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FINAL EXAMINATION
SEMESTER II
SESSION 2016/2017

COURSE NAME	:	PAVEMENT ENGINEERING
COURSE CODE	:	BFT 40203
PROGRAMME	:	BFF
EXAMINATION DATE	:	JUNE 2017
DURATION	:	3 HOURS
INSTRUCTION	:	ANSWER **ALL** QUESTIONS

THIS QUESTION PAPER CONSISTS **SEVENTEEN (17)** PAGES

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Q1 (a) State the differences between Equivalent Standard Axle Load (ESAL) and truck factor.

(3 marks)

(b) Flexible pavement is constructed of bitumen and granular materials based on mechanistic-empirical method. Based on that statement, explain the method of design and sketch the loading distributions which relate to the pavement performance.

(5 marks)

(c) A total load of 20,000 lb (89.0 kN) was applied on the surface of a two layer system through a rigid plate 12 in. (305 mm) in diameter as shown in **Figure Q1(a)**. Layer one has a thickness of 8 in. (203 mm) and layers two has an elastic modulus of 6,400 psi (44.2 MPa). Both layers are incompressible with a Poisson ratio of 0.5. If the deflection of the plate due to loading is 0.1 in. (2.54 mm), evaluate the elastic modulus of layer one.

(6 marks)

(d) South-North freeway with a three lane carriageway is constructed with the road surface, base and subbase layers using the following design parameters:

Equivalent Single Axle Load (ESAL) = 2×10^6
Initial Present Serviceability Index, $PSI_i = 4.5$
Terminal Present Serviceability Index, $PSI_t = 2.5$
Resilient modulus of asphalt concrete, M_{R1} = 450,000 psi (3102.6 MPa)
CBR of crushed stone base = 100%
CBR of gravel subbase = 22%
CBR of subgrade = 6%
Quality of drainage: Surface layer – Good
Base layer – Fair
Subbase layer – Fairly poor
Reliability, R = 99%
Standard deviation, $S_o = 0.35$

Design the thickness of flexible pavement design and draw the structure thickness layers, if the levels of pavement approaching to saturation condition are 30%.

Refer to **Figure Q1(b)** to **Figure Q2(f)**, and **Table 1** to **Table 3**.

(11 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. Based on this statement, write the pavement serviceability evaluation in flexible pavement design.

(3 marks)

(b) State the **FOUR (4)** factors that should be considered in structural design of rigid pavement.

(4 marks)

(c) Explain the difference between Pavement Serviceability Index (PSI) and Present Serviceability Rating (PSR).

(3 marks)

(d) A 6 in. (152.4 mm) layer of cement-treated granular material is to be used as sub-base for rigid pavement. **Table 4** shows the monthly values for the roadbed soil resilient modulus and the sub-base elastic (resilient) modulus. The rock depth is located at 5 ft. below the sub-grade surface and the rigid pavement slab thickness is 9 in (228.6mm).

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 Q2(a)** to **Figure Q2(c)** and **Table 4** to **Table 5** in Appendix when answering this question:

(15 marks)

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

(3 marks)

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

(4 marks)

(c) State and describe the types of stresses that are developed in rigid pavements.

(6 marks)

(d) **Figure Q3(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 20°F (11°C). Due to temperature change, the modulus of sub-grade reaction, $k = 54.2$ MN/m^3 (200 psi) and coefficient of thermal expansion of concrete, $\alpha_t = 5 \times 10^{-6}$ in./in./°F (9×10^6 mm/mm/°C). Analyze the maximum curling stress in the interior and the edge of the slab, if the modulus of concrete, $E = 4 \times 10^6$ psi and Poisson ratio is 0.15.

(12 marks)

Q4 (a) There are four typical pavement rehabilitation techniques work implemented at the road construction site. Explain **TWO (2)** of the techniques involved.

(6 marks)

(b) With the aid of diagrams, describe Pavement Serviceability Index and Road Maintenance.

(5 marks)

(c) Crocodile crack is one type of pavement distress. Describe the crocodile cracks and outline **THREE (3)** possible causes and the probable treatments for this type of pavement distress.

(6 marks)

(d) Describe **FOUR (4)** characteristics of pavement condition used to evaluate whether a pavement should be rehabilitated. If that so, determine an appropriate treatment.

(8 marks)

- END OF QUESTIONS –

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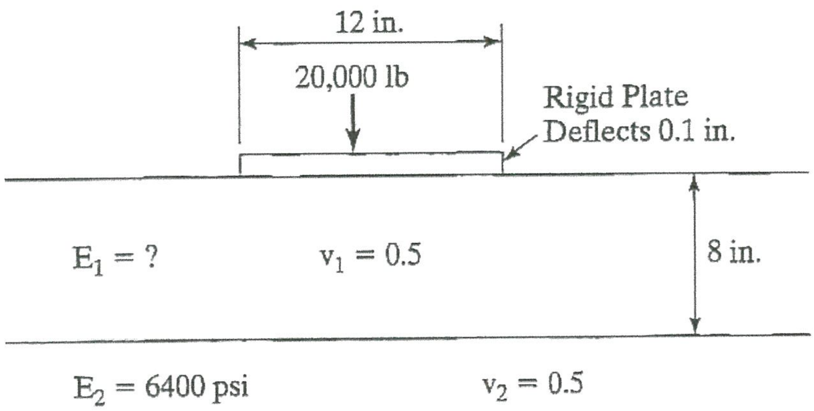

FIGURE Q1(a): Load applied on the surface of a two layer system through a rigid plate

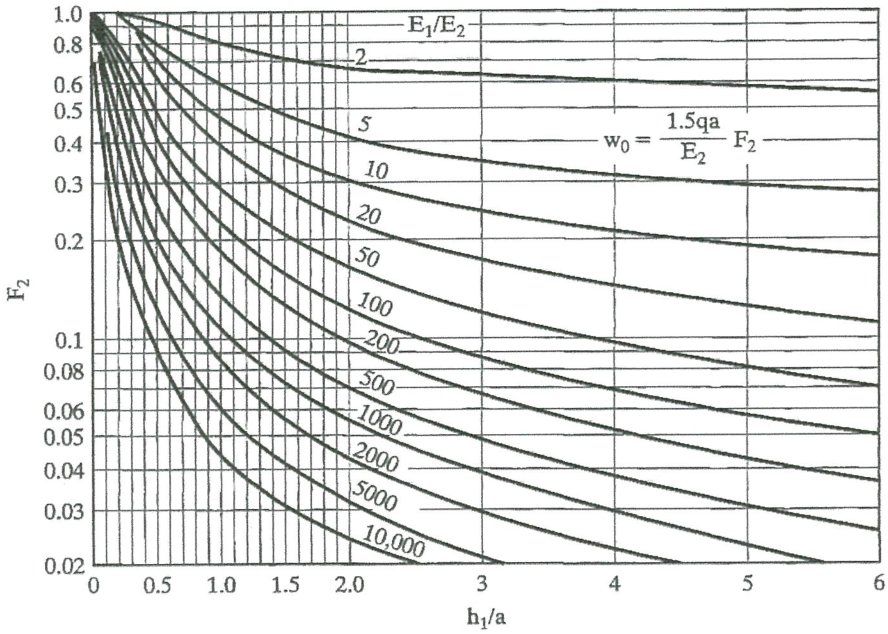

FIGURE Q1(b): Vertical surface deflection for two-layer systems

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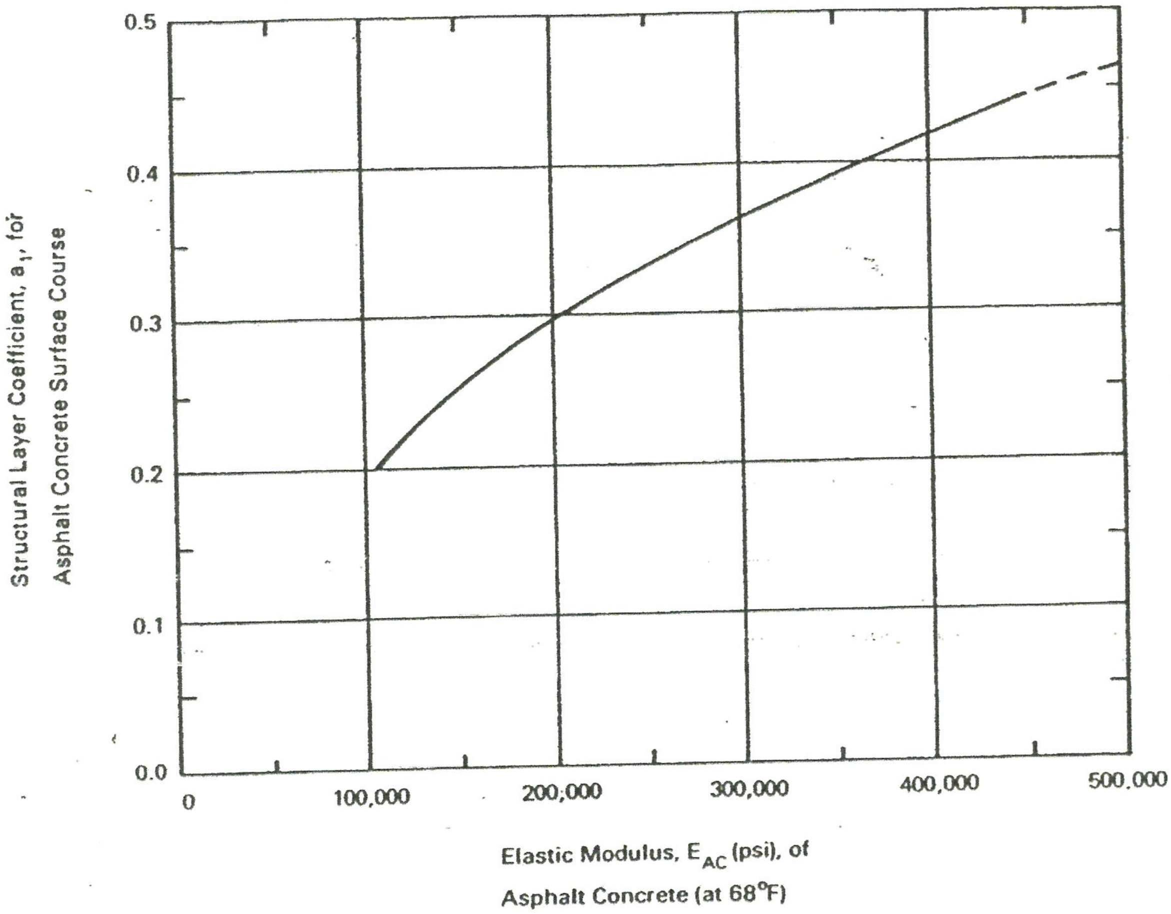

FIGURE Q1(c): Chart for Estimating Structural Layer Coefficient of Dense-Graded Asphalt Concrete Based On The Elastic (Resilient) Modulus. *Source: After AASTHO (1986)*

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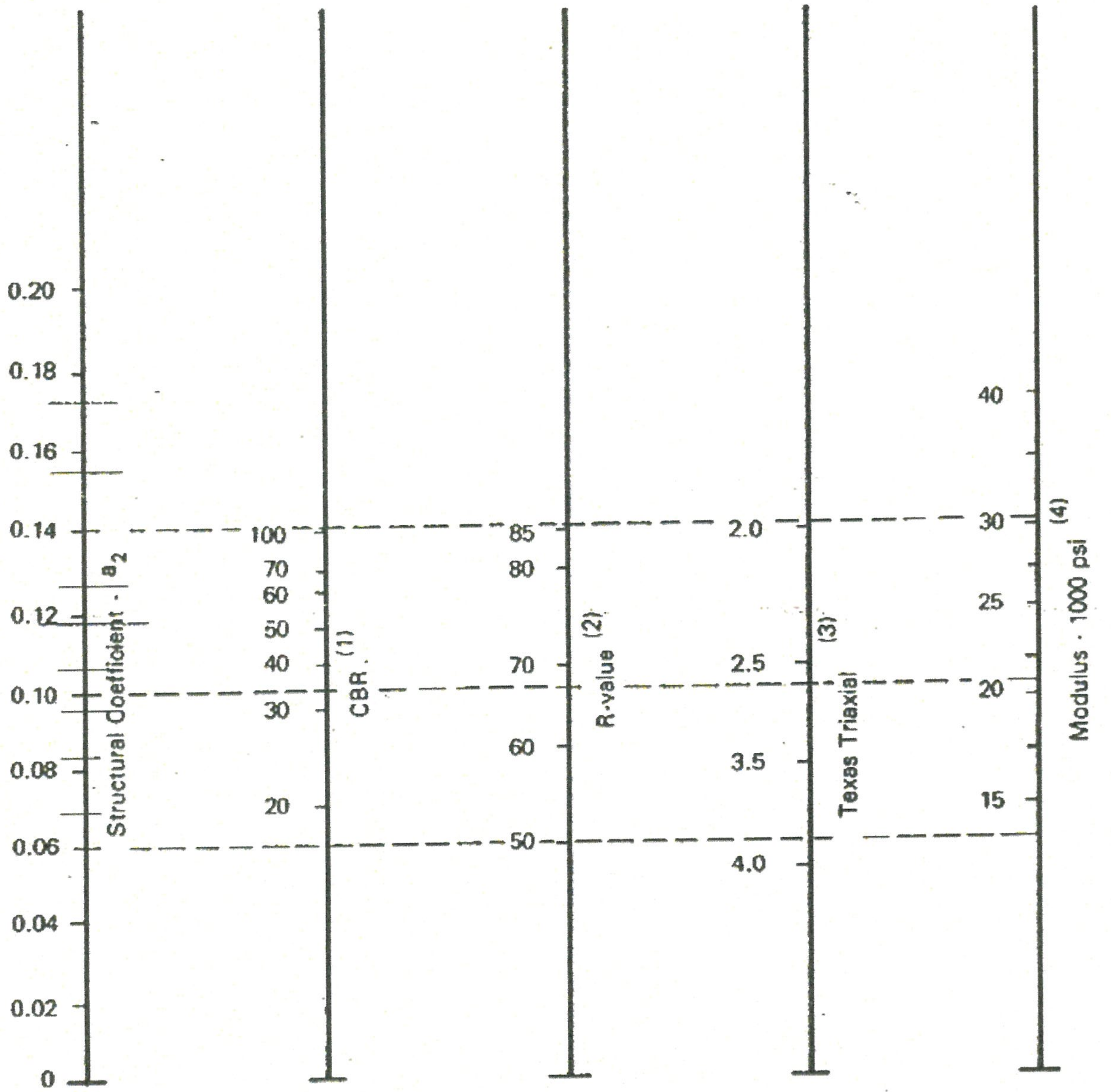

(1) Scale derived by averaging correlations obtained from Illinois.
(2) Scale derived by averaging correlations obtained from California, New Mexico and Wyoming.
(3) Scale derived by averaging correlations obtained from Texas.
(4) Scale derived on NCHRP project *(3)*.

FIGURE Q1(d): Variation in Granular Base Layer Coefficient (a_2) With Various Base Strength Parameters. *Source: After AASTHO (1986)*

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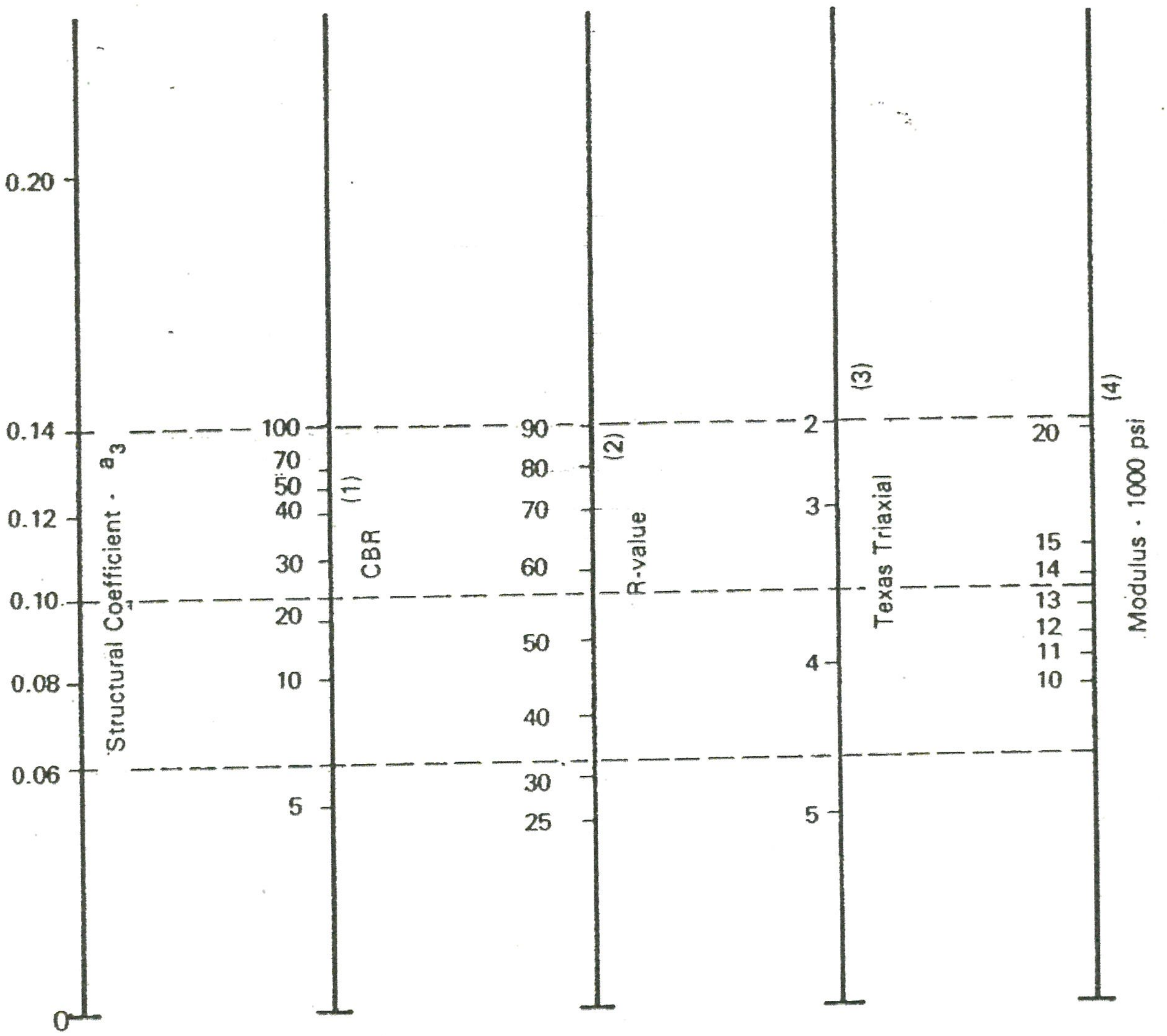

(1) Scale derived from correlations from Illinois.

(2) Scale derived from correlations obtained from The Asphalt Institute, California, New Mexico and Wyoming.

(3) Scale derived from correlations obtained from Texas.

(4) Scale derived on NCHRP project *(3)*.

FIGURE Q1(e): Variation in Granular Subbase Layer Coefficient (a_3) With Various Subbase Strength Parameters. *Source: After AASTHO (1986)*

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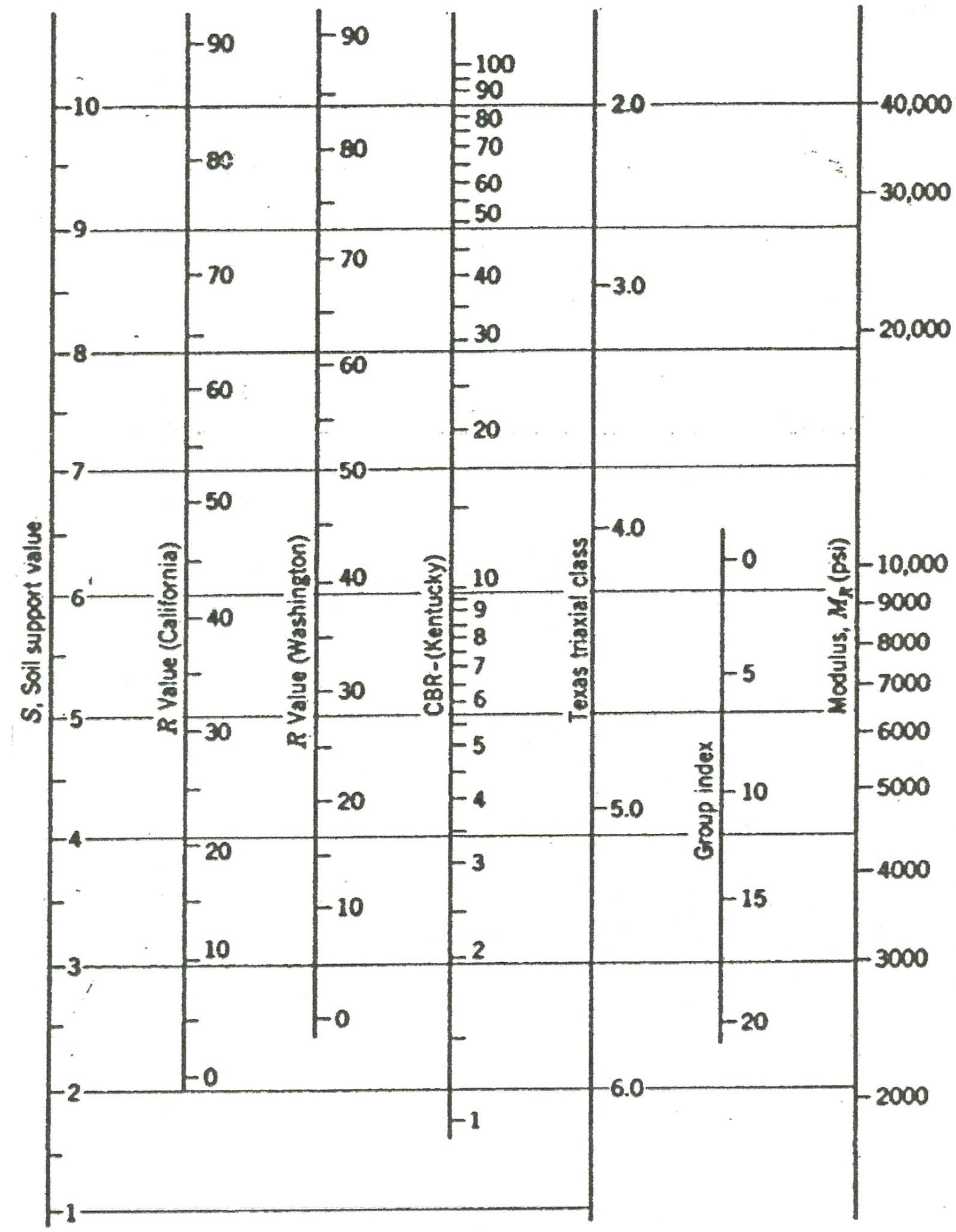

FIGURE Q1(f): Correlation chart for estimating resilient modulus of subgrade soil (1 psi = 6.9 kPa). *Source: After AASTHO (1986)*

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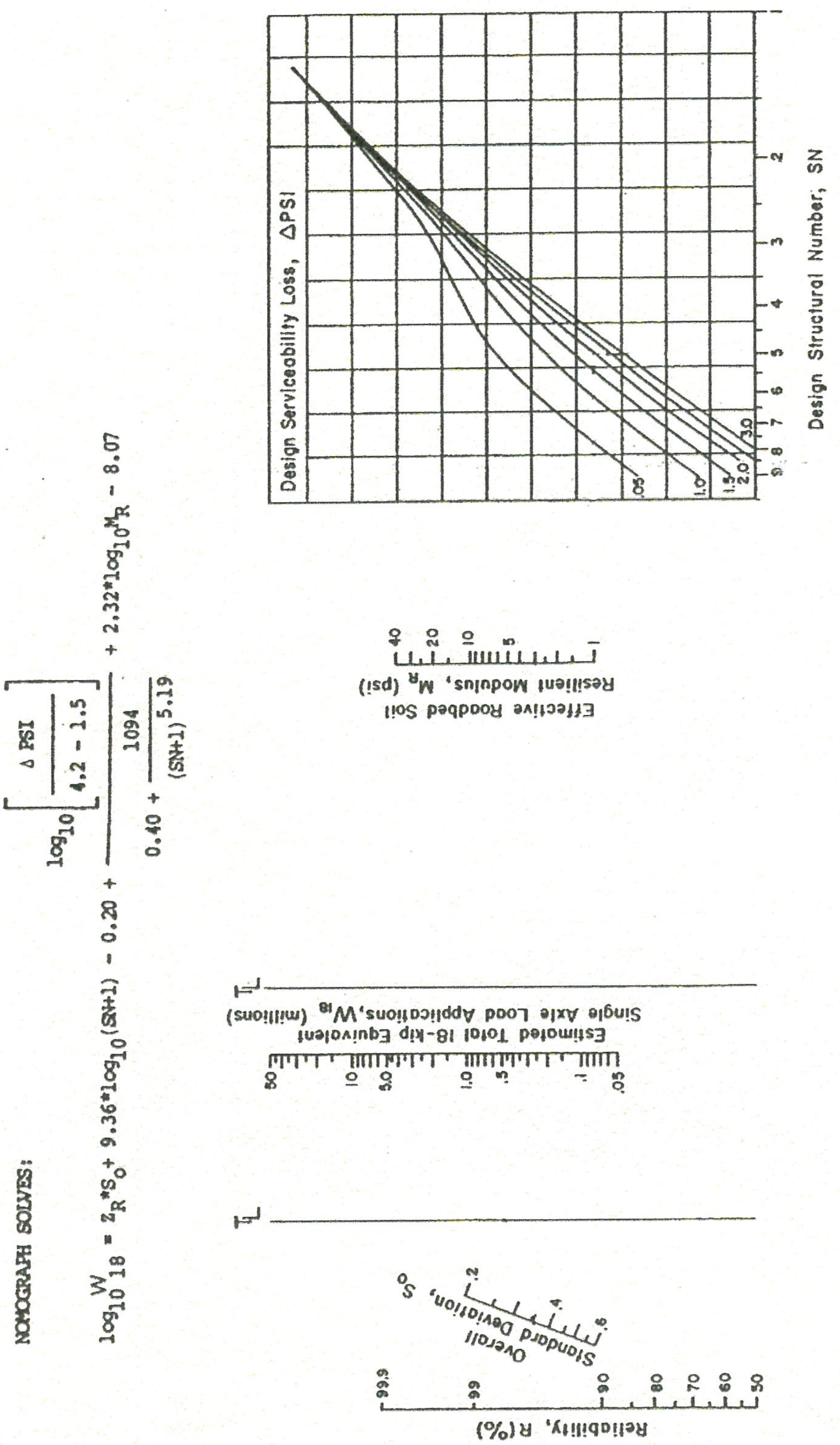

FIGURE Q1(g): Design Chart for Flexible Pavements Based on Using Mean Values for Each Input. *Source: After AASTHO (1986)*

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TABLE 1: 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: 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 3: 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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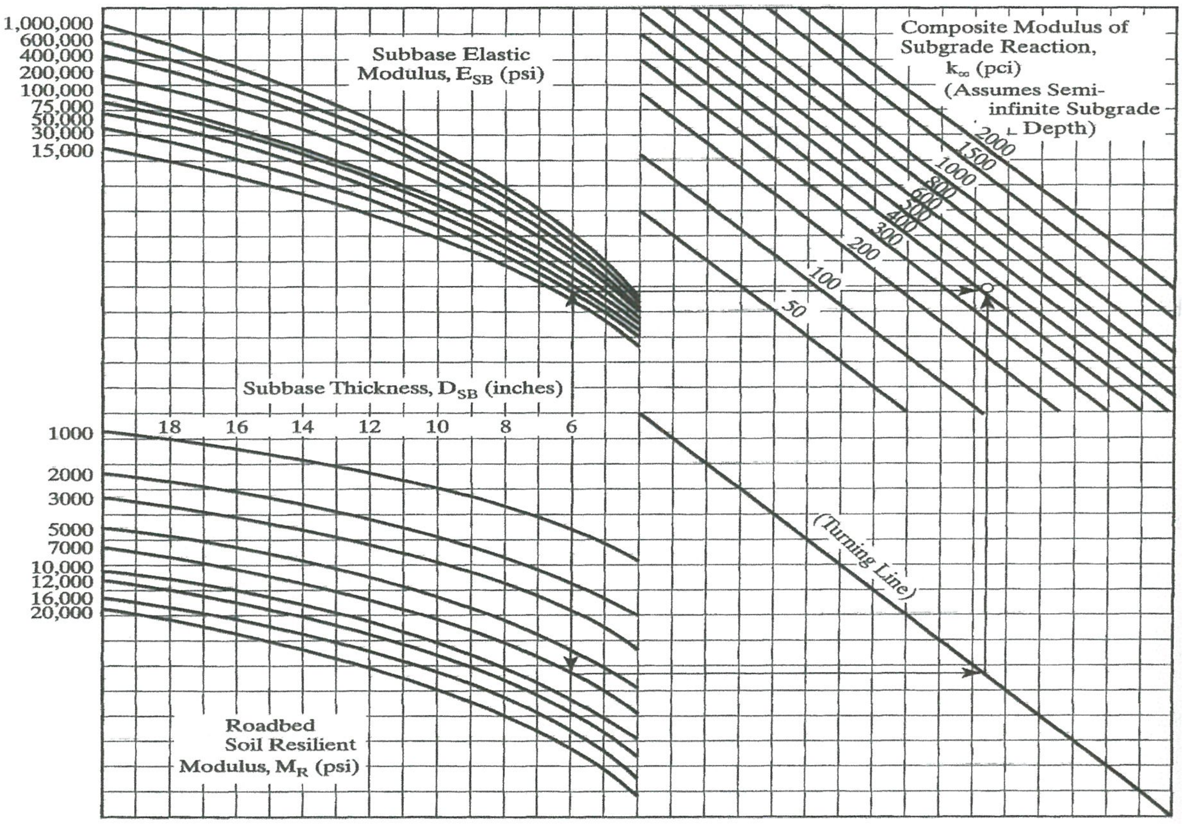

FIGURE Q2(a): Estimating Composite Modulus of Sub-grade Reaction

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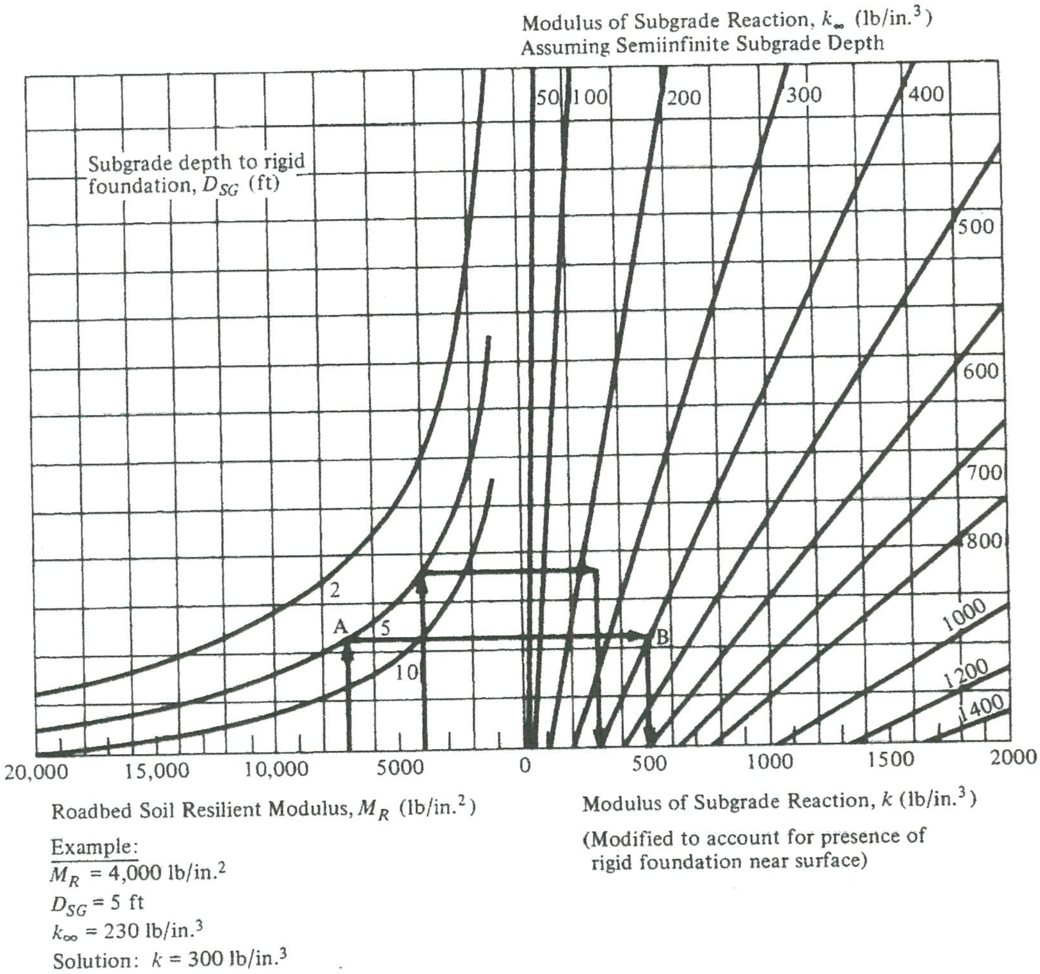

FIGURE Q2(b): Modifying Modulus of Sub-grade Reaction

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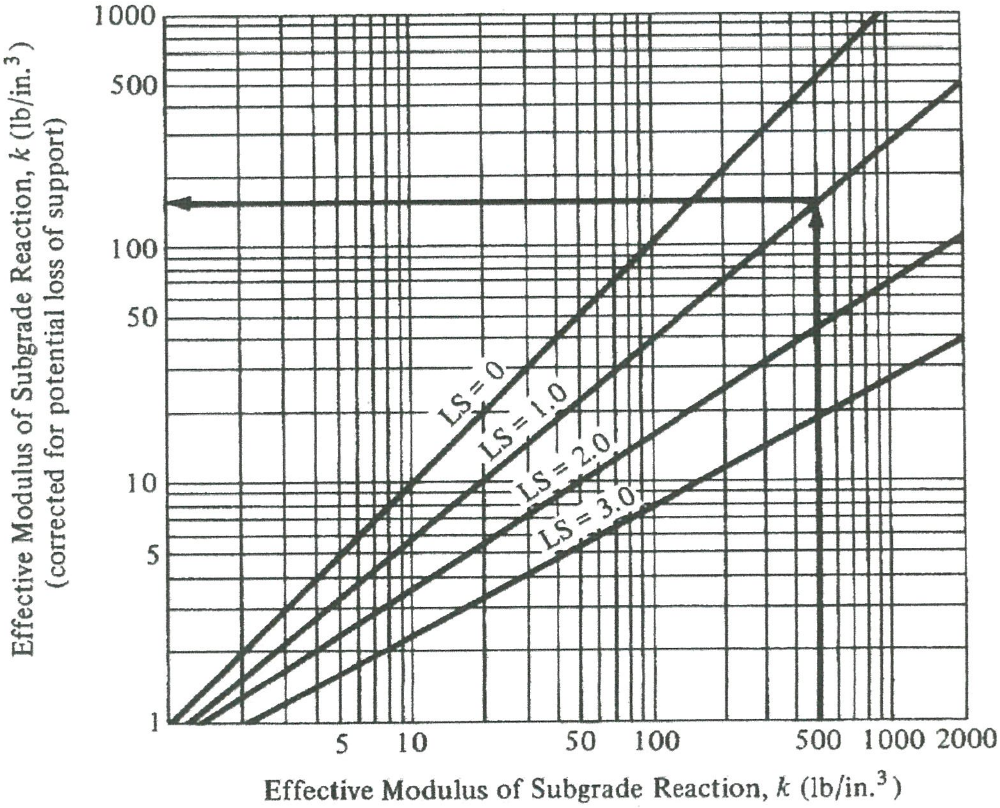

FIGURE Q2(c): Correction of Effective Modulus of Sub-grade Reaction

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TABLE 4: 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 5: 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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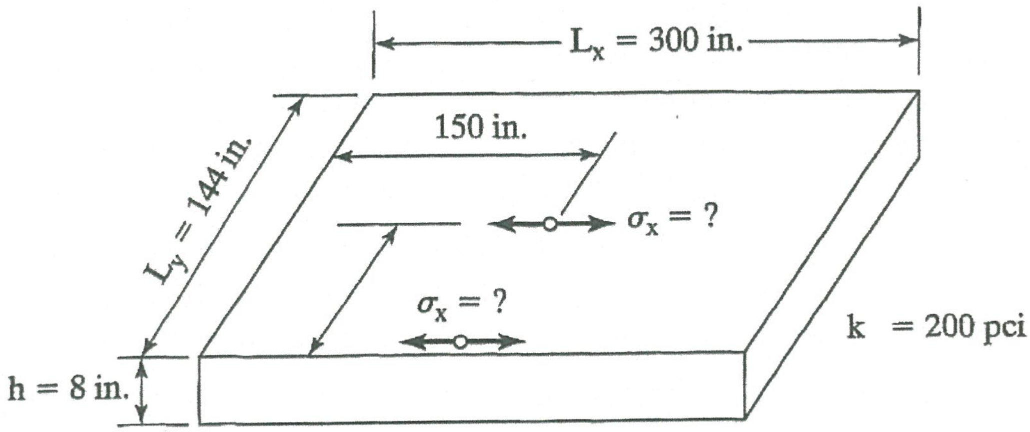

FIGURE Q3(a): Rigid Pavement Slab

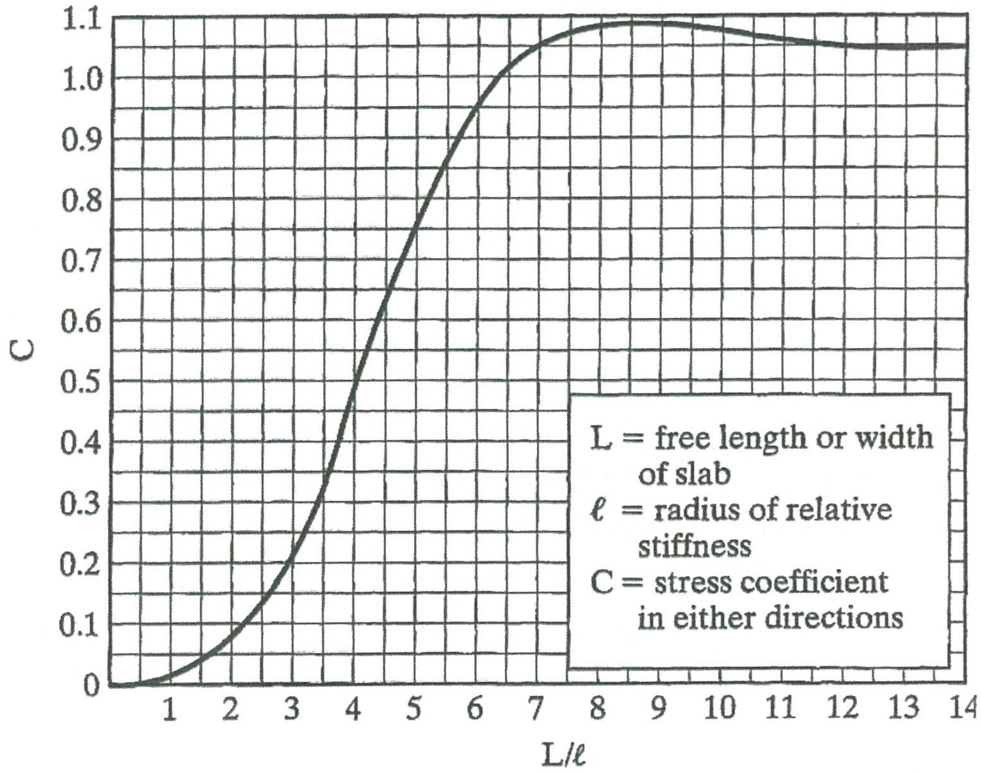

FIGURE Q3(b) : Stress Correction Factor for Finite Slab (After Bradbury, 1938)

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Formulae:

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

$$SN = a_1D_1 + a_2D_2 + a_3D_3$$

$$SN = a_1D_1 + a_2D_2m_2 + a_3D_3m_3$$

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

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

$$\sigma_y = \frac{E\alpha_t\Delta_t}{2(1-v^2)}(C_y + vC_x)$$

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

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

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

$$w_0 = \frac{1.18qa}{E_2}F_2$$