Universiti Tun Hussein Onn Malaysia

UNIVERSITI TUN HUSSEIN ONN MALAYSIA

FINAL EXAMINATION
SEMESTER II
SESSION 2022/2023

COURSE NAME	:	PAVEMENT ENGINEERING
COURSE CODE	:	BFT 40203
PROGRAMME CODE	:	BFF
EXAMINATION DATE	:	JULY/ AUGUST 2023
DURATION	:	3 HOURS
INSTRUCTIONS	1.	ANSWER ALL QUESTIONS
	2.	THIS FINAL EXAMINATION IS CONDUCTED VIA **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

Q1 (a) Briefly explain the difference between Pavement Serviceability Index (PSI) and Present Serviceability Rating (PSR).

(4 marks)

(b) Discuss how the stress and strain can influence fatigue cracking that affected on flexible pavement performance.

(5 marks)

(c) Propose and clarify how the behaviour of a linear viscoelastic materials affected on stress-strain on flexible pavement.

(8 marks)

(d) A new rural principal arterial road is to be designed to replace an existing highway. The new road properties have an Elastic modulus, E as 1400 MPa and the Poisson ratio, μ as 0.5. If the inflated vehicle tire is 600 kPa with 0.126 m tire radius is applied on depth of 0.1 m and radial offset of 0.0 m on the road pavement, calculate:

(i) the surface vertical deflection

(4 marks)

(ii) If the Elastic modulus, E decrease to 100 MPa due to heavy rain, compute the vertical deflection under the same tire and comment the effects of Elastic modulus, E on the surface vertical deflection.

(4 marks)

Q2 (a) Identify and discriminate why the analysis of road pavement need to be conducted.

5 marks)

(b) Road maintenance or rehabilitation activities and the amount of traffic can affect the ride quality rating of road surface pavement. With a sketch of diagrams, describe how the maintenance work can improve pavement serviceability index of the road.

(7 marks)

(c) A concrete pavement designed for a four-lane urban express constructed on 6 in. thickness of an untreated sub-base with resilient modulus of 30,000 psi (206.8 MPa) and roadbed resilient modulus of 7,000 psi (48.3 MPa). The road is proposed for a plain concrete pavement with construction joints and load transfer on asphalt shoulder. The initial and terminal serviceability indices are 4.2 and 2.5, respectively. Take the overall standard deviation S_o as 0.29 and the standard normal deviate, Z_R considered as -1.645. The working stress of the concrete is 650 psi (4.5 MPa), and the concrete elastic modulus is 5.0 $x10^6$ psi (34.5 GPa). The Equivalent Standard Single Axle Load (ESAL) was designed according on **Table Q2(c)(i).** It is estimated that the water removed within 2 hours from a base layer, which pavement exposure to moisture is 30 percent.

Refer **Table Q2(c)(ii)** to **Table Q2(c)(vi)**, and **Figure Q2(c)(i)** to **Q2(c)(iii)** in your calculation. Based on the American Association of State Highway and Transportation Officials (ASSHTO) design method;

(i) Design the suitable of concrete slab thickness.

(10 marks)

(ii) Analyse the relative damage of rigid pavement

(3 marks)

Q3 (a) Propose and demonstrate **THREE (3)** a possible method how to implement preventive measures on interlaced cracking patterns resulting from fatigue failure of pavement surface or a stabilized road base layer considered as typical deterioration defects on asphalt pavement.

(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 **Table Q3(b)(ii)** to **Table Q3(b)(ix)** and **Figure Q3(b)(i)** to **Figure Q3(b)(iii)** in your calculation.

(i) Design a slab thickness by starting the calculation with trial thickness of 190 mm using **Table Q3(b)(i).**

(15 marks)

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

(4 marks)

Q4 (a) The unevenness of pavement surface that has adversely effects on the ride comfort of a vehicle, increases fuel consumption and results in higher maintenance expenses. Based on those statements, propose and explain how a road agency can implement the strategies to improve serviceability which related to road physical deterioration to extend the lifespan, providing a safe and efficient for public transportation system.

(8 marks)

(b) An asphalt overlay is designed and will be constructed on an existing asphalt pavement which 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.

If the Equivalent Standard Axle Load (ESAL) before overlay for different Commercial Vehicles (CVs) with total number of 3283, 6060, 7900 and 800, and the equivalent factors are 0.001, 0.18, 1.56 and 7.2 respectively. By using Asphalt Institute fatigue criteria, appraise the allowable number of ESAL on the overlaid asphalt pavement.

(8 marks)

(c) Road construction and maintenance activities shall be properly providing a maintenance and information data for government decision-makers in future investment strategies within constrained to funding levels. Based on these statements. Write and justify a suitable tool analysis to evaluate the different investment strategies so they can maximize performance in further alternative for road construction and maintenance.

(9 marks)

- END OF QUESTIONS -

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Table Q2(c)(i): Traffic analysis

Vehicle Type	Number of Vehicles	Truck Factor	Growth Factor
Single unit's trucks			
2 axles (4 tires)	87,700	0.003	29.8
2 axles (6 tires)	53,200	0.25	29.8
3 axles or more	18,800	0.86	29.8
Tractor semitrailers and combinations			
4 axles or less	34,900	0.92	29.8
5 axles	61,200	1.25	29.8
6 axles or more	21,300	1.54	29.8

Table Q2(c)(ii): Suggested Levels of Reliability for Various Functional Classifications *(AASTHO, 1986)*

Functional Classification	Recommended level of reliability	
	Urban	Rural
Interstate and other freeway	85 – 99.9	80 – 99.9
Principal arterials	80 – 99	75 – 95
Collectors	80 – 95	75 – 95
Local	50 – 80	50 – 80

Table Q2(c)(iii): Load transfer coefficient for various pavement types and design conditions *(AASTHO, 1986)*

Type of Shoulder	Asphalt		Tied Portland Cement Concrete	
Load Transfer Devices	Yes	No	Yes	No
JPCP and JRCP	3.2	3.8 – 4.4	2.5 – 3.1	3.6 – 4.2
CRCP	2.9 – 3.2	N/A	2.3 – 2.9	N/A

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Table Q2(c)(iv): Recommended drainage coefficient for untreated bases and sub-bases in flexible pavements (AASTHO, 1986)

Quality of drainage		**Percentage of time pavement structure is exposed to moisture levels approaching saturation**			
Rating	**Water removed within**	**Less than 1%**	**1 – 5%**	**2 – 25%**	**Greater than 25%**
Excellent	2 hours	1.40 – 1.35	1.35 – 1.30	1.30 -1.20	1.20
Good	1 day	1.35 – 1.25	1.25 – 1.15	1.15 – 1.00	1.00
Fair	1 week	1.25 – 1.15	1.15 – 1.05	1.00 – 0.80	0.80
Poor	1 month	1.15 – 1.05	1.05 – 0.80	0.80 – 0.60	0.60
Very poor	Never drain	1.05 – 0.95	0.95 – 0.75	0.75 – 0.40	0.40

Table Q2(b)(v): Standard Normal Deviation for Various Levels of Reliability (AASTHO, 1986)

Reliability (%)	**Standard normal deviate (Z_R)**	**Reliability (%)**	**Standard normal deviate (Z_R)**
50	0.000	93	-1.476
60	-0.253	94	-1.555
70	-0.524	95	-1.645
75	-0.674	96	-1.751
80	-0.841	97	-1.881
85	-1.037	98	-2.054
90	-1.282	99	-2.327
91	-1.340	99.9	-3.090
92	-1.405	99.99	-3.750

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Table Q2(c)(vi): Ranges of loss of support factors for various types of materials (AASTHO, 1986)

Type of Material	**Resilient Modulus, *(E)* (lb/in^2)**	**Loss of Support (LS)**
Cement treated granular base	1,000,000 to 2,000,000	0.0 to 1.0
Cement aggregate mixtures	500,000 to 1,000,000	0.0 to 1.0
Asphalt treated base	350,000 to 1,000,000	0.0 to 1.0
Bituminous stabilized mixtures	40,000 to 300,000	0.0 to 1.0
Lime stabilized mixtures	20,000 to 70,000	1.0 to 3.0
Unbound granular materials	15,000 to 45,000	1.0 to 3.0
Fine grained or natural subgrade materials	3,000 to 40,000	2.0 to 3.0

Note: *E* in this table refers to the general symbol for elastic or resilient modulus of the material.

SOURCE: Adopted from B.F. McCullough and Gary E. Elkins, *CRC* Pavement Design Manual, Austin Research Engineers, Inc., Austin, Texas, October 1979.

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

Table Q3(b)(i): 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 =**	

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Table Q3(b)(ii): 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).

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Table Q3(b)(iii): 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 Q3(b)(iv): 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 Q3(b)(v): 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)

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Table Q3(b)(vi): 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 Q3(b)(vii): 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)

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Table Q3(b)(viii): 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 Q3(b)(ix): 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)

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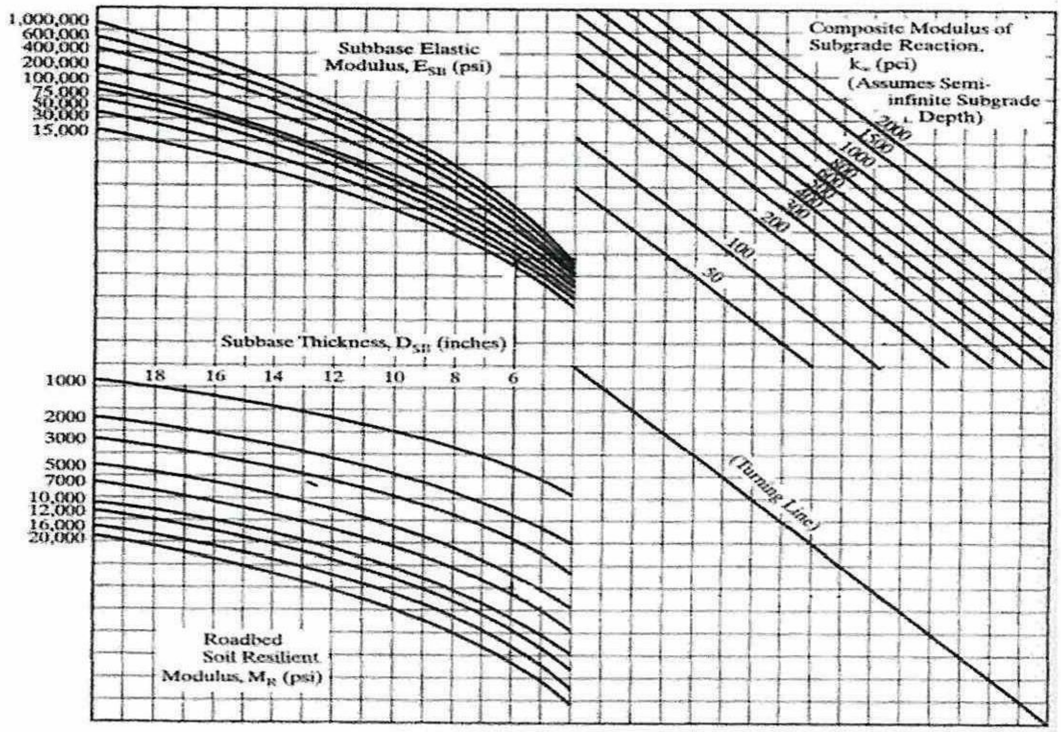

Figure Q2(c)(i): Chart for Estimating Composite Modulus of Sub-grade Reaction (AASHTO, 1986)

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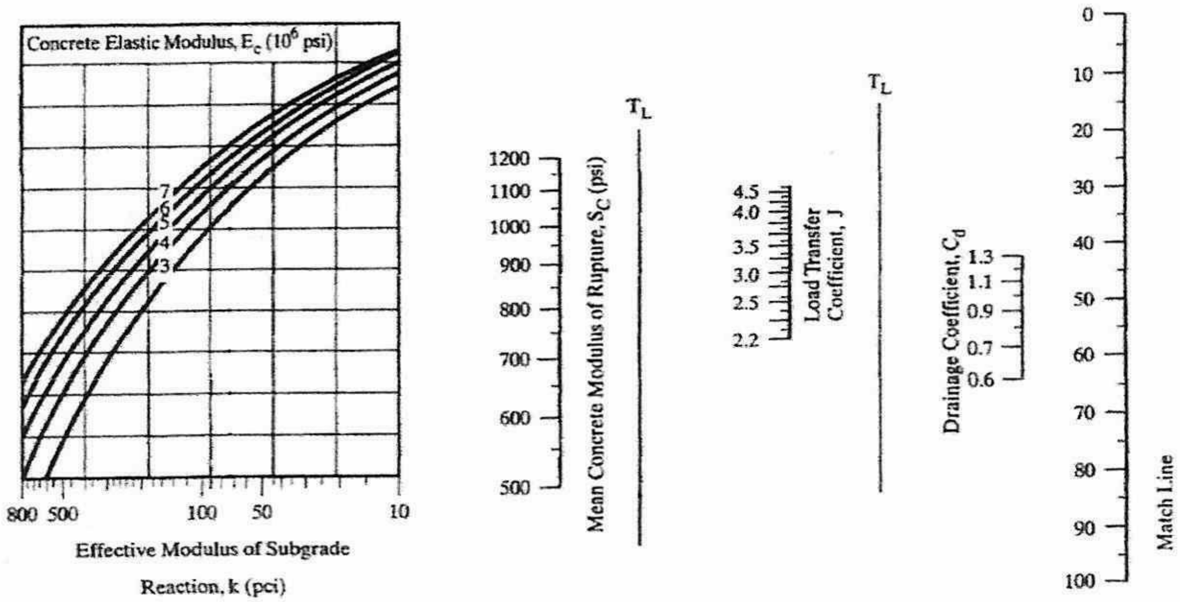

Figure Q2(c)(ii): Design chart for rigid pavements (AASHTO, 1986)

FINAL EXAMINATION

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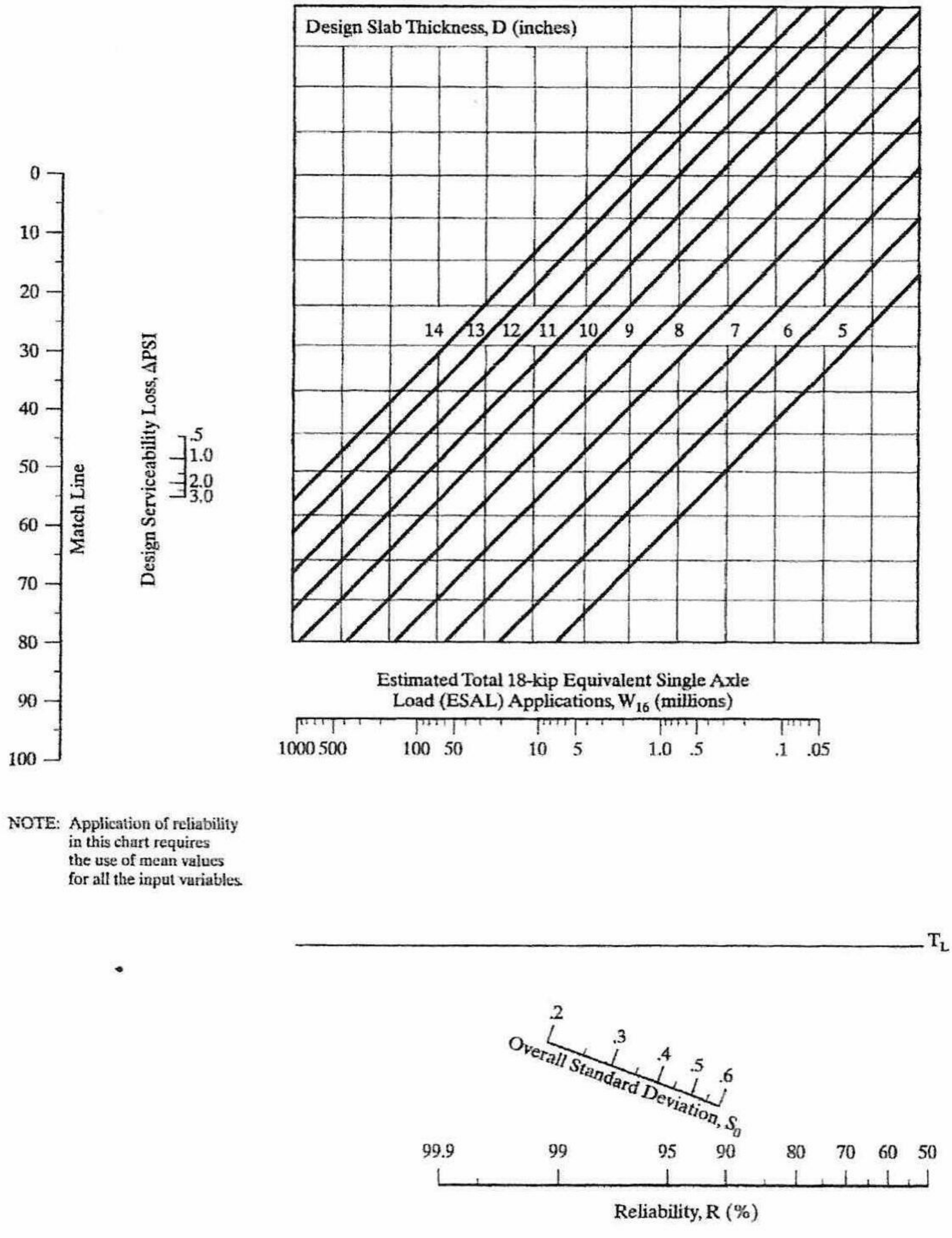

Figure Q2(c)(iii): Design chart for rigid pavements (continue) (AASHTO, 1986)

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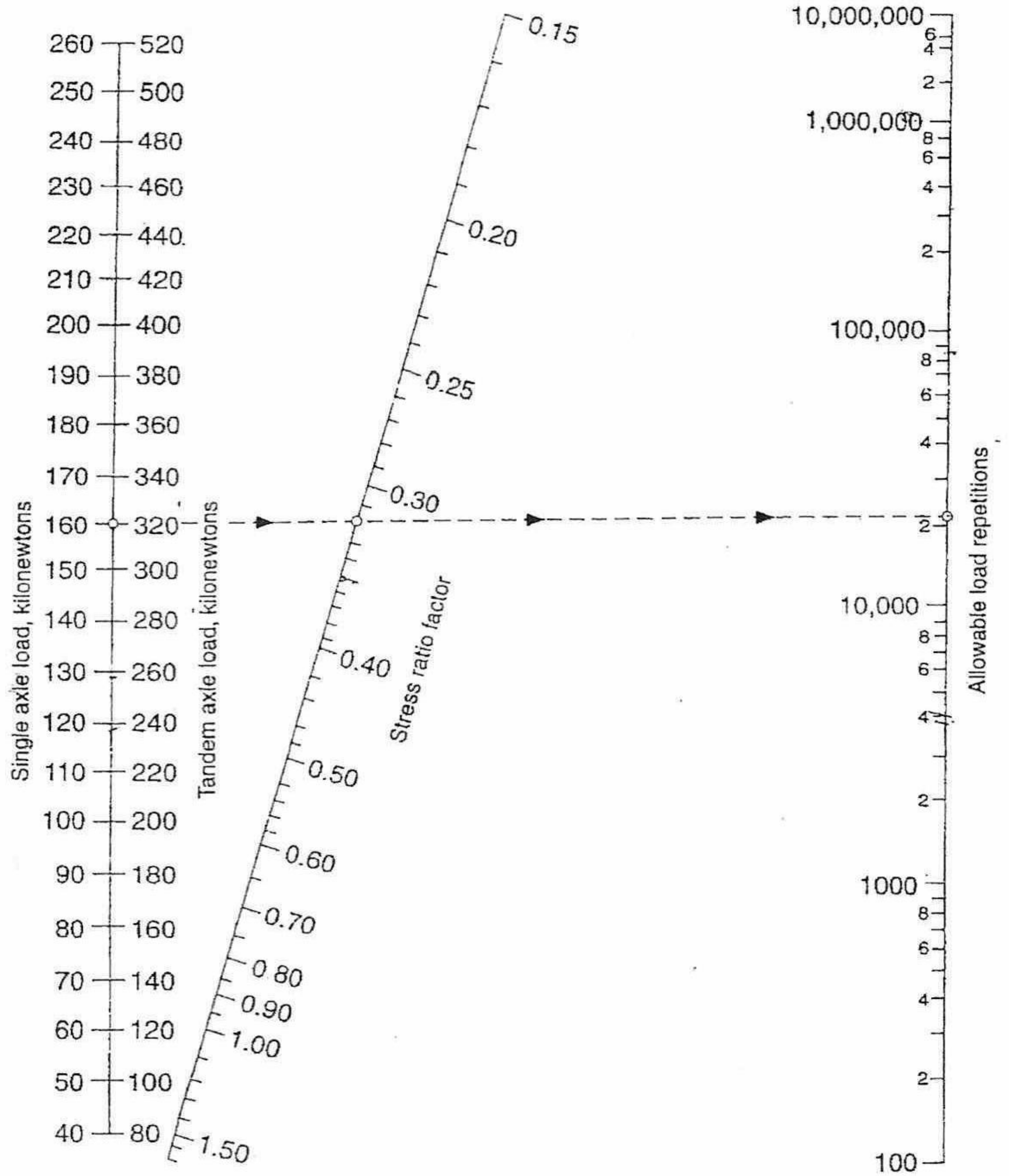

Figure Q3(b)(i): Fatigue Analysis – Allowable repetitions based on stress ratio factor (with or without concrete shoulder)

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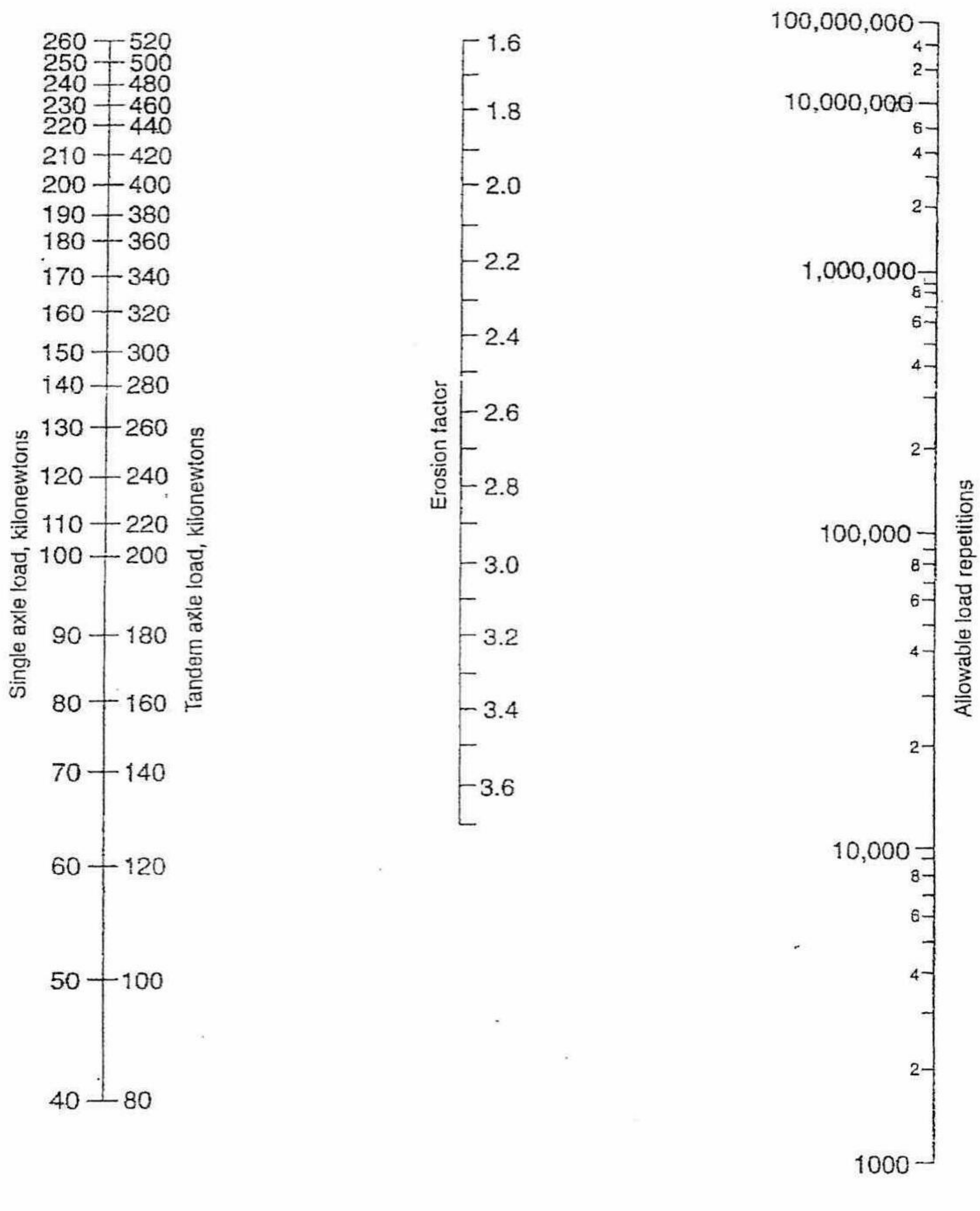

Figure Q3(b)(ii): Erosion Analysis – Allowable repetitions based on erosion factor (with concrete shoulder)

FINAL EXAMINATION

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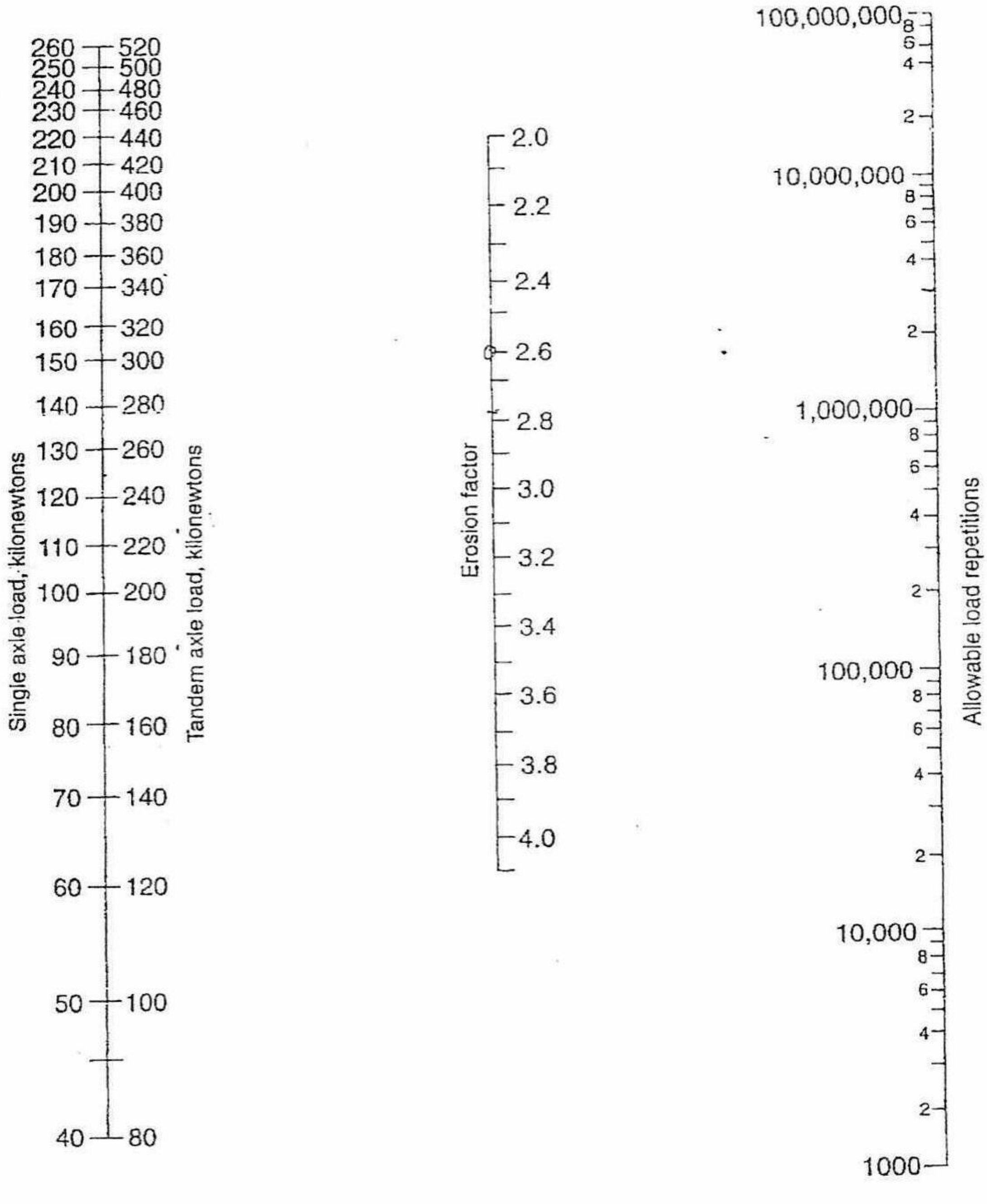

Figure Q3(b)(iii): Erosion Analysis – Allowable repetitions based on erosion factor (without concrete shoulder)

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FINAL EXAMINATION

SEMESTER/SESSION : SEMESTER II 2022/2023
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PROGRAMME CODE : BFF
COURSE CODE : BFT 40203

Appendix A: Formulas

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

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

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

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

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

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

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

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

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

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