2.6.2 Rigid Pavement

This type of pavement consists of concrete slab and base course (when used in rigid pavement it is called subbase course). These two layers are resting on subgrade soil.

2.6.2.1 Rigid Pavement Types

1. Jointed plain concrete pavement (JPCP)
2. Jointed reinforced concrete pavement (JRCP)
3. Continuous reinforced concrete pavement (CRCP)
4. Prestressed concrete pavements

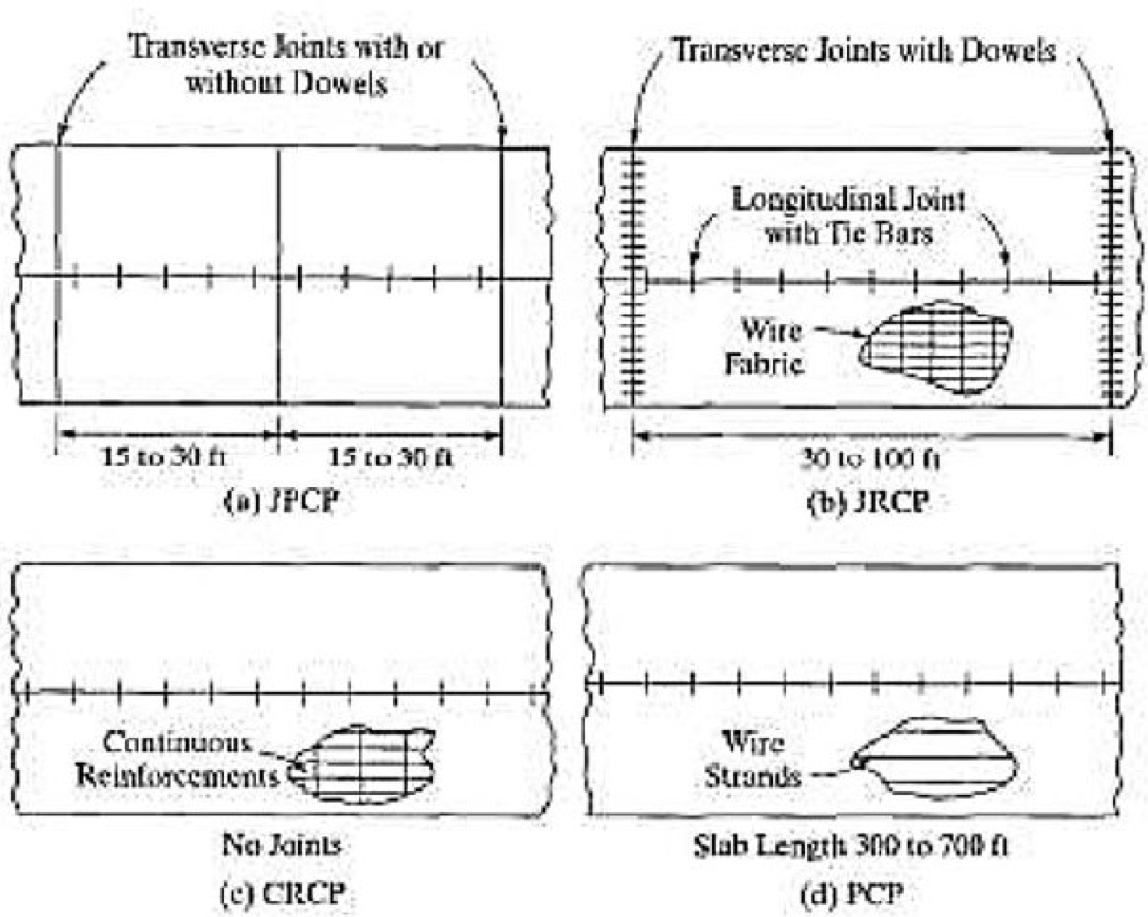


Figure 2.18: Different concrete pavement types (plan views)

2.6.2.2 Rigid Pavement Reinforcements

1. Temperature reinforcement (wire fabric)

2. Tie bars (1- Prevent lanes from separation and differential deflection. 2- Reduce transverse cracking)

3. Dowel bars (1- Minimise deflections and reduce stresses near the edges of the slabs. 2- Transferee load from one slab to another without preventing the joint from opening)

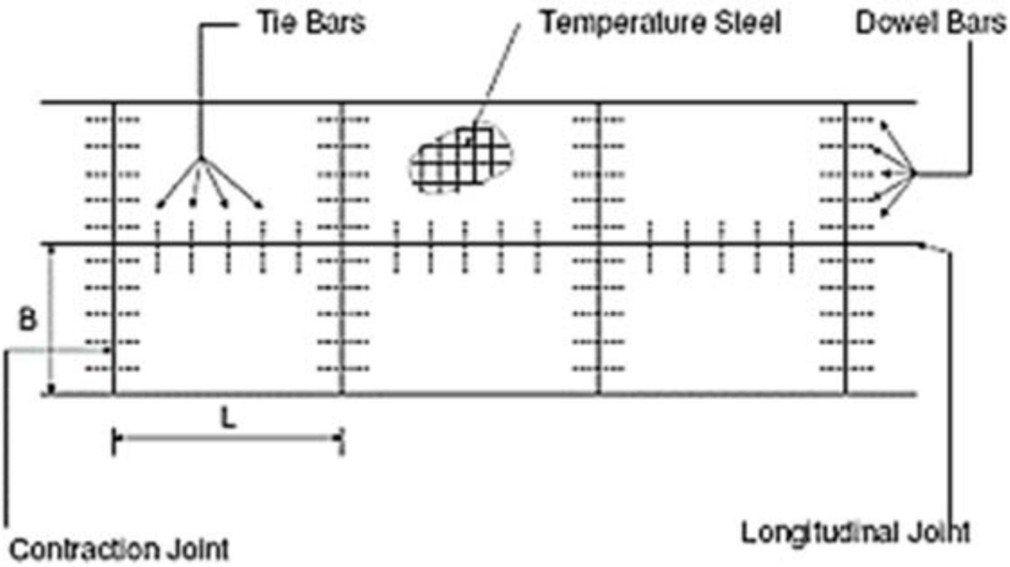


Figure 2.19: **Reinforcement illustration and general appearance of concrete pavement**

2.6.2.3 Joints in rigid pavement

1. Expansion joints

It is placed at a specific location to allow the pavement to expand without damaging adjacent structures or the pavement itself as shown in Figure 2.20

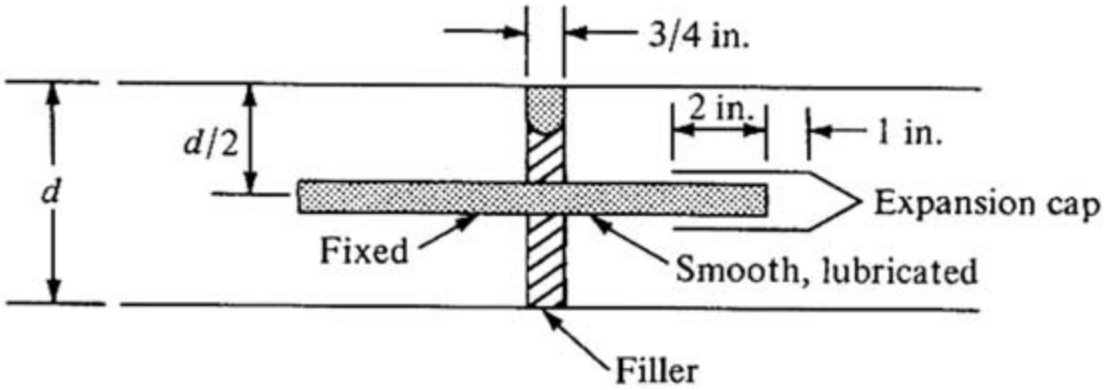


Figure 2.20: **Expansion joint**

2. Contraction joint

is a sawed, formed, or tooled groove in a concrete slab that creates a weakened vertical plane. It regulates the location of the cracking caused by dimensional changes in the slab.

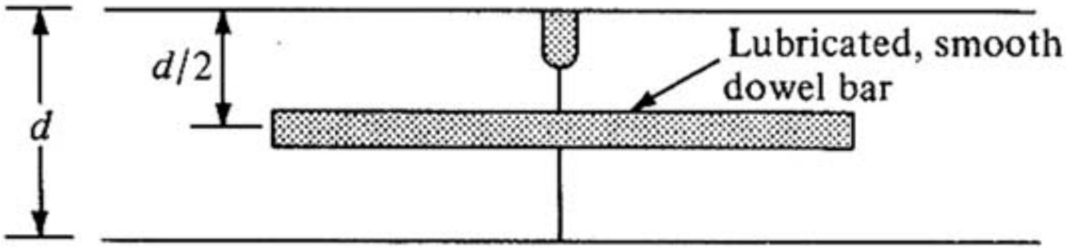


Figure 2.21: **Contraction joint**

3. Construction joints

It is a joint between slabs that results when concrete is placed at different times. Figure 2.22 shows this type of joint.

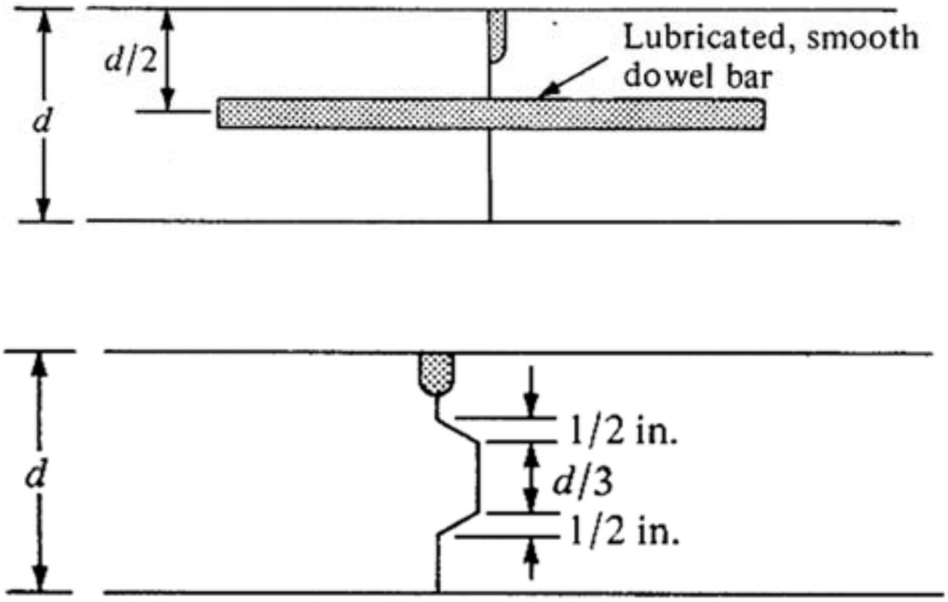


Figure 2.22: **Construction joint**

2.6.2.4 AASHTO 1993 thickness design method

In design of rigid pavement, AASHTO design method consider many factors. These are:

1. Pavement performance.
2. Subbase strength.
3. Subgrade strength.
4. Traffic.
5. Concrete properties.
6. Drainage.
7. Reliability.

Pavement performance

This factor is considered in similar way of that discussed in flexible pavement. However, the initial serviceability index (pi) is taken as 4.5. Final serviceability index value is as discussed in flexible pavement design.

Subbase strength

AASHTO 1993 design guide allow using of six subbase types (A to F) ranging from granular to stabilized materials. The requirements needed for these types are shown in Table 2.10. The minimum thickness as suggested by AASHTO method should not be less than 6 inches and this should be extended 1-3 ft outside pavement edges. Subbase materials is characterized by its elastic modulus E_{SB}.

Table 2.10: Recommended particle size distributions for different types of subbase materials

	Types of Subbase					
Sieve Designation	*Type A*	*Type B*	*Type C (Cement Treated)*	*Type D (Lime Treated)*	*Type E (Bituminous Treated)*	*Type F (Granular)*
Sieve analysis percent passing						
2 in.	100	100	—	—	—	—
1 in.	—	75–95	100	100	100	100
⅜ in.	30–65	40–75	50–85	60–100	—	—
No. 4	25–55	30–60	35–65	50–85	55–100	70–100
No. 10	15–40	20–45	25–50	40–70	40–100	55–100
No. 40	8–20	15–30	15–30	25–45	20–50	30–70
No. 200	2–8	5–20	5–15	5–20	6–20	8–25
(The minus No. 200 material should be held to a practical minimum.)						
Compressive strength lb/in^2 at 28 days			400–750	100		
Stability						
Hveem Stabilometer					20 min	
Hubbard field					1000 min	
Marshall stability					500 min	
Marshall flow					20 max	
Soil constants						
Liquid limit	25 max	25 max				25 max
Plasticity index[a]	N.P.	6 max	10 max[b]		6 max[b]	6 max

[a]As performed on samples prepared in accordance with AASHTO Designation T87.
[b]These values apply to the mineral aggregate prior to mixing with the stabilizing agent.
SOURCE: Adapted with permission from *Standard Specifications for Transportation Materials and Methods of Sampling and Testing*, American Association of State Highway and Transportation Officials, Washington, D.C., 2007.

Subgrade strength

To reflect the property of subgrade soils in rigid pavement design procedure, the modulus of subgrade reaction (k) is normally used. This modulus can be estimated by conducting plate bearing test. However, the correlation with other tests is used sometime to estimate this modulus. Figure 2.23 is an example of such correlations.

Current pavement design procedure suggests the use of effective modulus of subgrade reaction. This effective modulus depends on the following factors

1. Seasonal effect on subgrade resilient modulus (as discussed and illustrated in flexible pavement)

2. The type and the thickness of subbase layer being used.

3. The effect of subbase potential erosion.

4. The presence of bedrock layer within the 10 foot below the subgrade surface.

The composite modulus of subgrade reaction can be determined from Figure 2.24. The effective modulus of subgrade reaction is then computed to account for the potential erosion of subbase course. This can be done using Table 2.11 and Figure 2.25.

Furthermore, as mentioned previously, the presence of a bedrock layer within 10 foot below surface of subgrade may affect the subgrade reaction modulus. In fact presence of such rigid foundation may have a positive effect on the overall modulus. Figure 2.26 is used to take such effect into account.

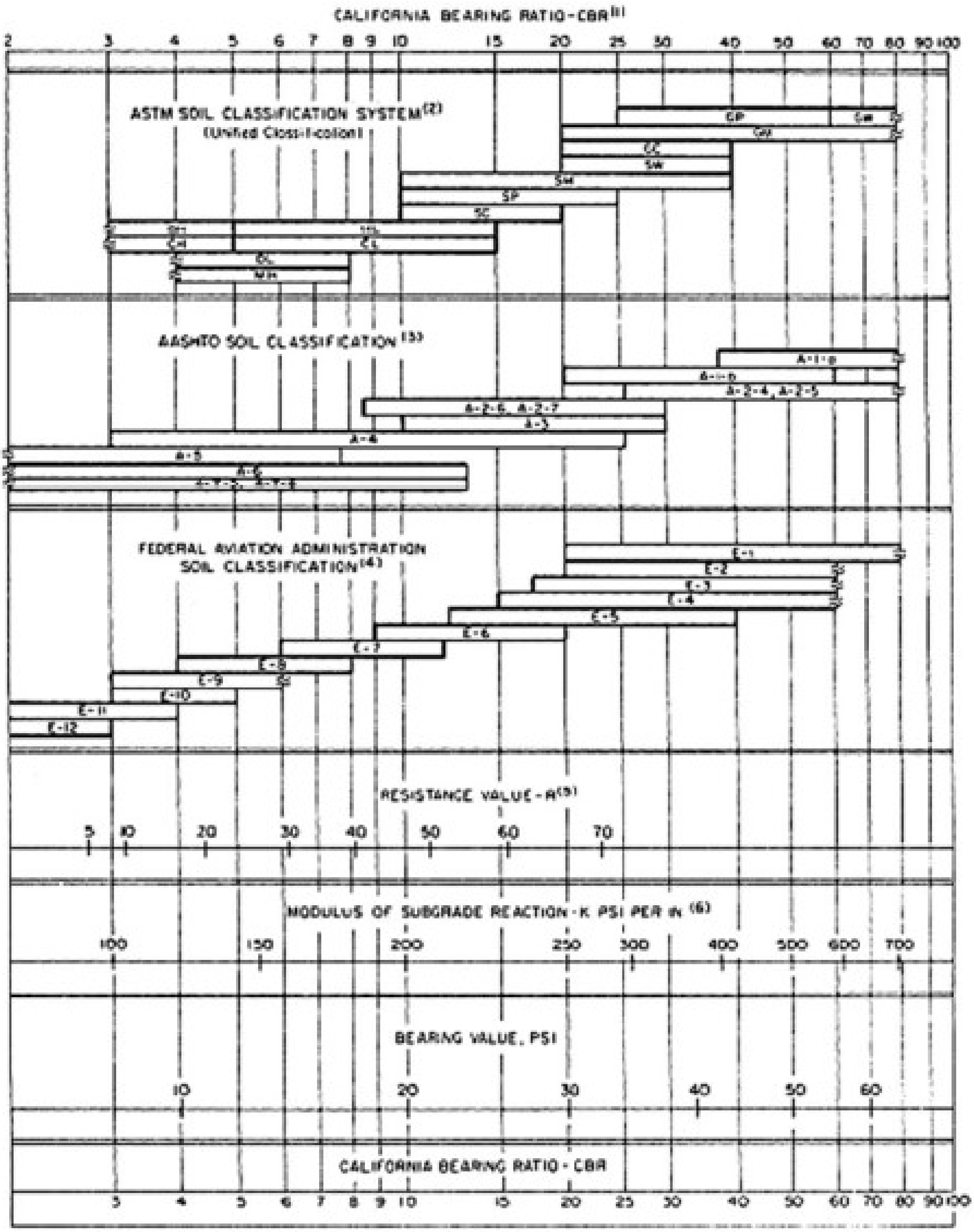
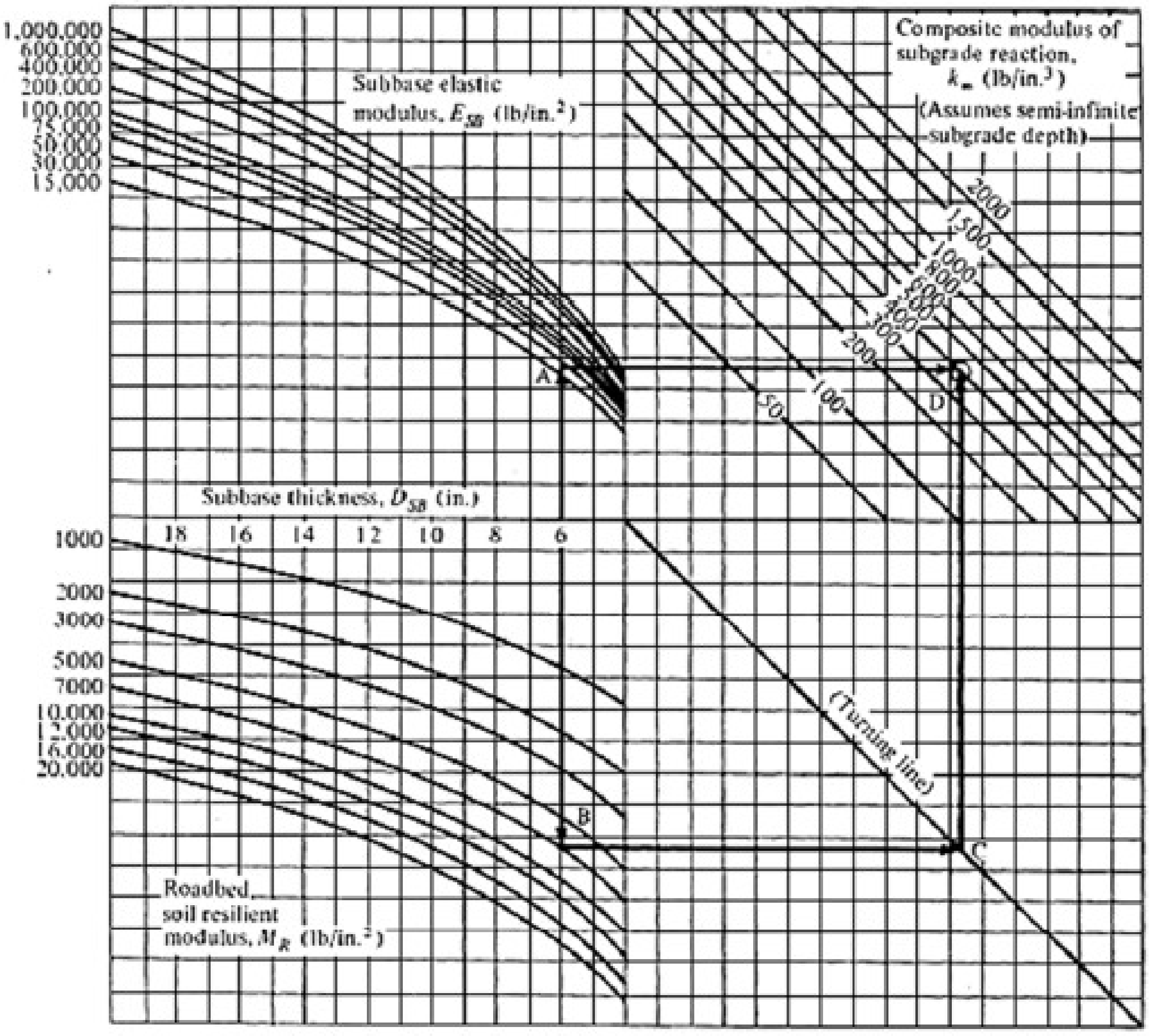


Figure 2.23: Correlation of different soils properties



Example:

D_{SB} = 6 in.

E_{SB} = 20,000 lb/in.^{2}

M_R = 7,000 lb/in.^{2}

Solution: k_∞ = 400 lb/in.^{3}

Figure 2.24: Chart for estimation the composite modulus of subgrade reaction

Table 2.11: Loss of support (LS) factors

Typical Ranges of Loss of Support (LS) Factors for Various Types of Materials (*6*)

Type of Material	Loss of Support (LS)
Cement Treated Granular Base (E = 1,000,000 to 2,000,000 psi)	0 0 to 1 0
Cement Aggregate Mixtures (E = 500,000 to 1,000,000 psi)	0 0 to 1 0
Asphalt Treated Base (E = 350,000 to 1,000,000 psi)	0 0 to 1 0
Bituminous Stabilized Mixtures (E = 40,000 to 300,000 psi)	0 0 to 1 0
Lime Stabilized (E = 20,000 to 70,000 psi)	1 0 to 3 0
Unbound Granular Materials (E = 15,000 to 45,000 psi)	1 0 to 3 0
Fine Grained or Natural Subgrade Materials (E = 3,000 to 40,000 psi)	2 0 to 3 0

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

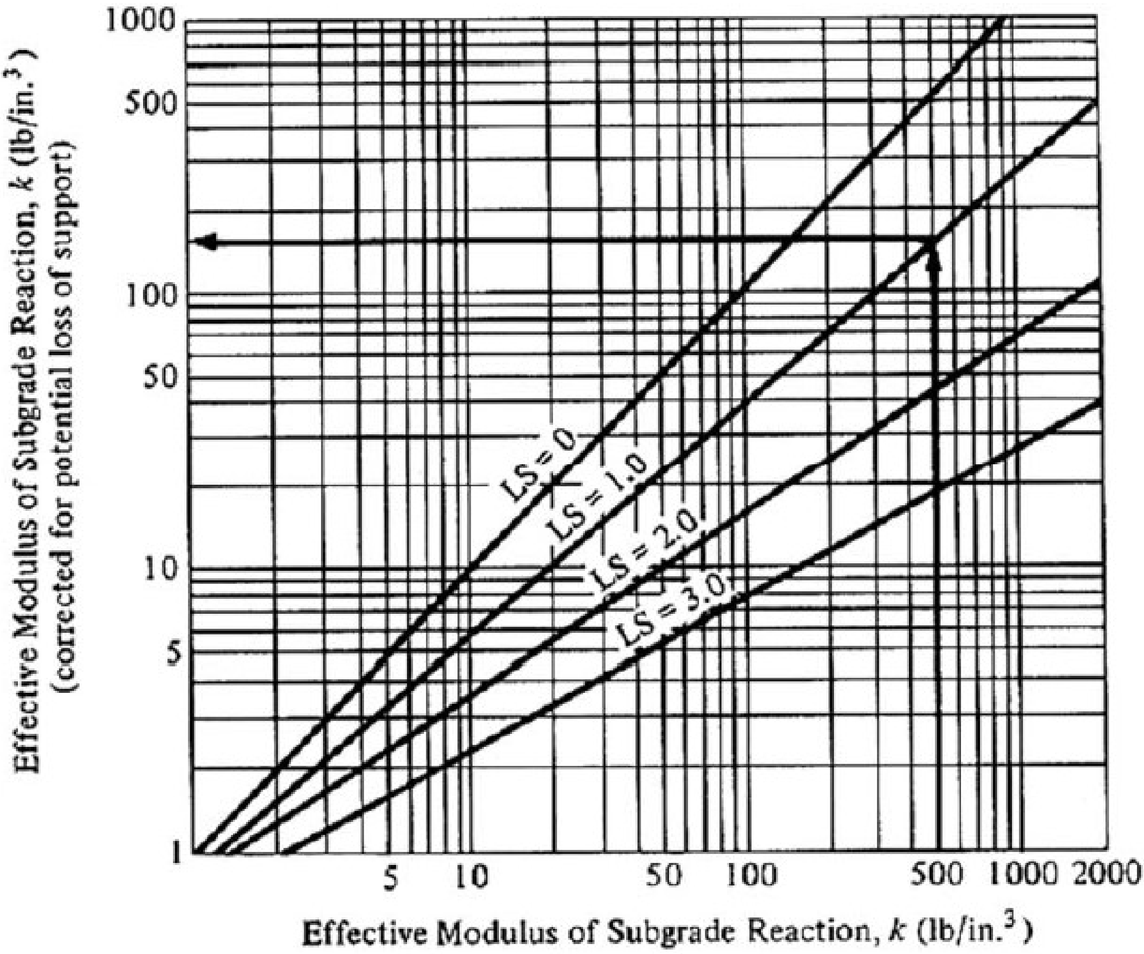


Figure 2.25: Chart for estimation the effective modulus of subgrade reaction corrected for potential loss of support

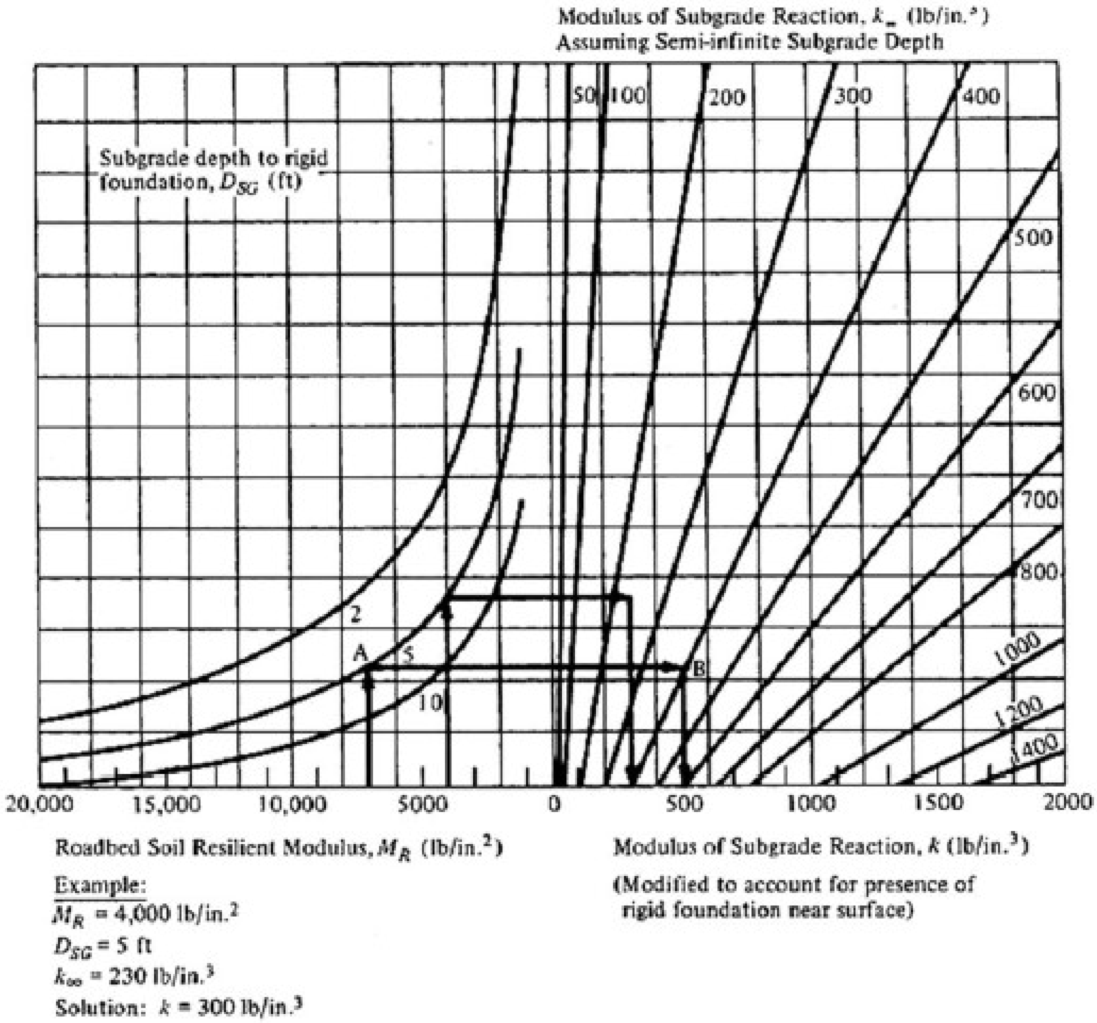

Modulus of Subgrade Reaction, k_∞ (lb/in.^{3})
Assuming Semi-infinite Subgrade Depth
Subgrade depth to rigid foundation, D_{SG} (ft)
50
100
200
300
400
500
600
700
800
1000
1200
1400
2
5
10
A
B
20,000
15,000
10,000
5000
0
500
1000
1500
2000
Roadbed Soil Resilient Modulus, M_R (lb/in.^{2})
Modulus of Subgrade Reaction, k (lb/in.^{3})
(Modified to account for presence of rigid foundation near surface)
Example:
M_R = 4,000 lb/in.^{2}
D_{SG} = 5 ft
k_∞ = 230 lb/in.^{3}
Solution: k = 300 lb/in.^{3}

Figure 2.26

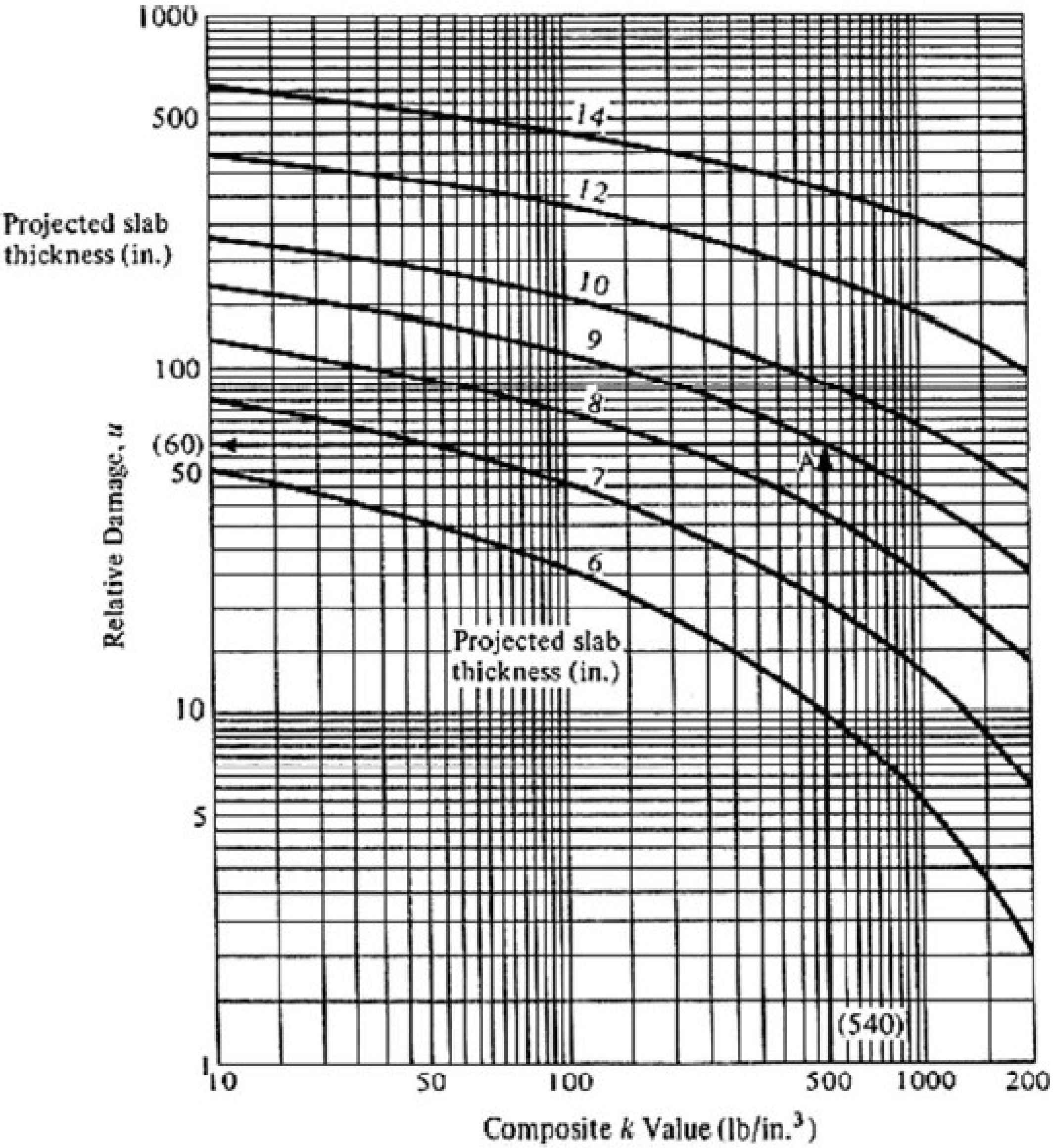


Figure 2.27: relation between composite K value and relative damage

Example: A 6 in. layer of cement-treated granular material is to be used as subbase for a rigid pavement. The monthly values for the roadbed soil resilient modulus and the subbase elastic (resilient) modulus are given in columns 2 and of Table 2.11. If the rock depth is located 5 ft. below the subgrade surface and the projected slab thickness is 9 in. Estimate the effective modulus of subgrade reaction using the AASHTO method

Table 2.11

Month	Roadbed Modulus M_r (Ib/in^2	Subbase Modulus E_{SB} (Ib/in^2	Composite k Value (Ib/in2) Figure 2.24	k Value (E_{SB}) on Rigid Foundation Figure (2.26)	Relative Damage u_r Figure (2.27)
Jan	20,000	50,000	**1100**	**1350**	**0.35**
Feb.	20,000	50,000	**1100**	**1350**	**0.35**
Mar.	2,500	15,000	**160**	**230**	**0.86**
Apr	4,000	15,000	**230**	**300**	**0.78**
May	4,000	15,000	**230**	**300**	**0.78**
Jun.	7,000	20,000	**400**	**500**	**0.6**
Jul.	7,000	20,000	**400**	**500**	**0.6**
Aug.	7,000	20,000	**400**	**500**	**0.6**
Sep	7,000	20,000	**400**	**500**	**0.6**
Oct.	7,000	20,000	**400**	**500**	**0.6**
Nov.	4,000	15,000	**230**	**300**	**0.78**
Dec.	20,000	15,000	**1100**	**1350**	**0.35**
Total					**7.25**

Type: Granular

Thickness of subbase (in) = 6

Loss of Support, L.S=1.0

Depth to rigid foundation (ft) =5

Projected Slab thickness (in) = 9

Average: $\bar{u}_r = \frac{\sum u_r}{n} = \frac{7.25}{12} = 0.6$

Therefore, Effective modulus of subgrade reaction *k* (Ib/in^2) =500

Corrected for loss of support: *k* (Ib/in^2) = 170

Concrete properties

Flexural strength (modulus of rupture) and elastic modulus at 28-day is used to represent the property of concrete.

Drainage

The concept of introducing the drainage into pavement design guide is similar to that discussed previously in flexible pavement design. However, the drainage coefficient (C_d) is determined from Table 2.12

Table 2.12: Recommended values for drainage coefficient Cd for rigid pavements

Quality of Drainage	Percent of Time Pavement Structure is Exposed to Moisture Levels Approaching Saturation			
	Less Than 1%	1–5%	5–25%	Greater Than 25%
Excellent	1.2–1.20	1.20–1.15	1.15–1.10	1.10
Good	1.20–1.15	1.15–1.10	1.10–1.00	1.00
Fair	1.15–1.10	1.10–1.00	1.00–0.90	0.90
Poor	1.10–1.00	1.00–0.90	0.90–0.80	0.80
Very poor	1.00–0.90	0.90–0.80	0.80–0.70	0.70

SOURCE: Adapted from *AASHTO Guide for Design of Pavement Structures*, American Association of State Highway and Transportation Officials, Washington, D.C., 1993. Used with permission.

Reliability

This concept is as discussed in flexible pavement design

Structural pavement design

AASHTO pavement design guide suggest the following equation to determine the slab thickness

$$\log_{10} W_{18} = Z_R S_o + 7.35 \log_{10}(D+1) - 0.06 + \frac{\log_{10}[\Delta PSI/(4.5-1.5)]}{1+[(1.624\times 10^7)/(D+1)^{8.46}]} + (4.22 - 0.32P_t)\log_{10}\left\{\frac{S'_c C_d}{215.63J}\left(\frac{D^{.75}-1.132}{D^{.75}-[18.42/(E_c/k)^{.25}]}\right)\right\}$$

Where:

Z_R = standard normal variant corresponding to the selected level of reliability
S_o = overall standard deviation (see flexible pavement design)
W_{18} = predicted number of 18 kip ESAL applications that can be carried by the pavement structure after construction
D = thickness of concrete pavement to the nearest half-inch
ΔPSI = design serviceability loss = $p_i - p_t$
p_i = initial serviceability index
p_t = terminal serviceability index
E_c = elastic modulus of the concrete to be used in construction (lb/in^2)
S'_c = modulus of rupture of the concrete to be used in construction (lb/in^2)
J = load transfer coefficient = 3.2 (assumed)
C_d = drainage coefficient

The above equation can be solved to obtain the thickness (*D*) in inches by using either a computer program or the two charts in Figure 2.28 and Figure 2.29.

Example: Design a rigid pavement using AASHTO method using following Data:

Effective modulus of subgrade reaction, k = 72 Ib/in^3

Mean concrete modulus of rupture, S_c' = 650 Ib/in^2

Load transfer coefficient, J= 3.2

Drainage coefficient, C_d= 1.0

These values are used to determine a value on the match line as shown in Figure 2.28 (Segment 1), (Sold line ABCDEF)

Input parameters for segment 2 (Figure 2.29) on the chart are:

Match line value determined in segment 1 (74)

Design serviceability loss ΔPSI = 4.5-2.5=2

Reliability, *R%* =95% (Z_R= 1.645)

Overall standard deviation, $S_\circ$ = 0.29

Cumulative 18 kip ESAL = 5* 10^6

Based on above values, the required thickness slab is then obtained as shown in figure 2.29, as 10 in. (nearest half-inch)

Q: it is required to design a flexible pavement structure for a rural highway to carry a traffic load of 6*106, expressed in terms of ESAL. Experiemental results showed that the water takes about a month to drain from within the pavement structure. Weather forecasts indicated that the pavement structure may be saturated for 10% of the time. All other required information resulted from basic characterization is shown in figure below. Using ASSHTO 1993 pavement design guide to estimate thicknesses of pavement layers. Use P_i =4.5, p_t=2.5 and S_o=0.45