1993 AASHTO Overlay Design

◎Overlay Type Feasibility

◎Important Considerations in Overlay Design

◎Pavement Evaluation for Overlay Design

※Design of Overlay Along Project

※Functional Evaluation of Existing Pavement

※Structural Evaluation of Existing Pavement

(Figure 5.1)

SC_0, SC_f

SC_{eff} (=SN_{eff} for AC, or D_{eff} for PCC and Composite Pavements)

$SC_{OL} = SC_f - SC_{eff}$

1. Visual Survey & Material Testing
2. NDT
3. Remaining Life (Figure 5.2)

$$RL = 100\left(1 - \frac{N_p}{N_{1.5}}\right)$$

$$CF = \frac{SC_n}{SC_0}$$

$$SN_{eff} = CF(SN_0)$$

Note: N_p, $N_{1.5}$ for traffic or ESAL

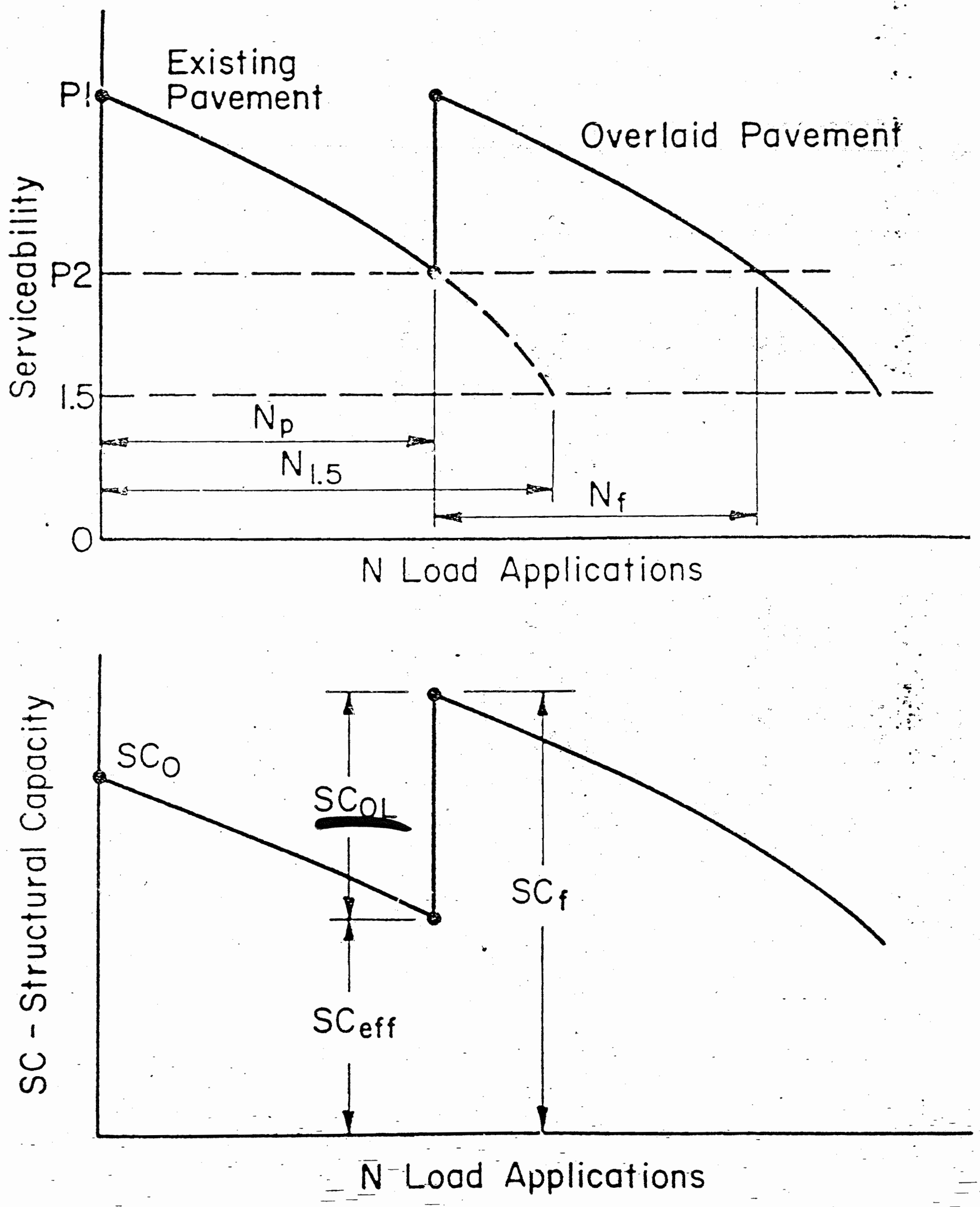


Figure 5.1. Illustration of Structural Capacity Loss Over Time and with Traffic

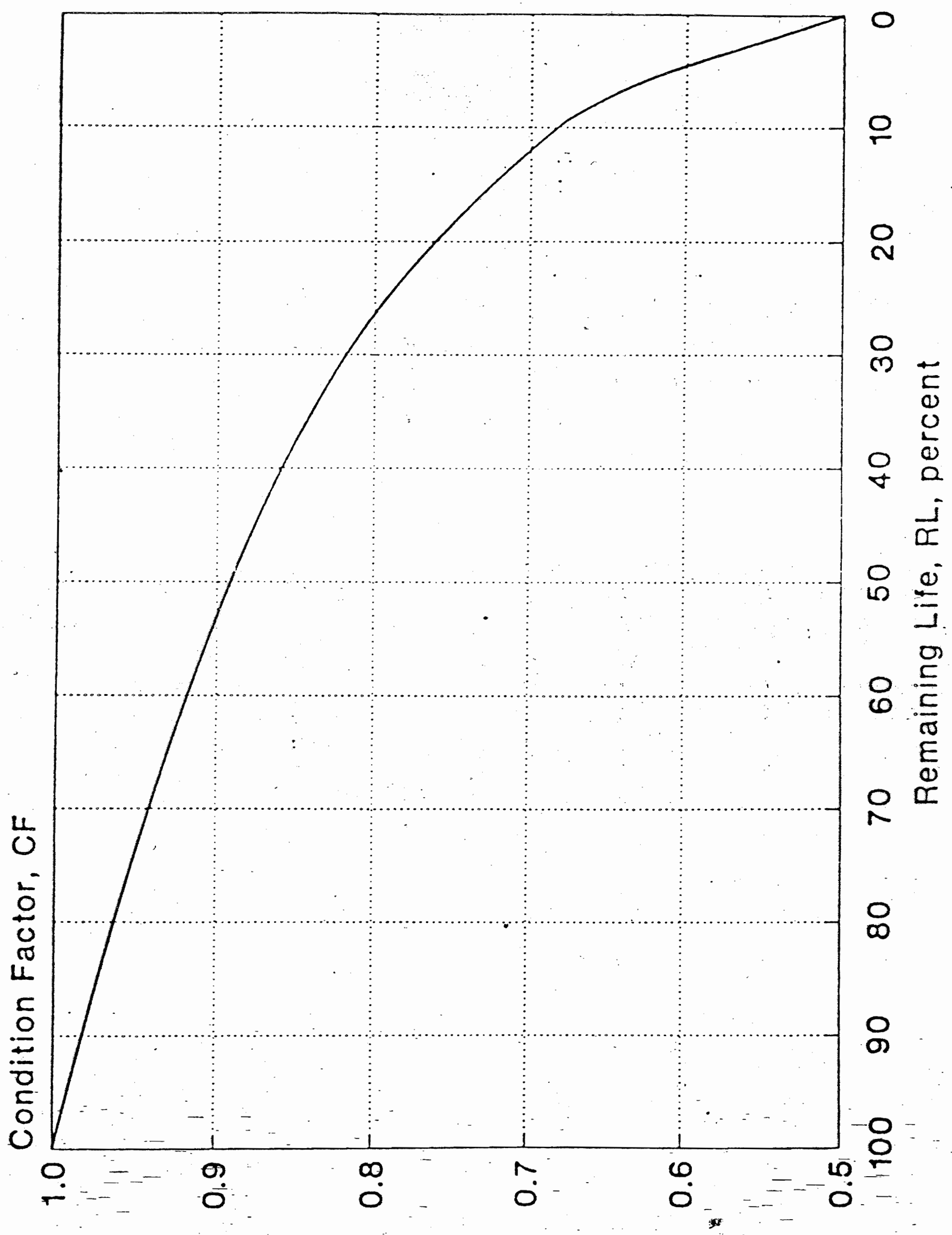


Figure 5.2. Relationship Between Condition Factor and Remaining Life

※Determination of Design M_R (Figure 5.4)

1. Lab. Testing
2. NDT Backcalculation
3. Estimate from Correlation Studies
4. Original Design & Construction Data

$$Design\ M_R = C\left(\frac{0.24\,P}{d_r r}\right)$$

$$C \leq 0.33$$

Note: r = sufficient large distance from the loading plate

◎AC Overlay of AC Pavement

$$SN_{OL} = a_{OL}(D_{OL}) = SN_f - SN_{eff}$$

Step 1: Existing Pavement Design & Construction

Step 2: Traffic Analysis

Step 3: Condition Survey

Step 4: Deflection Testing (Strongly Recommended)

1. Subgrade Resilient Modulus (M_R)

$$M_R = \left(\frac{0.24\,P}{d_r r}\right)$$

其中 M_R 為路床回彈模數值(*psi*)，P 為施加荷重(*lbs*；規範建議使用 *9000 lb*)，d_r 為離荷重中心距離所量得之撓度值(*in*)，r 為離荷重中心距離(*in*)，距離 r 的選取則建議 $r \geq 0.7a_e$，求取公式如下。

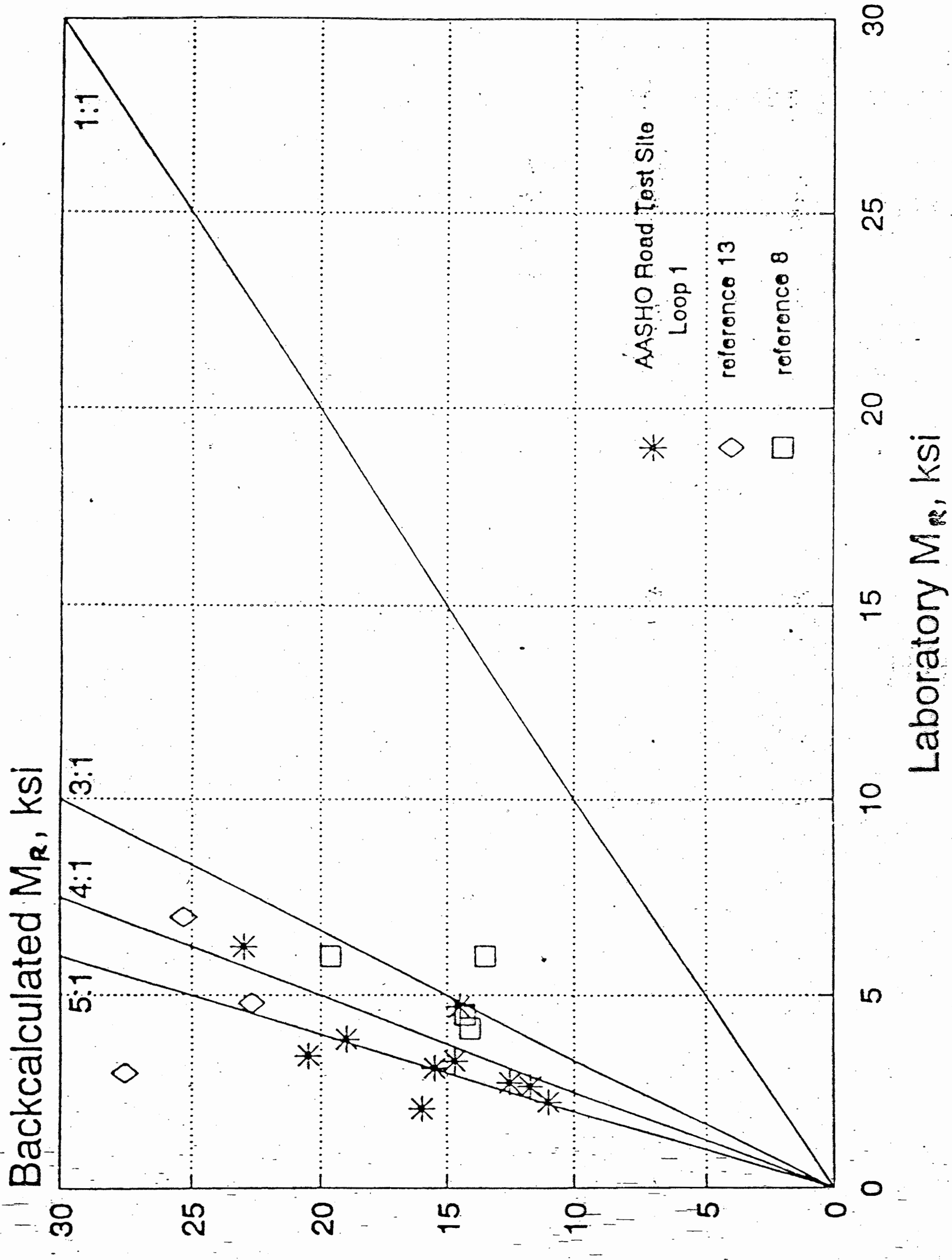


Figure 5.4. Backcalculated Resilient Modulus Versus Laboratory Results on Shelby Tube Samples from the AASHO Road Test Site Plus Data from Two Additional States

(d_r must be measured far enough away to provide a good estimate of subgrade modulus, independent of the effects of any layers above, but also close enough that is not too small to measure accurately)

$$a_e = \sqrt{\left[a^2 + \left(D * \sqrt[3]{\left(E_p / M_R\right)}\right)^2\right]}$$

公式中 a_e 為路床與鋪面之間應力分佈半徑(*in*；*stress bulb*)，*a* 為荷重盤半徑(*in*；建議取 *5.9 in*)，*D* 為鋪面各層總厚度(*in*)，E_p 為路床以上鋪面有效回彈模數值(*psi*)，M_R 為路床回彈模數值(*psi*)。

2. Temperature of AC Mix

3. Effective Modulus of the Pavcment (E_p)

$$d_0 = 1.5pa\left[\frac{1}{M_R\sqrt{1+\left(\frac{D}{a} * \sqrt[3]{\left(E_p / M_R\right)}\right)^2}} + \frac{1 - \frac{1}{\sqrt{1+\left(D/a\right)^2}}}{E_p}\right]$$

由 Figure 5.5 ➔ E_p / M_R ➔ 求 E_p = ?

d_0 = adjusted to a standard temperature 68 ºF (Figure 5.6 - Figure 5.7)

Yoder's Book

Boussinesq eq. ($\mu = 0.5$) one layer

$$d = \frac{1.5pa}{E} F_b(z)$$

$$F_b(z) = \frac{1}{\sqrt{1+\left(\frac{z}{a}\right)^2}}$$

⇒ Odemark (1949) Equivalent Thickness (1940 Barber)

Find

$$d_o = \frac{1.5pa}{E_p}$$

$$d_D = \frac{1.5pa}{E_p} \times \frac{1}{\sqrt{1+\left(\frac{D}{a}\right)^2}}$$

$$d_p = d_o - d_D = \frac{1.5pa}{E_p}\left\{1 - \frac{1}{\sqrt{1+\left(\frac{D}{a}\right)^2}}\right\} \quad \text{(pvmt)}$$

$$d_s = \frac{1.5pa}{M_R} \times \frac{1}{\sqrt{1+\left(\frac{D_e}{a}\right)^2}} \quad \text{(subgrade)}$$

$$D_e = D \times \sqrt[3]{\frac{E_p}{M_R}}$$

$$d = d_s + d_p$$

(d_r must be measured far enough away to provide a good estimate of subgrade modulus, independent of the effects of any layers above, but also close enough that is not too small to measure accurately)

$$a_e = \sqrt{\left[a^2 + \left(D * \sqrt[3]{\left(E_p / M_R\right)}\right)^2\right]}$$

公式中 a_e 為路床與鋪面之間應力分佈半徑(*in*；*stress bulb*)，*a* 為荷重盤半徑(*in*；建議取 *5.9 in*)，*D* 為鋪面各層總厚度(*in*)，E_p 為路床以上鋪面有效回彈模數值(*psi*)，M_R 為路床回彈模數值(*psi*)。

2. Temperature of AC Mix
3. Effective Modulus of the Pavcement (E_p)

$$d_0 = 1.5pa\left[\frac{1}{M_R\sqrt{1+\left(\frac{D}{a} * \sqrt[3]{\left(E_p / M_R\right)}\right)^2}} + \frac{1 - \frac{1}{\sqrt{1+(D/a)^2}}}{E_p}\right]$$

由 Figure 5.5 ➔ E_p / M_R ➔ 求 $E_p = ?$

d_0 = adjusted to a standard temperature 68 °F (Figure 5.6 - Figure 5.7)

如何建立? Burmister 2-layer?

由d_0公式(1) × M_R 得之.

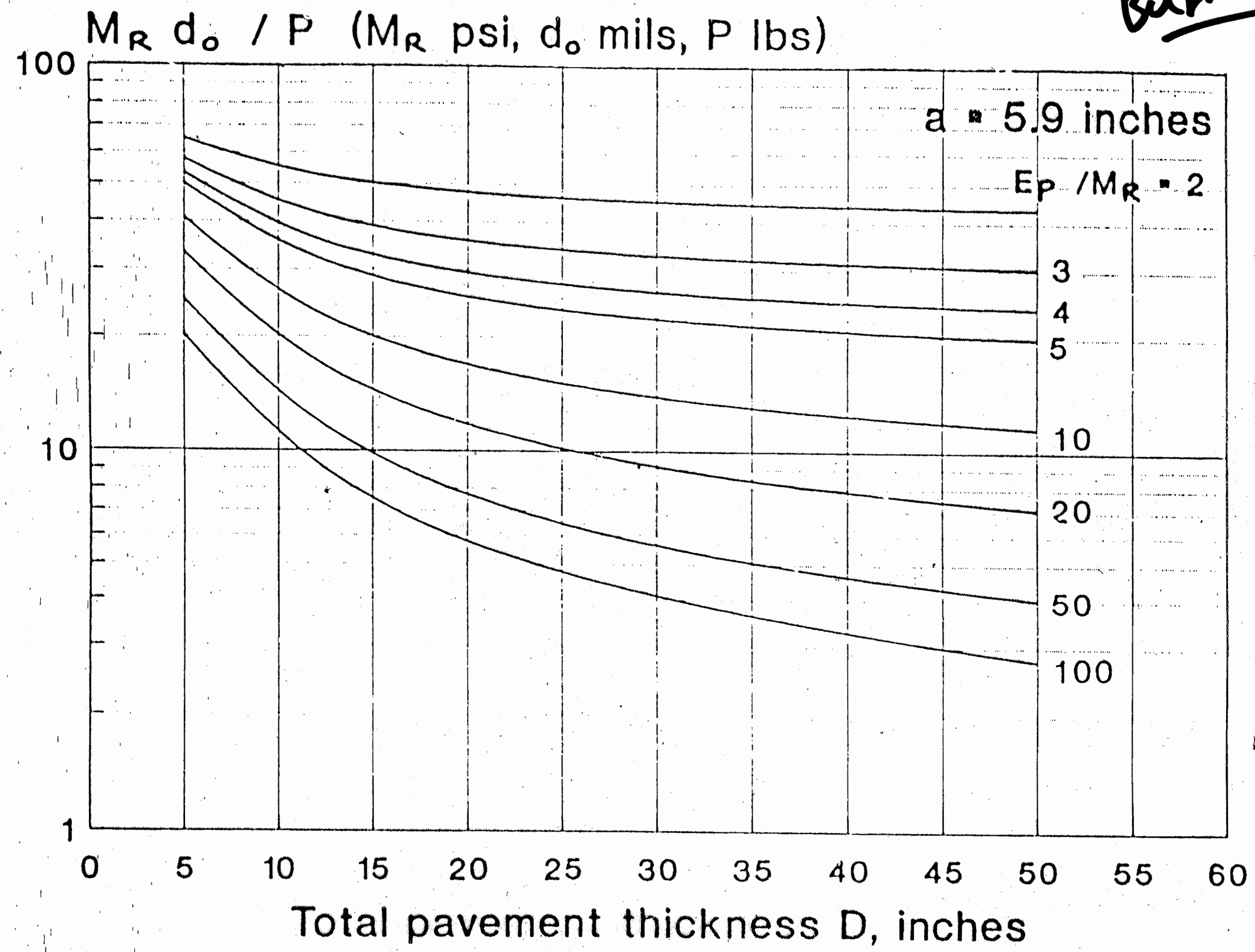


Figure 5.5. Determination of E_p/M_R

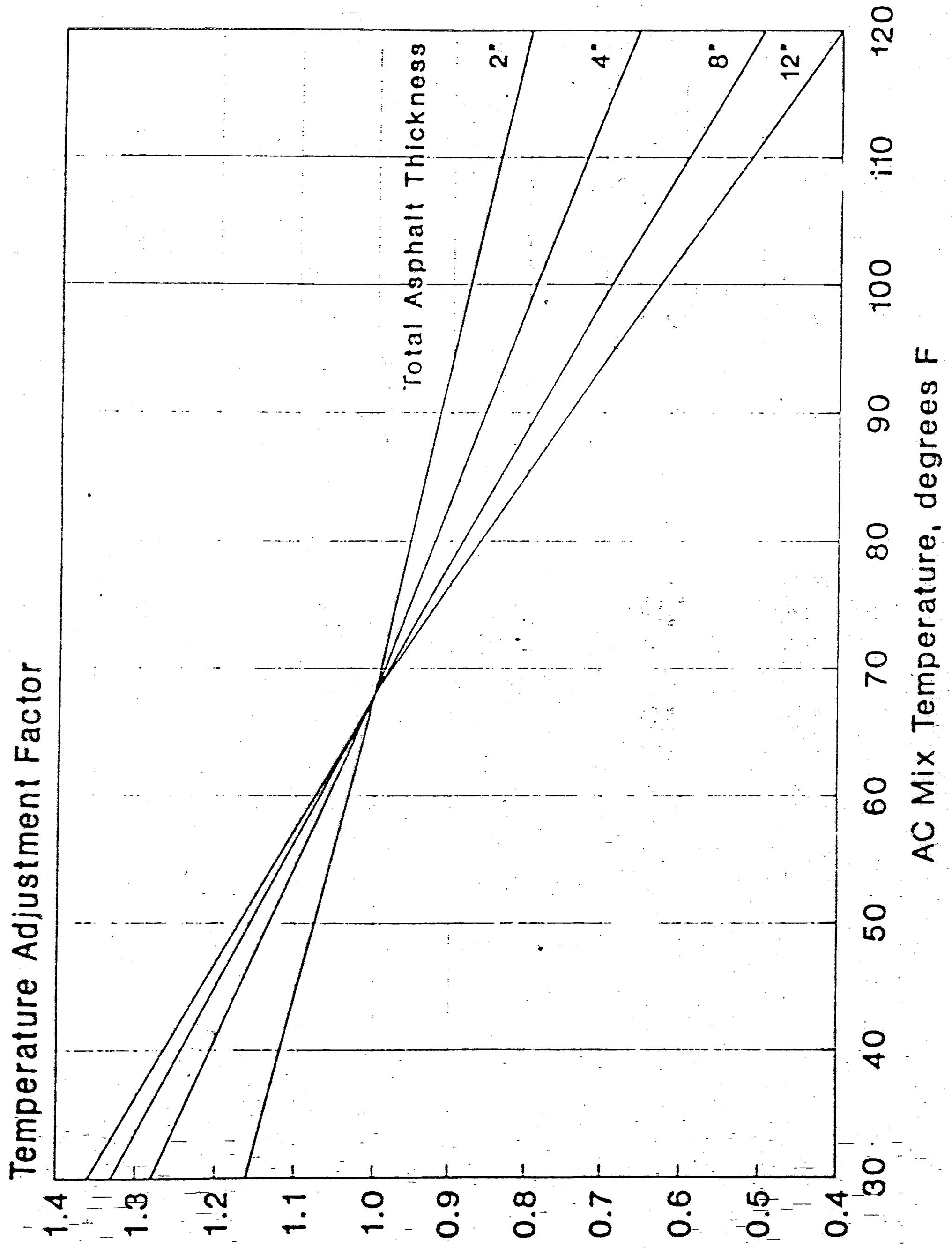


Figure 5.6. Adjustment to d_0 for AC Mix Temperature for Pavement with Granular or Asphalt-Treated Base

Step 5: Coring and Material Testing (Strongly Recommended)

M_R=1500CBR (may be too high)

Step 6: Determine the Required Structural Number (SN_f)for Future Traffic

$$Design\ M_R = C\left(\frac{0.24\ P}{d_r r}\right)$$

$$C \le 0.33$$

➔求 SN_f (Using AASHTO Design Equation)

Step 7: Determine SN_{eff}

1. SN_{eff} from NDT for AC Pavements

$$SN_{eff} = 0.0045D\sqrt[3]{E_p}$$

(Figure 5.8)

2. SN_{eff} from Condition Survey

$$SN_{eff} = a_1 D_1 + a_2 D_2 m_2 + a_3 D_3 m_3$$

(Table 5.2)

e.g., a_1 = 0.34 (good), 0.25 (fair), 0.15(poor)

3. SN_{eff} from Remaining Life

$$RL = 100\left(1 - \frac{N_p}{N_{1.5}}\right)$$

$$SN_{eff} = CF(SN_0)$$

Step 8: Determine Overlay Thickness (D_{OL})

$$D_{OL} = SN_{OL} / a_{OL} = (SN_f - SN_{eff}) / a_{OL}$$

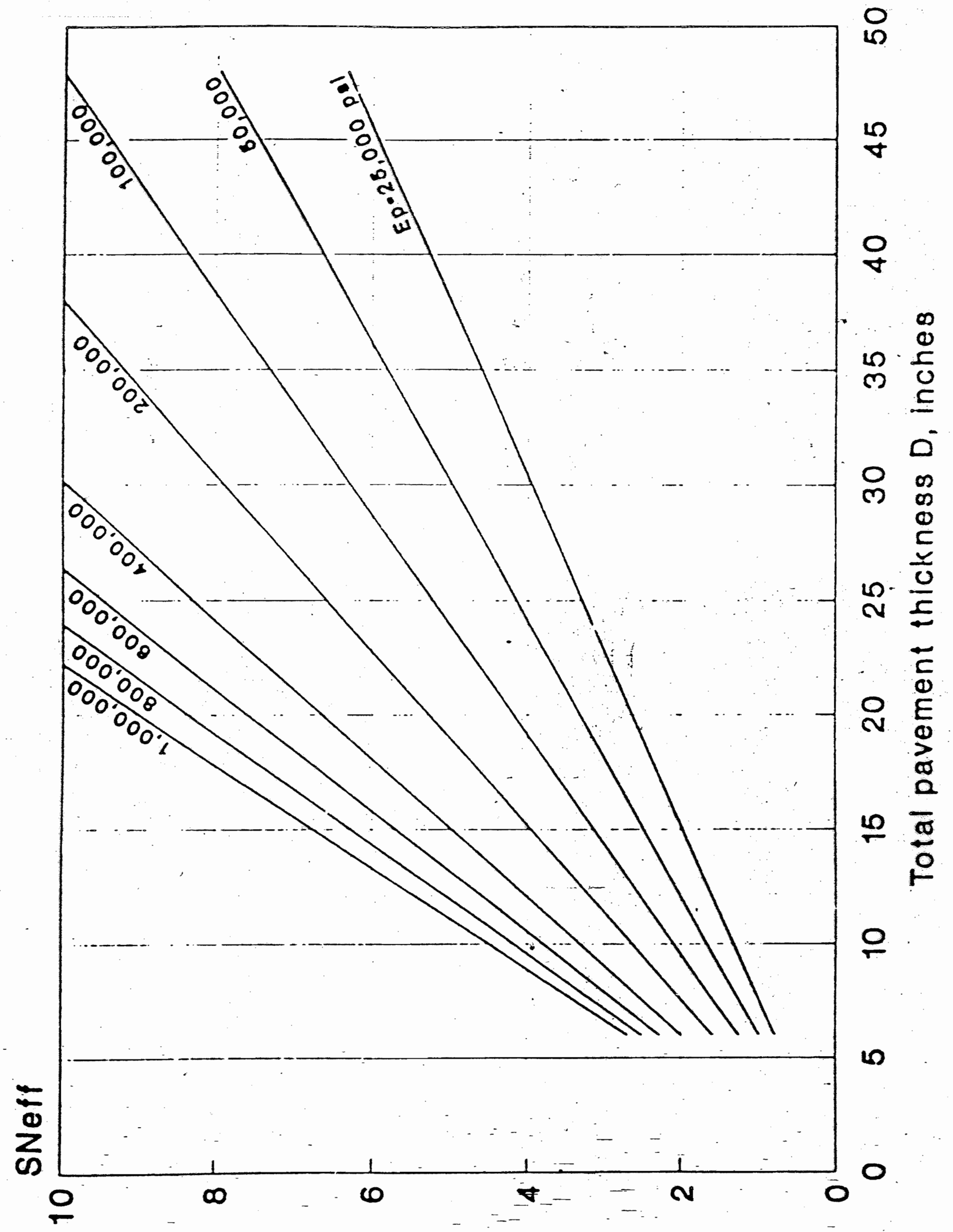


Figure 5.8. SN_{eff} from NDT Method

Table 5.2. Suggested Layer Coefficients for Existing AC Pavement Layer Materials

MATERIAL	SURFACE CONDITION	COEFFICIENT
AC Surface	Little or no alligator cracking and/or only low-severity transverse cracking	0.35 to 0.40
	< 10 percent low-severity alligator cracking and/or < 5 percent medium- and high-severity transverse cracking	0.25 to 0.35
	> 10 percent low-severity alligator cracking and/or < 10 percent medium-severity alligator cracking and/or > 5-10 percent medium- and high-severity transverse cracking	0.20 to 0.30
	> 10 percent medium-severity alligator cracking and/or < 10 percent high-severity alligator cracking and/or > 10 percent medium- and high-severity transverse cracking	0.14 to 0.20
	> 10 percent high-severity alligator cracking and/or > 10 percent high-severity transverse cracking	0.08 to 0.15
Stabilized Base	Little or no alligator cracking and/or only low-severity transverse cracking	0.20 to 0.35
	< 10 percent low-severity alligator cracking and/or < 5 percent medium- and high-severity transverse cracking	0.15 to 0.25
	> 10 percent low-severity alligator cracking and/or < 10 percent medium-severity alligator cracking and/or > 5-10 percent medium- and high-severity transverse cracking	0.15 to 0.20
	> 10 percent medium-severity alligator cracking and/or < 10 percent high-severity alligator cracking and/or > 10 percent medium- and high-severity transverse cracking	0.10 to 0.20
	> 10 percent high-severity alligator cracking and/or > 10 percent high-severity transverse cracking	0.08 to 0.15
Granular Base or Subbase	No evidence of pumping, degradation, or contamination by fines	0.10 to 0.14
	Some evidence of pumping, degradation, or contamination by fines	0.00 to 0.10

SN_{eff} = Effective structural number of the existing pavement, from Step 7

The thickness of overlay determined from the above relationship should be reasonable when the overlay is required to correct a structural deficiency. See Section 5.2.17 for discussion of factors which may result in unreasonable overlay thicknesses.

5.4.6 Surface Milling

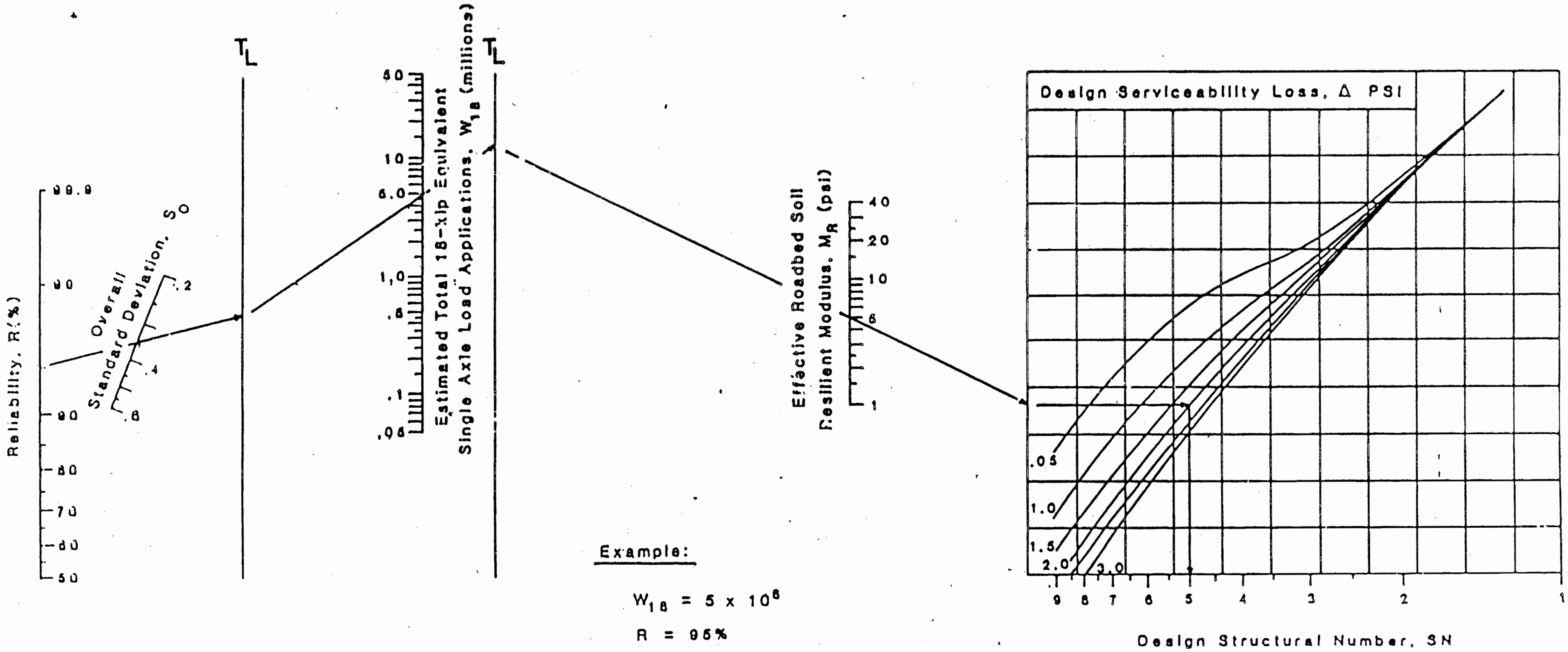
If the AC pavement is to be milled prior to overlay, the depth of milling must be reflected in the SN_{eff} analyses. No adjustment need be made to SN_{eff} values determined by NDT if the depth of milling does not exceed the minimum necessary to remove surface ruts. If a greater depth is milled, the NDT-determined SN_{eff} may be reduced by an amount equal to the depth milled times a structural coefficient for the AC surface based on the condition survey.

5.4.7 Shoulders

See Section 5.2.10 for guidelines.

NOMOGRAPH SOLVES:

$$\log_{10} W_{18} = Z_R * S_o + 9.36 * \log_{10}(SN + 1) - 0.20 + \frac{\log_{10}\left[\frac{\Delta PSI}{4.2 - 1.5}\right]}{0.40 + \frac{1094}{(SN+1)^{5.19}}} + 2.32 * \log_{10} M_R - 8.07$$



Example:

$W_{18} = 5 \times 10^6$

$R = 95\%$

$S_o = 0.35$

$M_R = 5000$ psi

$\Delta PSI = 1.9$

Solution: $SN = 5.0$

Figure 2. AASHTO Flexible Pavement Thickness Design Nomograph (1).

~~2. Use R_{Lx} and R_{ly} to determine F_{RL}~~

~~The procedure is very confusing and was removed in the new AASHTO Guide (1993).~~

※Overlay design analysis

1993 年 AASHTO Guide 各類加鋪組合之加鋪厚度計算公式如下表所示：

表一 加鋪厚度計算公式

加鋪材料	現存鋪面	加鋪設計公式
AC	AC	$hol = SNol / a$ $= (Snf - SNeff)/a$
AC	Break/PCC	$hol = SNol / a$ $= (Snf - SNeff)/a$
AC	PCC	$Dol = A(Df - Deff)$
AC	AC/PCC	$Dol = A(Df - Deff)$
Bound PCC	PCC	$Dol = Df - Deff$
Unbound PCC	PCC	$D^2ol = D^2f - D^2eff$
PCC	AC	$Dol = Df$

◎AC Overlay of Fractured PCC Slab Pavement

$$SN_{OL} = a_{OL}(D_{OL}) = SN_f - SN_{eff}$$

Step 1 ~ Step 5: Same as Before

Step 6: Determine SN_f

$$Design\ M_R = C\left(\frac{0.24P}{d_r r}\right)$$

$$C = 0.25\ or\ less$$

➔求 SN_f (Using AASHTO Design Equation)

(Design ΔPSI, Overlay Design Reliability R, Overlay Standard Deviation S_0)

Step 7: Determine SN_{eff} (from Condition Survey)

$$SN_{eff} = a_2 D_2 m_2 + a_3 D_3 m_3$$

Step 8: Same as Before

◎AC Overlay of JPCP, JRCP, and CRCP Pavement

$$D_{OL} = A(D_f - D_{eff})$$

$$A = 2.2233 - 0.1534(D_f - D_{eff}) + 0.0099(D_f - D_{eff})^2$$

A= Factor to convert PCC thickness deficiency to AC overlay thickness

Step 1 ~ Step 3: Same as Before

Step 4: Deflection Testing (Strongly Recommended)

FWD, AREA

$$AREA = 6\left(1 + 2\frac{d_{12}}{d_0} + 2\frac{d_{24}}{d_0} + \frac{d_{36}}{d_0}\right)$$

1. Effective Dynamic k-value (k_{dyn})

   由 d_0, AREA ==> Find k_{dyn} = ? (查圖)

   (K. T. Hall's Closed-Form Solution)

2. Effective Static k-value (k_{stat})

   $k_{stat} = k_{dyn} / 2$

3. Elastic Modulus of PCC Slab (E)

   由 AREA, k_{dyn} ==> ED^3 ==> Find E = ?

   (Typical E = 3 ~ 8 Mpsi)

4. Joint Load Transfer for JPCP/JRCP

$$\Delta LT = 100\left(\frac{\Delta_{UL}}{\Delta_L}\right)B$$

$$B = \frac{d_{0center}}{d_{12center}}$$

   B= Slab Bending Correction Factor

   (Typical B = 1.05 ~ 1.15)

   (Don't measure it if air temperature ≥ 80°F)

   a. Determine JPCP/JRCP Load Transfer Coefficient (J), J = 3.2 ~ 3.5 ~ 4.0

      (%LT>70 ~ 50<%LT<70 ~ %LT<50)

   b. For CRCP, use J = 2.2 ~ 2.6 for Overlay Design

Step 5: Coring and Material Testing (Strongly Recommended)

PCC Modulus of Rupture, S_c'

$$S_c' = 210 + 1.02IT \quad \text{(psi)}$$

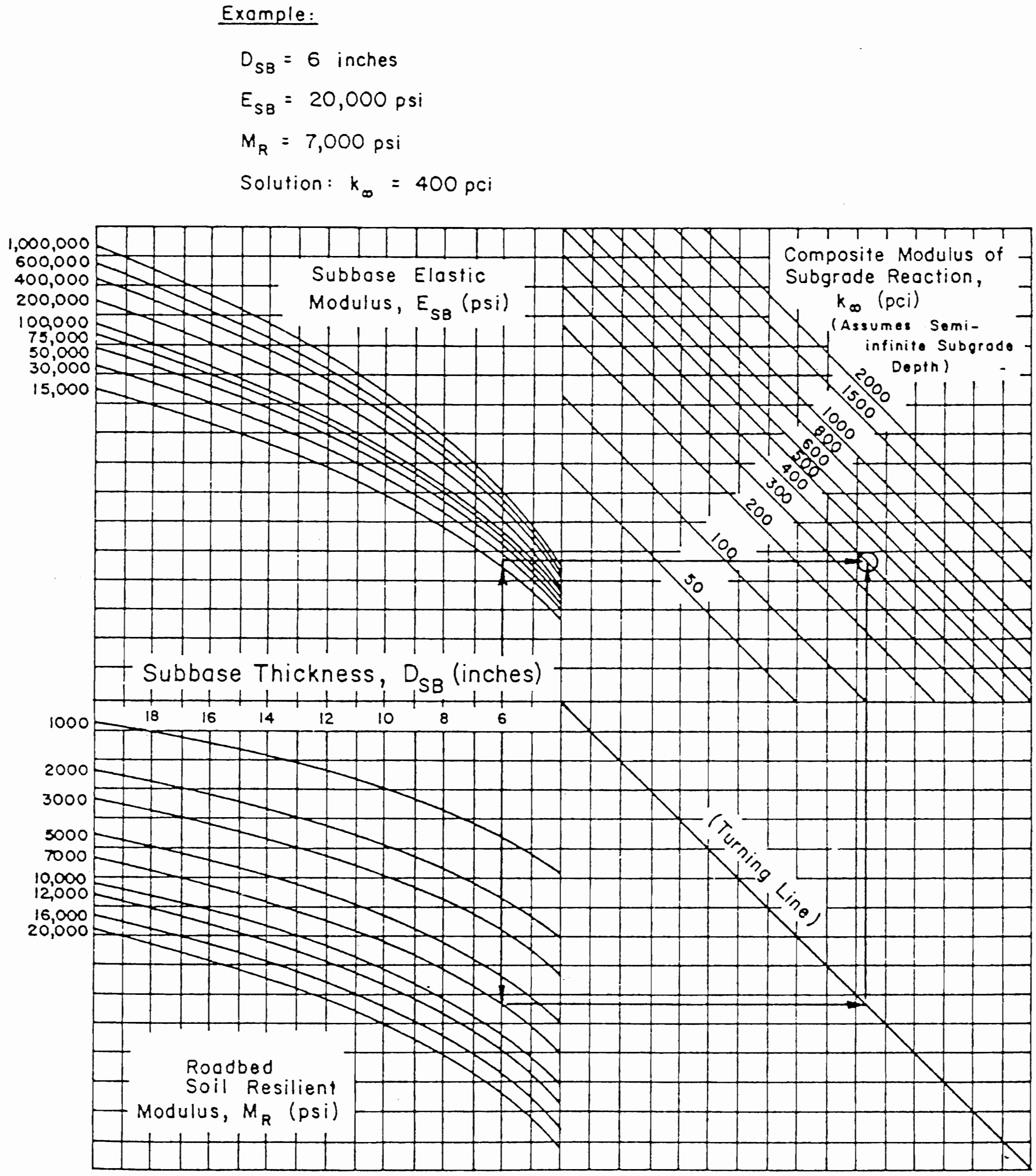


Figure 3.3. **Chart for Estimating Composite Modulus of Subgrade Reaction, k_∞, Assuming a Semi-Infinite Subgrade Depth. (For practical purposes, a semi-infinite depth is considered to be greater than 10 feet below the surface of the subgrade.)**

NOMOGRAPH SOLVES:

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

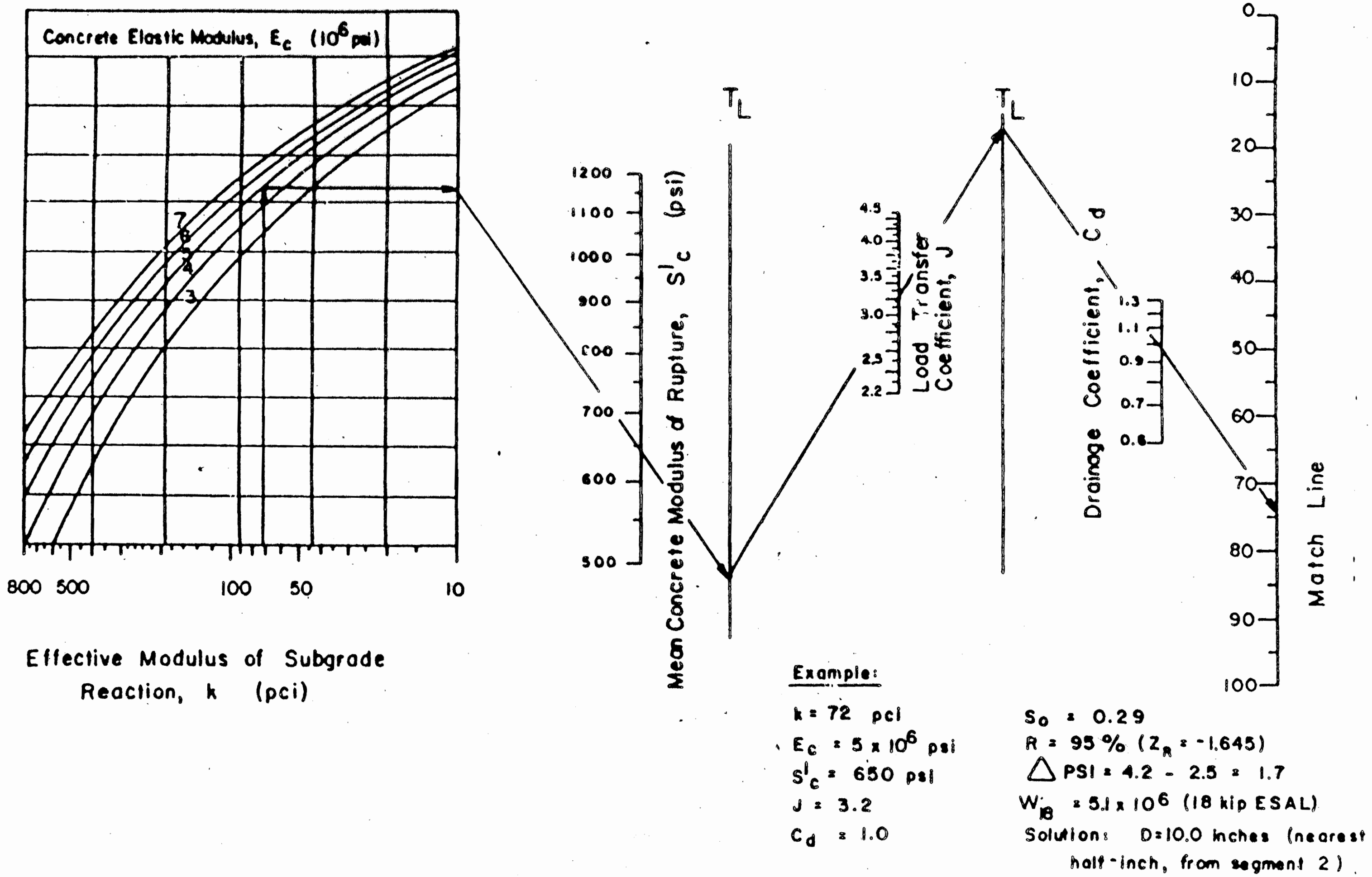


Figure 26. Design chart for rigid pavement based on using mean values for each input variable (Segment 1).

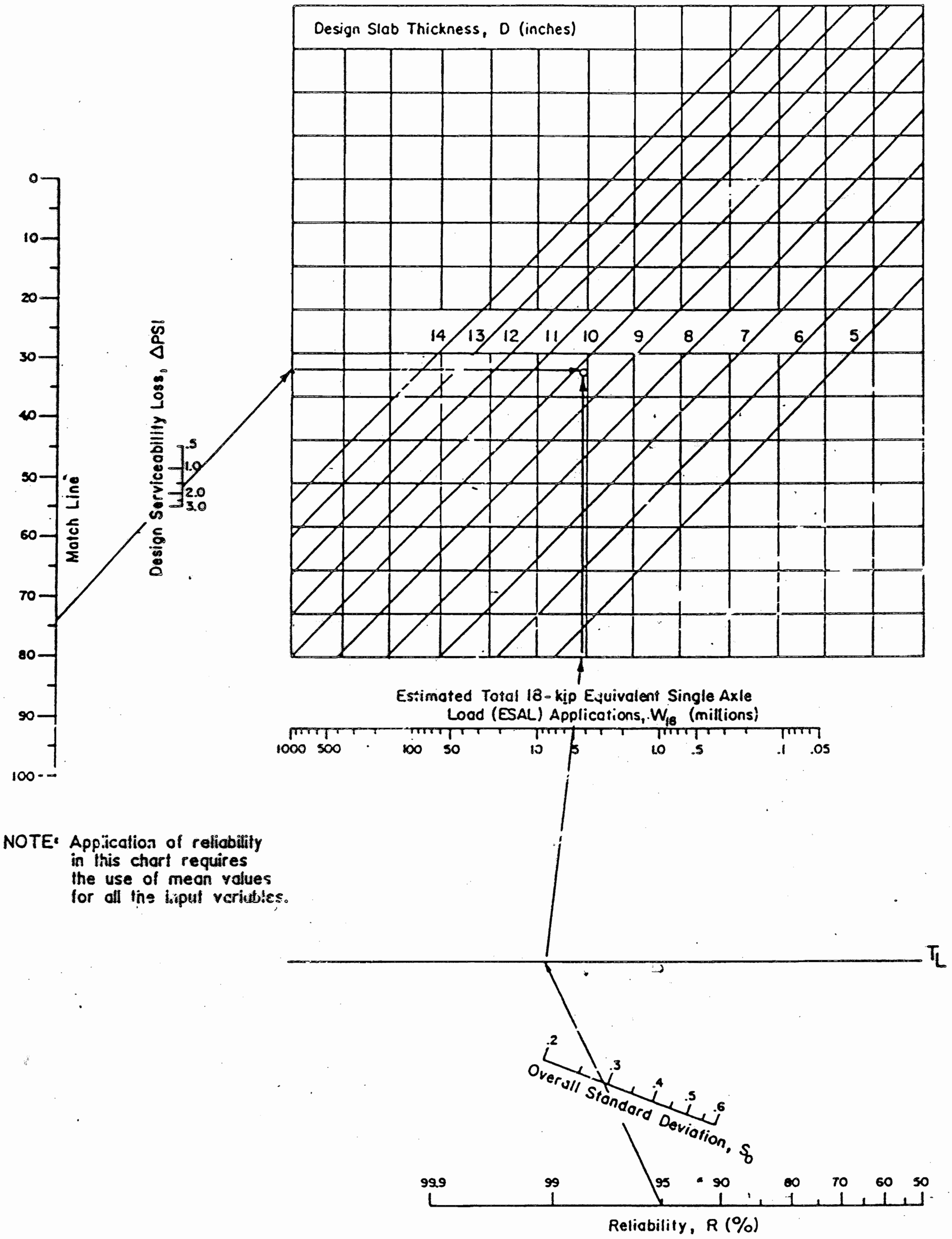


Figure 26. Design chart for rigid pavements based on using mean values for each input variable (Segment 2) (continued.)

IT= indirect tensile strength of 6" diameter cores, psi

Step 6: Determine D_f

1. Effective Static k-value (k_{stat})
   a. $k_{stat} = k_{dyn} / 2$ (k_{dyn} from Backcalculation)
   b. Conduct plate load test
   c. Estimate from soils data and base type and thickness from charts
2. Design ΔPSI
3. J Load Transfer Coefficient
4. PCC Modulus of Rupture

$$S_c' = 210 + 1.02IT \quad \text{(psi)}$$

$$S_c' = 43.5\left(\frac{E}{10^6}\right) + 488.5 \quad \text{(psi)}$$

   E = Backcalculated E_{pcc}
5. E_{pcc}
6. Loss of Support of Existing Slab
   For OL design, assume fully supported LS=0
7. R, S_o, C_d(drainage)
   (Using AASHTO Design Equation)

Step 7: Determine D_{eff}

1. D_{eff} from Visual Survey

$$D_{\text{eff}} = F_{jc}(F_{dur})(F_{fat})D$$

F_{jc} = joints and cracks (0.5 ~ 1.0), if repaired all cracks F_{jc} = 1.0

F_{dur} = durability (0.8 ~ 1.0)

F_{fat} = fatigue damage (0.9 ~ 1.0)

2. D_{eff} from Remaining Life

$$RL = 100\left(1 - \frac{N_p}{N_{1.5}}\right)$$

$$D_{eff} = CF(D)$$

(From RL ==> determine CF)

Step 8: Determine Overlay Thickness (D_{OL})

$$D_{OL} = A(D_f - D_{eff})$$

$$A = 2.2233 - 0.1534(D_f - D_{eff}) + 0.0099(D_f - D_{eff})^2$$

◎AC Overlay of AC/JPCP, AC/JRCP, and AC/CRCP

$$D_{OL} = A(D_f - D_{eff})$$

$$A = 2.2233 - 0.1534(D_f - D_{eff}) + 0.0099(D_f - D_{eff})^2$$

Step 1 ~ Step 3: Same as Before

Step 4: Deflection Testing (Strongly Recommended)

1. Temperature of AC Mix
2. Elastic Modulus of AC

$$\log E_{ac} = f(P_{200}, \mathrm{F}, \mathrm{V_v}, \eta_{70oF,10^6 poise}, P_{ac}, t_p)$$

(% passing #200, load frequency Hz, air voids, absolute viscosity, % asphalt, AC mix temperature)

3. Effective Dynamic k-value (k_{dyn}) beneath PCC Slab

a. Compute compression between AC (d_{0comp})

$$d_{0compress} = -0.0000328 + 121.5006\left(\frac{D_{ac}}{E_{ac}}\right)^{1.0798} \quad \text{Bonded}$$

$$d_{0compress} = -0.00002133 + 38.6872\left(\frac{D_{ac}}{E_{ac}}\right)^{0.94551} \quad \text{Unbonded}$$

b. Compute $AREA_{PCC}$

$$AREA_{PCC} = 6\left(1 + 2\frac{d_{12}}{d_{0PCC}} + 2\frac{d_{24}}{d_{0PCC}} + \frac{d_{36}}{d_{0PCC}}\right)$$

d_{0PCC} = PCC deflection in the center of loading plate = d_0 - $d_{0compress}$

d_i = deflection at 12, 24, 36"

c. Backcalculate k_{dyn}
(K. T. Hall's Closed-Form Solution)

4. Effective Static k-value (k_{stat})
$k_{stat} = k_{dyn} / 2$

5. Elastic Modulus of PCC Slab (E)
由 AREA, k_{dyn} ==> ED^3 ==> Find E = ?

6. Joint Load Transfer for JPCP/JRCP

$$\Delta LT = 100\left(\frac{\Delta_{UL}}{\Delta_L}\right)B$$

$$B = \frac{d_{0center}}{d_{12center}}$$

B and J factor: same as before

Step 5: Coring and Material Testing (Strongly Recommended)

1.Modulus of AC Surface

$$\log E_{ac\ t^oF} = \left(\frac{\log E_{ac\ 70^oF} - \log E_{ac\ 90^oF}}{70-90} \right) *$$

$$(t^oF - 70^oF) + \log E_{ac\ 70^oF}$$

2. PCC Modulus of Rupture, S_c'

$$S_c' = 210 + 1.02IT \quad \text{(psi)}$$

Step 6: Determine D_f

1. Determine k_{stat}, ΔPSI, J, S_c', E_{pcc} , LS, R, S_o, C_d

$$S_c' = 210 + 1.02IT \quad \text{(psi)}$$

$$S_c' = 43.5\left(\frac{E}{10^6}\right) + 488.5 \quad \text{(psi)}$$

2. Using AASHTO Design Equation

Step 7: Determine D_{eff}

$$D_{\text{eff}} = D_{PCC}(F_{jc})(F_{dur}) + \frac{D_{ac}}{2.0}(F_{ac})$$

F_{jc} = joints and cracks (0.5 ~ 1.0), if repaired all cracks F_{jc} = 1.0

F_{dur} = durability (0.8 ~ 1.0)

F_{ac} = AC quality adjustment (0.8 ~ 1.0)

Step 8: Determine D_{OL}

$$D_{OL} = A(D_f - D_{eff})$$

$$A = 2.2233 - 0.1534(D_f - D_{eff}) + 0.0099(D_f - D_{eff})^2$$

◎Bonded Concrete Overlay of JPCP, JRCP, and CRCP

$$D_{OL} = D_f - D_{eff}$$

Step 1 ~ Step 2: Same as Before

Step 3: Condition Survey

JPCP/JRCP: Joint Deterioration, Transverse Cracks, Expansion Joints, Durability, Faulting, Pumping

CRCP: Punchouts, Deteriorated Transverse Cracks

Step 4: Deflection Testing (Strongly Recommended)

1. AREA (same definition)
2. Effective Dynamic k-value (k_{dyn}) from Backcalculation

(K. T. Hall's Closed-Form Solution)

3. Effective Static k-value, $k_{stat} = k_{dyn} / 2$
4. Elastic Modulus of PCC Slab (E)

由 AREA, k_{dyn} ==> ED^3 ==> Find E = ?

6. Joint Load Transfer for JPCP/JRCP

$$\Delta LT = 100\left(\frac{\Delta_{UL}}{\Delta_L}\right)B$$

$$B = \frac{d_{0center}}{d_{12center}}$$

B and J factor: same as before

Step 5: Coring and Material Testing (Strongly Recommended)

$$S_c' = 210 + 1.02IT \quad \text{(psi)}$$

Step 6: Determine D_f

Using AASHTO Design Equation (Same as before)

Step 7: Determine D_{eff}

1. Visual Survey

$$D_{\text{eff}} = (F_{jc})(F_{dur})(F_{fat})D$$

2. Remaining Life

$$RL = 100\left(1 - \frac{N_p}{N_{1.5}}\right)$$

$$D_{eff} = CF(D)$$

Step 8: Determine D_{OL}

$$D_{OL} = D_f - D_{eff}$$

◎Unbonded JPCP, JRCP & CRCP Overlay of JPCP, JRCP, CRCP, and AC/PCC

$$D_{OL} = \sqrt{D_f^{\,2} - D_{eff}^{\,2}}$$

Step 1 ~ Step 3: Same as Before

Step 4: Deflection Testing (Strongly Recommended)

1. AREA (same definition)
2. Effective Dynamic k-value (k_{dyn}) from Backcalculation
   (K. T. Hall's Closed-Form Solution)
3. Effective Static k-value, $k_{stat} = k_{dyn} / 2$

Step 5: Coring and Material Testing (Not Needed)

Step 6: Determine D_f

Using AASHTO Equation (Same as before)

Step 7: Determine D_{eff}

1. Visual Condition Survey

$$D_{\text{eff}} = (F_{jcu})D$$

F_{jcu} = joints and cracks adjustment factor for unbonded PCC (0.95 ~ 1.0)

Note:

a. existing AC in neglected

b. F_{dur} and F_{fat} are not used for unbonded PCC overlay

c. F_{jcu} factor is modified and reduced

2. Remaining Life

$$RL = 100\left(1 - \frac{N_p}{N_{1.5}}\right)$$

$$D_{eff} = CF(D)$$

Step 8: Determine D_{OL}

$$D_{OL} = \sqrt{D_f^{\,2} - D_{eff}^{\,2}}$$

◎ JPCP, JRCP & CRCP Overlay of AC Pavement

$$D_{OL} = D_f$$

Step 1 ~ Step 3: Same as Before

Step 4: Deflection Testing (Strongly Recommended)

1. Subgrage Resilient Modulus, M_R (same as before)
2. Effective Dynamic k-value (k_{dyn}) from Backcalculation

Use M_R, E_P, D (total thickness above subgrade), and Figure 3.3 (Page II-39) ➔ Find K_{dyn} = ? (Don't need C=0.33 here!!!)

Step 5: Coring and Material Testing (Usually Not Needed)

Step 6: Determine D_f

Using AASHTO Equation (Same as before)

Step 7: Determine D_{OL}

$$D_{OL} = D_f$$