九、 Design of Overlays for Concrete Pavements

参考資料：

1. Darter, M. I. " Techniques for Pavement Rehabilitation," Training Course, FHWA, 1987. (Block 5)
2. AASHTO, "AASHTO Guide for Design of Pavement Structures," Volume I, 1993. (Chapter 5)

◎Introduction (Objectives)

◎Approaches

1. Engineering Judgement
2. Structural Deficiency:
   AASHTO structural number approach
3. Mechanistic Fatigue Damage Approach:
   (a) characteristic of pavements, E's
   (b) past damage
   (c) remaining life
   (d) required overlay thickness
   ➔ Not widely utilized
4. Others, e.g., deflection approach

◎Types of Overlays over Rigid Pavements

AC, PCC (same as before)

◎AASHTO Overlay Design Methodology

1. Based on serviceability-performance relationships

2. Implicit remaining life concept
3. Strongly recommends NDT testing

※Basic AASHTO Design Procedure:

Figure 1 Relationship between serviceability-capacity condition factor and traffic

$$SC_{xeff} = C_x SC_0$$

$$SC_{OL}{}^n = SC_y{}^n - F_{RL}(SC_{xeff})^n$$

C_x = overall pavement condition factor
SC_{xeff} = effective structural capacity
F_{RL} = remaining life factor ≤ 1.0

◎AASHTO AC Overlay Design Over Rigid Pavements

Major Seven Steps:

1. Analysis unit delineation
2. Traffic analysis
3. Material and environmental study
4. Effective structural capacity analysis (SC_{xeff})
5. Future overlay structural capacity analysis (SC_y)
6. Remainling life factor deterimination (F_{RL})
7. Overlay design analysis

※Analysis Unit Delineation

1. determine boundaries along the project
2. accurate historic data available / unavailable

※Traffic Analysis (ESAL)

※Material and Environmental Study

1. existing pavement layer properties
   (a) NDT ➔ backcalculation techniques
   (b) Use "interior" loading position
   (c) cracked / non-cracked slabs
2. existing subgrade properties
   Figure 2 Composite subgrade modulus
3. design properties of overlay layers

※Effective Structural Capacity Analysis (SC_{xeff})

1. NDT Method (Figure 3)
2. Non-NDT Approximate Procedure
   (a) Visual condition factor (Figure 4)
   (b) Nominal size of PCC slab fragments (Figure 5)
   (c) Remaining life (Figure 6)

$$D_{xeff} = C_x D_0$$

※Future overlay structural capacity analysis (SC_y)

SN_y (AC) or D_y (PCC)

Simply a new pavement design

※Remaining life factor determination (F_{RL})

1. Approaches:
   NDT, Traffic Approach, Time Approach (Figure 7), Serviceability Approach (Figure 8), Visual Condition Survey Approach (Figure 9)

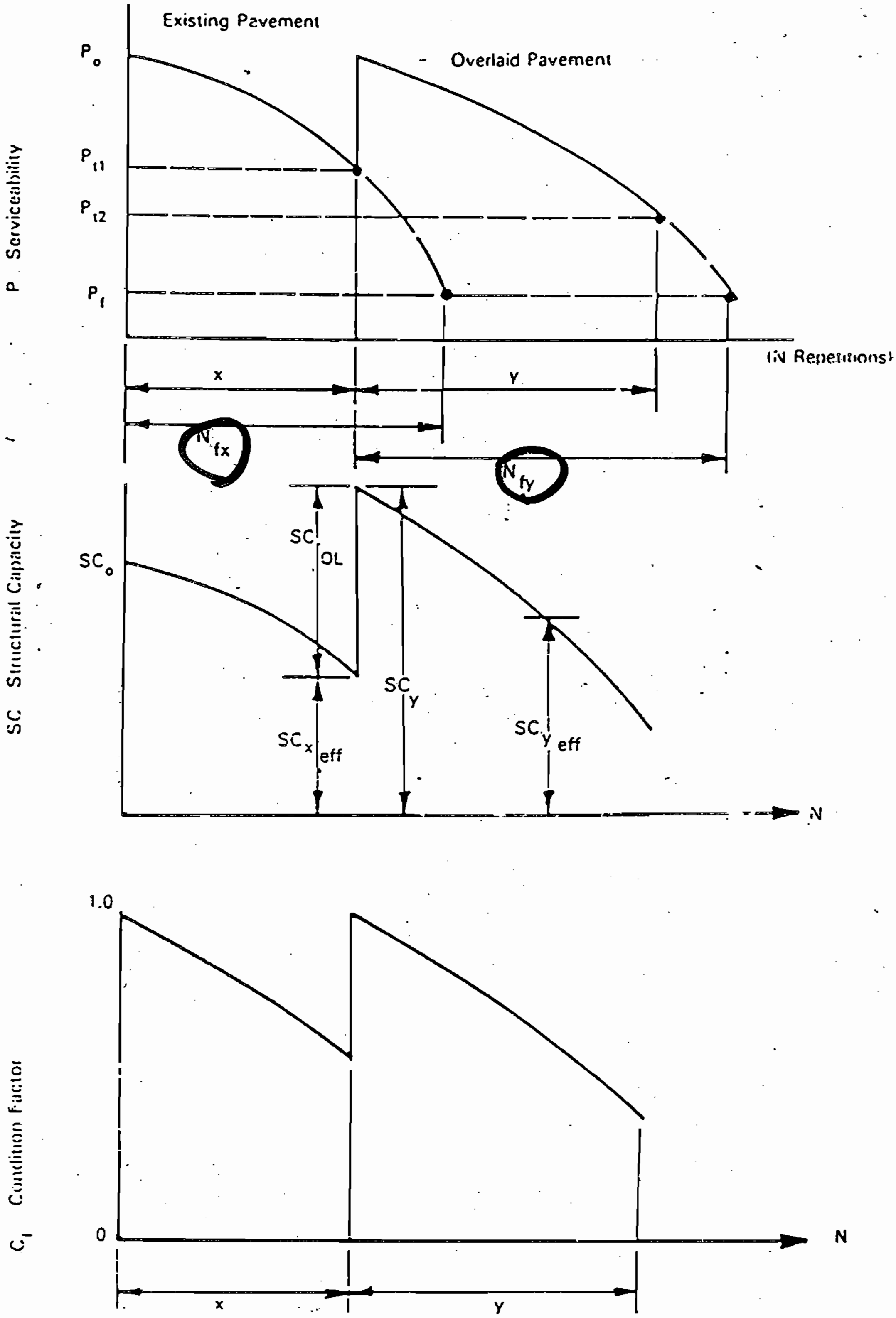


Figure 1. Relationship Between Serviceability-Capacity Condition Factor and Traffic (1).

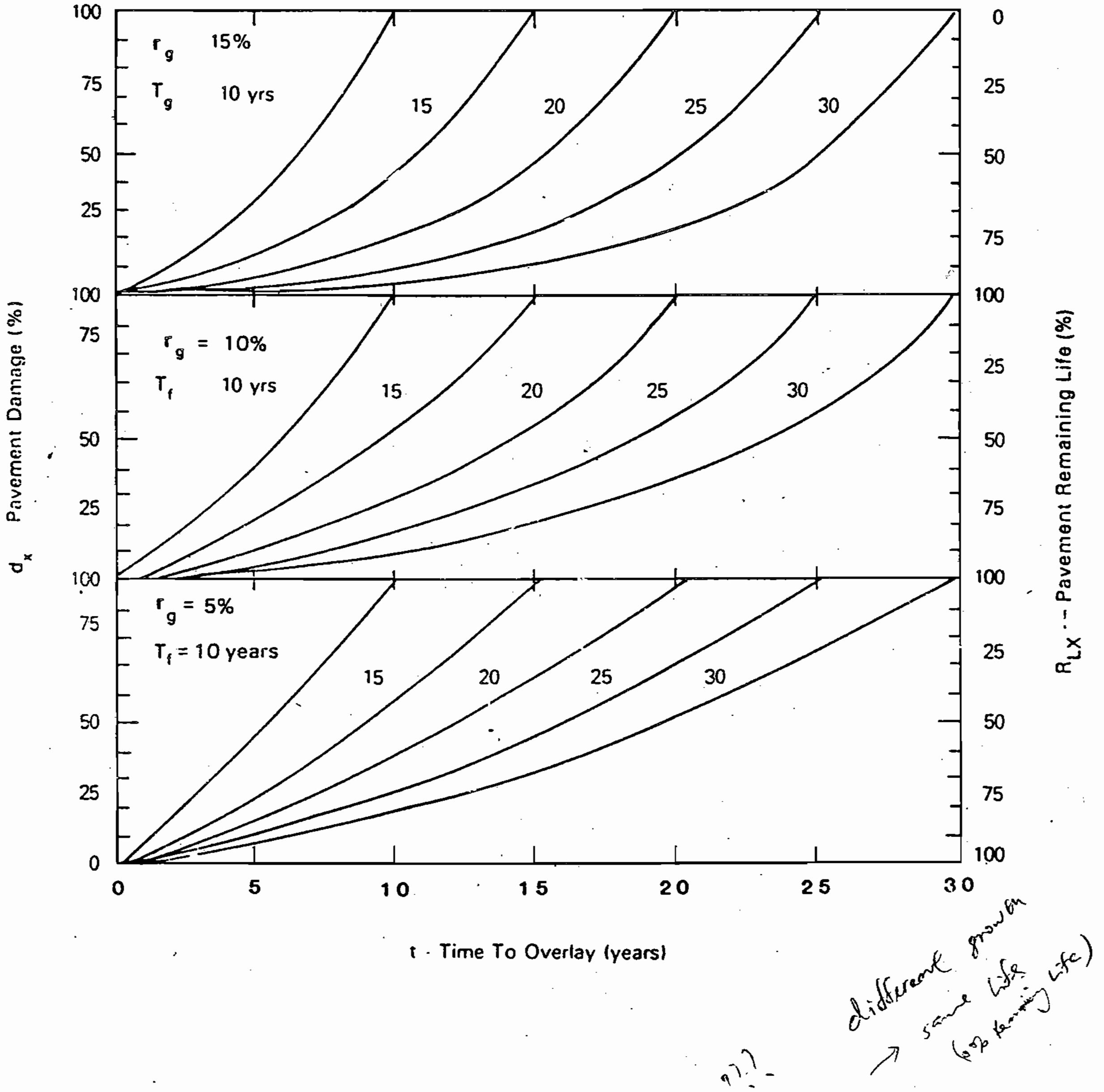


Figure 7. Remaining life estimate based on time considerations for various traffic growth rates.

Example:

D_{SB} = 6 inches

E_{SB} = 20,000 psi

M_R = 7,000 psi

Solution: k_∞ = 400 pci

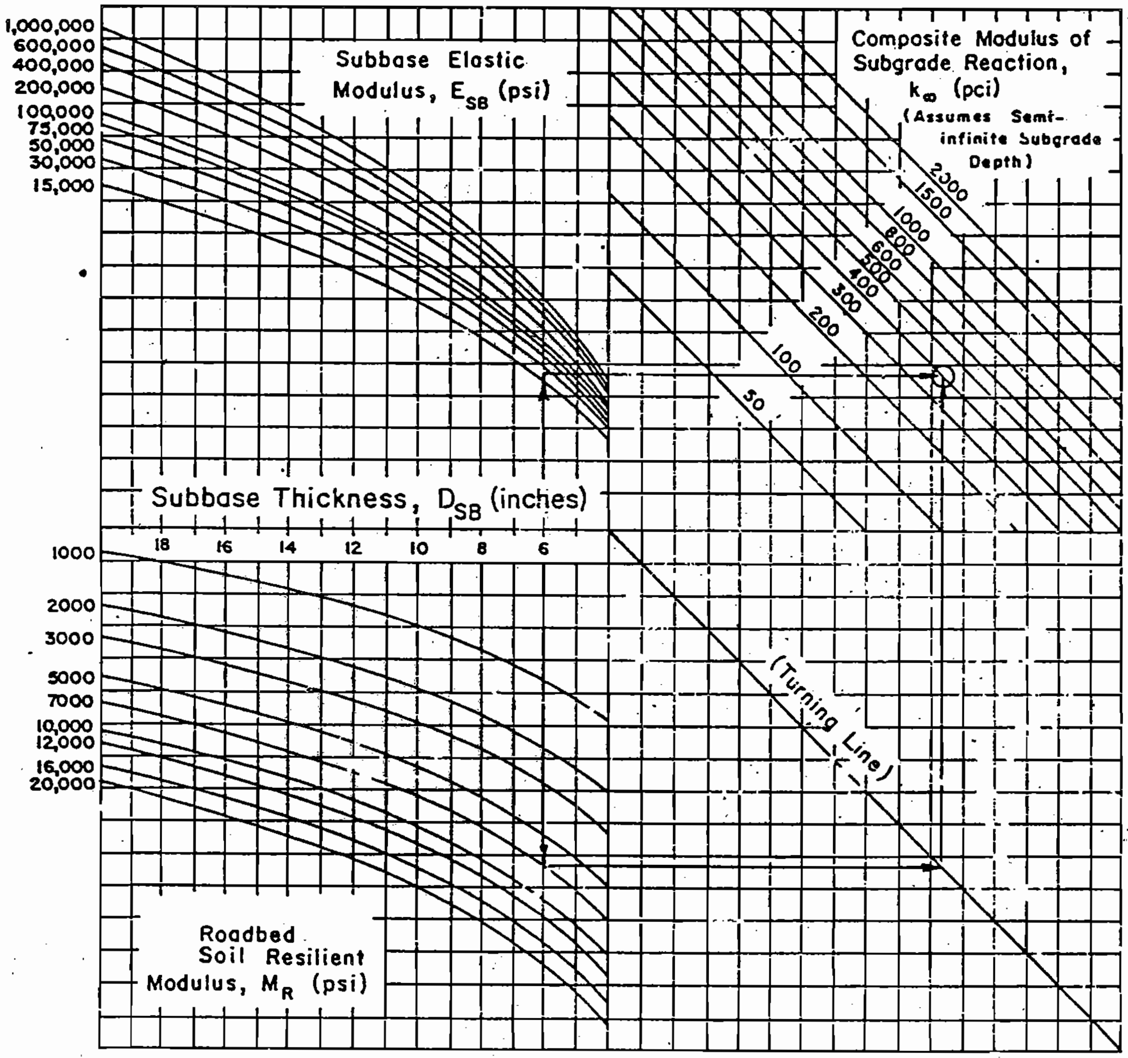


Figure 2. Chart for estimating composite modulus of subgrade reaction, k_{00}, assuming a semi-infinite subgrade depth. (For practical purposes, a semi-infinite depth is considered to be greater than 10 feet below the surface of the subgrade.)

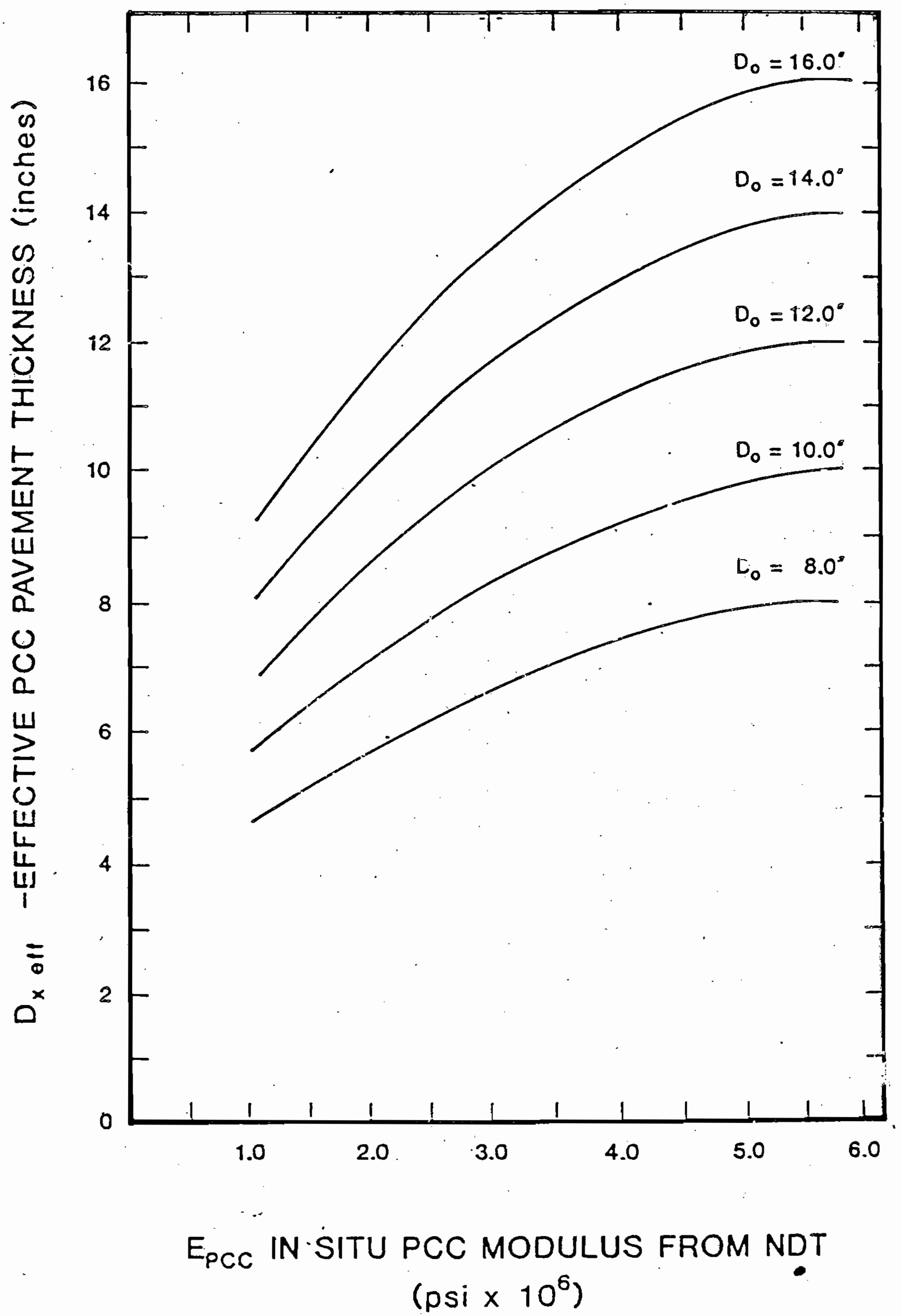


Figure 3. Determination of Effective PCC Structural Capacity for NDT-Derived PCC Modulus (1).

2. Use R_{Lx} and R_{Ly} to determine F_{RL} (Figure 10)
The procedure is very confusing and was removed in the new AASHTO Guide (1993).

※AC overlay thickness determination
(Figure 11 - Equations used)

1. Normal AC structural overlay approach
   $h_{ol} = SN/a_{ol}$
2. Use of thick overlays to minimize reflective cracking
3. Crack and seat approach to minimize reflective cracking

◎AASHTO PCC Overlays Over Rigid Pavements
Major Seven Steps: (Same as before)

1. Analysis unit delineation
2. Traffic analysis
3. Material and environmental study
4. Effective structural capacity analysis (SC_{xeff})
5. Future overlay structural capacity analysis (SC_y)
6. Remainling life factor deterimination (F_{RL})
7. Overlay design analysis

※Figure 16 unbonded, partially bonded, or fully bonded(by cold milling or shot blasting)

$$D_{OL}{}^n = D_y{}^n - F_{RL}(D_{xeff})^n$$

◎Example Problems

※Major Steps

Step 1 – Collect basic information and design criteria

Step 2 – Determine the structural number for a new pavement to support the future traffic

Step 3 – Determine the effective SC of the existing pavement

Step 4 – Determine the remaining life factor

Step 5 – Computation of final overlay design thickness

Step 6 – Reflection crack control

※Design of flexible overlays over rigid pavements (Figure 23 ~ Figure 25)

※Design of flexible overlays over cracked and seated rigid pavements

※Design of rigid overlays over rigid pavements (Figure 26)

12.0 EXAMPLE PROBLEMS

12.1 AASHTO Design Procedure For The Design Of Flexible Overlays Over Rigid Pavements

(Note: This is a simplified example in that all of the procedures to determine the inputs are not considered or illustrated. See the AASHTO Guide, Reference 1, for further details.)

Step 1 -- Collect basic information and design criteria

Four-lane highway, age = 18 years

Existing pavement:	9.0-inch JRCP 6.0-inch granular subbase 40-foot joint spacing Load transfer: dowel bars
Roadbed soil:	Silty clay
Major distress:	Working transverse cracks, joint deterioration and pumping
Drainage:	Non-drainable subbase and roadbed soil (i.e., 1 month, and percent time pavement structure is saturated is > 25 percent time) Materials have "poor" drainage characteristics (Cd = 0.80)
Existing serviceability index:	2.7
Accumulated 18-kip ESALs:	5×10^6 outer traffic lane
Design period:	20 years
Future overlay design traffic:	10×10^6 outer traffic lane

See Figure 23 for illustration.

Step 2 -- Determine the structural number for a new pavement to support the future traffic (SN_y)

Use Figure 2 from Module 5C - AASHTO thickness design nomograph to determine SN_y. The following input variables were used:

Design reliability: 85 percent
Overall standard deviation: 0.50
Design 18-kip ESAL over 10 years: 10×10^6
Roadbed soil effective resilient modulus: 8,000 psi
Loss of seviceability:
4.5 (after overlay) - 2.5 (design terminal) = 2.0

SOLUTION: $SN_y = 4.6$

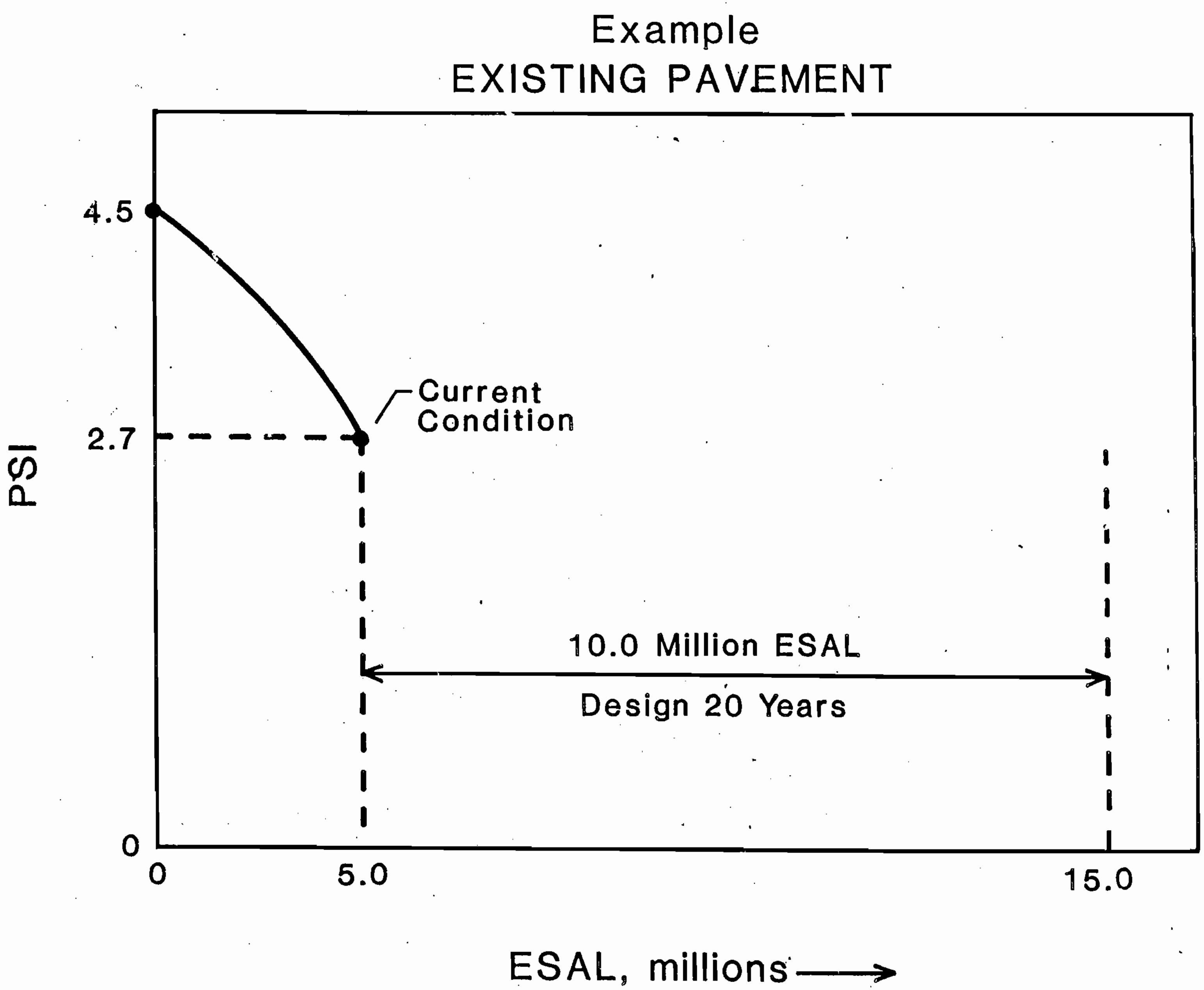


Figure 23. Existing condition of rigid pavement and future design traffic.

Step 3 -- Determine the effective SN of the existing pavement (SN_{xeff})

$$SN_{xeff} = C_x \times D_{xeff} + SN_{xeff\text{-}rp}$$

where:

SN_{xeff} = Total effective structural number of the existing pavement

C_x = Structural condition value

D_{xeff} = Effective existing slab thickness

$SN_{xeff\text{-}rp}$ = Effective structural number of the subbase

In order to determine the effective existing slab thickness, the in situ pavement properties are required. Corings and borings through the depth of the pavment and into the roadbed soil were taken along the project. Falling Weight Deflectometer deflection basins were also measured along the project at 9,000-pound load levels and the deflection basins were analyzed. The moduli of the pavement layers and the roadbed soil were back-calculated using elastic layer concepts. Results of these tests are as follows (all values are averages):

Layer	Core/Bore Thickness	Back-calculated Modulus
PCC	8.8 inches	2.0×10^6 psi *
Gr. Subbase	5.8 inches	15,000 psi
Roadbed Soil	--	8,000 psi

* The E_{pcc} must reflect the amount of cracking in the slabs, thus deflection measurements must be taken near working cracks if they are not to be full depth repaired with doweled joints. This value was back-calculated over several representative working cracks that will not be repaired. The modulus of the concrete was about 5 million psi in non-cracked areas, which indicates a sound concrete with high strength.

The effective existing slab thickness (D_{xeff}) is determined using Figure 3 with a back-calculated modulus for the PCC surface of 2.0×10^6 and the pavement's existing thickness of 8.8 inches.

SOLUTION: $D_{xeff} = 6.2$ inches

The structural condition value (C_x) is determined using the following equation:

SOLUTION: $C_x = D_{xeff}/D_o = 6.2/8.8 = 0.70$

The structural number of the subbase layer ($SN_{xeff\text{-}rp}$) is calculated using the following equation:

$$SN_{xeff\text{-}rp} = D_{SB} \times a_{SB}$$

where:

D_{SB} = Thickness of the subbase = 6.0 inches
a_{SB} = Structural coefficient for the subbase
= 0.11 (from Figure 8, Module 5C) p 703

SOLUTION: $SN_{xeff\text{-}rp} = 5.8 \times 0.11 = 0.66$

With this information the total effective structutal number of the existing pavement (SN_{xeff}) can be calculated:

SOLUTION: $SN_{xeff} = 0.70(6.2) + 0.66 = 5.00$

Step 4 -- Determine the remaining life factor (F_{RL})

The F_{RL} value depends upon:

R_{Lx} = Percent remaining life of existing pavement from a serviceability of 2.7 to 2.0 (0 - 100) = 17

Figure 24 shows the concepts and calculation of R_{Lx}, percent remaining life of the existing pavement.

R_{Ly} = Percent remaining life of the overlaid pavement from a serviceability of 2.5 to 2.0 (0 - 100) = 17

Figure 25 shows the concepts and calculation of R_{Ly}, percent remaining life of the overlaid pavement.

The F_{RL} value is then determined using Figure 10. (It is recommended to ignore the curved up lines and simply extend them horizontally.)

SOLUTION: $F_{RL} = 0.58$

Step 5 -- Computation of final overlay design thickness

$$SN_{OL} = SN_y - F_{RL} \times SN_{xeff}$$
$$= 4.6 - 0.58 \times 5.0 = 1.7$$

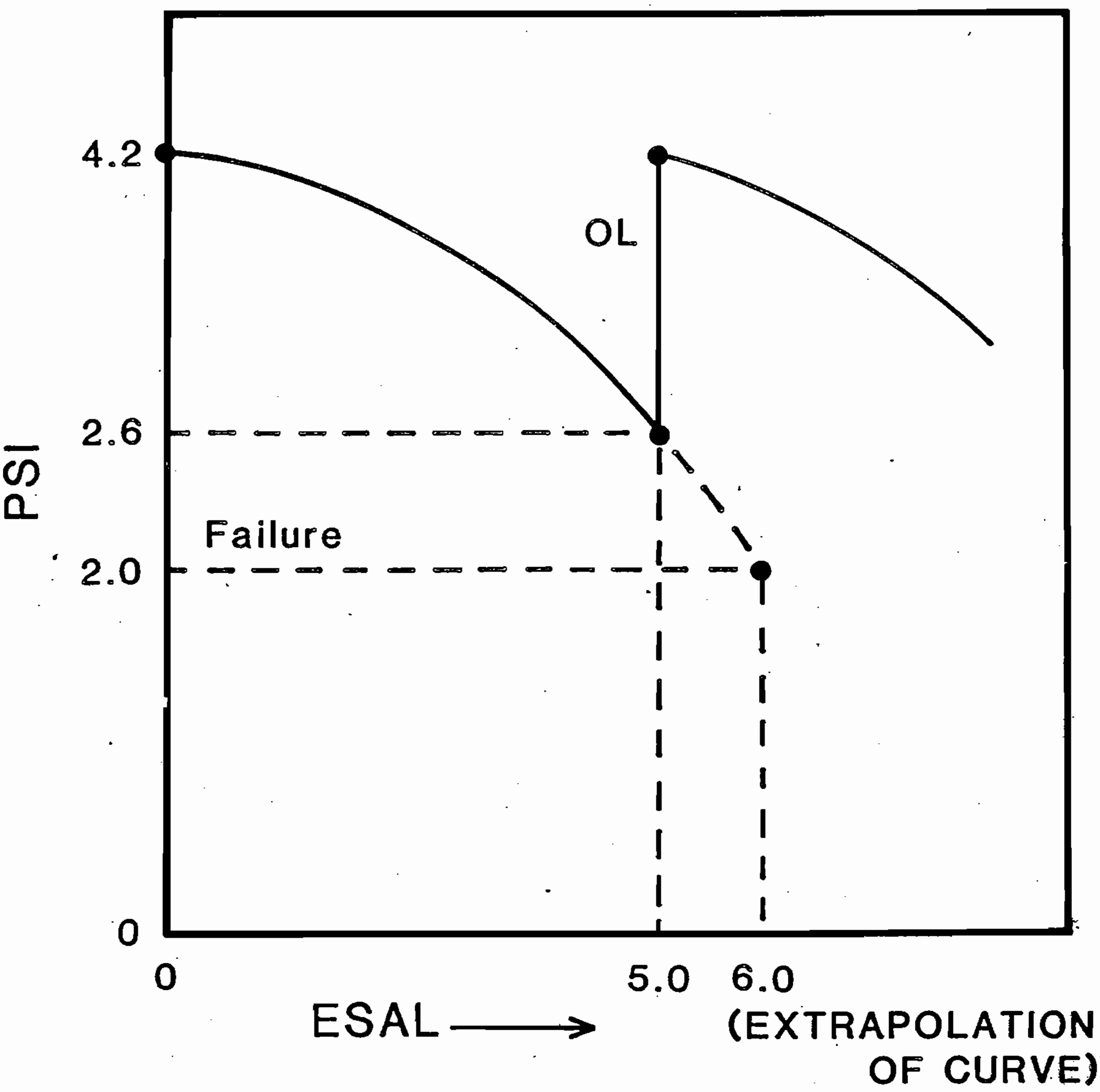
$$SN_{OL} = a_{OL} \times D_{OL}$$

The overlay thickness is computed assuming its elastic modulus is 450,000 psi at 68 degrees F. The structural coefficient is 0.44 for asphalt concrete (see Figure 4, Module 5C)

SOLUTION: $D_{OL} = 1.7/0.44 = 3.9$ inches

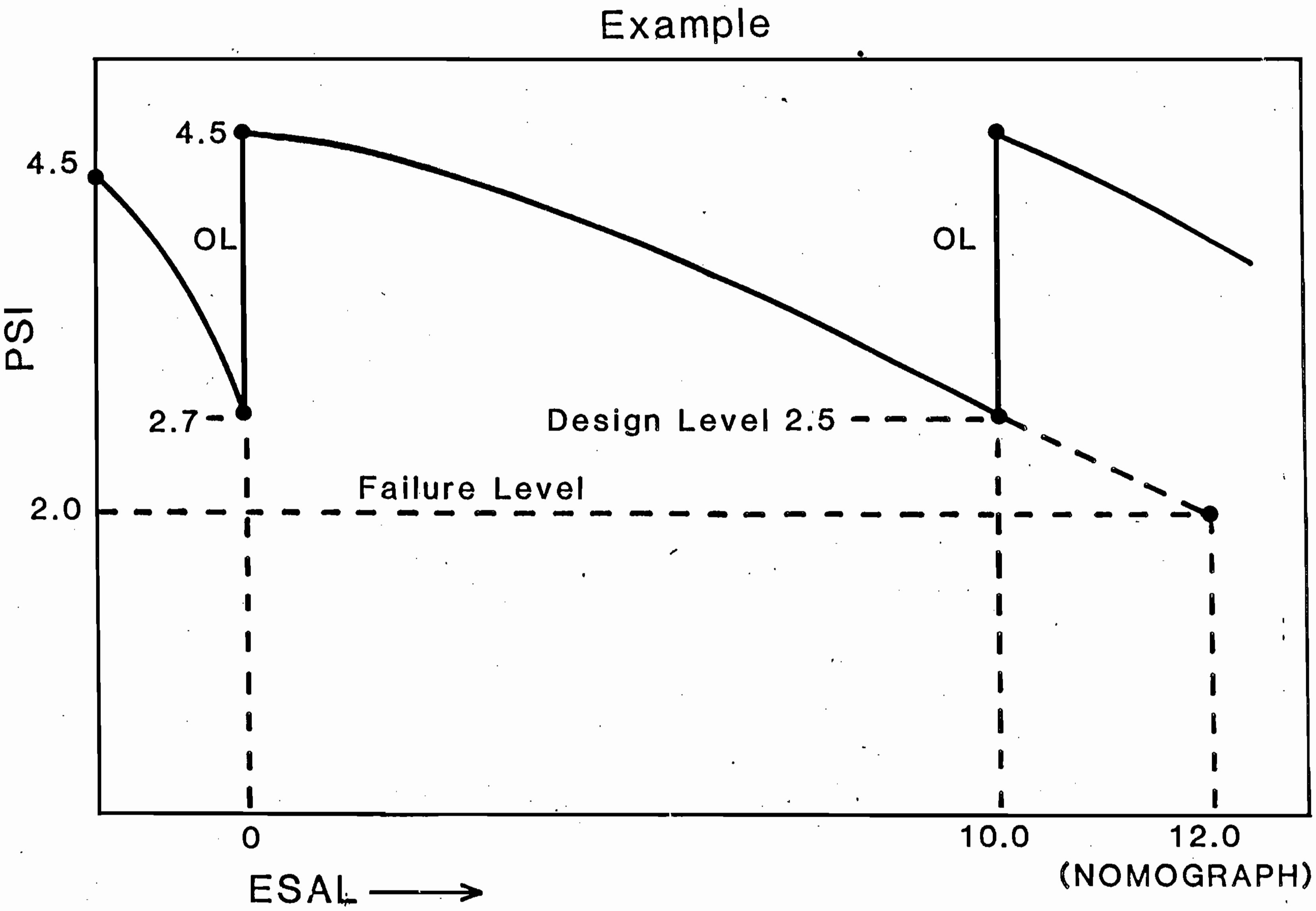
USE: 4 inches AC

Example



$$R_{LX} = \frac{6.0 - 5.0}{6.0} \times 100 = 17$$

Figure 24. Illustration of calculation concepts and procedures for the percent remaining life of the existing pavement (from PSI = 2.6 to 2.0).



$$R_{LY} = \frac{12.0 - 10.0}{12.0} \times 100 = 17$$

Figure 25. Illustration of calculation and concepts for the percent remaining life of the overlayed pavement (from 2.5 to 2.0).

MODULE 5B Design of Overlays for Rigid Pavements

1. Introduction

2. Approaches:
   - Engineering Judement
   - Structural Deficiency:
     AASHHTO structural number approach
   - Mechanistic Fatigue Damage Approach:
     (i) characteristic of pavements, E's
     (ii) past damage
     (iii) remaining life
     (iv) required overlay thickness
     not widely utilized
   - Others, e.g., deflection approach

3. Types of Overlays over Rigid Pavements
   - AC
   - PCC
   (same as before)

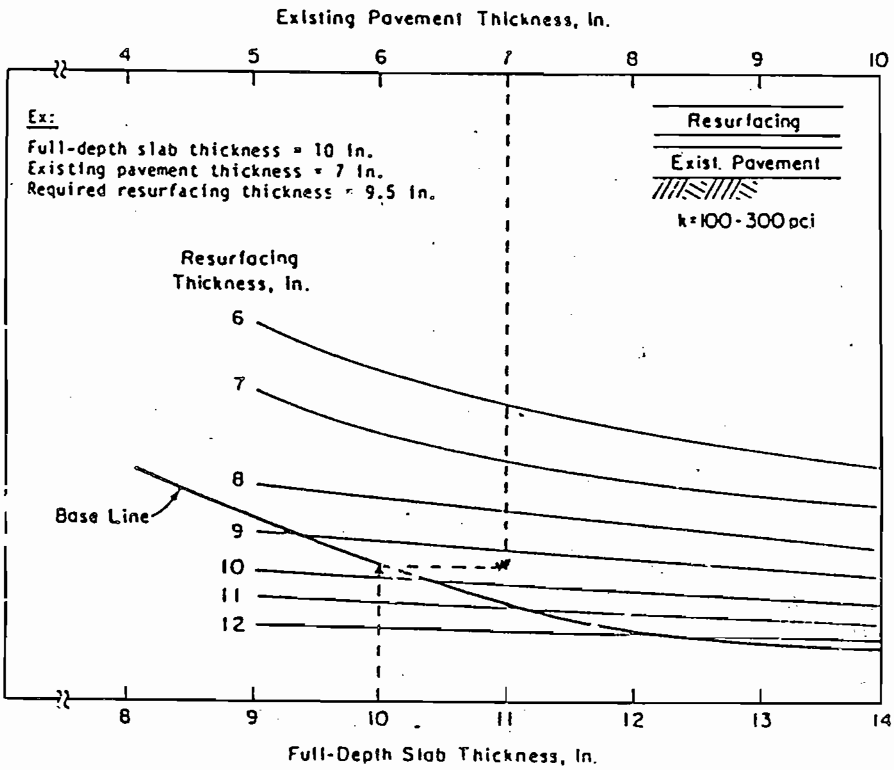
4. AASHTO Overlay Design Methodology
   - Based on serviceability- performance relatiohships
   - implicit remaining life concept
   - strongly recommends the use of nondestructive testing

   Figure 1 (p 631) - Basic AASHTO Design Procedure
   Po, Pt1, Pt2, Pf
   SCxeff = Cx SCo, Cx is

   N_{fx} N_{fy}

$$SC_{OL}^{n} = SC_{y}^{n} - F_{RL}(SC_{xeff})^{n}$$

PCA Overlay PCC – Unbonded



$f_{te} = f_t - 1.65(S_f)$

$f_r = A \cdot B \cdot f_{te}$

↑ Design flexural strength

Figure 18. Design Chart for Case 1 Condition of Existing Pavement (13).

t_n, in.	t_e, in.	Resurfacing Thickness, in		
		Case 1	Case 2	Case 3
8	8	6.8	(6.0)	(6.0)
	7	7.2	6.0	6.0
	6	7.6	6.8	6.0
10	9	9.0	7.0	(6.0)
	8	9.2	7.8	6.0
	7	9.4	8.8	8.0
12	9	11.5	10.4	9.0
	8	11.7	10.8	10.0
	7	11.8	11.2	10.8

Notes: t_n = equivalent full depth new pavement thickness
t_e = existing pavement thickness
Cases 1, 2 and 3 refer to condition of existing pavement described in the text
Values in parentheses indicate minimum thickness requirement of 6 in.

Figure 21. Representative Values of Resurfacing Thickness (13).

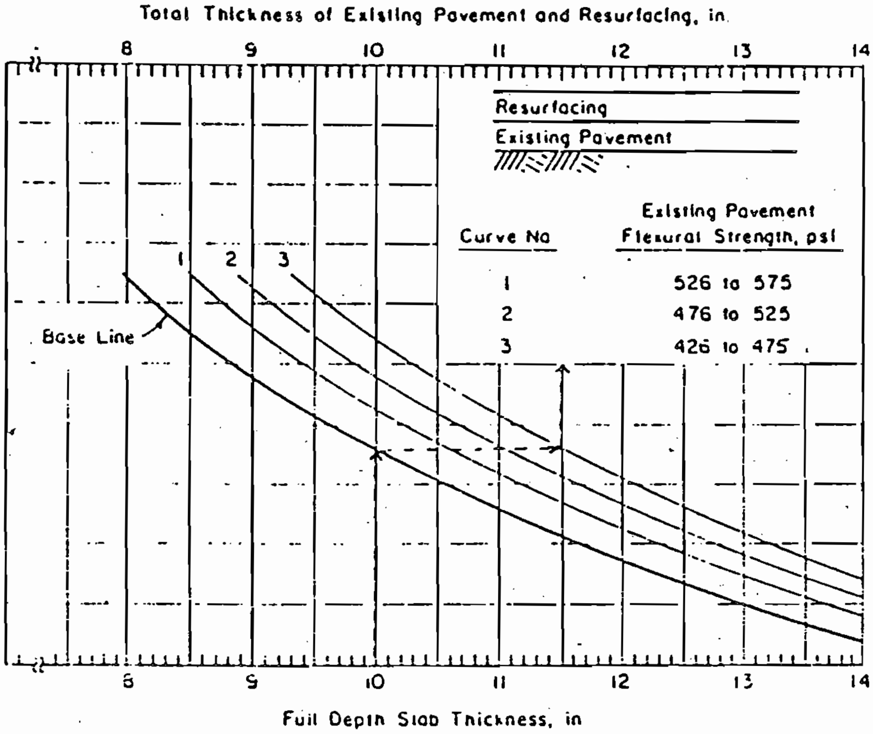


Figure 22. Design Chart for Bonded Resurfacing (13).