AASHTO RIGID PAVEMENT DESIGN METHOD

Design Equation

$$\log_{10}(W_{18}) = Z_R S_o + 7.35\log_{10}(D+1) - 0.06 + \frac{\log_{10}\left[\frac{\Delta PSI}{4.5-1.5}\right]}{1+\frac{1.64\text{x}10^7}{(D+1)^{8.46}}} + (4.22-0.32p_t)\log_{10}\left[\frac{S_c' C_d (D^{0.75}-1.132)}{215.63J\left[D^{0.75}-\frac{18.42}{(E_c/k)^{0.25}}\right]}\right]$$

PCC Thickness

W_{18} = design traffic (18-kip ESALs)

Z_R = standard normal deviate

S_o = combined standard error of traffic and performance prediction

D = thickness (inches) of pavement slab

ΔPSI = difference between initial and terminal serviceability indices

p_t = terminal serviceability value

S_c' = modulus of rupture (psi) for Portland cement concrete

J = load transfer coefficient

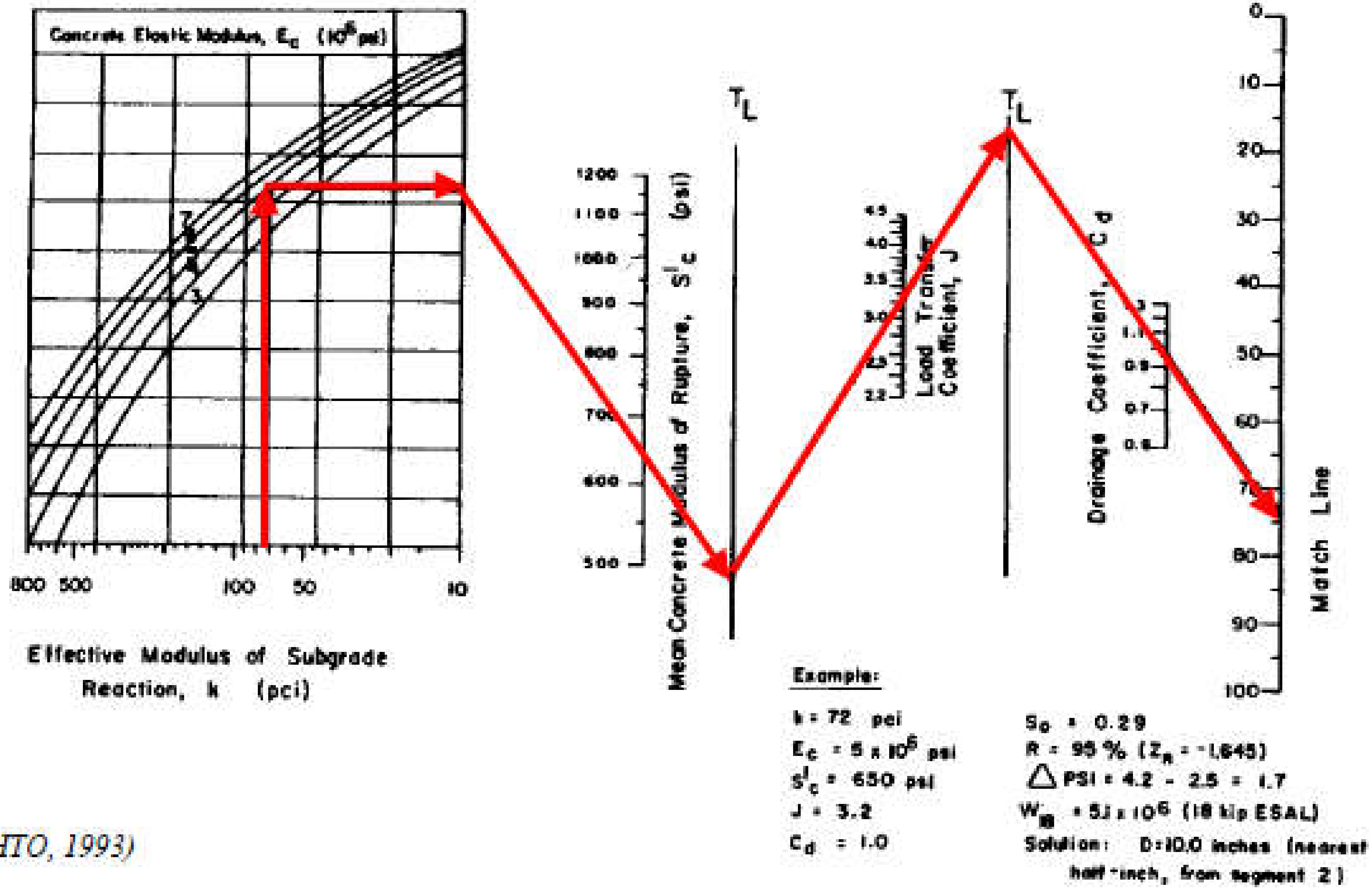
C_d = drainage coefficient

E_c = modulus of elasticity (psi) for Portland cement concrete

k = modulus of subgrade reaction (pci)

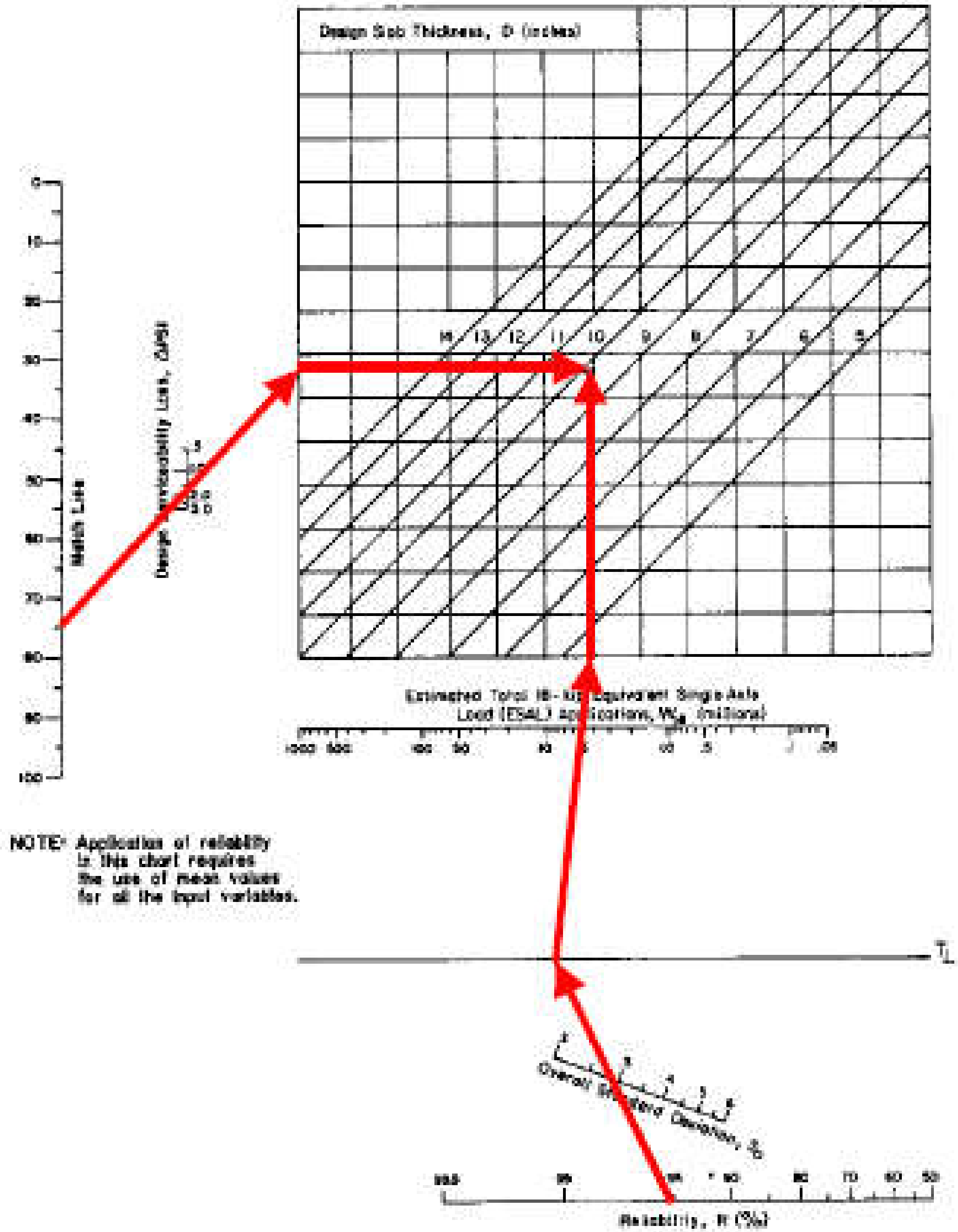
NOMOGRAPH SOLVES:

$$\log_{10}W_{18} = Z_R{*}S_o + 7.35{*}\log_{10}(D+1) - 0.06 + \frac{\log_{10}\left[\frac{\Delta PSI}{4.5-1.5}\right]}{1+\frac{1.624{*}10^7}{(D+1)^{8.46}}} + (4.22-0.32p_t){*}\log_{10}\left[\frac{S_c'{*}C_d\left[D^{0.75}-1.132\right]}{215.63{*}J\left[D^{0.75}-\frac{18.42}{(E_c/k)^{0.25}}\right]}\right]$$



(AASHTO, 1993)

Figure 3.7. Design Chart for Rigid Pavement Based on Using Mean Values for Each Input Variable (Segment 1)



NOTE: Application of reliability in this chart requires the use of mean values for all the input variables.

Figure 3.7. Continued--Design Chart for Rigid Pavements Based on Using Mean Values for Each Input Variable (Segment 2)

(AASHTO, 1993)

Design Inputs

W_{18} = design traffic (18-kip ESALs)

Z_R = standard normal deviate

S_o = combined standard error of traffic and performance prediction

ΔPSI = difference between initial and terminal serviceability indices

p_t = terminal serviceability index (implicit in flexible design)

All consistent with flexible pavements!

Additional Design Inputs

- S'_c = modulus of rupture for concrete
- J = joint load transfer coefficient
- C_d = drainage coefficient (similar in concept to flexible pavement terms)
- E_c = modulus of elasticity for concrete
- k = modulus of subgrade reaction

Additional inputs reflect differences in materials and structural behavior.

Modulus of Rupture S_c'

(AASHTO, 1993)

Because of the treatment of reliability in this Guide, it is strongly recommended that the normal construction specification for modulus of rupture (flexural strength) *not* be used as input, since it represents a value below which only a small percent of the distribution may lie. If it is desirable to use the construction specification, then some adjustment should be applied, based on the standard deviation of modulus of rupture and the percent (PS) of the strength distribution that normally falls below the specification:

$$S_c'(\text{mean}) = S_c + z(SD_s)$$

where

S_c' = estimated mean value for PCC modulus of rupture (psi),
S_c = construction specification on concrete modulus of rupture (psi),
SD_s = estimated standard deviation of concrete modulus of rupture (psi), and
z = standard normal variate:
= 0.841, for PS = 20 percent,*
= 1.037, for PS = 15 percent,
= 1.282, for PS = 10 percent,
= 1.645, for PS = 5 percent, and
= 2.327, for PS = 1 percent.

*NOTE: Permissible number of specimens, expressed as a percentage, that may have strengths less than the specification value.

Joint Load Transfer Coefficient *J*

Pavement Type (no tied shoulders)	***J***
JCP/JRCP w/ load transfer devices	3.2
JCP/JRCP w/out load transfer devices	3.8-4.4
CRCP	2.9

Types of Rigid Pavements

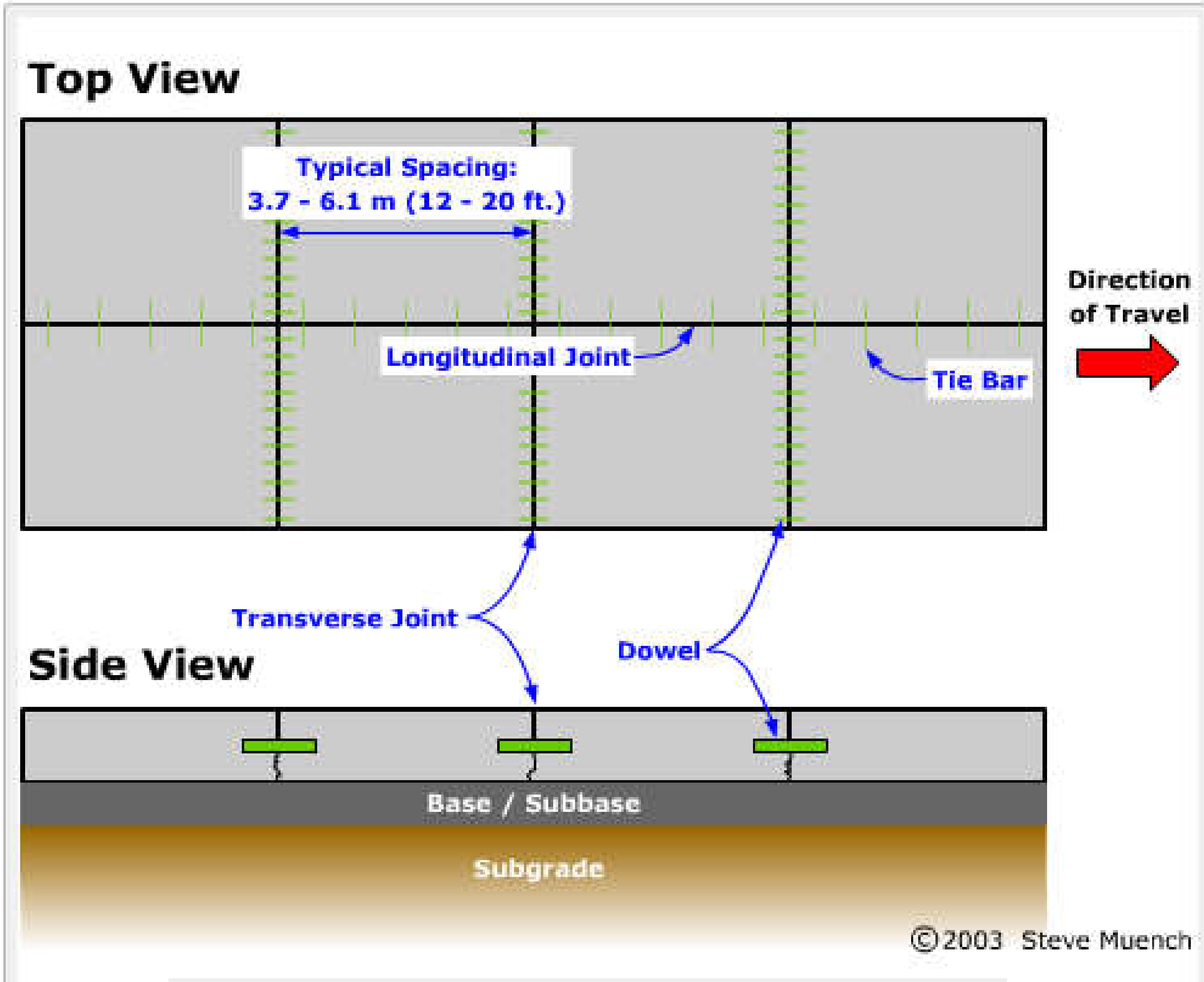
- **Jointed Plain Concrete Pavement (JPCP)** **or JCP**
  – does not use any reinforcing steel

- **Jointed Reinforced Concrete Pavement (JRCP)**
  – Reinforcing steel placed at mid height and discontinued at the joints.

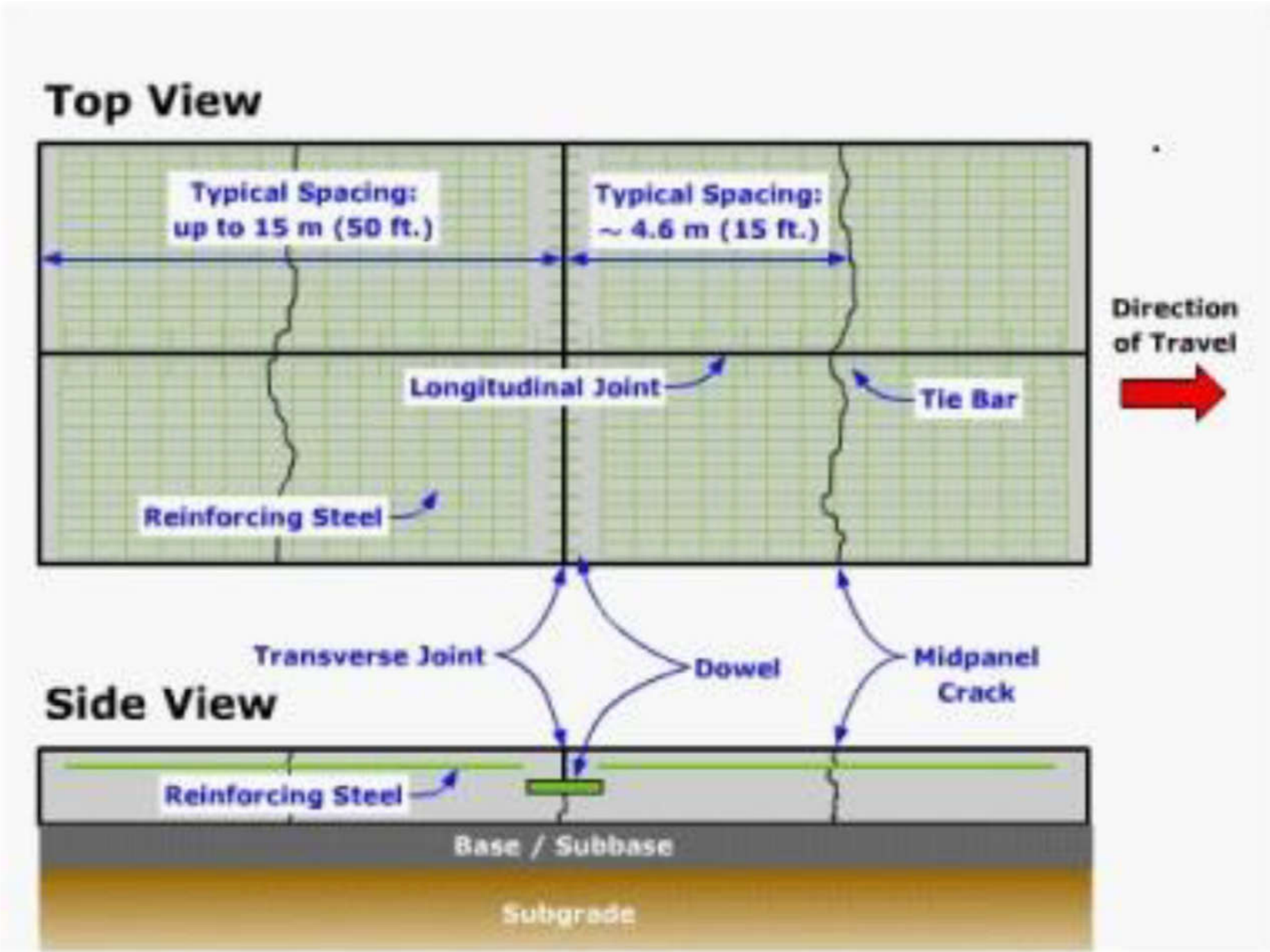
- **Continuously Reinforced Concrete Pavement (CRCP)**
  – This method is very costly

- **Pre-stressed Concrete Pavement (PCP)**
  – Comprises new and innovative construction methods

  – Precast pavement components are fabricated and installed on a prepared foundation (existing pavement or re-graded foundation).



Jointed Plain Concrete Pavement (JPCP)



Jointed Reinforced Concrete Pavement (JRCP)

Continuously Reinforced Concrete Pavement (CRCP)

Different types of Load Transfer Devices

Joint Load Transfer Coefficient *J*

Additional benefits of tied shoulders:

Table 2.6. Recommended Load Transfer Coefficient for Various Pavement Types and Design Conditions

Shoulder	Asphalt		Tied P.C.C.	
Load Transfer Devices	**Yes**	**No**	**Yes**	**No**
Pavement Type				
1. Plain jointed and jointed reinforced	3.2	3.8–4.4	2.5–3.1	3.6–4.2
2. CRCP	2.9–3.2	N/A	2.3–2.9	N/A

(AASHTO, 1993)

Drainage Coefficient C_d

- Two effects:
  - Subbase and subgrade strength/stiffness
  - Joint load transfer effectiveness

Table 2.5. Recommended Values of Drainage Coefficient, C_d, for Rigid Pavement Design

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	1.25–1.20	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

(AASHTO, 1993)

PCC Modulus of Elasticity E_c

- Measure directly per ASTM C469
- Correlation w/ compressive strength:

$$E_c = 57{,}000\,(f_c')^{0.5}$$

E_c = elastic modulus (psi)
f_c' = compressive strength (psi) per AASHTO T22, T140, or ASTM C39

Effective Subgrade Modulus *k*

- Depends on:
  - Roadbed (subgrade) resilient modulus, M_R
  - Subbase resilient modulus, E_{SB}
- Both vary by season

Determining Effective *k* (See Table 3.2)

- Identify:
  - Subbase types
  - Subbase thicknesses
  - Loss of support, LS (erosion potential of subbase)
  - Depth to rigid foundation (feet)
- Assign roadbed soil resilient modulus (M_R) for each season
- Assign subbase resilient modulus (E_{SB}) for each season
  - 15,000 psi (spring thaw) $< E_{SB} <$ 50,000 psi (winter freeze)
  - $E_{SB} < 4(M_R)$

Table 3.2. Table for Estimating Effective Modulus of Subgrade Reaction

Trial Subbase: Type ________ Depth to Rigid Foundation (feet) ________

Thickness (inches) ________ Projected Slab Thickness (inches) ________

Loss of Support, LS ________

(1) Month	(2) Roadbed Modulus, M_R (psi)	(3) Subbase Modulus, E_{SB} (psi)	(4) Composite k-Value (pci) (Fig. 3.3)	(5) k-Value (pci) on Rigid Foundation (Fig. 3.4)	(6) Relative Damage, u_r (Fig. 3.5)
Jan.					
Feb.					
Mar.					
Apr.					
May					
June					
July					
Aug.					
Sept.					
Oct.					
Nov.					
Dec.					

Summation: Σu_r = ________

Average: $\bar{u}_r = \frac{\Sigma u_r}{n}$ = ________

Effective Modulus of Subgrade Reaction, k (pci) = ________

Corrected for Loss of Support: k (pci) = ________

(AASHTO, 1993)

Determining Effective *k* (cont'd)

- Determine composite *k* for each season
  - For $D_{SB} = 0$: $k = M_R/19.4$
  - For $D_{SB} > 0$: Use Figure 3.3
- If depth to rigid foundation < 10 feet, correct *k* for effect of rigid foundation near the surface (Figure 3.4)
- Estimate required thickness of slab (Figure 3.5) and determine relative damage u_r for each season
- Use average u_r to determine effective *k* (Figure 3.5)
- Correct *k* for potential loss of support *LS* (Figure 3.6)

Composite Modulus of Subgrade Reaction

$k = f\,(M_R\,,\,E_{SB}\,,\,D_{SB}\,)$

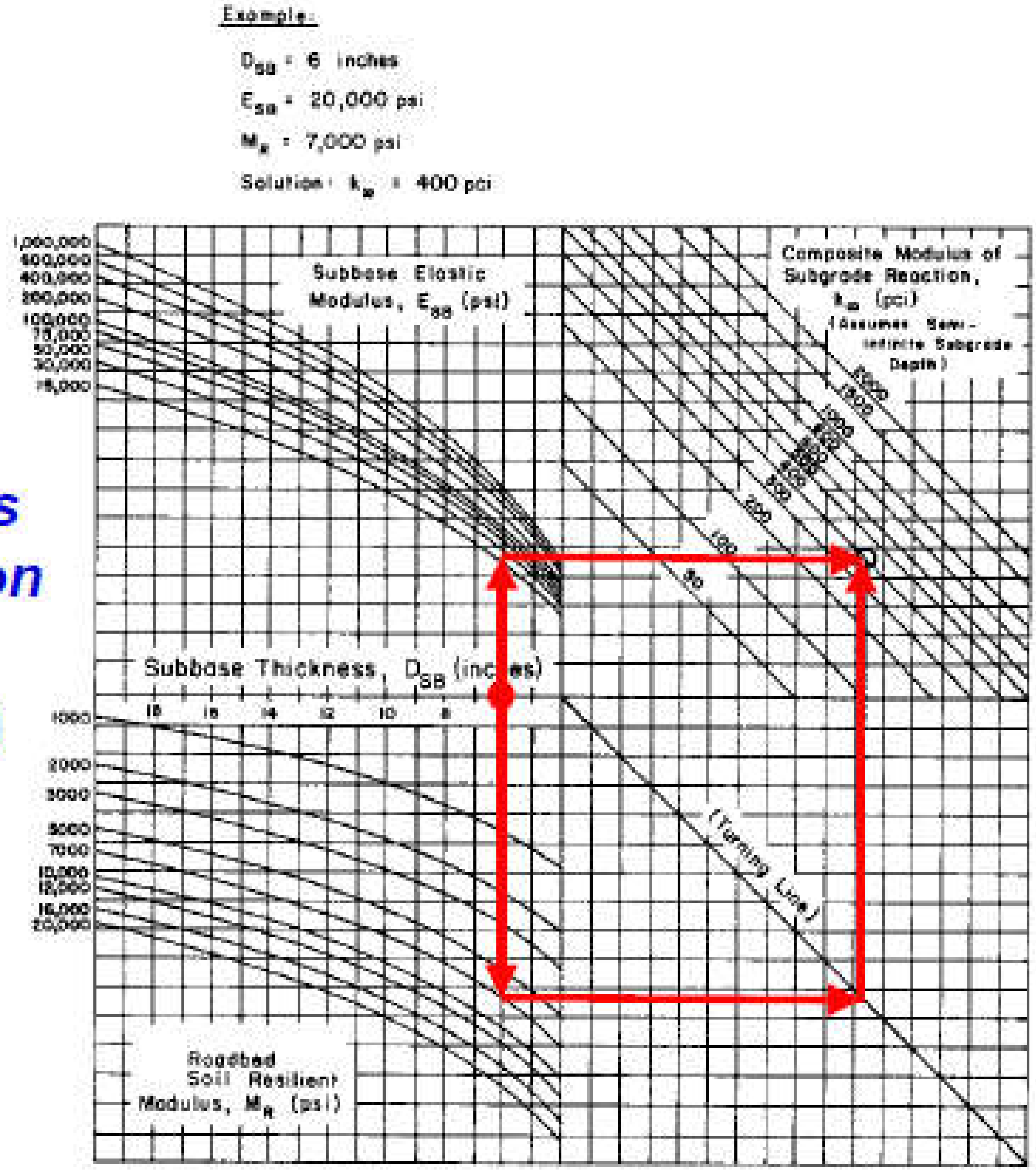


Figure 3.3. **Chart for Estimating Composite Modulus of Subgrade Reaction, k_∞, Assuming a Semi-Infinite Subgrade Depth. (For practical purposes, a semi-infinite depth is considered to be greater than 10 feet below the surface of the subgrade.)**

(AASHTO, 1993)

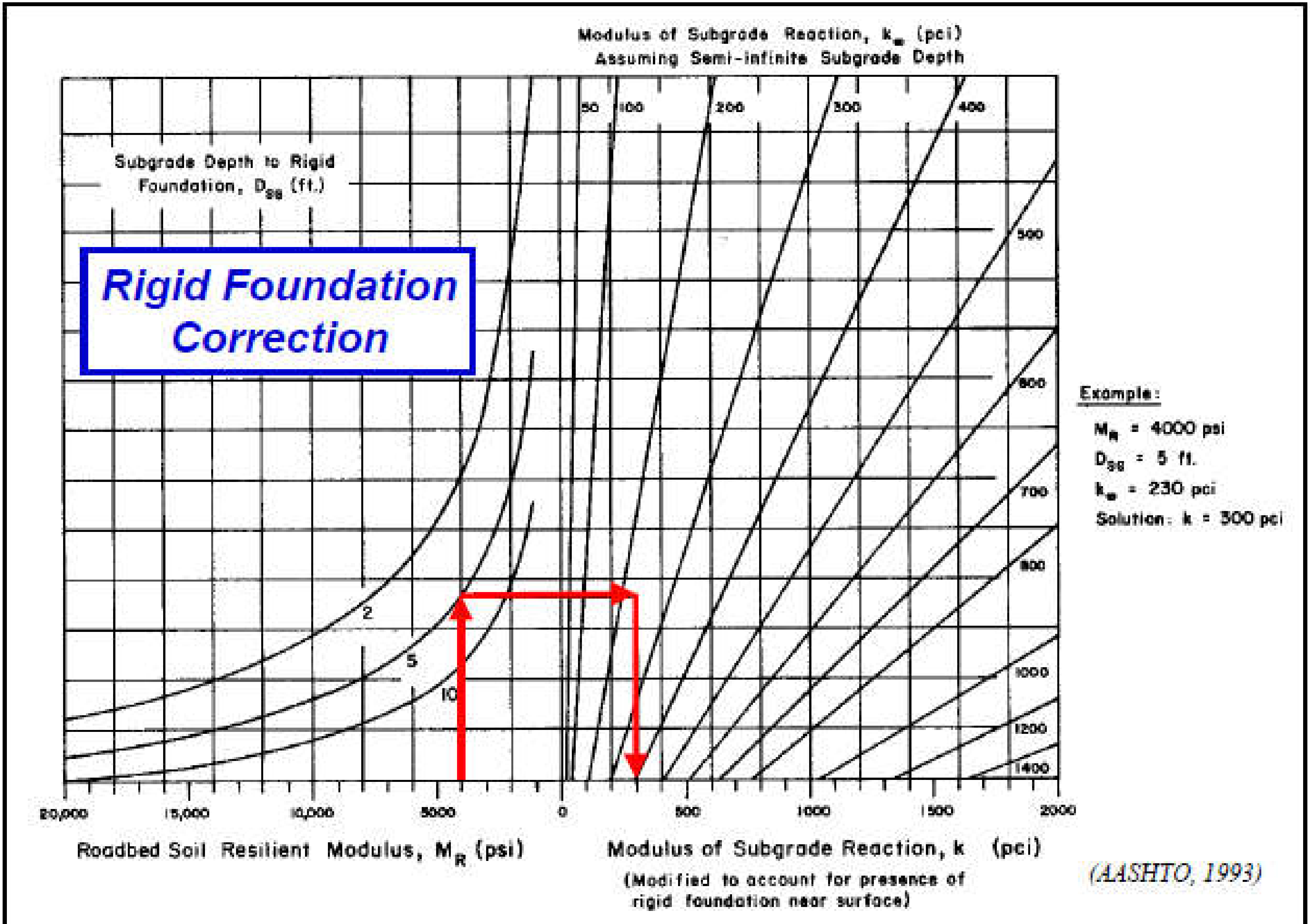


Figure 3.4. Chart to Modify Modulus of Subgrade Reaction to Consider Effects of Rigid Foundation Near Surface (within 10 feet)

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

Relative Damage

$$u_r = f(k, D)$$

Note:
The minimum allowable thickness of PCC pavement shall be 230 mm (9.0 inches) for interstate routes and 200 mm (8.0 inches) for all other road ways.

(AASHTO, 1993)

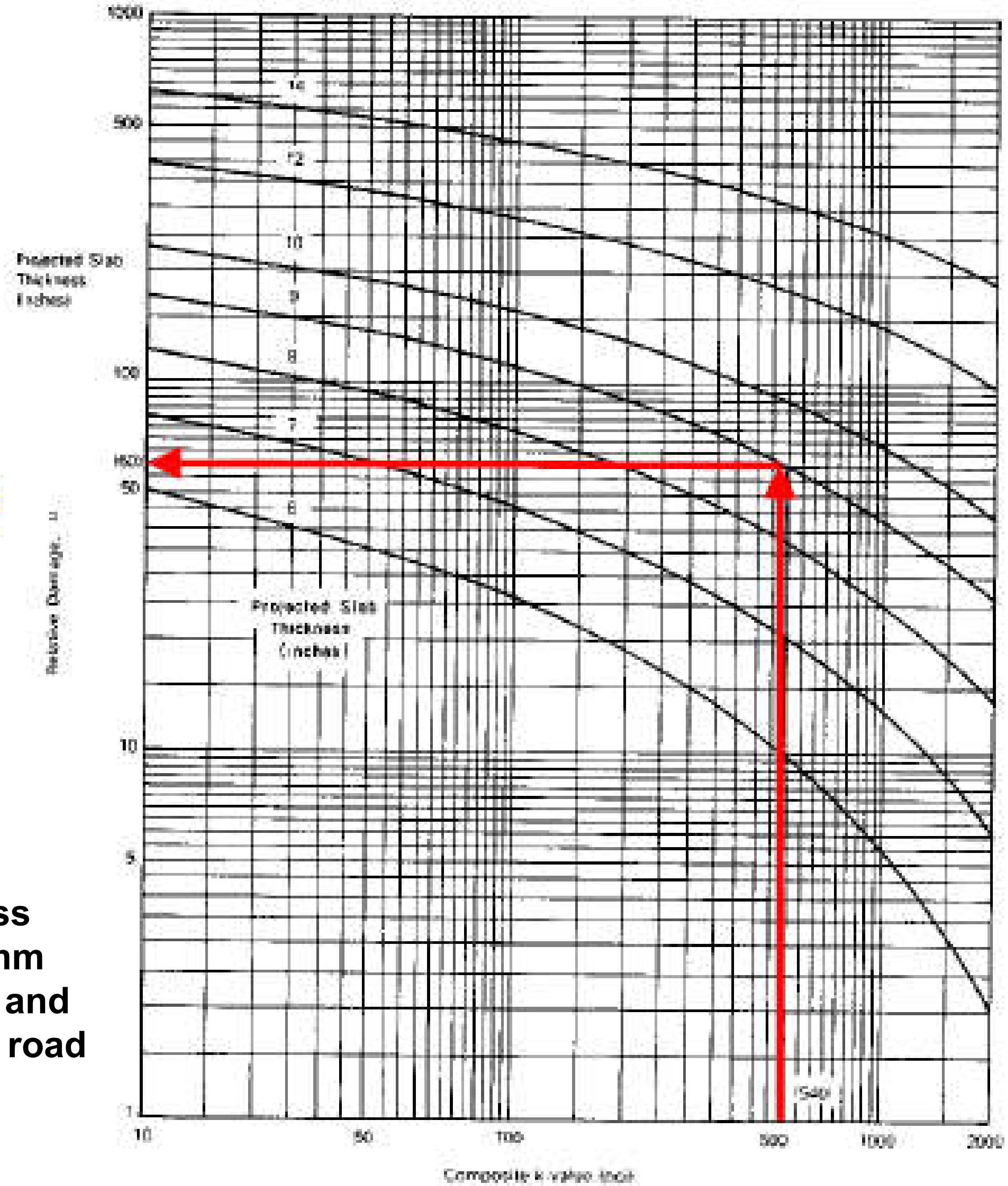


Figure 3.5. Chart for Estimating Relative Damage to Rigid Pavements Based on Slab Thickness and Underlying Support

Table 3.3. Example Application of Method for Estimating Effective Modulus of Subgrade Reaction

Trial Subbase: Type Granular

Thickness (inches) 6

Loss of Support, LS 1.0

Depth to Rigid Foundation (feet) 5

Projected Slab Thickness (inches) 9

(1) Month	(2) Roadbed Modulus, M_R (psi)	(3) Subbase Modulus, E_{SB} (psi)	(4) Composite k-Value (pci) (Fig. 3.3)	(5) k-Value (pci) on Rigid Foundation (Fig. 3.4)	(6) Relative Damage, u_r (Fig. 3.5)
Jan.	20,000	50,000	1,100	1,350	0.35
Feb.	20,000	50,000	1,100	1,350	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
June	7,000	20,000	410	540	0.60
July	7,000	20,000	410	540	0.60
Aug.	7,000	20,000	410	540	0.60
Sept.	7,000	20,000	410	540	0.60
Oct.	7,000	20,000	410	540	0.60
Nov.	4,000	15,000	230	300	0.78
Dec.	20,000	50,000	1,100	1,350	0.35
				Summation: Σu_r =	7.25

Average: $\bar{u}_r = \frac{\Sigma u_r}{n} = \frac{7.25}{12} = 0.60$

Effective Modulus of Subgrade Reaction, k (pci) = 540

Corrected for Loss of Support: k (pci) = 170

(AASHTO, 1993)

Loss of Support, *LS*

Table 2.7. 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.

Subbase/subgrade erosion at joints causes Loss of Support, impairs load transfer.

(AASHTO, 1993)

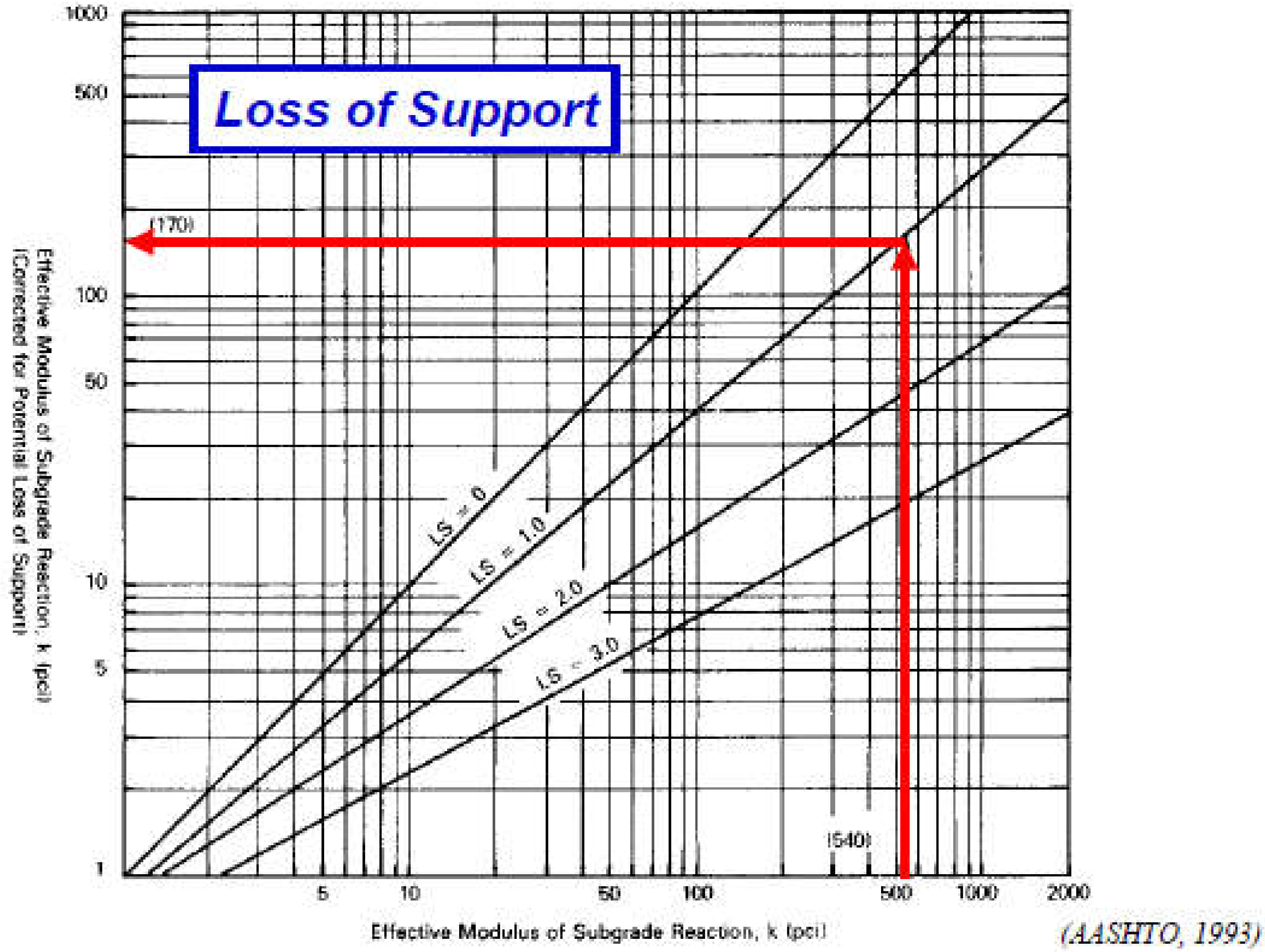


Figure 3.6. Correction of Effective Modulus of Subgrade Reaction for Potential Loss of Subbase Support (*6*)

Table 3.3. Example Application of Method for Estimating Effective Modulus of Subgrade Reaction

Trial Subbase: Type Granular

Thickness (inches) 6

Loss of Support, LS 1.0

Depth to Rigid Foundation (feet) 5

Projected Slab Thickness (inches) 9

(1) Month	(2) Roadbed Modulus, M_R (psi)	(3) Subbase Modulus, E_{SB} (psi)	(4) Composite k-Value (pci) (Fig. 3.3)	(5) k-Value (pci) on Rigid Foundation (Fig. 3.4)	(6) Relative Damage, u_r (Fig. 3.5)
Jan.	20,000	50,000	1,100	1,350	0.35
Feb.	20,000	50,000	1,100	1,350	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
June	7,000	20,000	410	540	0.60
July	7,000	20,000	410	540	0.60
Aug.	7,000	20,000	410	540	0.60
Sept.	7,000	20,000	410	540	0.60
Oct.	7,000	20,000	410	540	0.60
Nov.	4,000	15,000	230	300	0.78
Dec.	20,000	50,000	1,100	1,350	0.35
				Summation: $\Sigma u_r =$	7.25

Average: $\bar{u}_r = \frac{\Sigma u_r}{n} = \frac{7.25}{12} = 0.60$

Effective Modulus of Subgrade Reaction, k (pci) = 540

Corrected for Loss of Support: k (pci) = 170

(AASHTO, 1993)

Examples:

- Apply AASHTO procedure to design a concrete pavement slab thickness for ESAL = 11×10^6. The design reliability is 95% with a standard deviation of 0.3. The initial and terminal serviceability levels are 4.5 and 2.5, respectively. Other design parameters are $E_c = 5 \times 10^6$ psi, $S'_c = 650$ psi, $J = 3.2$, $C_d = 1.0$ and $k = 72$ pci.

- A concrete pavement is constructed on a 6 inch thick sub-base with elastic modulus of 20000 lb/in^2. The resilient modulus of the subgrade soil is 7000 lb/in^2. The depth of subgrade to bed rock is 5 ft. Compute composite modulus of subgrade reaction.
- The values of composite k determined at 1 month interval are 145, 145, 160, 160, 180, 180, 175, 175, 175, 175, 175 and 175 pci. Determine effective modulus of subgrade reaction by considering relative damage and LS. Use D_{min} = 9” and LS = 1.0.