UNIVERSITI TUN HUSSEIN ONN MALAYSIA

FINAL EXAMINATION
SEMESTER II
SESSION 2014/2015

COURSE NAME	:	PAVEMENT ENGINEERING
COURSE CODE	:	BFT 40203
PROGRAMME	:	BACHELOR OF CIVIL ENGINEERING WITH HONOURS
EXAMINATION DATE	:	JUNE 2015/JULY 2015
DURATION	:	3 HOURS
INSTRUCTION	:	ANSWER **FOUR (4)** QUESTIONS ONLY

THIS QUESTION PAPER CONSISTS **FIFTEEN (15)** PAGES

Q1 (a) How does an Equivalent Standard Axle Load (ESAL) differ from a truck factor?

(4 marks)

(b) State **TWO (2)** functions of the following flexible pavement courses.

(i) Sub-Base
(ii) Base
(iii) Binder
(iv) Wearing

(8 marks)

(c) An inflated tire with 600 kPa carrying 30 kN resting on a semi-infinite elastic space with the Poisson ratio, μ = 0.5 and the Elastic modulus, E = 1400 MPa. The location of interest is at depth of 0.1 m and radial offset of 0.0 m.

(i) Compute the vertical and radial normal stress.
(ii) Compute the surface vertical deflection under the same tire.
(iii) If the Elastic modulus, E increase to = 5000 MPa, compute the vertical deflection under the same tire and comment the effects of Elastic modulus, E on the surface vertical deflection.

(13 marks)

Q2 (a) The American Association of State Highway and Transportation Officials (AASHTO) design method for road pavement is based on empirical equation obtained from American Association of State Highway Officials (AASHO) road test.

(i) State the **THREE (3)** factors that should be considered in flexible pavement design.

(3 marks)

(ii) Recommend the design values of the pavement serviceability index (PSI) for major highways and highways with lower traffic volumes.

(2 marks)

(b) **<u>FIGURE Q2(a)</u>** in Appendix shows a flexible pavement system with given resilient moduli and layer thicknesses. If the predicted Equivalent Standard Axle Load (ESAL) = 18.8 x 10^6, reliability (R) = 95%, standard deviation (So) = 0.30, initial serviceability (*Po*) = 4.4, and terminal serviceability (*Pt*) = 2.9, calculate the thickness of flexible pavement design and draw the structure layers if water removed from the base and subbase layers is very poor and never drain, which pavement exposure to moisture is 30%.

You may refer to **FIGURE Q2(b)** to **FIGURE Q2(d)**, **TABLE 2(a)** to **TABLE 2(f)** and the following equations in Appendix, when answering this question.

(20 marks)

Q3 (a) Define the phenomenon of pumping and its effects on rigid pavements.

(5 marks)

(b) A 6 in layer of cement-treated granular material is to be used as sub-base for rigid pavement. **TABLE Q3(a)** shown the monthly values for the roadbed soil resilient modulus and the sub-base elastic (resilient) modulus. The rock depth is located in 5 ft below the sub-grade surface and the rigid pavement slab thickness is 9 in.

Using the American Association of State Highway and Transportation Officials (AASHTO) method, estimate the effective modulus of sub-grade reaction.

You may refer to **FIGURE Q3(a)** to **FIGURE Q3(c)** and **TABLE 3(a)** to **TABLE 3(e)** in Appendix when answering this question:

(20 marks)

Q4 (a) Describe **TWO (2)** types of highway rigid pavements which constructed with steel reinforcement and give the conditions under which each type will be constructed.

(6 marks)

(b) List and describe the types of stresses that are developed in rigid pavements.

(6 marks)

(c) **FIGURE Q4(a)** shows a rigid pavement slab 25 ft (7.62 m) long, 12 ft (3.66 m) wide and 8 in. (203 mm) thick, subjected to a temperature differential of 11°C. If the modulus of sub-grade reaction, k = 54.2 MN/m^3 and coefficient of thermal expansion of concrete, α_t = 9 x 10^6 mm/mm/°C, determine the maximum curling stress in the interior and the edge of the slab.

(13 marks)

Q5 (a) A full depth asphalt pavement consisting of a 51 mm Hot Mix Asphalt (HMA) and 152 mm of emulsified asphalt base course with the equivalent factor = 0.83 is to be overlaid. Even though there are cracks on the surface, the crackings are not open, and the pavement appears to be stable. If the pavement has a Pavement Serviceability Index (PSI) of 2.0 and the conversion factor is 0.7, determine its effective thickness.

(4 marks)

(b) What is the difference between Pavement Serviceability Index (PSI) and Present Serviceability Rating (PSR)?

(5 marks)

(c) Describe the **FOUR (4)** characteristics of pavement condition used to evaluate whether a pavement should be rehabilitation, and if so, determine the appropriate treatment.

(8 marks)

(d) An asphalt overlay is placed on an existing asphalt pavement that has been subjected to an Equivalent Standard Axle Load (ESAL) of 7×10^{6}. The horizontal tensile strain at the bottom of the asphalt layer is 1×10^{-4} before overlay and 7×10^{-5} after overlay. By using Asphalt Institute fatigue criteria assuming an elastic modulus of 5×10^{5} psi (3.5 GPa) for the Hot Mix Asphalt (HMA), determine the allowable number of ESAL on the overlaid pavement.

(8 marks)

- END OF QUESTION -

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Surface

E_1 M_{R1} = **400,000** psi

Base

E_2 M_{R2} = 30,000 psi

Subbase

E_3 M_{R3} = 11,000 psi

Subgrade M_{R4} = 5,700 psi

FIGURE Q2(a): Structure Layers of Flexible Pavement

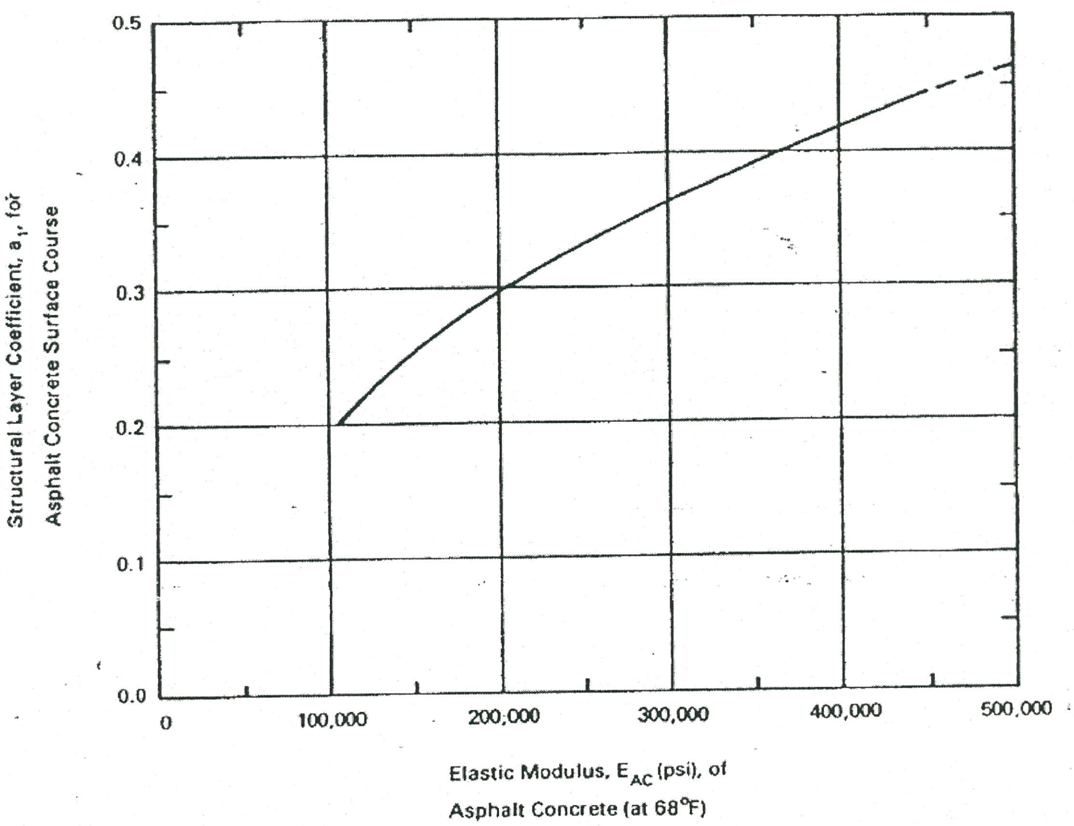

FIGURE Q2(b): Chart for Estimating Structural Layer Coefficient of Dense-Graded Asphalt Concrete Based On The Elastic (Resilient) Modulus. *Source: After AASTHO (1986)*

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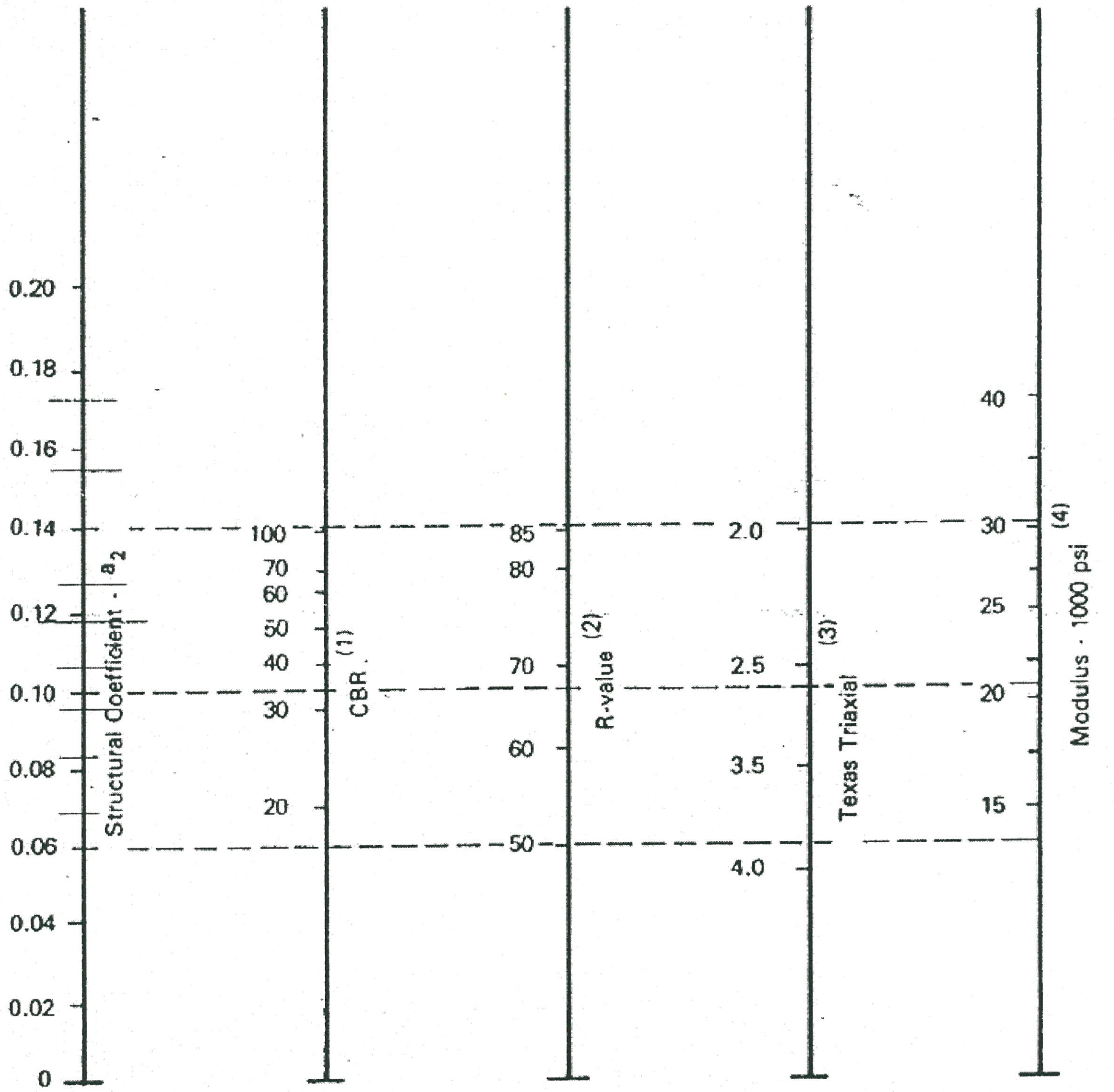

(1) Scale derived by averaging correlations obtained from Illinois.
(2) Scale derived by averaging correlations obtained from California, New Mexico and Wyoming.
(3) Scale derived by averaging correlations obtained from Texas.
(4) Scale derived on NCHRP project *(3)*.

FIGURE Q2(c): Variation in Granular Base Layer Coefficient (a_2) With Various Base Strength Parameters. *Source: After AASTHO (1986)*

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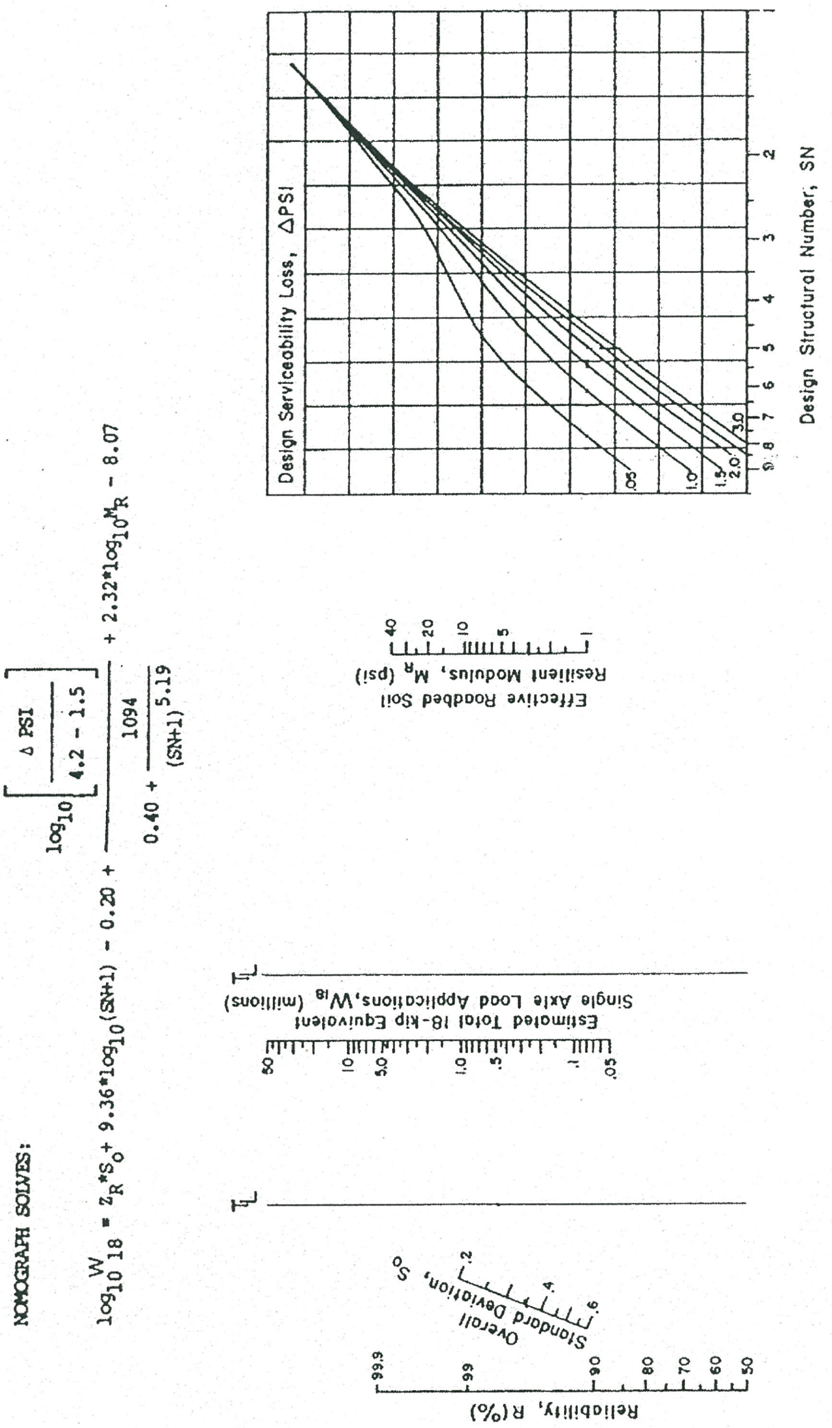

FIGURE Q2(d): Design Chart for Flexible Pavements Based on Using Mean Values for Each Input. *Source: After AASTHO (1986)*

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TABLE 2(a): Suggested Levels of Reliability for Various Functional Classifications

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

Source: After AASTHO (1986)

TABLE 2(b): Recommended Drainage Coefficient for Untreated Bases and Sub bases in Flexible Pavements

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

Source: After AASTHO (1986)

TABLE 2(c): Minimum Thickness for Asphalt Surface and Aggregate Base

Traffic (ESAL)	Asphalt Concrete (in.)	Aggregate Base (in.)
< 50,000	1.0	4
50,000 – 150,000	2.0	4
150,001 – 500,000	2.5	4
500,001 – 2,000,000	3.0	6
2,000,001 – 7,000,000	3.5	6
> 7,000,000	4.0	6

Source: After AASTHO (1986)

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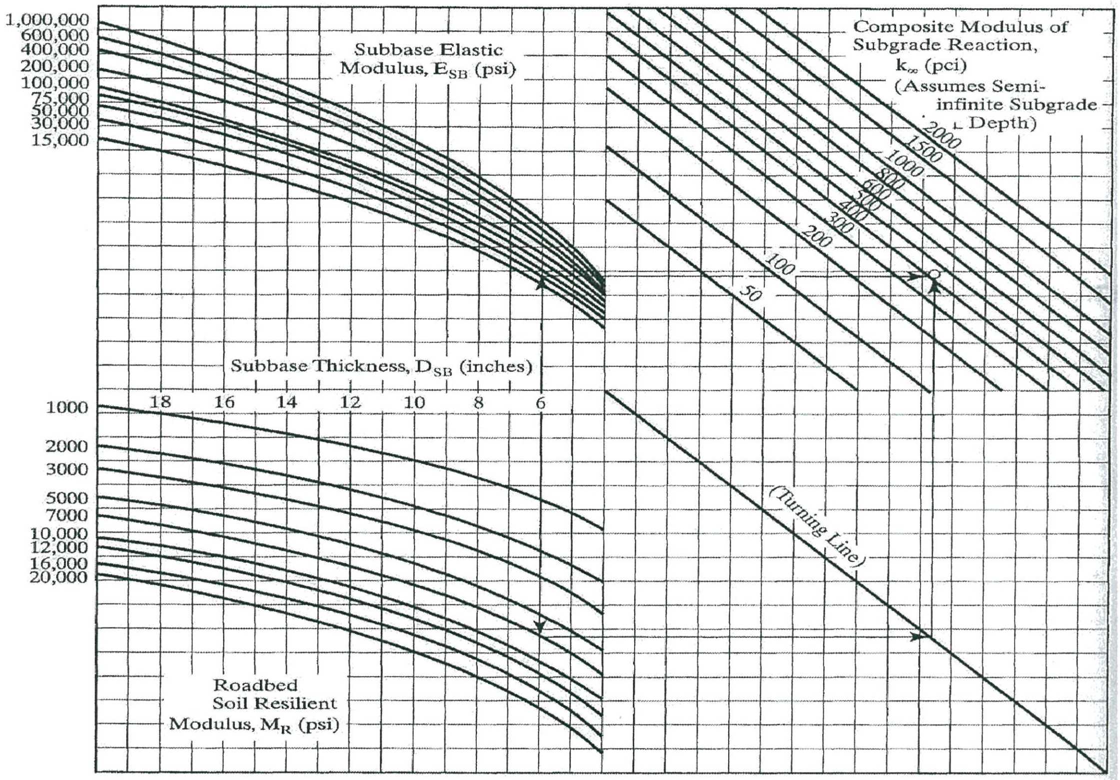

FIGURE Q3(a): Estimating Composite Modulus of Sub-grade Reaction

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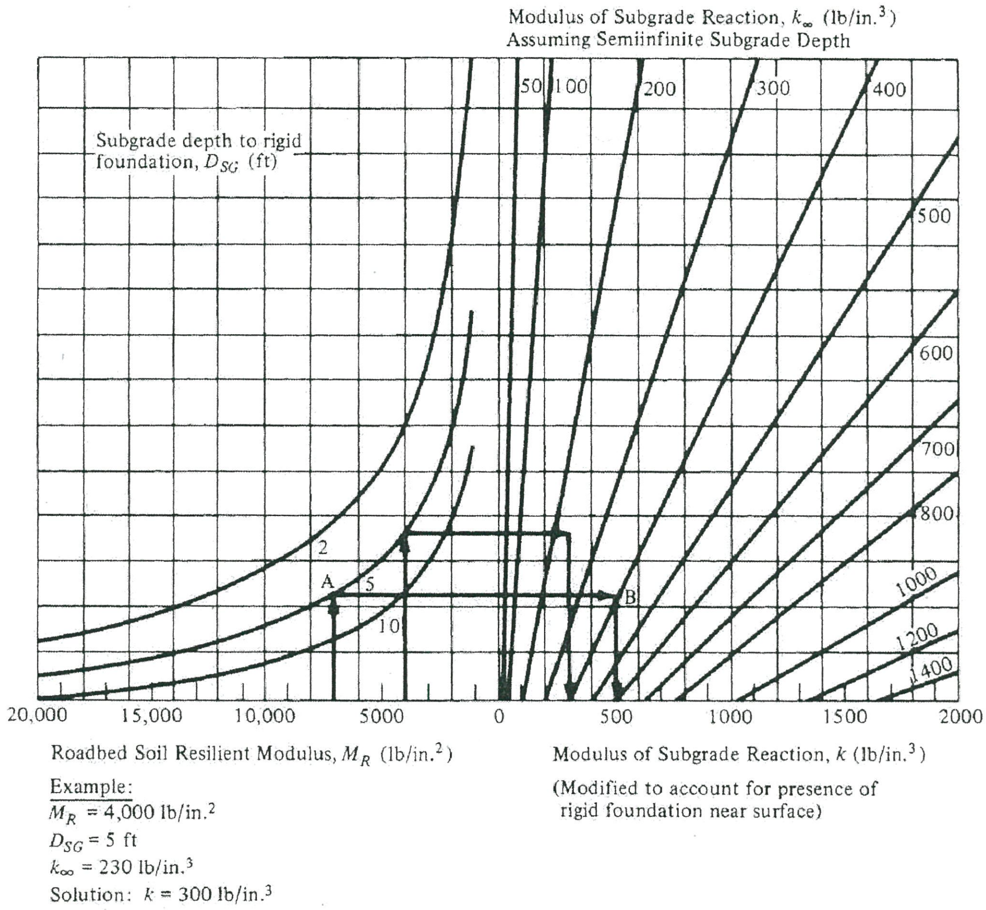

FIGURE Q3(b): Modifying Modulus of Sub-grade Reaction

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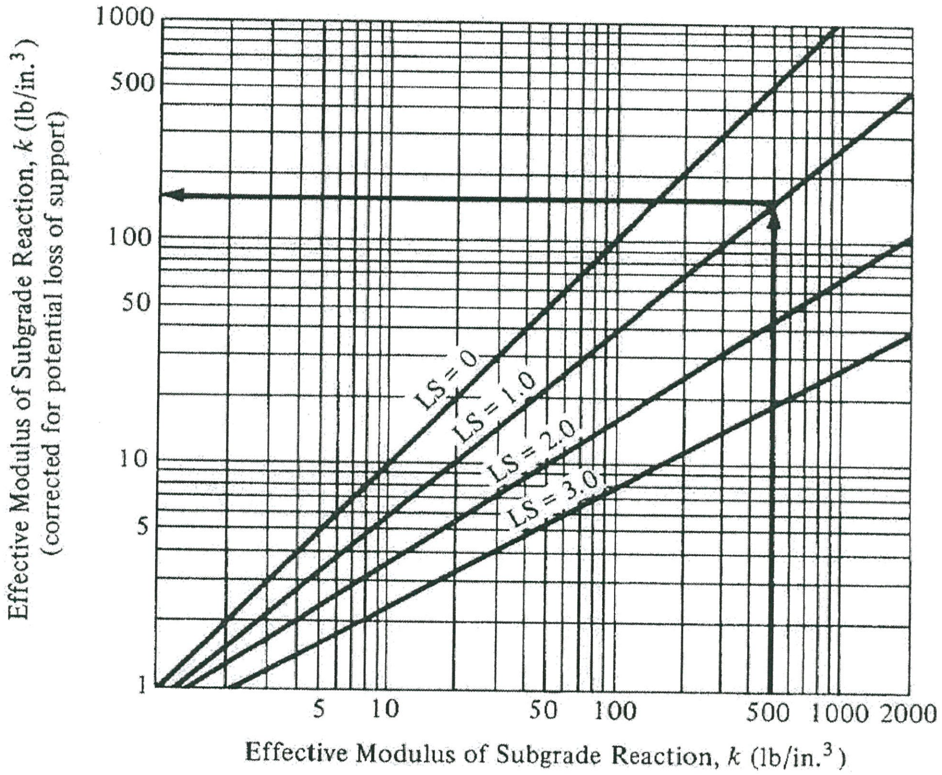

FIGURE Q3(c): Correction of Effective Modulus of Sub-grade Reaction

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TABLE 3(a): The Modulus of Rigid Pavement

Month	Roadbed Modulus, M_R (Ib/in^2)	Sub-base Modulus, E_{SB} (Ib/in^2)	Composite, k value (lb/in.^{2})	k value (E_{SB}) on Rigid Foundation	Relative Damage, u_f
January	20,000	50,000	1100	1350	0.35
February	20,000	50,000	1100	1350	0.35
March	2,500	15,000	160	230	0.86
April	4,000	15,000	230	300	0.78
May	4,000	15,000	230	300	0.78
June	7,000	20,000	400	500	0.60
July	7,000	20,000	400	500	0.60
August	7,000	20,000	400	500	0.60
September	7,000	20,000	400	500	0.60
October	7,000	20,000	400	500	0.60
November	4,000	15,000	230	300	0.78
December	20,000	50,000	1100	1350	0.35

TABLE 3(b): Ranges of Loss of Support Factors for Various Types of Materials

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

Note: E in this table refers to the general symbol for elastic or resilient modulus of the material.
SOURCE: Adapted from B.F. McCullough and Gary E. Elkins, *CRC Pavement Design Manual*, Austin Research Engineers, Inc., Austin, Tex., October 1979.

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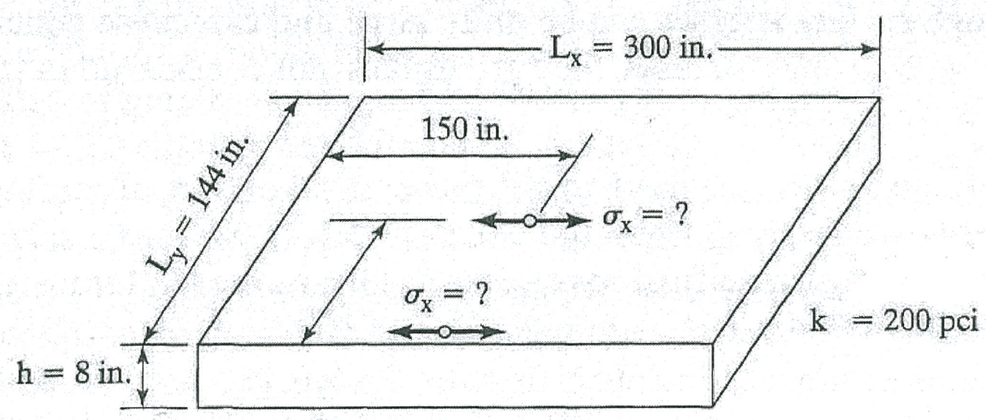

FIGURE Q4(a): Rigid Pavement Slab

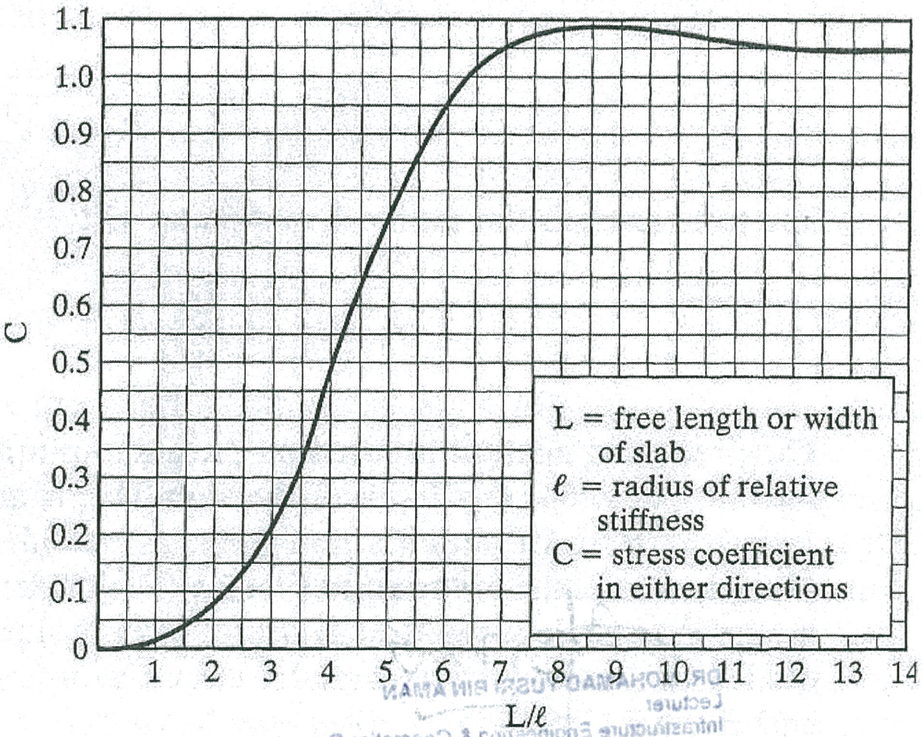

FIGURE Q4(b) : Stress Correction Factor for Finite Slab (After Bradbury, 1938)

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Formulae:

$$\log\left(\frac{W_{tx}}{W_{t18}}\right) = 4.79\log(18+1) - 4.79\log(L_x + L_2) + 4.33\log L_2 + \frac{G_t}{\beta_x} - \frac{G_t}{\beta_{18}}$$

$$\beta_x = 0.40 + \frac{0.081(L_x + L_2)^{3.23}}{(SN+1)^{5.19} L^{3.23}}$$

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

$$G_t = \log\left(\frac{4.2 - p_t}{4.2 - 1.5}\right)$$

$$ESAL = (ADT)_0(T)(T_r)(G)(D)(L)(365)(Y)$$

$$SN = a_1D_1 + a_2D_2 + a_3D_3$$

$$SN = a_1D_1 + a_2D_2m_2 + a_3D_3m_3$$

$$D_1 = \frac{SN_1}{a_1m_1},\quad D_2 = \frac{SN_2 - SN_1*}{a_2m_2},\quad D_3 = \frac{SN_3 - SN_2* - SN_1*}{a_3m_3}$$

$$\sigma_x = \frac{E\alpha_t\Delta_t}{2(1-v^2)}(C_x + vC_y)$$

$$\ell = \left[\frac{Eh^3}{12(1-v^2)k}\right]^{0.25}$$

$$\sigma = \frac{CE\alpha_t\Delta_t}{2}$$

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

$$N_f = 0.0685(\in_t)^{-5.671}(E_1)^{-2.363}$$

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

$$h_e = \sum_{i=1}^{n} h_i C_i E_i$$

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

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

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

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

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

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

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

$$w_0 = \frac{2\left(1 - v^2\right)pa}{E}$$

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