN was given at point with contact radius 0.14 m.

(9 marks)

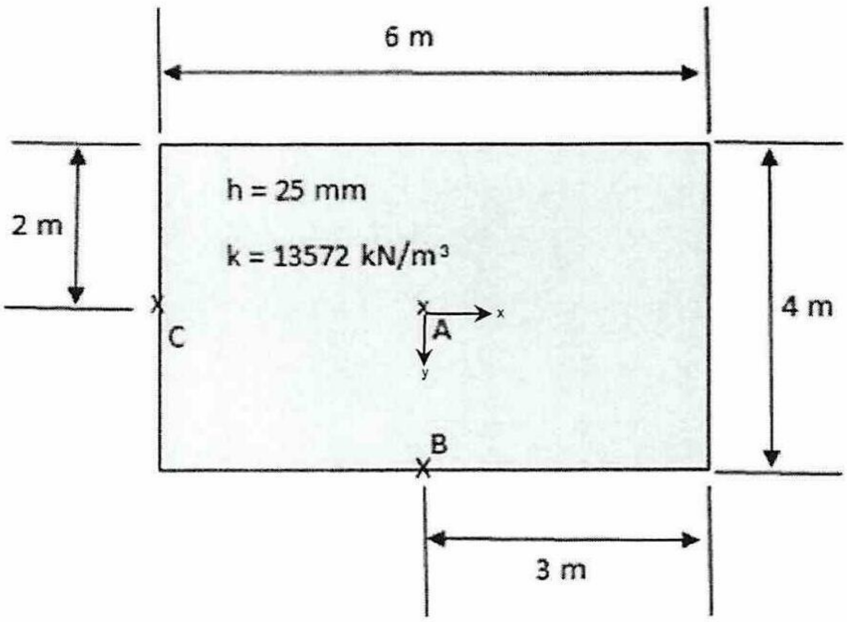

Figure Q2.1: Concrete block section.

Q3 (a) Interlaced cracking patterns resulting from fatigue failure are considered as typical deterioration defects of road pavement structures. Propose and explain **THREE (3)** possible methods to implement preventive measures that can improve the overall performance and longevity of asphalt pavements.

(6 marks)

(b) A concrete pavement designed with doweled joints and concrete shoulders has been proposed for a four-lane interstate highway. The pavement will be laid unto a combined subbase/subgrade with modulus of subgrade reaction as 30 MPa/m. The following data have been provided:

- Concrete flexural strength = 4.5 MPa
- Load safety factor = 1.2
- Design life = 20 years
- Design daily truck traffic is 20% from the average daily traffic of 30,000.

Refer to **Table APPENDIX B.1** to **Table APPENDIX B.9** and **Figure APPENDIX B.1** to **Figure APPENDIX B.3** for your calculation.

(i) Design the slab thickness by starting the calculation with trial thickness of 190 mm using **Table APPENDIX B.1.**

(15 marks)

(ii) Based on the answer in **Q3(b)(i),** discuss the adequacy of the concrete slab thickness.

(4 marks)

Q4 (a) The present serviceability index (PSI) is based on the ride quality rating of road surface pavement, which is designed to meet user needs can be influenced by the volume of traffic and the effectiveness of maintenance or rehabilitation activities. Sketch and elaborate a suitable diagram that depicts the condition of the road before and after maintenance works.

(7 marks)

(b) An asphalt overlay is planned for an existing asphalt pavement with an Elastic Modulus of 5×10^5 psi (3.5 GPa) for the Hot Mix Asphalt (HMA). The horizontal tensile strain at the bottom of the asphalt layer is 1×10^{-4} before overlay and 7×10^{-5} after overlay.

Using the Asphalt Institute fatigue criteria, calculate the allowable number of Equivalent Standard Axle Loads (ESALs) on the overlaid asphalt pavement for different Commercial Vehicles (CVs) with total numbers of 3283, 6060, 7900 and 800, and equivalent factors of 0.001, 0.18, 1.56, and 7.2, respectively.

(8 marks)

(c) A Decision Support System (DSS) tool is required for government decision-makers to evaluate different investment strategies and future alternatives within the constraints of funding levels and accurate maintenance requirement data information. Justify how DSS can maximize performance in road construction and maintenance, and cost-effective strategies.

(10 marks)

- END OF QUESTIONS -

APPENDIX A: Design Charts and Tables

Table APPENDIX A.1: Recommended m value for modifying structural layer coefficient of untreated base and subbase materials in flexible pavement.

Percent of Time Pavement Structure is Exposed to Moisture Levels Approaching Saturation				
Quality of drainage	**Less than 1%**	**1%-5%**	**5%-25%**	**Greater than 25%**
Excellent	1.40-1.35	1.35-1.30	1.30-1.20	1.20
Good	1.35-1.25	1.25-1.15	1.15-1.00	1.00
Fair	1.25-1.15	1.15-1.05	1.00-0.80	0.80
Poor	1.15-1.05	1.05-0.08	0.80-0.60	0.60
Very Poor	1.05-0.95	0.95-0.75	0.75-0.40	0.40

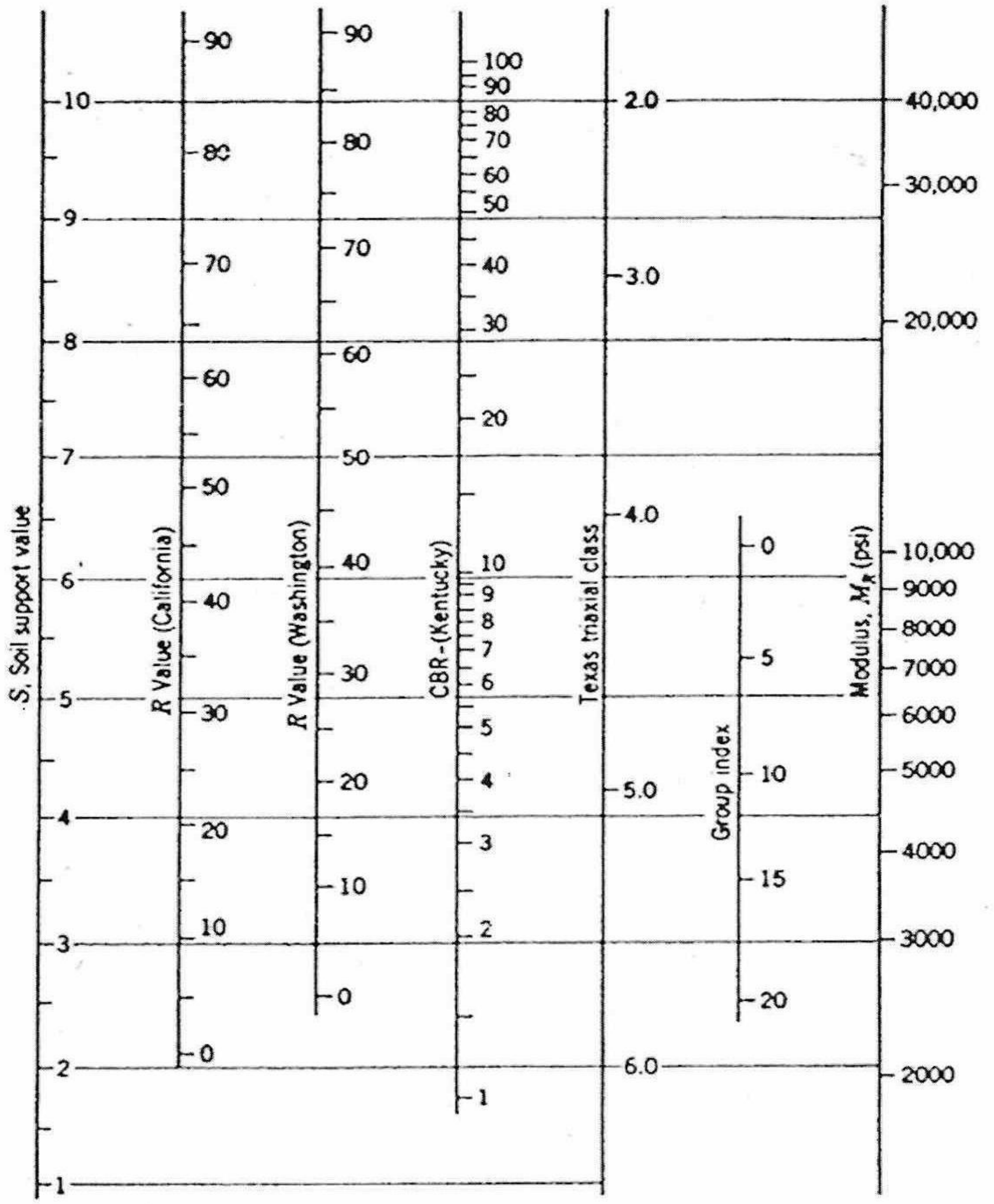

Figure APPENDIX A.1: Correlation chart for estimating resilient modulus of subgrade soil.

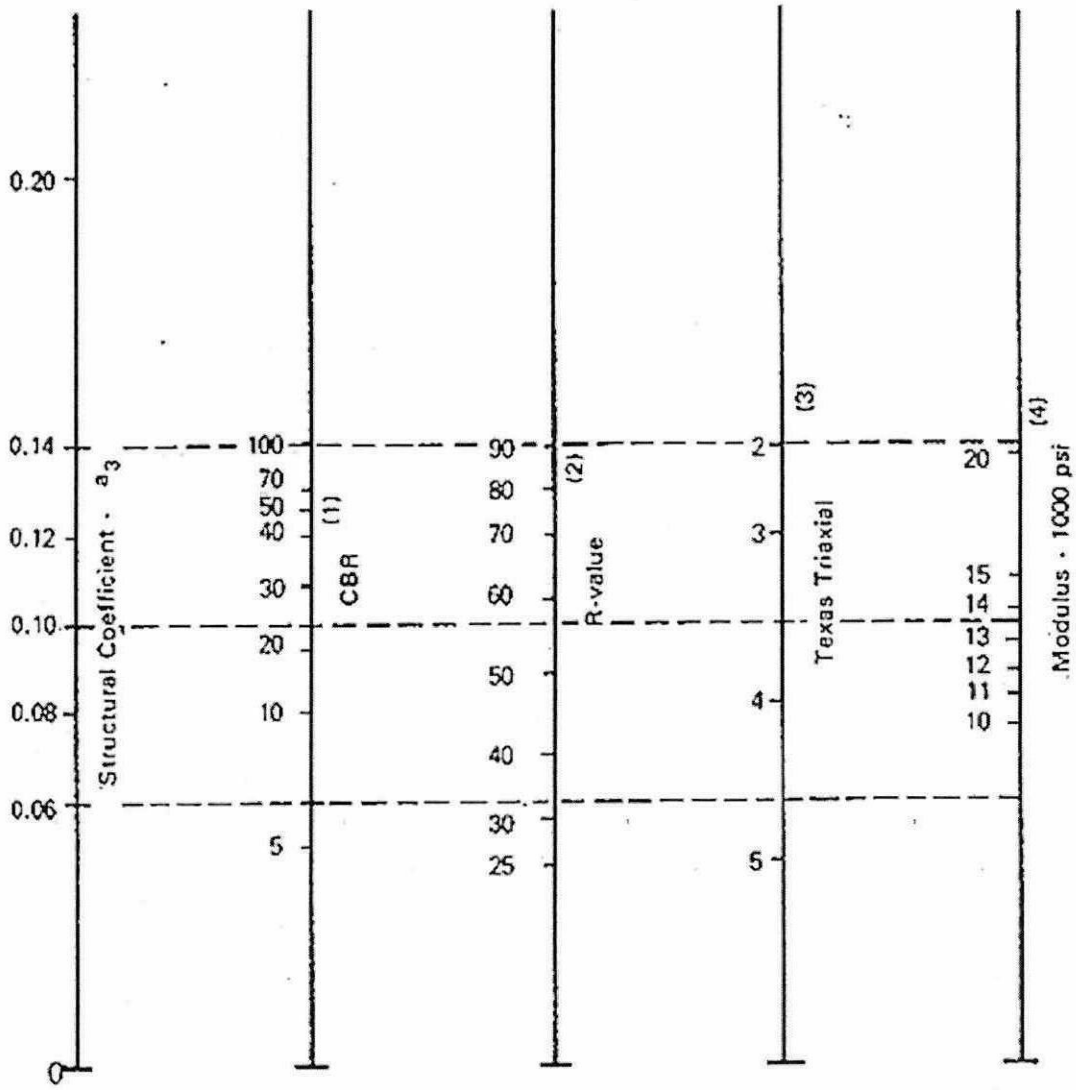

Figure APPENDIX A.2: Variation in granular subbase layer coefficient (a_3)

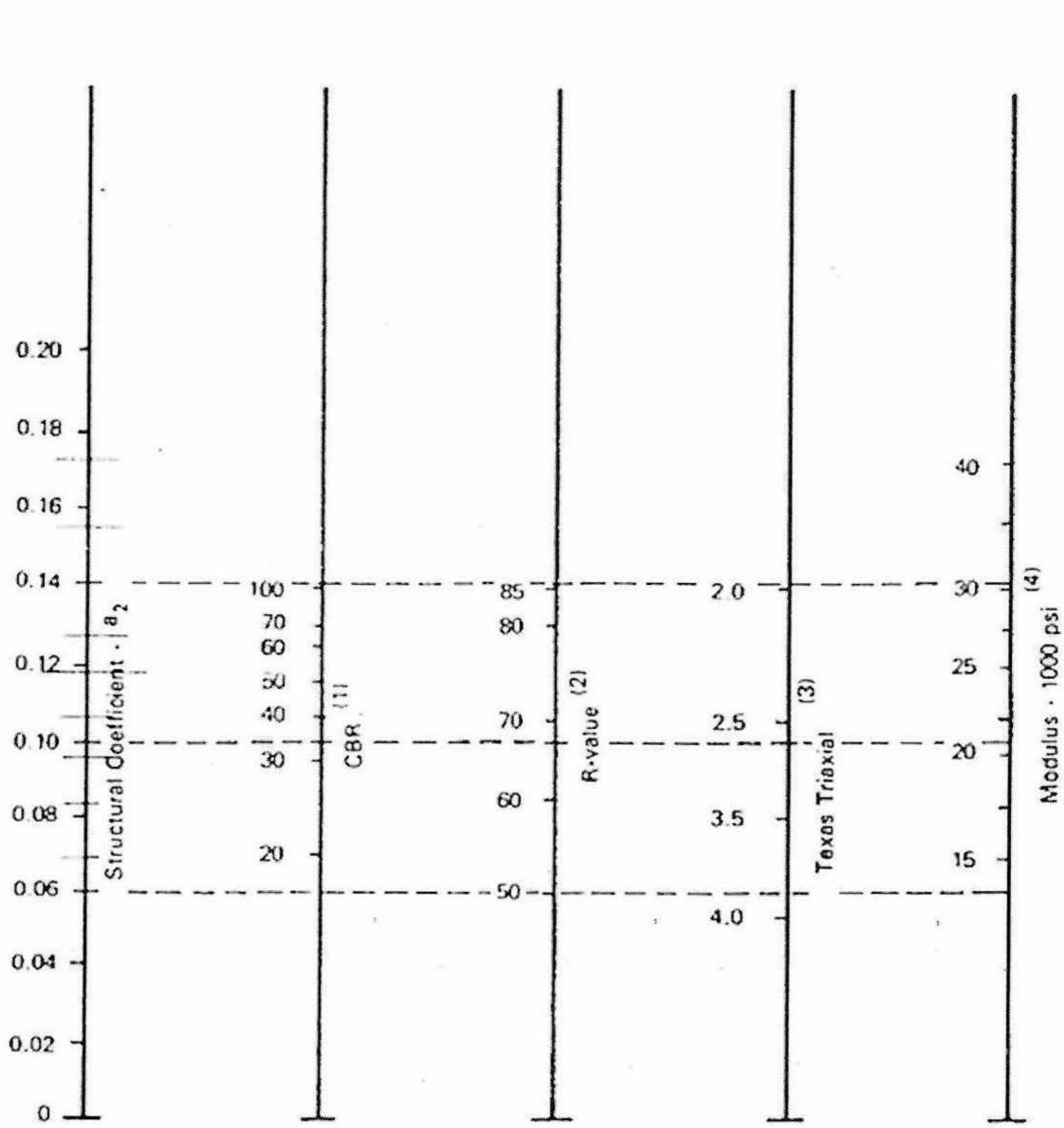

Figure APPENDIX A.3: Variation in granular base layer coefficient (a_2)

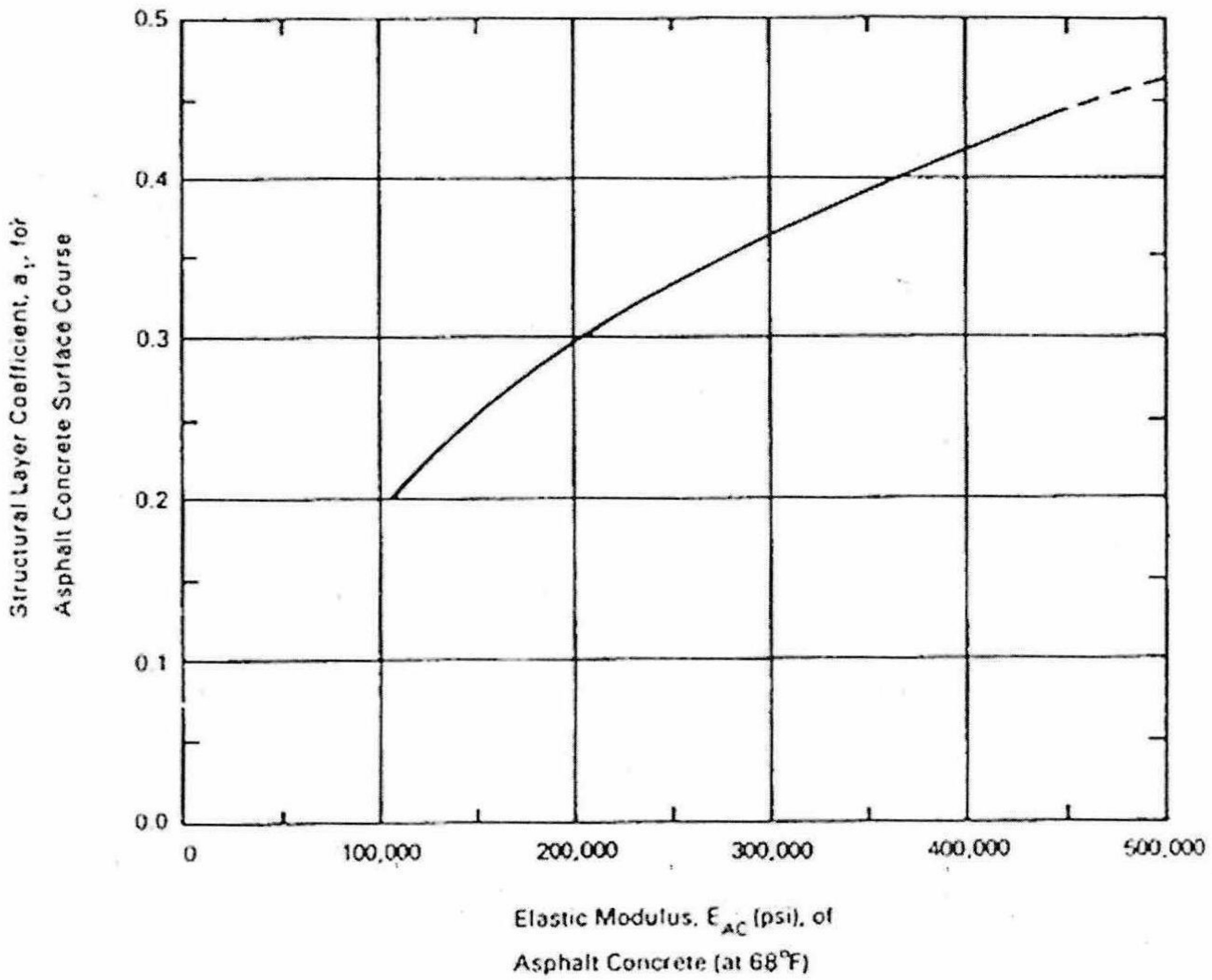

Figure APPENDIX A.4: Chart for estimating structural layer coefficient of dense graded asphalt concrete base on the elastic (resilient modulus)

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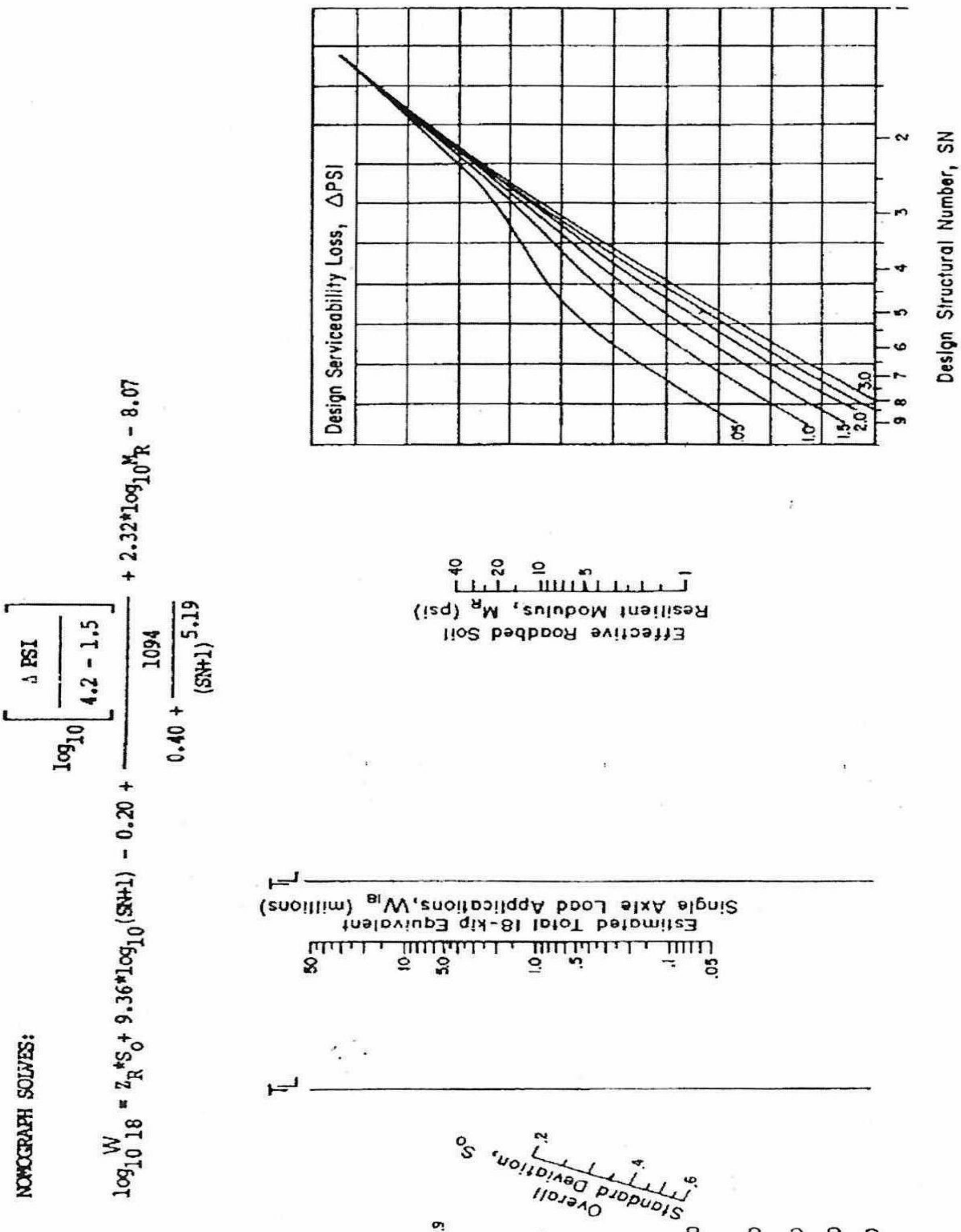

Figure APPENDIX A.5: AASHTO design chart for flexible pavement based on using mean values for each input.

APPENDIX B:

Name: …………………………………………………… **Matric No: …………………**

Note: If you are answering **Q3(b)**, please submit this sheet along with your answer script.

Table APPENDIX B.1: Calculation of Pavement Thickness

Trial Thickness : **190.00** mm
Subbase - subgrade, *k*: ______MPa/m
Modulus of rupture, M_R : ______MPa
Load safety factor, LSF : ______

Doweled joints : **Yes** ____ / **No**____
Concrete shoulder : **Yes** ____ / **No** ____
Design period : ____ years

Axle load (kN)	Multiplied by LSF	Expected repetitions	Fatigue analysis		Erosion analysis	
			Allowable repetitions	Fatigue percent	Allowable repetitions	Damage percent
1	2	3	4	5	6	7

8. Equivalent stress : ______
9. Stress ratio factor : ______

10. Erosion factor : ______

Single Axles

Axle Load (kN)	Axle Load by LSF	Expected repetition	Alowable repetition (fatigue)	Fatigue percent	Allowable repetition (erosion)	Damage percent
125						
107						
98						
80						

11. Equivalent stress : ______
12. Stress ratio factor : ______

13. Erosion factor : ______

Tandem Axles

Axle Load (kN)	Axle Load by LSF	Expected repetition	Alowable repetition (fatigue)	Fatigue percent	Allowable repetition (erosion)	Damage percent
231						
213						
178						
142						
			Total =		**Total =**	

Table APPENDIX B.2: Truck Distribution for Multiple-Lane Highways

One-way ADT	Two lanes in each direction		Three or more lanes in each direction		
	Inner	Outer	Inner[a]	Center	Outer
2000	6	94	6	12	82
4000	12	88	6	18	76
6000	15	85	7	21	72
8000	18	82	7	23	70
10,000	19	81	7	25	68
15,000	23	77	7	28	65
20,000	25	75	7	30	63
25,000	27	73	7	32	61
30,000	28	72	8	33	59
35,000	30	70	8	34	58
40,000	31	69	8	35	57
50,000	33	67	8	37	55
60,000	34	66	8	39	53
70,000	—	—	8	40	52
80,000	—	—	8	41	51
100,000	—	—	9	42	49

[a] Combined inner one or more lanes.
Source. After Darter et al. (1985).

Table APPENDIX B.3: Effect of untreated subbase on k-values

Subgrade k value (MPa/m)	*Subgrade-subbase k values (MPa/m)*			
	100 mm	150 mm	225 mm	300 mm
20	23	26	32	38
40	45	49	57	66
60	64	66	76	90
80	87	90	100	117

Table APPENDIX B.4: Effect of cement-treated subbase on k-values

Subgrade k value (MPa/m)	*Subgrade-subbase k values (MPa/m)*			
	100 mm	150 mm	225 mm	300 mm
20	60	80	105	135
40	100	130	185	230
60	140	190	245	-

Table APPENDIX B.5: Equivalent stress (with concrete shoulder)

Slab thickness (mm)	*k* of subgrade-subbase (MPa/m)				
	20	40	60	80	140
100	4.18/3.48	3.65/3.10	3.37/2.94	3.19/2.85	2.85/2.74
110	3.68/3.07	3.23/2.71	2.99/2.56	2.83/2.47	2.55/2.35
120	3.28/2.75	2.88/2.41	2.67/2.26	2.54/2.17	2.29/2.05
130	2.95/2.49	2.60/2.17	2.41/2.02	2.29/1.94	2.07/1.82
140	2.68/2.27	2.36/1.97	2.19/1.83	2.08/1.75	1.89/1.63
150	2.44/2.06	2.15/2.41	2.00/1.67	1.90/1.59	1.73/1.48
160	2.24/1.93	1.97/1.66	1.84/1.53	1.75/1.46	1.59/1.35
170	2.06/1.79	1.82/1.54	1.70/1.42	1.62/1.35	1.48/1.24
180	1.91/1.67	1.69/1.43	1.57/1.32	1.50/1.25	1.37/1.15
190	1.77/1.57	1.57/1.34	1.46/1.23	1.40/1.17	1.28/1.07
200	1.65/1.48	1.46/1.26	1.37/1.16	1.30/1.10	1.19/1.00
210	1.55/1.40	1.37/1.19	1.28/1.09	1.22/1.03	1.12/0.93
220	1.45/1.32	1.29/1.12	1.20/1.03	1.15/0.97	1.05/0.88
230	1.37/1.26	1.21/1.07	1.13/0.98	1.08/0.92	0.99/0.83
240	1.29/1.20	1.15/1.01	1.07/0.93	1.02/0.87	0.94/0.79
250	1.22/1.14	1.08/0.97	1.01/0.88	0.97/0.83	0.89/0.75

(Single axle/Tandem axle)

Table APPENDIX B.6: Equivalent stress (without concrete shoulder)

Slab thickness (mm)	*k* of subgrade-subbase (MPa/m)				
	20	40	60	80	140
100	5.42/4.39	4.75/3.83	4.38/3.59	4.13/3.44	3.66/3.22
110	4.74/3.88	4.16/3.35	3.85/3.12	3.63/2.97	3.23/2.76
120	4.19/3.47	3.69/2.98	3.41/2.75	3.23/2.62	2.88/2.40
130	3.75/3.14	3.30/2.68	3.06/2.46	2.89/2.33	2.59/2.13
140	3.37/2.87	2.97/2.43	2.76/2.23	2.61/2.10	2.34/1.90
150	3.06/2.64	2.70/2.23	2.51/2.04	2.37/1.92	2.13/1.72
160	2.79/2.45	2.47/2.06	2.29/1.87	2.17/1.76	1.95/1.57
170	2.56/2.28	2.26/1.91	2.10/1.74	1.99/1.63	1.80/1.45
180	2.37/2.14	2.09/1.79	1.94/1.62	1.84/1.51	1.66/1.34
190	2.19/2.01	1.94/1.67	1.80/1.51	1.71/1.41	1.54/1.25
200	2.04/1.90	1.80/1.58	1.67/1.42	1.59/1.33	1.43/1.17
210	1.91/1.79	1.68/1.49	1.56/1.34	1.48/1.25	1.34/1.10
220	1.79/1.70	1.57/1.41	1.46/1.27	1.39/1.18	1.26/1.03
230	1.68/1.62	1.48/1.34	1.38/1.21	1.31/1.12	1.18/0.98
240	1.58/1.55	1.39/1.28	1.30/1.15	1.23/1.06	1.11/0.93
250	1.49/1.48	1.32/1.22	1.22/1.09	1.16/1.01	1.05/0.88

(Single axle/Tandem axle)

Table APPENDIX B.7: Erosion factors (doweled joints, without concrete shoulder)

Slab thickness (mm)	*k* of subgrade-subbase (MPa/m)				
	20	40	60	80	140
100	3.76/3.80	3.75/3.79	3.74/3.77	3.74/3.76	3.72/3.72
110	3.63/3.71	3.62/3.67	3.61/3.65	3.61/3.63	3.59/3.60
120	3.52/3.61	3.50/3.56	3.49/3.54	3.49/3.52	3.47/3.49
130	3.74/3.52	3.39/3.47	3.39/3.44	3.38/3.43	3.37/3.39
140	3.31/3.43	3.30/3.38	3.29/3.35	3.28/3.33	3.27/3.30
150	3.22/3.36	3.21/3.30	3.20/3.27	3.19/3.25	3.17/3.21
160	3.14/3.28	3.12/3.22	3.11/3.19	3.10/3.17	3.09/3.13
170	3.06/3.22	3.04/3.15	3.03/3.12	3.02/3.10	3.01/3.06
180	2.99/3.16	2.97/3.09	2.96/3.06	2.95/3.03	2.93/2.99
190	2.92/3.10	2.90/3.03	2.88/2.99	2.88/2.97	2.86/2.93
200	2.85/3.05	2.83/2.97	2.82/2.94	2.81/2.91	2.79/2.87
210	2.79/2.99	2.77/2.92	2.75/2.88	2.75/2.86	2.73/2.81
220	2.73/2.95	2.71/2.87	2.69/2.83	2.69/2.80	2.67/2.76
230	2.67/2.90	2.65/2.82	2.64/2.78	2.63/2.75	2.61/2.70
240	2.62/2.86	2.60/2.78	2.58/2.73	2.57/2.71	2.55/2.66
250	2.57/2.80	2.54/2.73	2.53/3.69	2.52/2.66	2.50/2.61

(Single axle/Tandem axle)

Table APPENDIX B.8: Erosion factors (doweled joints, with concrete shoulder)

Slab thickness (mm)	*k* of subgrade-subbase (MPa/m)				
	20	40	60	80	140
100	3.27/3.25	3.24/3.17	3.22/3.14	3.21/3.12	3.17/3.11
110	3.16/3.16	3.12/3.07	3.10/3.03	3.09/3.00	3.05/2.98
120	3.05/3.08	3.01/2.98	2.99/2.93	2.98/2.90	2.94/2.86
130	2.96/3.01	2.92/2.90	2.89/2.85	2.88/2.81	2.84/2.76
140	2.87/2.94	2.82/2.83	2.80/2.77	2.78/2.74	2.75/2.67
150	2.79/2.88	2.74/2.77	2.72/2.71	2.70/2.67	2.67/2.60
160	2.71/2.82	2.66/2.71	2.64/2.65	2.62/2.60	2.59/2.53
170	2.64/2.77	2.59/2.65	2.57/2.59	2.55/2.55	2.51/2.46
180	2.57/2.72	2.52/2.60	2.50/2.54	2.48/2.49	2.44/2.41
190	2.51/2.67	2.46/2.56	2.43/2.49	2.41/2.44	2.38/2.35
200	2.45/2.63	2.40/2.51	2.37/2.44	2.35/2.40	2.31/2.31
210	2.39/2.58	2.34/2.47	2.31/2.40	2.29/2.35	2.26/2.26
220	2.34/2.54	2.29/2.43	2.26/2.36	2.24/2.31	2.20/2.22
230	2.29/2.50	2.23/2.39	2.21/2.32	2.19/2.27	2.15/2.18
240	2.24/2.46	2.18/2.35	2.16/2.28	2.13/2.23	2.10/2.14
250	2.19/2.43	2.14/2.31	2.11/2.24	2.09/2.20	2.05/2.10

(Single axle/Tandem axle)

Table APPENDIX B.9: Erosion factors (aggregate-interlock joints, without concrete shoulder)

Slab thickness (mm)	*k* of subgrade-subbase (MPa/m)				
	20	40	60	80	140
100	3.94/4.00	3.92/3.93	3.90/3.90	3.88/3.88	3.84/3.84
110	3.82/3.90	3.79/3.82	3.78/3.79	3.76/3.76	3.72/3.72
120	3.71/3.81	3.68/3.73	3.67/3.69	3.65/3.66	3.62/3.62
130	3.61/3.73	3.58/3.65	3.56/3.60	3.55/3.57	3.52/3.52
140	3.52/3.66	3.49/3.57	3.47/3.52	3.46/3.49	3.43/3.43
150	3.43/3.59	3.40/3.50	3.38/3.45	3.37/3.42	3.34/3.36
160	3.35/3.53	3.32/3.43	3.30/3.38	3.29/3.35	3.26/3.28
170	3.28/3.48	3.24/3.37	3.22/3.32	3.21/3.28	3.18/3.22
180	3.21/3.42	3.17/3.32	3.15/3.26	3.14/3.23	3.11/3.16
190	3.15/3.37	3.11/3.27	3.08/3.21	3.07/3.17	3.04/3.10
200	3.09/3.33	3.04/3.22	3.02/3.16	3.01/3.12	2.98/3.05
210	3.04/3.28	2.99/3.17	2.96/3.11	2.95/3.07	2.92/3.00
220	2.98/3.24	2.93/3.13	2.90/3.07	2.89/3.03	2.86/2.95
230	2.93/3.20	2.88/3.09	2.85/3.03	2.83/2.98	2.80/2.91
240	2.89/3.16	2.83/3.05	2.80/2.99	2.78/2.94	2.75/2.66
250	2.84/3.13	2.783.01	2.75/2.95	2.73/2.91	2.70/2.82

(Single axle/Tandem axle)

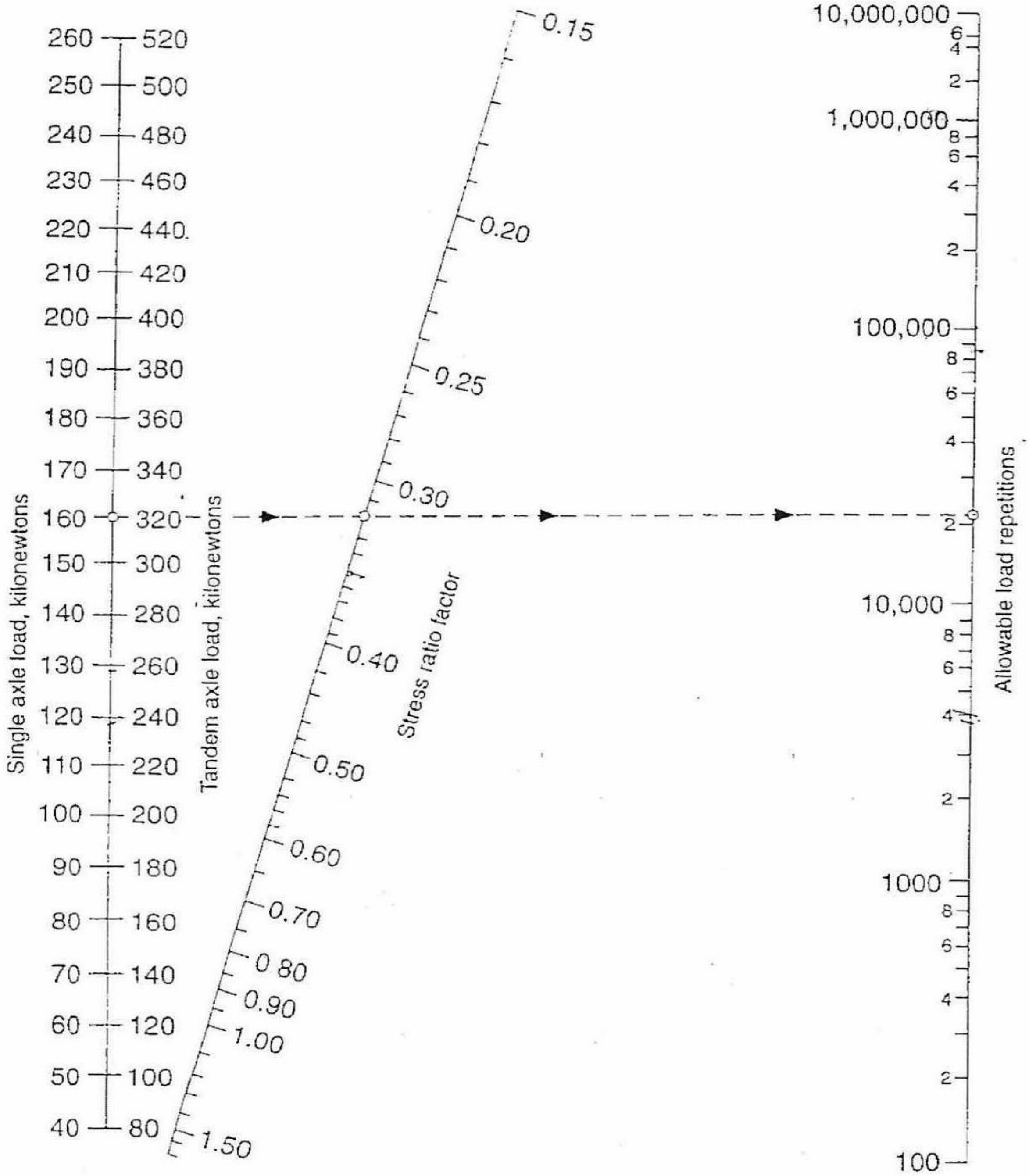

Figure APPENDIX B.1: Fatigue Analysis – Allowable repetitions based on stress ratio factor (with or without concrete shoulder)

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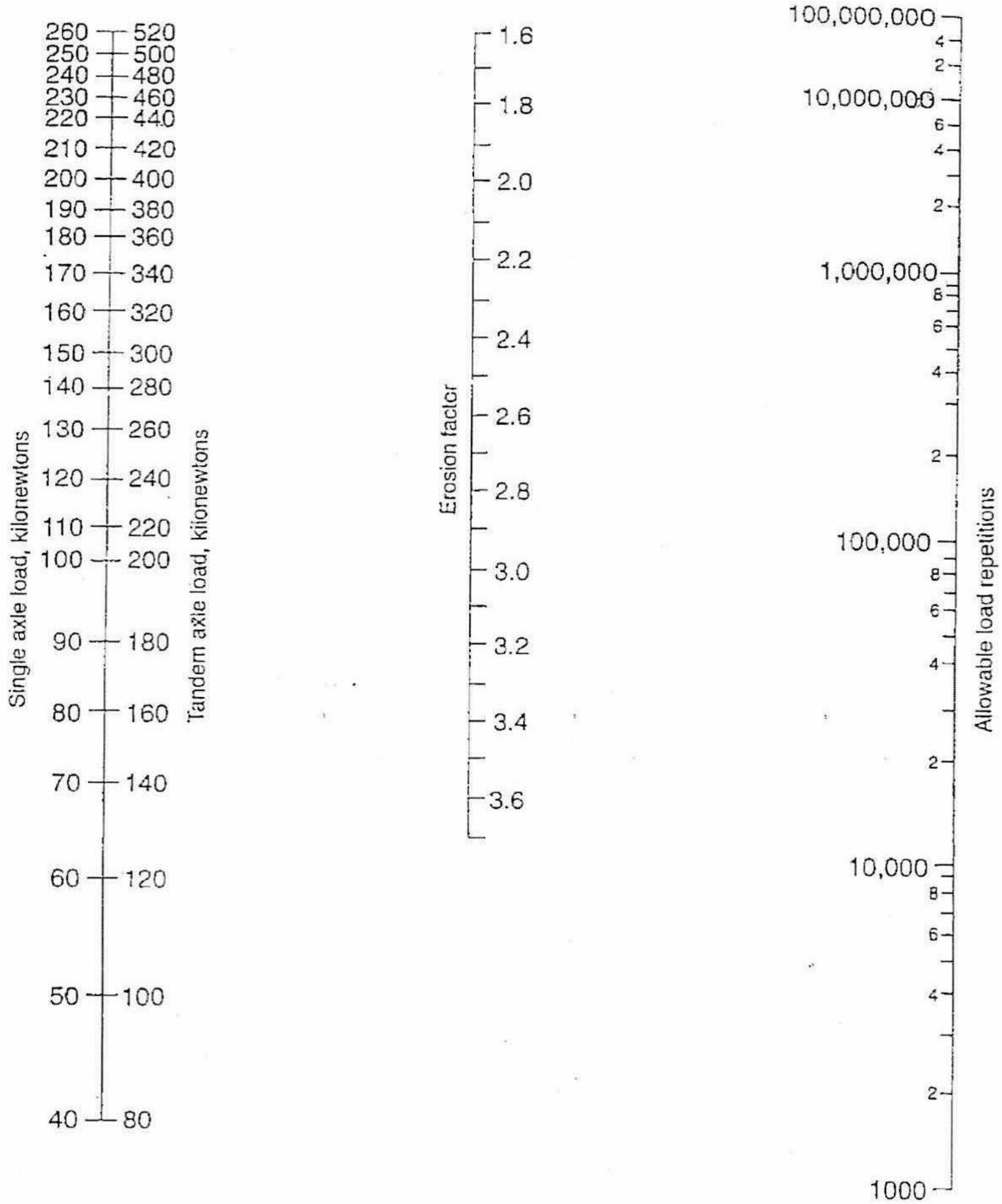

Figure APPENDIX B.2: Erosion Analysis – Allowable repetitions based on erosion factor (with concrete shoulder)

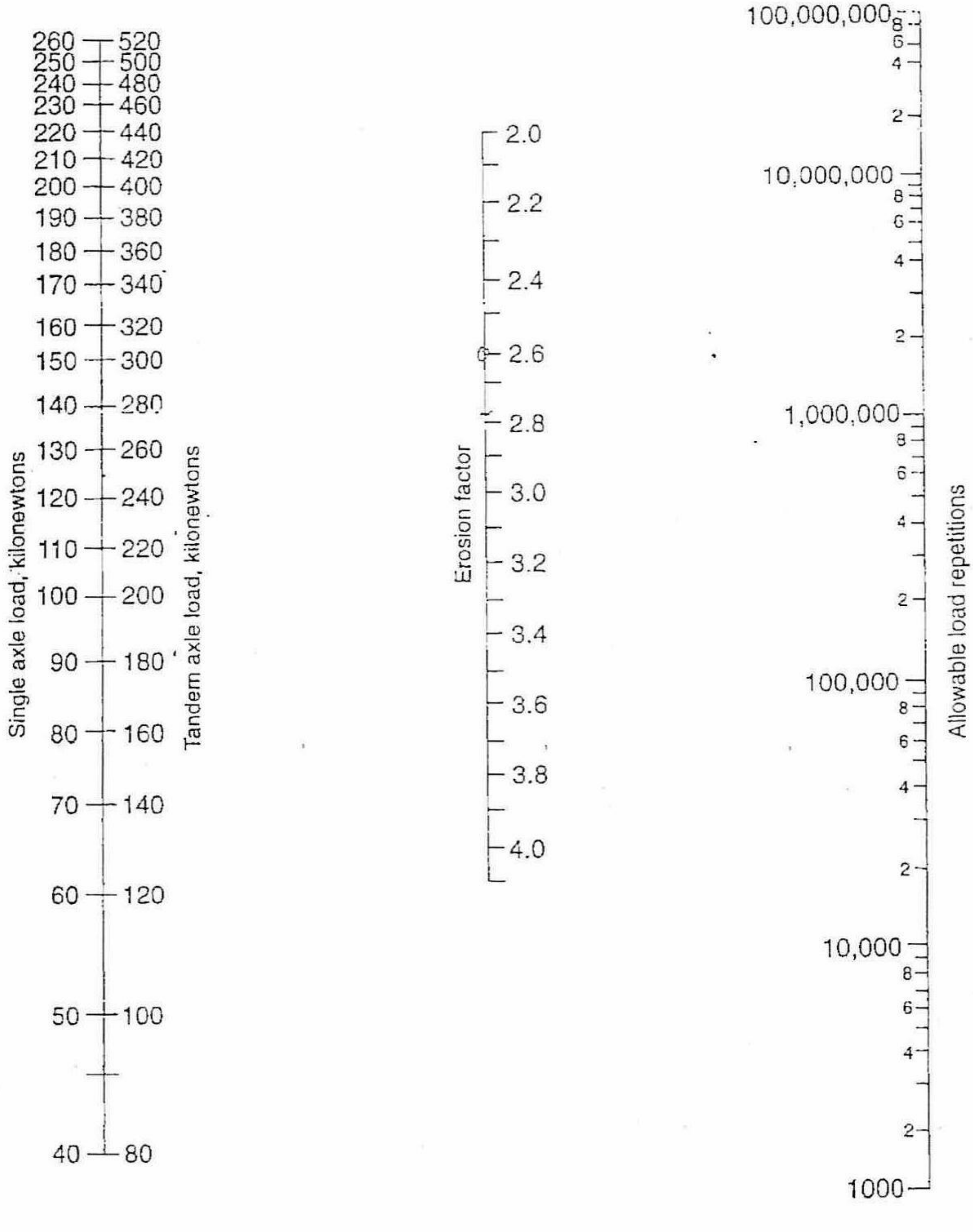

Figure APPENDIX B.3: Erosion Analysis – Allowable repetitions based on erosion factor (without concrete shoulder)

APPENDIX C:List of Formulas

D_1=SN2/(a_1m_1); SN1*>SN1; D_2=SN2-SN1/(a_2m_2) , SN1*+SN2* >SN2

D_3=SN3-SN2-SN1/(a_3m_3); SN1*+SN2*+SN3* >SN3

$$a = \sqrt{\frac{q}{i\pi}}$$

$$\sigma_z = p\left[1 - \frac{z^3}{(a^2 + z^2)^{\frac{3}{2}}}\right]$$

$$\sigma_r = \sigma_{\theta} = \frac{p}{2}\left[(1 + 2\mu) - \frac{2(1 + \mu)z}{\sqrt{(a^2 + z^2)}} + \frac{z^3}{(a^2 + z^2)^{3/2}}\right]$$

$$w = \frac{2[1 - (v)^2]Pa}{E}$$

$$w = \frac{3pa^2}{2E(a^2 + z^2)^{0.5}}$$

$$w = \frac{(1 + v)pa}{E}\left[\frac{a}{(a^2 + z^2)^{0.5}} + \frac{1 - 2v}{a}[(a^2 + z^2)^{0.5} - z]\right]$$

$$\epsilon_z = \frac{(1 + v)p}{E}\left[1 - 2v + \frac{2vz}{(a^2 + z^2)^{0.5}} - \frac{z^3}{(a^2 + z^2)^{\frac{3}{2}}}\right]$$

$$u_r = (D^{0.75} - 0.39k^{0.25})^{3.42}$$

$$N_f = 0.0796\,(\epsilon_t)^{-3.291}\,(E_1)^{-0.854}$$

$$\frac{n_r}{N_a} = 1 - \frac{n_e}{N_a}$$

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