DEVELOPMENT OF AN IMPROVED OVERLAY PROCEDURE FOR OREGON

VOLUME III

FIELD MANUAL

by

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16. Abstract

This report is the third in a three-volume series dealing with the development of an improved overlay design procedure for Oregon. This report presents technical guidelines for using the proposed overlay design procedure.

Four areas are described, including preliminary work for an overlay design, deflection data analysis methods, overlay design procedures for four types of pavement combination (AC/AC, AC/PCC, PCC/AC, and PCC/PCC) and a guideline for the use of the design procedure.

Detailed descriptions of AASHTO NDT method 1 and method 2 have been included. Three computer programs necessary to implement the NDT method 1 are described. Computerized approach for the NDT method 2 has been developed. Examples of overlay design using the proposed procedure are also provided.

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DISCLAIMER

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1.0 INTRODUCTION

This is Volume III of the report titled "Development of an Improved Overlay Design Procedure for Oregon." Volume I describes fully the development of the overlay design procedure (1). Volume II presents an evaluation of five pavement structures with this improved method (2). Volume III provides technical guidelines for using the proposed overlay design procedure.

This manual includes four major sections. Section 2.0 describes the preliminary work for an overlay design. Section 3.0 discusses the deflection data analysis methods. Section 4.0 presents four types of overlay design procedures. Finally, Section 5.0 provides a guideline for the use of the design procedures. The appendices include detailed descriptions of AASHTO NDT Method 1 and Method 2 as well as overlay design examples.

2.0 PRELIMINARY WORK

Seven steps are included in an overlay design. A brief description of each follows.

2.1 Step 1 - Delineation of Analysis Unit

The objective of analysis unit delineation is to determine boundaries within the project that subdivide it into statistically homogeneous pavement units possessing uniform pavement cross sections, subgrade (foundation) support, construction histories, and subsequent pavement condition. Figure 2.1 presents a flow diagram for determining analysis units given two extreme cases.

Case 1: Accurate Historic Data Unavailable. For this case, an NDT deflection study should be conducted. Deflection testing should normally be done in the outer wheel path of the lane adjacent to the shoulder. The testing should be conducted with deflections taken at equal intervals of 300 to 500 ft.

Case 2: Accurate Historic Data Available. A random testing approach is recommended. Using this approach, 10 to 15 test points are randomly selected within each unit.

2.2 Step 2 - Traffic Analysis

Two types of traffic data are required. These include:

Cumulative 18 KSAL Repetitions: These data play an important role in estimating the remaining life of the existing pavement prior to an overlay. If these data are not available, an NDT approach can be used in evaluating the remaining life of the existing pavement.

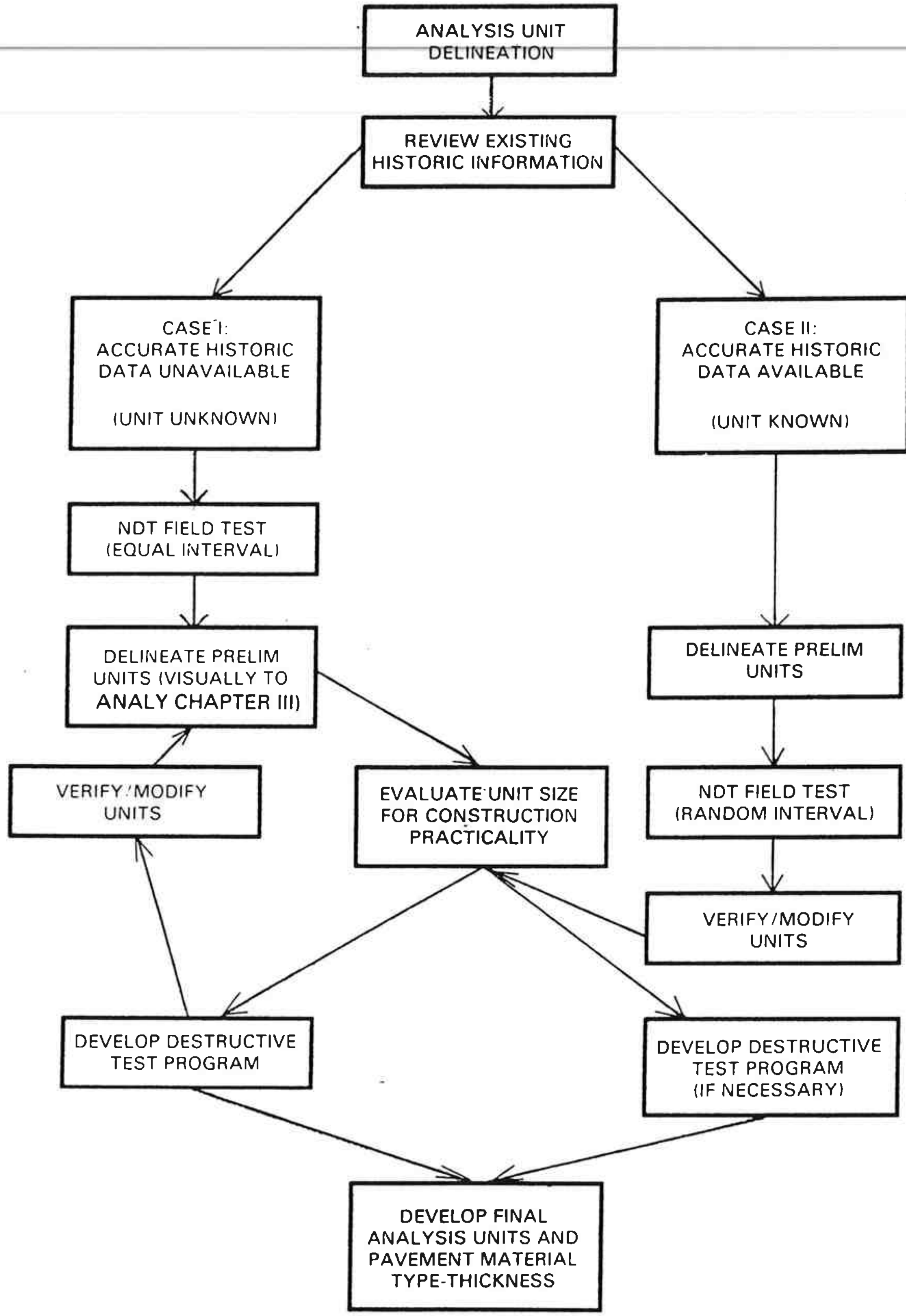


Figure 2.1. General Flow Diagram for Delineating Analysis Units (3).

Cumulative Equivalent 18 KSAL Repetitions Anticipated on the Future Overlaid Pavement: These data are required for designing a structural overlay.

2.3 Step 3 - Materials and Environmental Study

This step consists of determining the best estimates of the properties of 1) the existing pavement layers, including subgrade; and 2) the overlay. The elastic modulus of each layer is the most important property and can be determined from destructive testing (tests on cores) or by backcalculation. The backcalculation technique uses results of NDT deflection basin measurements together with a multilayer elastic computer program to solve for the layer moduli.

2.4 Step 4 - Effective Structural Capacity Analysis (SC_{xeff})

Two methods may be used to estimate the structural capacity of an existing pavement: NDT Method 1 and NDT Method 2. Basically, NDT Method 1 utilizes the deflection basin data to backcalculate layer moduli and subsequently the SC_{xeff}. NDT Method 2 uses the maximum deflection value and in situ subgrade modulus in the determination of SC_{xeff}. Each of these approaches are discussed below.

2.4.1 NDT Method 1

This method requires the use of a backcalculation program to determine the layer moduli of a pavement structure. Three programs are included in this manual: ELSDEF, BISDEF, and MODCOMP2. A detailed description for NDT Method 1 and each of the backcalculation programs is given in Appendix A.

2.4.2 NDT Method 2

This method does not require a backcalculation as is necessary in NDT Method 1. However, a trial-and-error process must be employed to determine the existing pavement capacity. A computer approach for this method has been developed and is presented in Appendix B.

2.5 Step 5 - Future Overlay Structural Capacity Analysis (SC_y)

The SC_y value may be determined from the design charts shown in Figure 2.2 for flexible pavements and Figure 2.3 for rigid pavements.

2.5.1 Flexible Pavements

For flexible pavements, the following data are required to determine the future overlay structural number (SN_y)

W_{18} = predicted number of 18-kip equivalent single axle load repetitions

R = level of reliability

S_o = overall standard deviation

M_R = subgrade resilient modulus (psi)

ΔPSI = design serviceability loss

Figure 2.2 can be used to determine this value.

2.5.2 Rigid Pavements

For rigid pavements, the following data are required to determine the future overlay structural thickness (D_y):

W_{18} = predicted number of 18-kip equivalent single axle load repetitions

R = level of reliability

S_o = overall standard deviation

ΔPSI = design serviceability loss

K = effective modulus of subgrade reaction (pci)

NOMOGRAPH SOLVES:

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

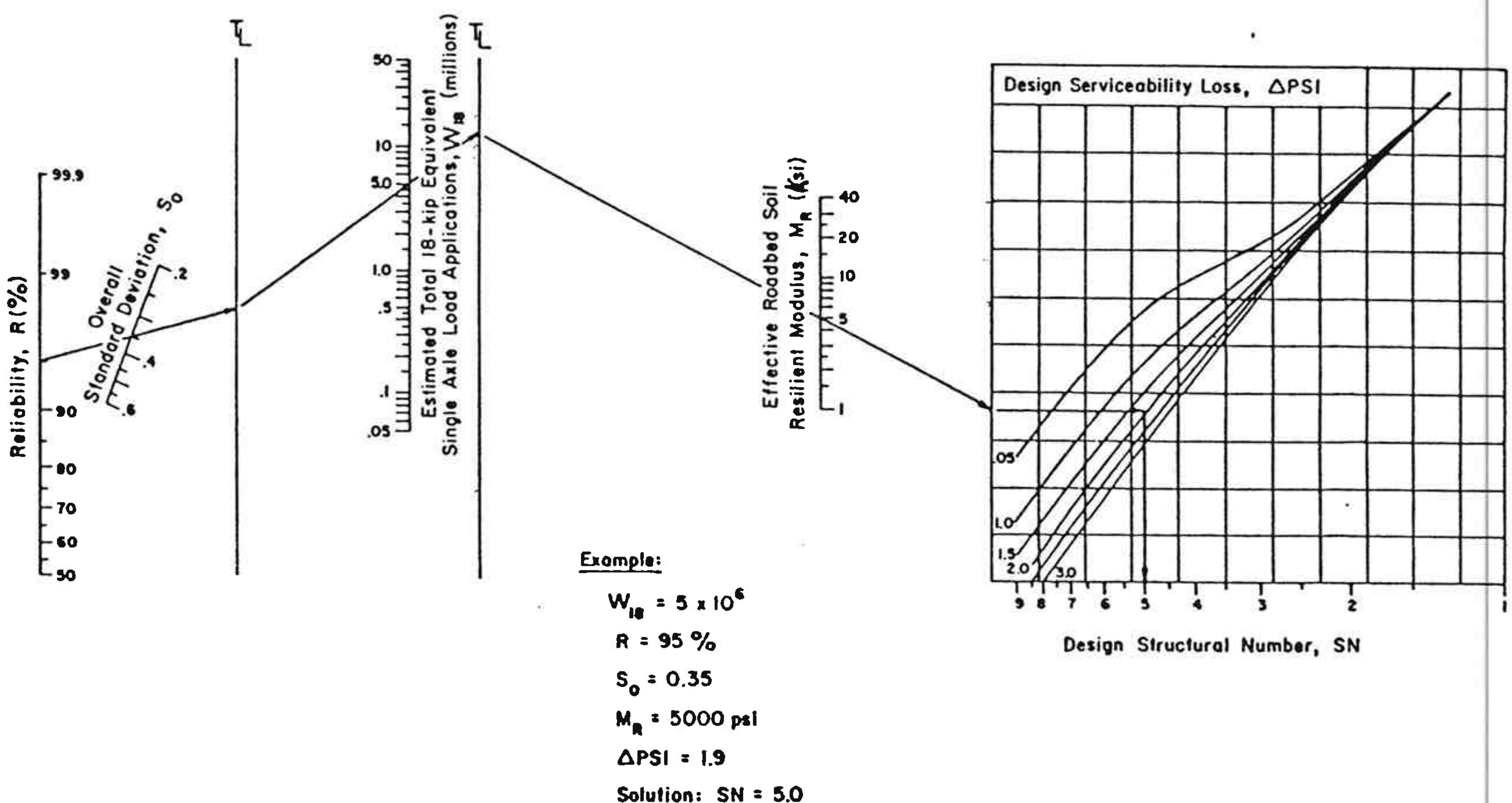


Figure 2.2. Design Chart for Flexible Pavements Based on Using Mean Values for Each Input (3).

NOMOGRAPH SOLVES:

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

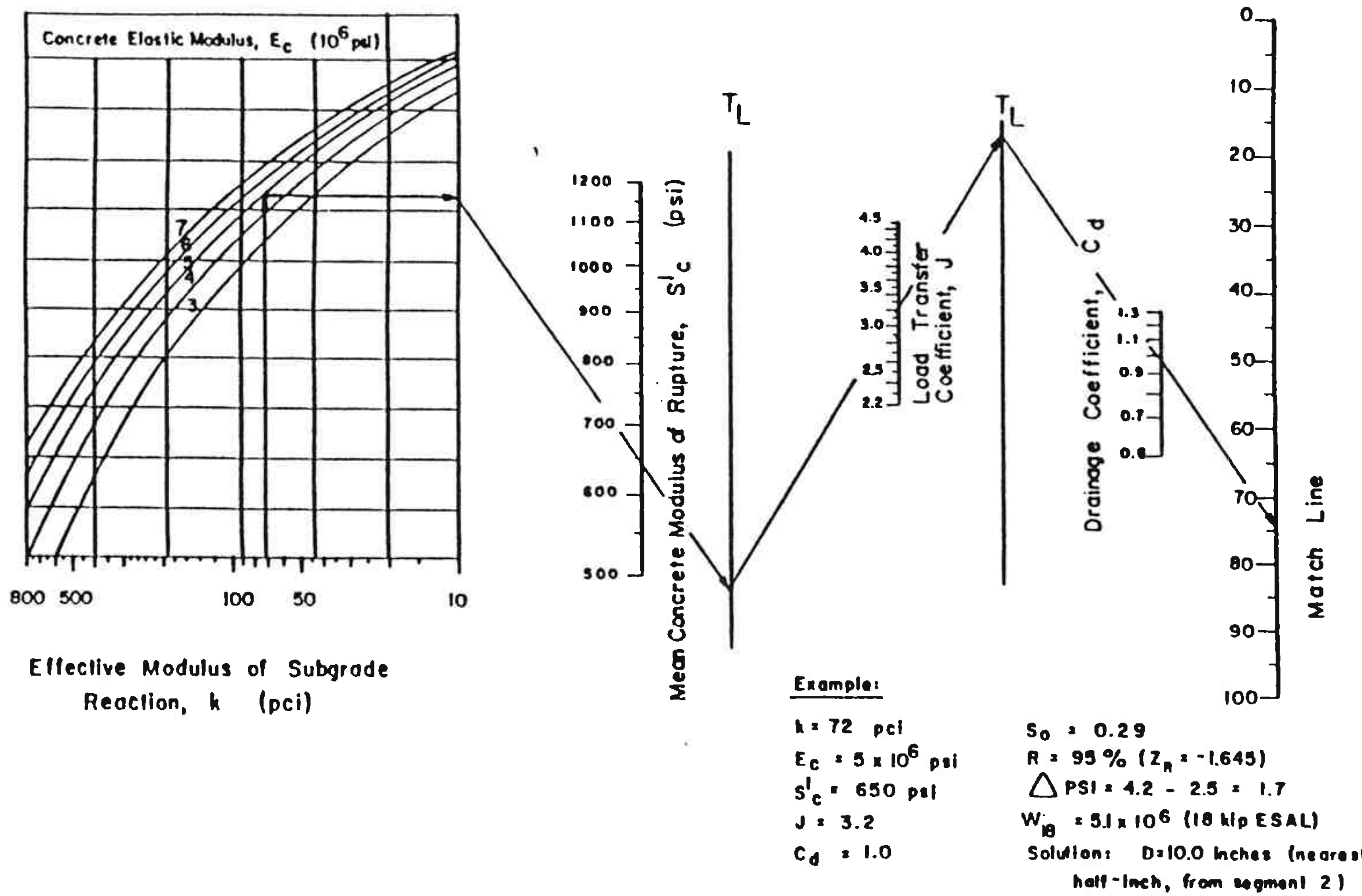


Figure 2.3a. Design Chart for Rigid Pavements Based on Using Mean Values for Each Input Variable (Segment 1) (3).

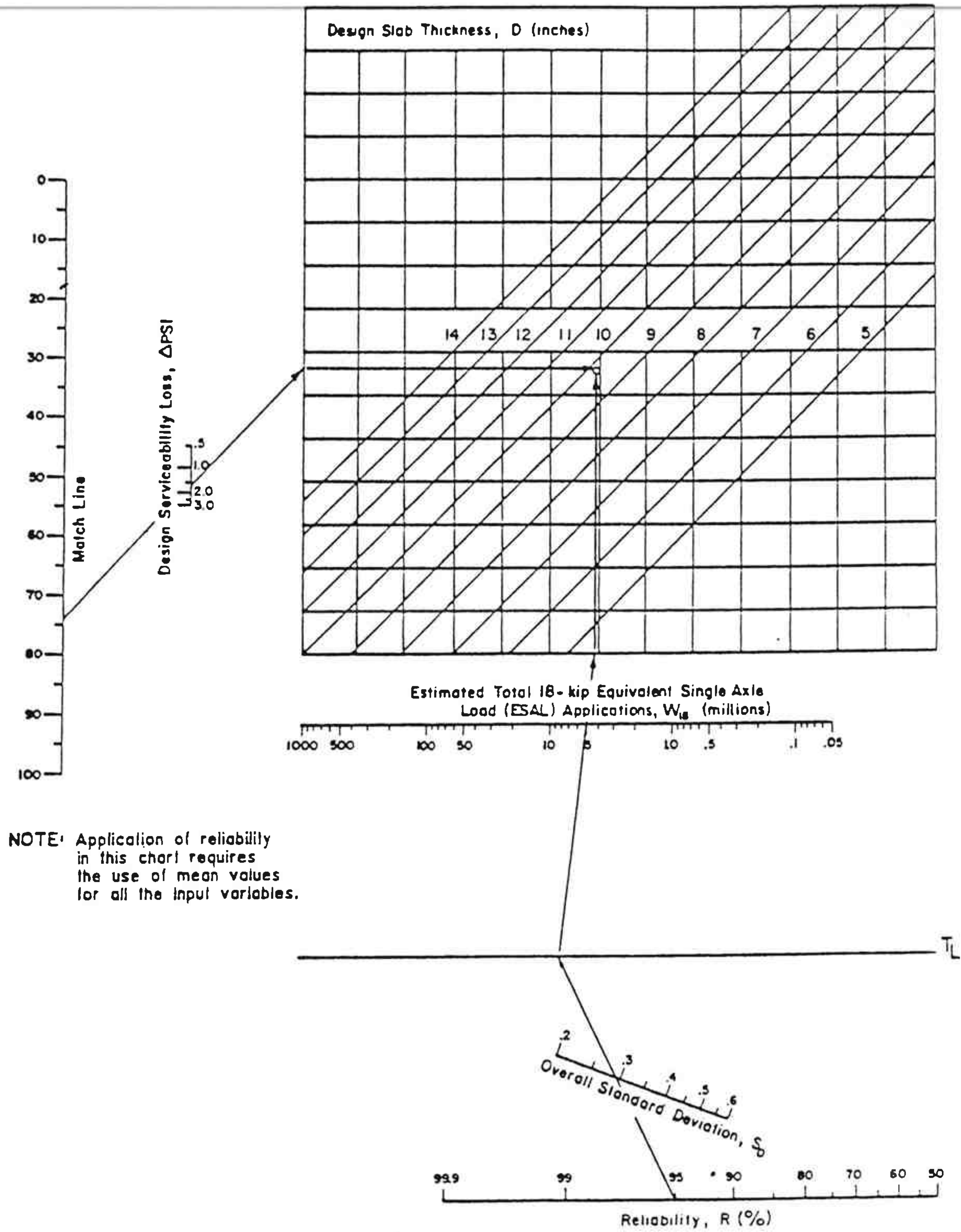


Figure 2.3b. Design Chart for Rigid Pavements Based on Using Mean Values for Each Input Variable (Segment 2) (3).

E_c = concrete elastic modulus

S_c = mean concrete modulus of rupture

J = load transfer coefficient

C_d = drainage coefficient

Figure 2.3 can be used to determine this value.

2.6 Step 6 - Remaining Life Factor Determination (F_{RL})

The remaining life factor, F_{RL}, is an adjustment factor applied to the effective capacity parameter (SN_{xeff} or D_{xeff}) to reflect a more realistic assessment of the weighted effective capacity during the overlay period. This factor is dependent upon the remaining life value of the existing pavement prior to overlay (R_{LX}) and the remaining life of the overlaid pavement system after the overlay has been placed (R_{LY}). As a consequence, both of these values (R_{LX} and R_{LY}) must be known.

2.6.1 Remaining Life of the Existing Pavement (R_{LX})

The remaining life of the existing pavement can be estimated by five possible methods. These include the following:

NDT Approach: The remaining life of the existing pavement (R_{LX}) is related to a pavement condition factor, C_x, which is a function of the existing pavement structural capacity and the initial structural capacity, expressed by the following:

$$C_x = SN_{xeff}/SN_o \quad \text{or} \quad C_x = D_{xeff}/D_o$$

where:

SN_{xeff} = effective structural number for an existing flexible pavement

D_{xeff} = effective thickness for a PCC pavement

SN_o = original structural number

D_o = original PCC pavement thickness.

Knowing the value of C_x, the remaining life, R_{LX} can be determined from Figure 2.4.

Traffic Approach: The remaining life of the existing pavement (R_{LX}) is determined depending upon the accurate historic traffic information. The R_{LX} value is computed from:

$$R_{LX} = (N_{fx} - x)/N_{fx}$$

where:

N_{fx} = number of repetitions for an existing pavement to reach P_f ($P_f = 2.0$)

x = number of repetitions prior to an overlay.

Time Approach: The remaining life (R_{LX}) may be determined from Figure 2.5, knowing pavement damage (d_x), annual traffic growth rate (V_g), best estimate of the probable time (in years) that the particular pavement type typically lasts before an overlay is required (T_f), and time (in years) the highway section has been in service prior to overlay (t).

Serviceability Approach: The remaining life (R_{LX}) may be determined using Figure 2.6, knowing the present serviceability index (rating) of a pavement and the initial structural capacity.

Visual Condition Survey Approach: The remaining life (R_{LX}) may be determined through a condition survey and using Figure 2.4. The overall pavement condition is expressed by pavement condition factor C_x and calculated by the equation

$$C_x = (h_1C_{v1} + h_2C_{v2} + \ldots + h_nC_{vn})/(h_1 + h_2 + \ldots + h_n)$$

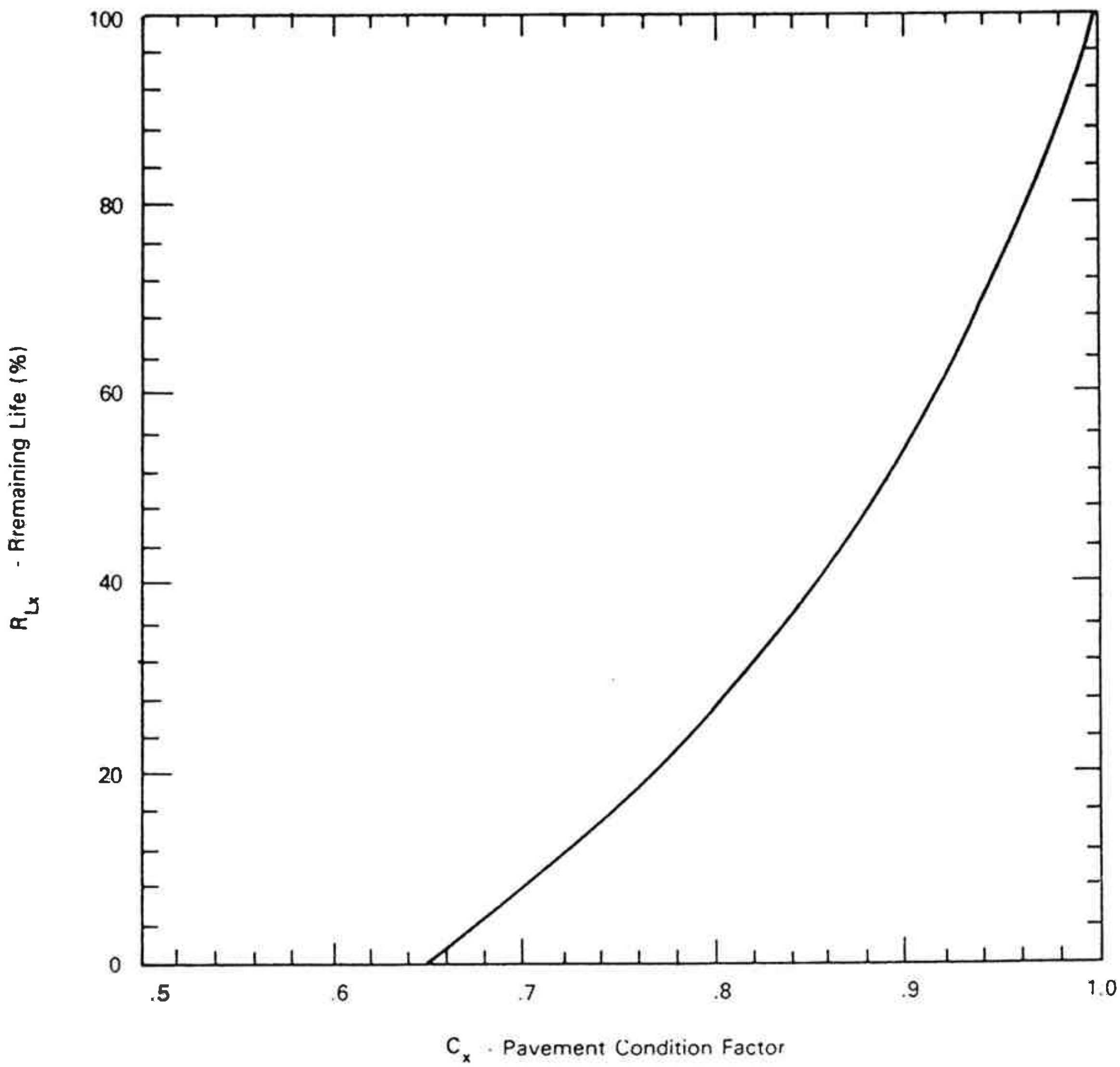


Figure 2.4. Remaining Life Estimate Predicted from Pavement Condition Factor (3).

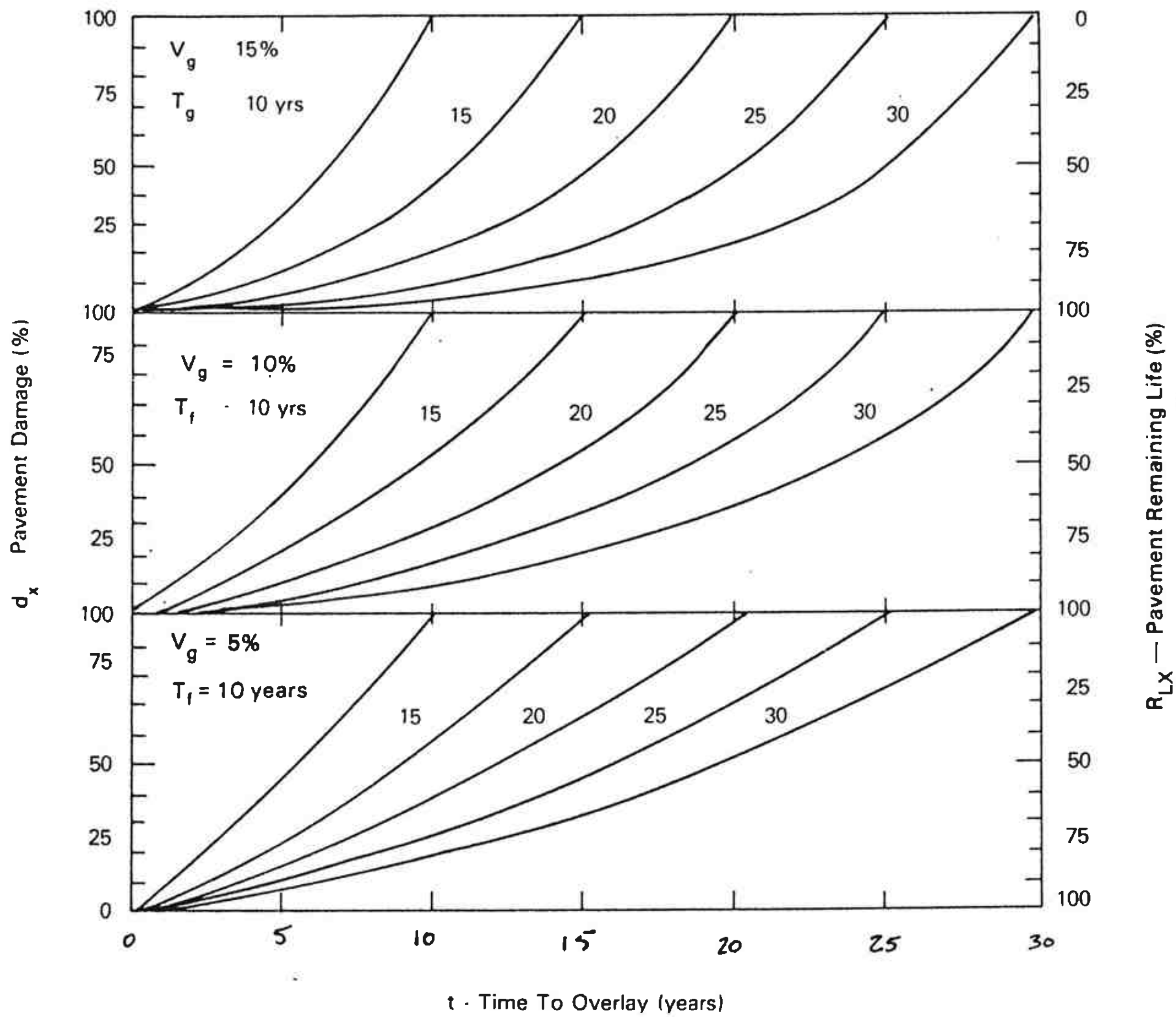


Figure 2.5. Remaining Life Estimate Based on Time Considerations for Various Traffic Growth Rates (3).

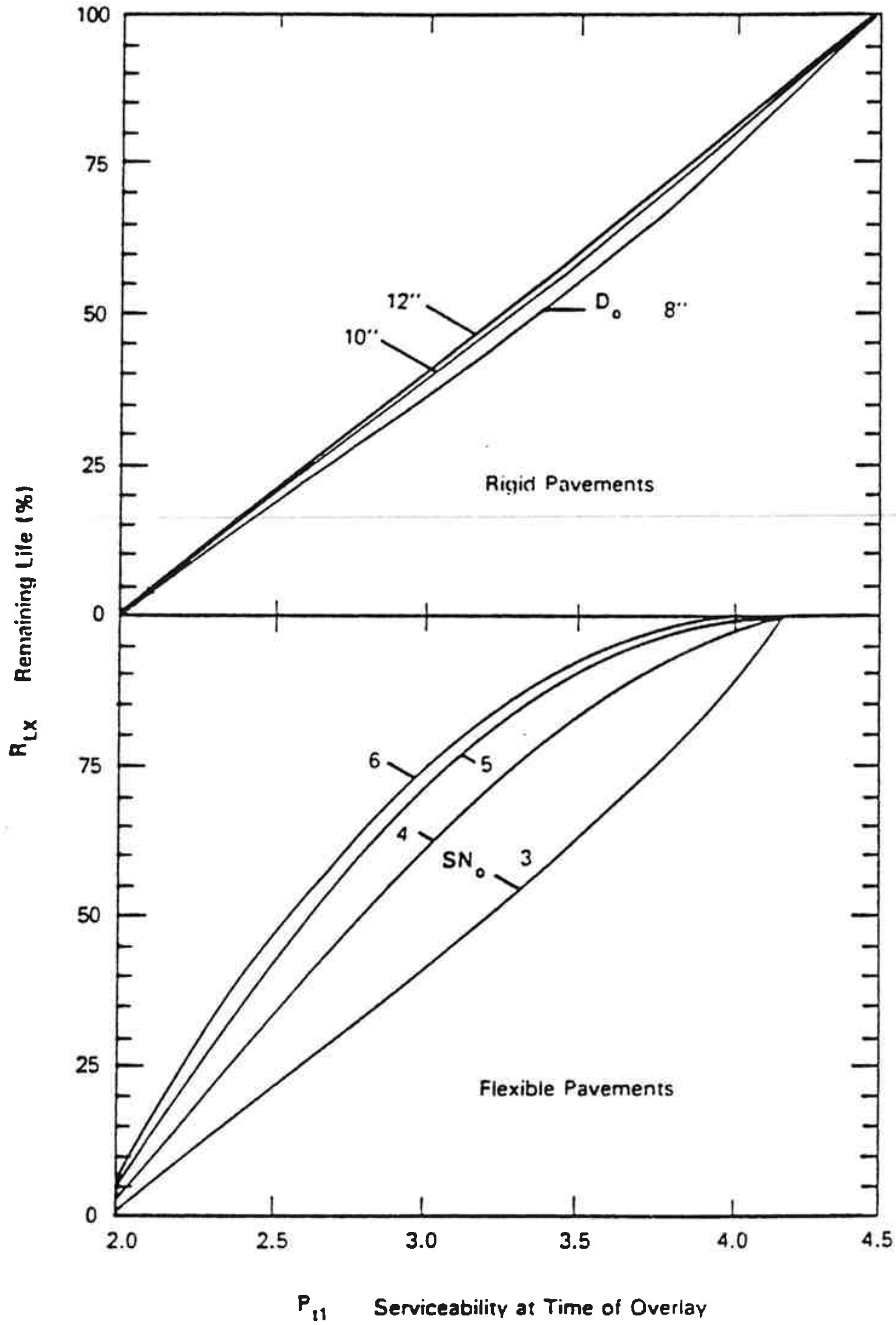


Figure 2.6. Remaining Life Estimate Based Upon Present Serviceability Value and Pavement Cross Section (3).

where:

h_i = layer thickness, in.

C_{vi} = individual pavement layer condition

The C_v values can be determined from Table 2.1.

2.6.2 Remaining Life of Overlaid Pavement (R_{LY})

The remaining life of overlaid pavement (R_{LY}) is determined using the equation:

$$R_{LY} = (N_{fy} - y)/N_{fy}$$

where:

N_{fy} = the ultimate number of repetitions to failure

y = the design overlay traffic repetitions

2.6.3 Remaining Life Factor (F_{RL})

Knowing both R_{LX} and R_{LY}, the remaining life factor (F_{RL}) can be determined from Figure 2.7.

2.7 Step 7 - Determination of Overlay Thickness

For different types of existing pavement with different types of overlay, the required structural capacity can be determined by the equations provided in Table 2.2.

The D_{oL} shown in Table 2.2 is the slab thickness required for a rigid overlay, while for a flexible overlay the thickness can be found using the following equation:

$$h_{oL} = SN_{oL}/a_{oL} = (SN_y - F_{RL} * SN_{xeff})/a_{oL}$$

where:

Table 2.1. Summary of Visual (C_V) and Structural (C_X) Condition Values (3).

Layer Type	Pavement Condition	C_V Visual Condition Factor Range	C_X Structural Condition Factor Range
Asphaltic	1. Asphalt layers that are sound, stable, uncracked, and have little or no deformation in the wheel paths.	0.9-1.0	.95
	2. Asphalt layers that exhibit some intermittent cracking with slight to moderate wheel path deformation but are still stable.	0.7-0.9	.85
	3. Asphalt layers that exhibit some moderate to high cracking, have raveling or aggregate degradation, and show moderate to high deformation in wheel path.	0.5-0.7	.70
	4. Asphalt layers that show very heavy (extensive) cracking, considerable raveling or degradation, and very appreciable wheel path deformations.	0.3-0.5	.60
PCC	1. PCC pavement that is uncracked, stable, and undersealed, exhibiting no evidence of pumping.	0.9-1.0	.95
	2. PCC pavement that is stable and undersealed but shows some initial cracking (with tight, nonworking cracks) and no evidence of pumping.	0.7-0.9	.85
	3. PCC pavement that is appreciably cracked or faulted with signs of progressive crack deterioration: slab fragments may range in size from 1 to 4 sq. yds., pumping may be present.	0.5-0.7	.70
	4. PCC pavement that is very badly cracked or shattered into fragments 2 to 3 ft in size.	0.3-0.5	.60
Pozzolanic Base/ Subbase	1. Chemically stabilized bases (CTB, LCF, ...) that are relatively crack free, stable, and show no evidence of pumping.	0.9-1.0	.95
	2. Chemically stabilized bases (CTB, LCF, ...) that have developed very strong patterns or fatigue cracking, with wide and working cracks that are progressive in nature; evidence of pumping or other causes of instability may be present.	0.3-0.5	.60
Granular Base/ Subbase	1. Unbound granular layers showing no evidence of shear or densification distress, reasonably identical physical properties as when constructed or existing at the same "normal" moisture density conditions as when constructed.	0.9-1.0	.95
	2. Visible evidence of significant distress within layers (shear or densification), aggregate properties have changed significantly due to abrasion, intrusion of fines from subgrade or pumping, and/or significant change in in-situ moisture caused by surface infiltration or other sources.	0.3-0.5	.60

Special Notes:
1. The visual condition factor, C_V, is related to the structural condition factor, C_X, by: $C_X = C_X^2$.
2. The structural condition factor, C_X, and <u>not</u> the C_V value, is the variable used in the structural overlay design equation (for all overlay-existing pavement types). It is defined by: $SC_{xeff} = C_X \, SC_o$.

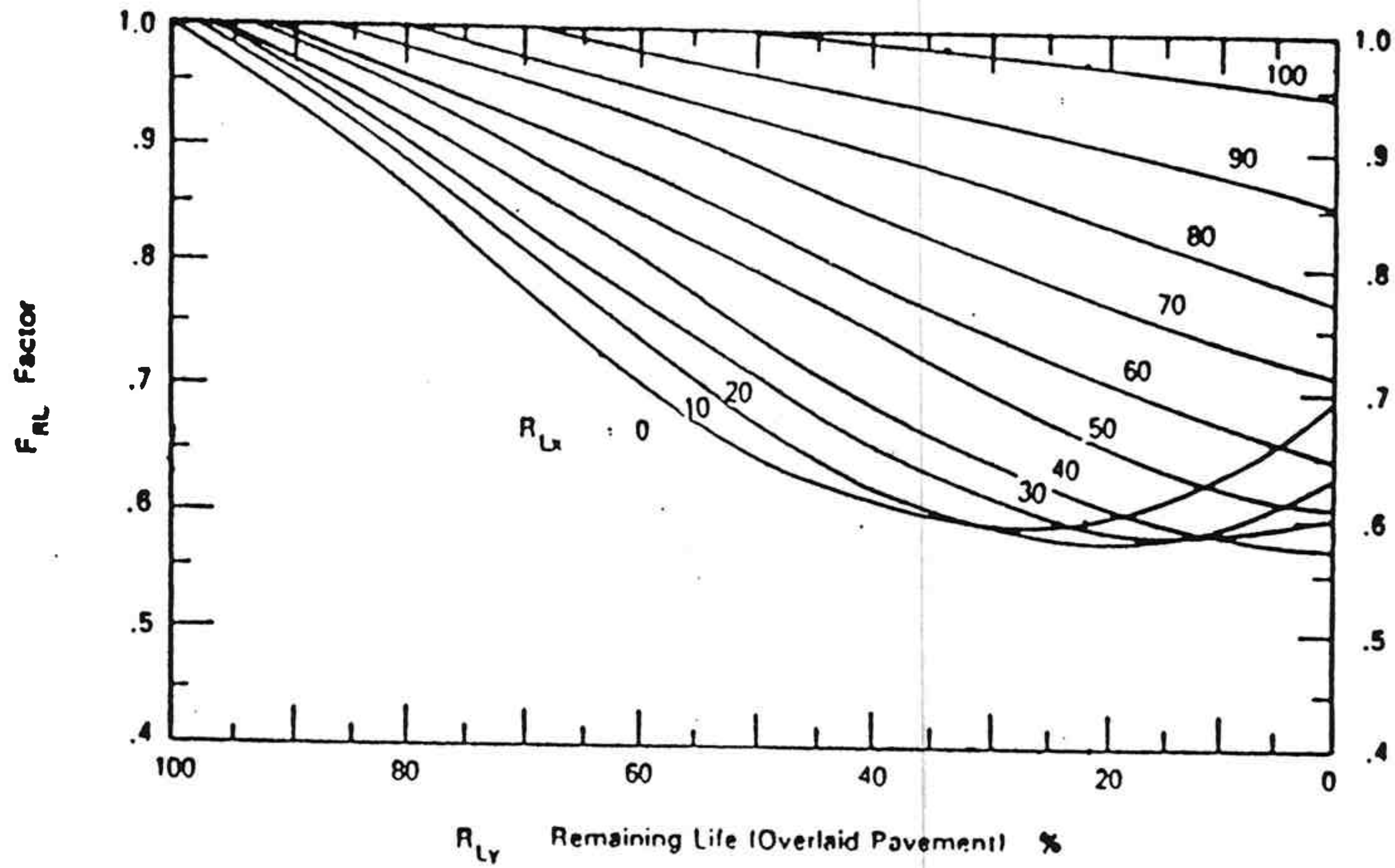


Figure 2.7. Remaining Life Factor as a Function of Remaining Life of Existing and Overlaid Pavements (3).

Table 2.2. Specific Overlay Equation Form Utilized (3).

Type Overlay	Type Existing Pavement	Specific Equation	Conditions/Remarks
Flexible	Flexible	$SN_{oL} = SN_y - F_{RL}\, SN_{xeff}$	SC = SN; n = 1.0
Flexible	Rigid	$SN_{oL} = SN_y - F_{RL}\, SN_{xeff}$	SC = SN; n = 1.0 (see Table 4.1 for equations used)
Rigid	Flexible	$D_{oL} = D_y$ (see remarks)	Treat overlay analysis as new rigid pavement design using existing flexible pavement as new foundation (subgrade)
Rigid	Rigid	$D_{oL} = D_y - F_{RL}\,(D_{xeff})$	SC = D; n = 1.0 (Bonded Overlay)
		$D_{oL}^{1.4} = D_y^{1.4} - F_{RL}\,(D_{xeff})^{1.4}$	SC = D; n = 1.4 (Partial Bond Overlay)
		$D_{oL}^{2} = D_y^{2} - F_{RL}\,(D_{xeff})^{2}$	SC = D; n = 2.0 (Unbonded Overlay)

General Structural Capacity Form: $SC_{oL}^{n} = SC_y^{n} - F_{RL}\,(SC_{xeff})^{n}$

a_{oL} = the structural layer coefficient of the overlay material, and

SN_{oL} = the structural capacity required for overlay.

3.0 ANALYSIS OF DEFLECTION DATA

This chapter discusses the procedures to be used in the selection of analysis basins and methods used for backcalculation of layer modulus using deflection data.

3.1 Selection of Analysis Basin

With most current NDT testing devices, deflection data can be collected with no difficulty. However, it may require a substantial amount of time to analyze all these data. Also because of the nonlinear property of highway material, the measured deflection may vary for each test location even for a well-delineated road section. Therefore, representative deflection basins should be considered.

The maximum deflection (first sensor) can be used as a guide to selecting typical basins. Similarly, one could also look at the deflection of the furthermost sensor from the load. The first sensor indicates the uniformity of the load capacity of the total pavement. The last sensor provides an indication of the quality of the subgrade.

The procedure presented herein considers average measured maximum deflections and deflection variation along selected roadway units. The deflection basins selected for analysis are those having a maximum deflection between the average maximum deflection ($\bar{d}$) and the average maximum deflection plus 1.5 standard deviations (s), expressed as follows:

$$\bar{d} \leq d_m \leq \bar{d} + 1.5\ s$$

where d_m is the maximum deflection at a particular test location. The $\bar{d}$ value may be determined using equation,

$$\bar{d} = \frac{\sum_{i=1}^{n} d_i}{n}$$

in which: d_i = measured maximum deflection at ith location

n = number of test location.

$$S = \sqrt{\frac{\sum_{i=1}^{n} d_i^2 - \left(\sum_{i=1}^{n} d_i \right)^2 / n}{n-1}}$$

The above method may also be applied to select deflections representative of those subgrade responses such that a representative roadbed capacity may be found.

3.2 Backcalculation

The purpose of backcalculation is to determine moduli of each pavement layer using the deflection basin data measured in the field. Three computer programs (ELSDEF, BISDEF, and MODCOMP2) can be used for this purpose.

3.2.1 ELSDEF Program (5)

The ELSDEF program was developed by the U.S. Army Corps of Engineers at the Waterways Experiment Station. ELSDEF was written in FORTRAN and is operational on IBM-compatible microcomputers. A more detailed description and use of the program can be found in Appendix A.

3.2.2 BISDEF Program (6)

The BISDEF program was also developed by the U.S. Army Corps of Engineers at the Waterways Experiment Station. This program is similar to ELSDEF. BISDEF was also written in FORTRAN and is operational on IBM-compatible micro-computers. A more detailed description and use of the program can be found in Appendix A.

3.2.3 MODCOMP2 Program (7)

The MODCOMP2 program was developed at Cornell University. This program does not require the range of moduli in the data input process as is necessary in both ELSDEF and BISDEF. The other inputs, as well as its output, are basically the same as ELSDEF and BISDEF.

4.0 OVERLAY DESIGN PROCEDURE

This section provides a step by step procedure for overlay design. This includes design of asphalt concrete over asphalt concrete, asphalt concrete over portland cement concrete (PCC), PCC over asphalt concrete, and PCC over PCC pavement. Examples for these four types of overlay design can be found in Appendix C.

4.1 Asphalt Concrete over Asphalt Concrete

1. Select Analysis Section.
2. Determine predicted traffic for future (y).
3. NDT Method 1 (y/n)? (As opposed to NDT Method 2)

   y: Using a backcalculation computer program, predict pavement layer moduli for the layers and determine the structural layer coefficients from charts such as shown in Figure 4.1. The layer coefficients are then multiplied by the thickness of their respective layers and summed to obtain the SN_{xeff} of the existing pavement. Go to Step 12.

   n: Go to Step 4.
4. Assume modulus values for layers.
5. Calculate $H_e = .9h_i \sqrt[3]{\left(E_i\,(1-u_{sg}^2)\right)/\left(E_{SG}(1-u_i^2)\right)}$

   h_i = thickness layer i (in.),

   E_i = elastic modulus layer i (psi),

   u_i = Poisson's ratio of layer i,

   E_{SG} = subgrade modulus (psi), and

   u_{sg} = Poisson's ratio of subgrade.
6. Determine radius of loading plate a_c (in.).
7. Find F_b from Figure 4.2 knowing H_e/a_c and u.

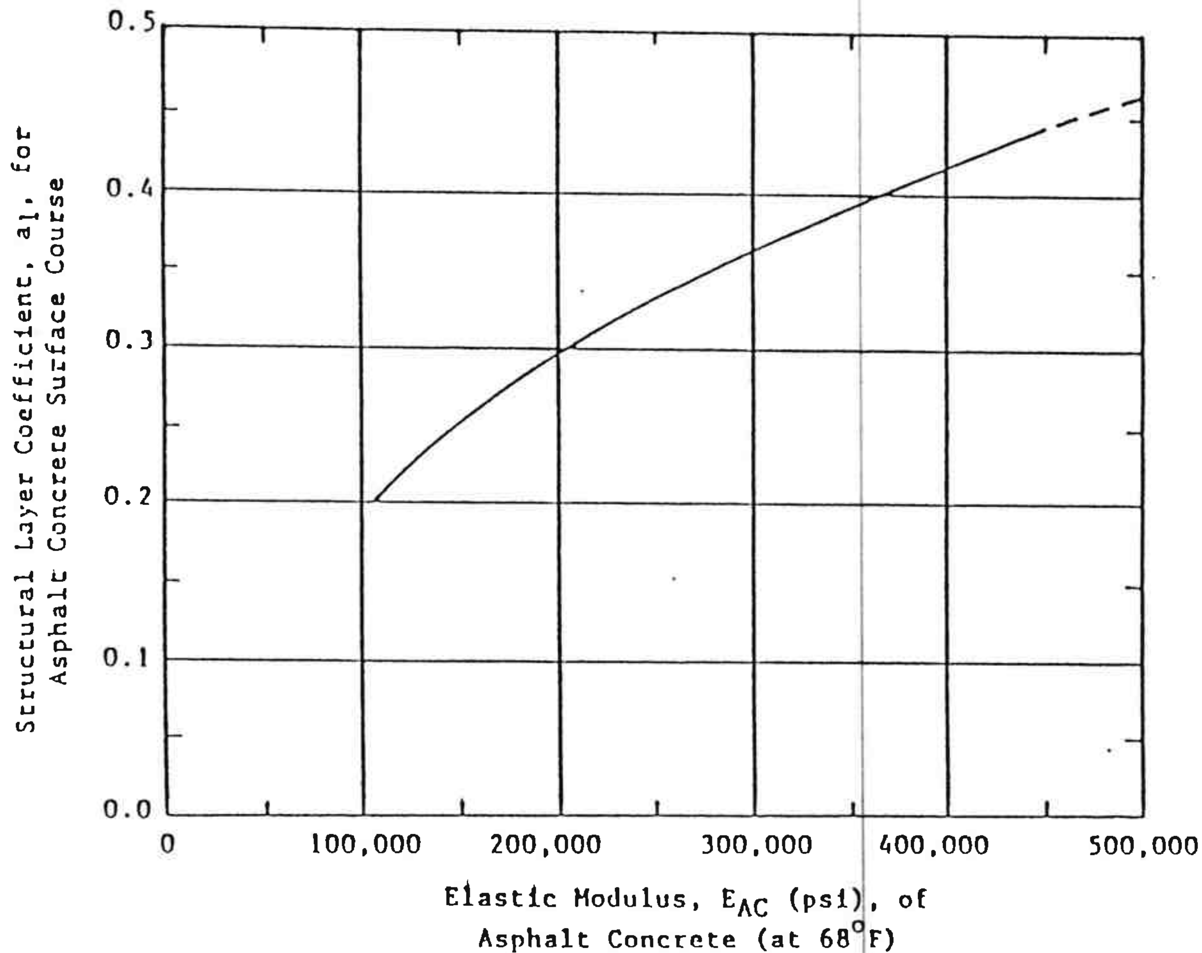


Figure 4.1. Chart for Estimating Structural Layer Coefficient of Dense-Graded Asphalt Concrete Based on the Elastic Modulus (8).

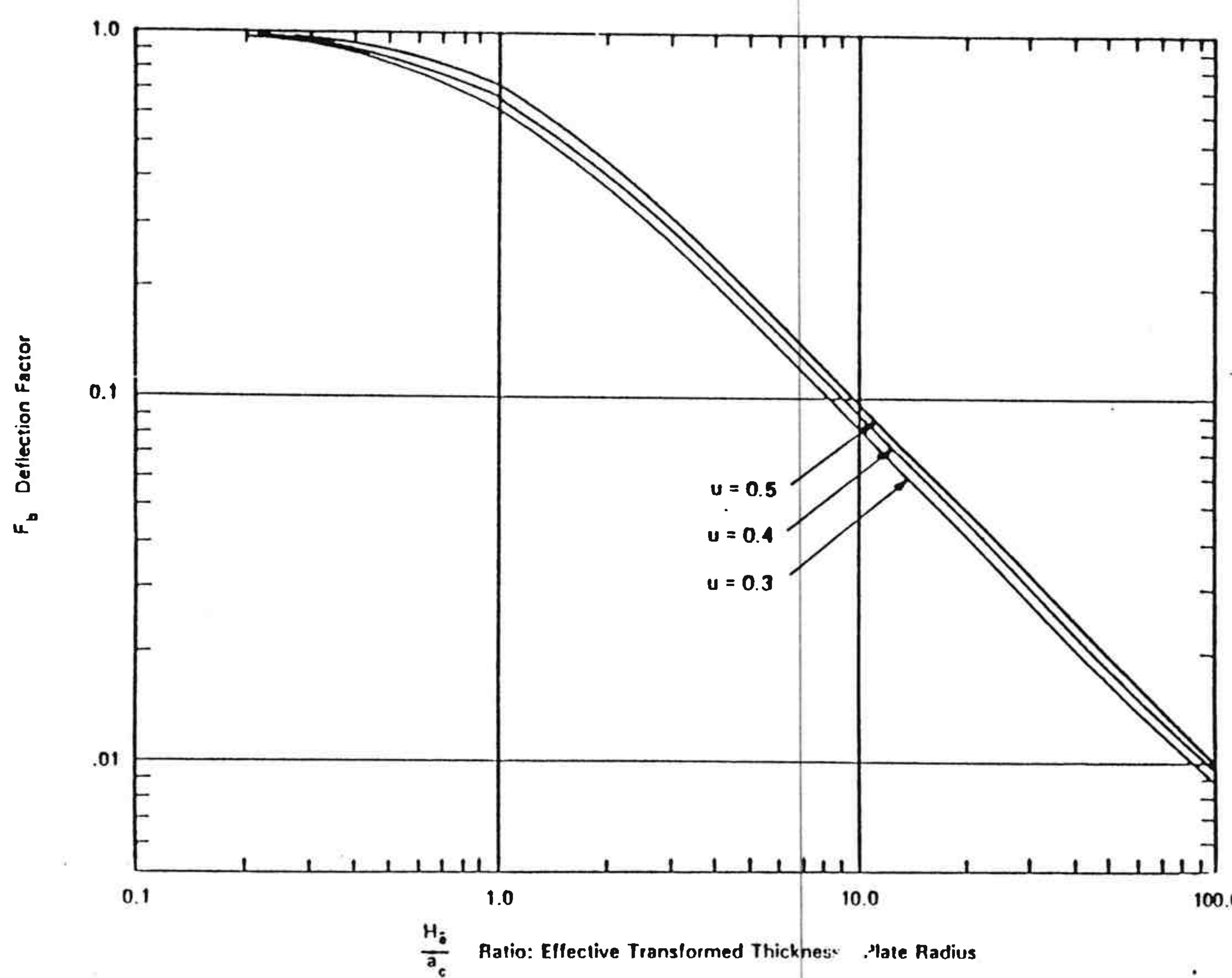


Figure 4.2. Deflection Factor vs. Effective Depth Ratio (3).

8. Calculate $a_e = a_c/F_b$.

9. Determine S_f from Figure 4.3 and solve for E_{SG} using the following equation:

$$E_{SG} = (PS_f)/d_r r,$$

where:

P = dynamic load,

S_f = subgrade modulus prediction factor,

d_r = measured NDT deflection at a radial distance,

r = radial distance from plate load center, and

E_{SG} = subgrade modulus of elasticity.

10. Once E_{SG} is obtained, check to ensure $r/a_e \geq 1$. If $r/a_e < 1$, increase the distance to the outer geophone so that only the deflection from the subgrade is recorded. Recalculate the subgrade modulus using step 9.

11. The structural number is determined using trial-and-error using the following equation:

a. Assume SN

b. Compute F_b

c. Determine d_o

$$F_b = \left(\sqrt{1 + \left(\frac{h_e}{a_c}\right)^2} - \frac{h_e}{a_c} \right) \left(1 + \frac{h_e/a_c}{2(1-u_{sg}) \sqrt{1 + (h_e/a_c)^2}} \right)$$

$$\frac{h_e}{a_c} = \frac{209.3\ SN}{a_c} \sqrt[3]{\frac{(1 - u_{sg}^2)}{E_{SG}}}$$

$$d_o = \frac{\left(2P(.0043\ h_t)^3\right)}{\pi\ a_c\ SN^3} \left(1 + \left(\frac{SN^3\ (1-u_{sg}^2)}{E_{SG}(.0043\ h_t)^3} - 1 \right) F_b \right)$$

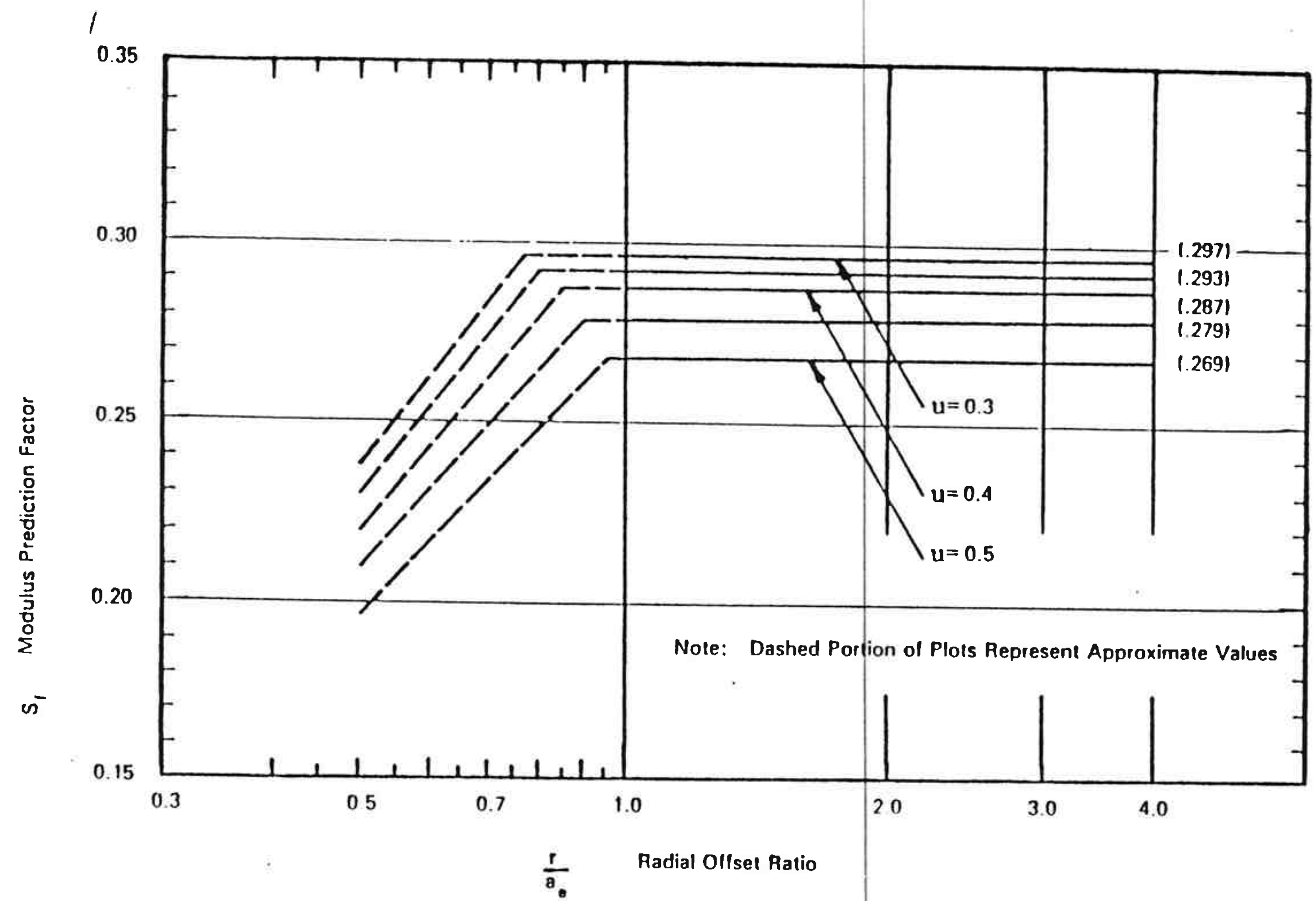


Figure 4.3. Subgrade Modulus Prediction Factor vs. Radial Offset Ratio (3).

When the calculated d_o is approximately equal to the maximum deflection value adjusted for temperature, then the SN_{xeff} can be interpolated.

12. This step determines the structural number, SN_y, as if the pavement was a new design. A reliability level and standard deviation for an appropriate confidence level needs to be assigned. Either the nomograph presented in Figure 2.2 or the equation below may be used:

$$\log_{10}W_{18} = Z_R S_0 + 9.36 \log_{10}(SN + 1) - .20 + \frac{\log_{10}\left[\frac{\Delta PSI}{4.2-1.5}\right]}{.40 + \frac{1094}{(SN+1)^{5.19}}} + 2.32 \log_{10}M_R - 8.07$$

where:

W_{18} = future cumulative traffic from Step 2

M_R = subgrade modulus from Step (3 or 10)

ΔPSI = difference in desired PSI at end of service and present P_t

Z_R = standard normal deviate (for 90% reliability, Z_R = -1.282. For 95% reliability, Z_R = -1.045)

S_0 = standard deviation (for flexible pavements, S_0 = 0.40 to 0.50; for rigid pavements, S_0 = 0.30 to 0.40).

13. Is historical traffic, x, known (y/n)?

a) y: Use Figure 2.2 for original SN of pavement to determine number of repetitions to reach P_t = 2.0 and set equal to N_{fx}.

$R_{LX} = (N_{FX} - X)/N_{Fx}$

Go to Step 15.

n: Want to use NDT approach (y/n)?

b) y: Knowing initial SN_o and SN_{xeff} from Step (3 or 11), solve for C_x.

$C_x = SN_{xeff}/SN_o$

Use C_x in Figure 2.4 to find R_{LX}.

Go to Step 15.

n: Use serviceability approach.

Knowing P_t at time overlay and initial SN_o, use Figure 2.6 to find R_{LX}.

14. Select the R_{LX} value using one of the above methods based on an engineering judgment.

15. Determine N_{FY} using SN_y (Step 12) and $P_t = 2.0$ from Figure 2.2.

$$R_{LY} = (N_{FY} - y)/N_{FY}$$

16. Knowing R_{LX} and R_{LY}, find F_{RL} from Figure 2.7.

17. All values are then substituted into

$$SN_{OL} = SN_y - F_{RL}(SN_{xeff})$$

F_{RL} = from Step 16,

SN_{xeff} = from Step (3 or 11), and

SN_y = from Step 12.

18. For asphalt overlays, the structural layer coefficient (a_i) may vary from 0.39 to 0.42. The required overlay thickness is:

$$h_{OL} = SN_{OL}/a_i$$

where SN_{OL} is determined in Step 17.

4.2 Asphalt Concrete over Portland Cement Concrete (Normal Structural Overlay)

1. Determine slab length, thickness PCC (D_o), and thickness of subbase (D_{sb}).

2. Determine P_{t1} (at time of overlay).

3. Determine P_{t2} (at end of overlay).

4. Determine future expected traffic.

5. Calculate SN_{xeff} using NDT Method 1 (y/n)?

   y: Determine $SN_{xeff-rp}$

   $SN_{xeff-rp} = D_{sb}\ a_{sb}$

   a_{sb} = from Figure 4.4 and backcalculated E_{sb}

   D_{sb} = Step 1

   There are two alternatives for determining D_{xeff}

   a. Determine E_{PCC} from backcalculation or coring. Knowing E_{PCC} and D_o, solve for D_{xeff} from Figure 4.5 and use equations from Table 4.1.

   b. Use visual condition rating to find a_{2r} from Figure 4.6. Using a_{2r} and D_o, input into equation from Table 4.1.

   n: Use NDT Method 2 (as outlined under AC/AC Steps 4-11).

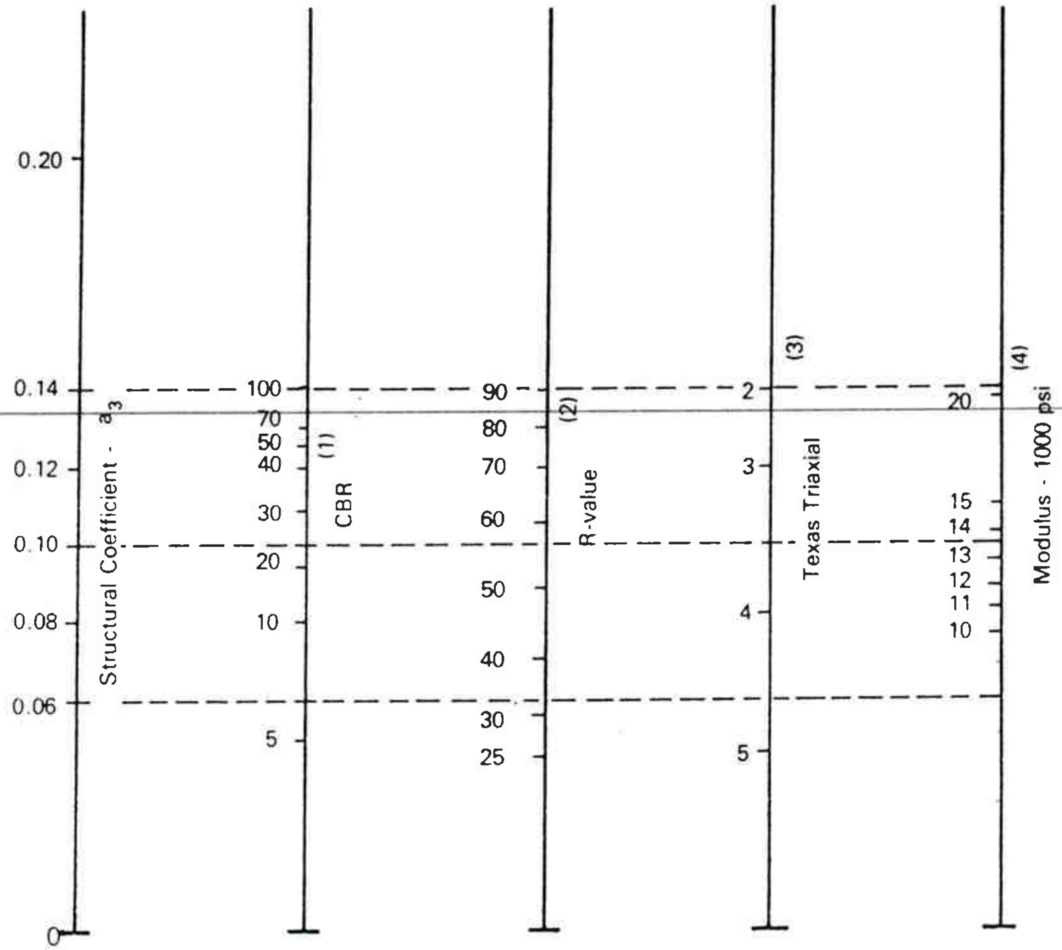
6. Choose a reliability factor and a standard deviation value.

7. Determine SN_y for new design from a nomograph in Figure 2.2.

8. Is previous traffic data available (y/n)?

   y: Use Figure 2.2 with original SN_o of pavement and determine number of repetitions to reach $P_t = 2.0$ to solve for N_{FX}.

   $R_{LX} = (N_{FX} - x)/N_{FX}$



(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 (8)

Figure 4.4. Variation in Granular Subbase Layer Coefficient (a_3) with Various Subbase Strength Parameters (8).

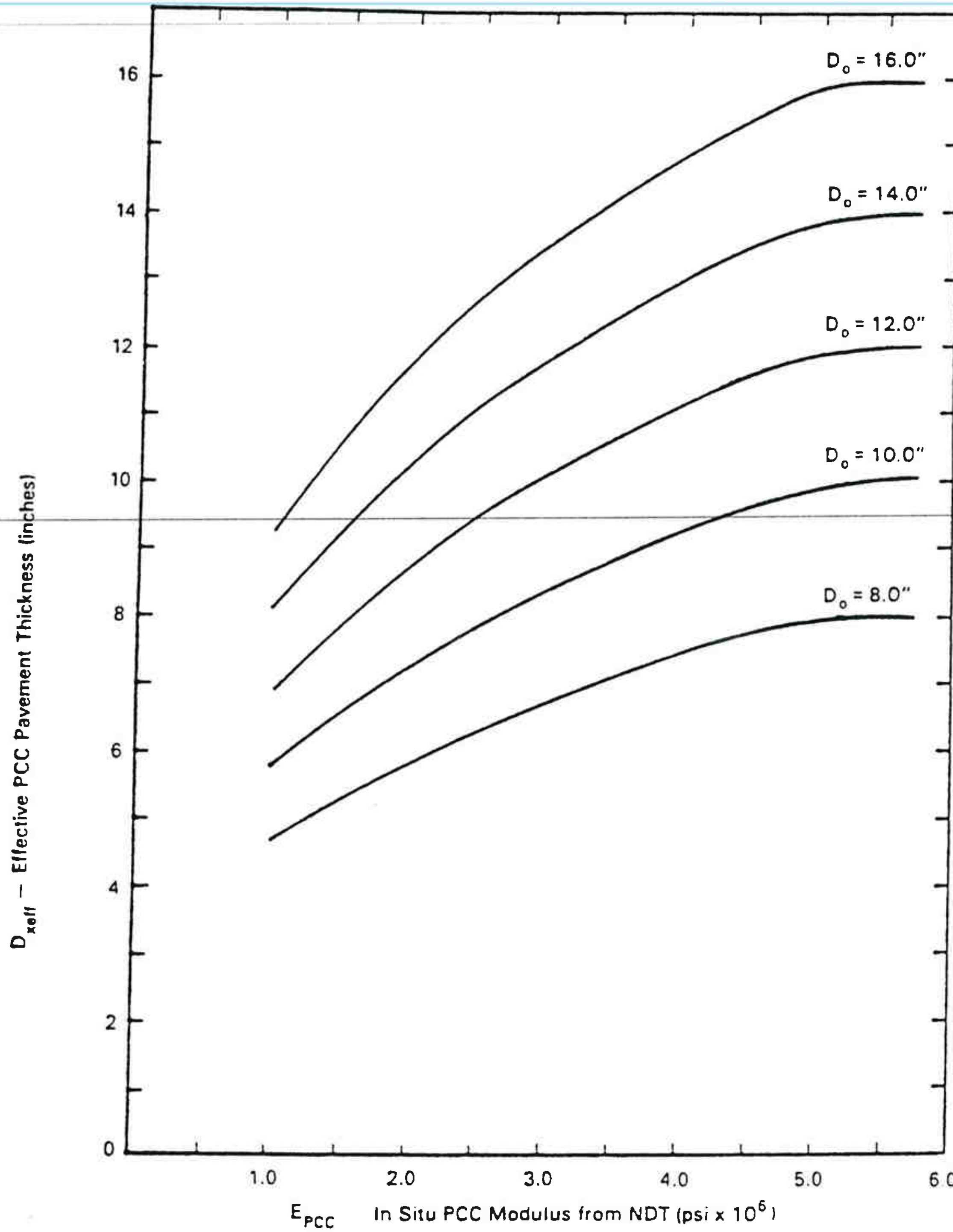


Figure 4.5. Determination of Effective PCC Structural Capacity from NDT Derived PCC Modulus (3).

Table 4.1. Summary of Overlay Equations Used in Flexible Overlay Over Existing Rigid Pavement Analysis (3).

Major Overlay Condition	Specific Method Used	SN_{OL} Equation
Normal Structural Overlay	NDT Method 1	$SN_{OL} = SN_y - F_{RL} (0.8\ D_{xeff} + SN_{xeff\text{-}rp})$
	NDT Method 2	$SN_{OL} = SN_y - F_{RL}\ SN_{xeff}$
	Visual Condition Factor	$SN_{OL} = SN_y - F_{RL} (a_{2r} D_o + SN_{xeff\text{-}rp})$
Break-Seat* Overlay	Estimating Nominal Crack Spacing	$SN_{OL} = SN_y - 0.7\ (0.4\ D_o + SN_{xeff\text{-}rp})$**
	Post Cracking NDT	
	a. NDT Method 1	$SN_{OL} = SN_y - 0.7\ (a_{bs} D_o + SN_{xeff\text{-}rp})$
	b. NDT Method 2	$SN_{OL} = SN_y - 0.7\ SN_{xeff}$

*Break-Seat overlays are not used in Oregon at present. These equations are included for completeness only.

**Special Note: The coefficient of D_o (i.e., 0.4) actually varies from 0.35 for a nominal crack spacing of approximately 2.0 ft to a value of 0.45 for a nominal crack spacing of approximately 3.0 ft.

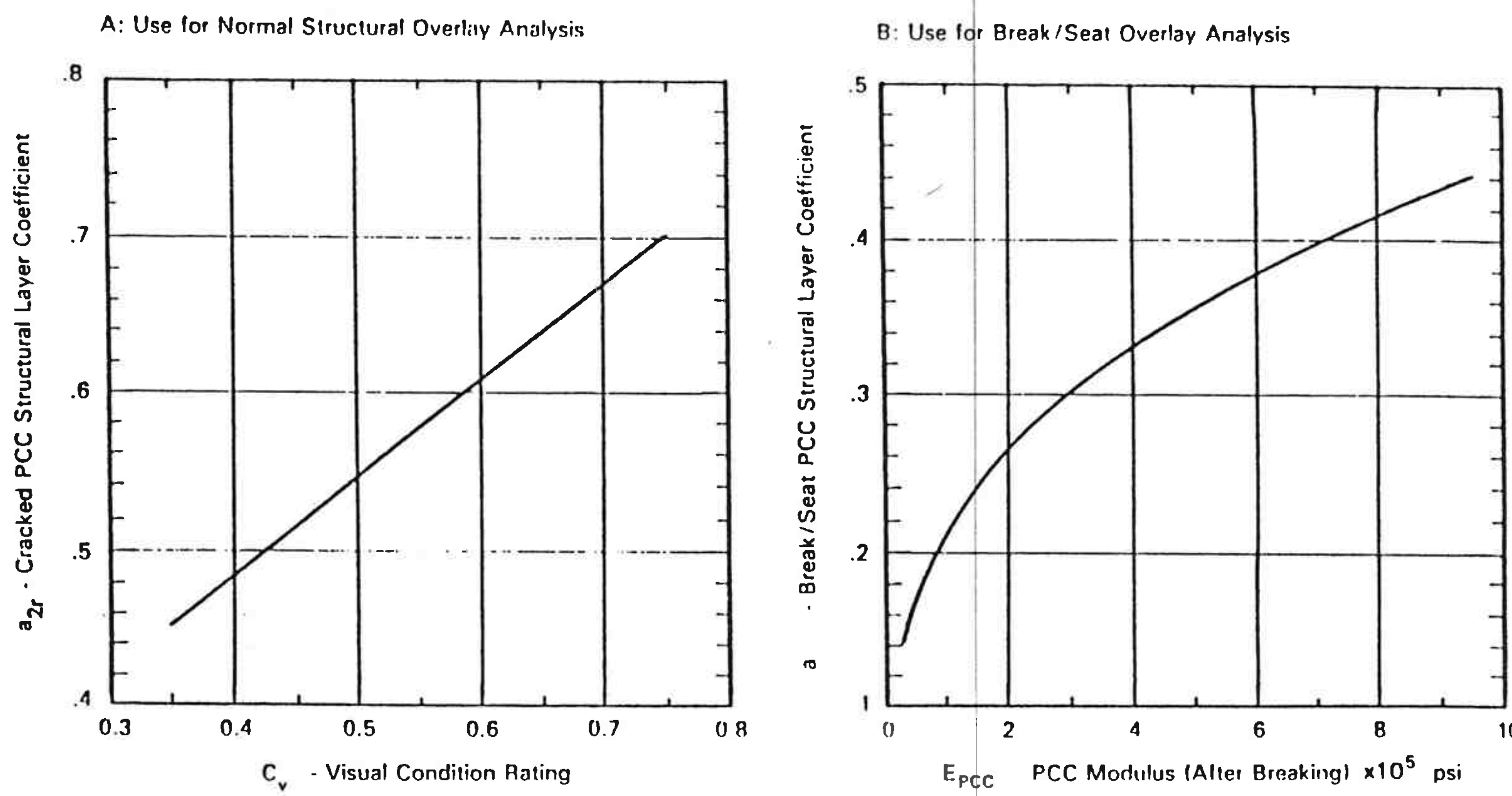


Figure 4.6. Structural Layer Coefficients for PCC Layer Used with AC Overlays (Normal Structural and Break-Seat Conditions) (3).

n: Use NDT results and find C_x (y/n)?

y: $C_x = D_{xeff}/D_o$

D_{xeff} = from Step 5a

D_o = from cores or construction records

Determine R_{LX} from C_x using Figure 2.4.

n: Knowing D_o (given) and P_{t1} from Step 2, find R_{LX} from Figure 2.6.

9. Find N_{FY} from Figure 2.2 using SN_y from Step 7 and P_{t2} (Step 3) to determine R_{LY} (use y from given).

$$R_{LY} = (N_{FY} - y)/N_{FY}$$

10. F_{RL} factor found using Figure 2.6 knowing R_{LX} from Step 8 and RL_Y from Step 9.

11. Solve for SN_{OL} using Table 4.1 where:

SN_y = Step 7,

F_{RL} = Step 10,

D_{xeff} = Step 5a or 5b,

$SN_{xeff-rp}$ = Step 5, and

D_o = slab thickness.

12. Find required thickness

$$h_{OL} = SN_{OL}/a_i$$

a_i = value from Figure 4.1 knowing E_{AC} for intended overlay (or use 0.39 to 0.42)

SN_{oL} = from Step 11.

4.3 <u>Portland Cement Concrete over Asphalt Concrete</u>

1. Solve for k_d using:

$$k_d = F_d \times C_d$$

k_d = deflection temperature adjustment factor to adjust pavement to 100°F,

F_d = adjustment for pavement temperature, Figure 4.7, and

C_d = a function of the existing pavement, Table 4.2.

2. Solve for maximum NDT deflection adjusted to critical in situ asphalt layer temperature.

$$d_{oc} = d_o \times k_d$$

d_{oc} = adjusted maximum deflection,

d_o = unadjusted NDT maximum deflection obtained at temperature t_p, and

k_d = from Step 1.

3. Solve for E_c using:

$$E_c = P/(D_p \times d_{oc})$$

E_c = modulus of composite layers,

P = NDT dynamic load,

D_p = NDT load plate diameter, and

d_{oc} = adjusted maximum deflection.

4. Find subgrade reaction k from Figure 4.8.

5. Go through procedure for new rigid pavement design using k value determined in Step 4.

6. Use nomograph (Figure 2.3) to find D_y.

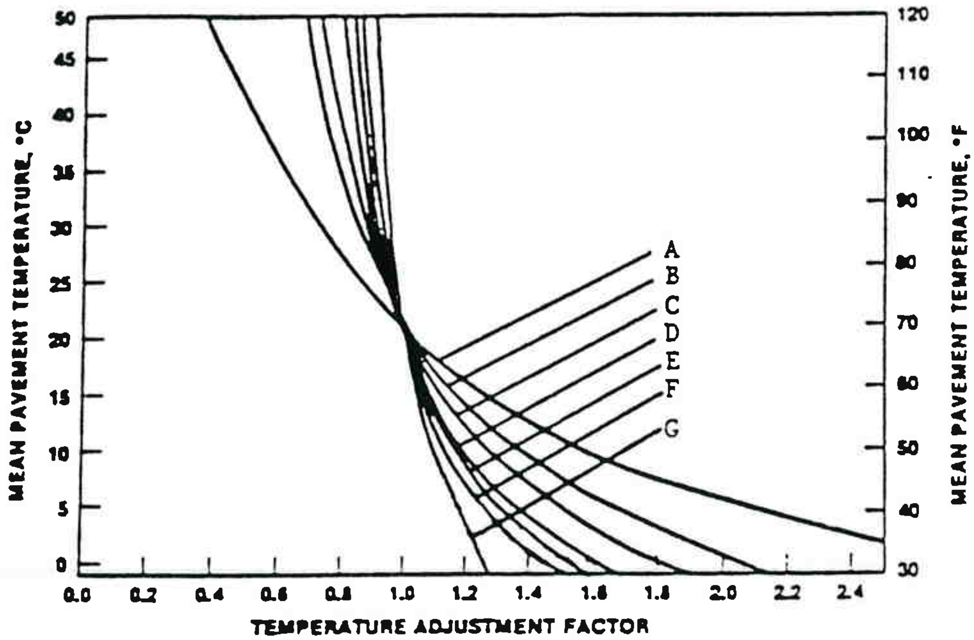
7. $D_{OL} = D_y$

   D_{OL} = overlay slab required

4.4 <u>Portland Cement Concrete over Portland Cement Concrete</u>

1. Decide on bonding option.

2. Determine E_{PCC} from backcalculation or laboratory testing.



Curve Identification

Base Material	Curve (Base Thickness)
Asphalt (Full Depth)	A (All Thicknesses)
Asphalt (Deep Strength)	B (4" of Granual Subbase)*
Portland Cement Concrete	G
Granular (Nonstabilized)	C (6"); D (12"); E (20"); F (25")
Cement Treated Base	
Sound	D (4"); E (8")
Cracked	C (4"); D (8")

(*) If more than 4" of granular material present use "Granular (Nonstabilized)" base material category

Figure 4.7. Deflection-Temperature Adjustment Factor (3).

Table 4.2. Sample C_d Values for Various Pavement Types (3).

Existing Pavement Type	C_d Value
Full Depth/Deep Strength Asphalt Pavements	1.70
Flexible Pavements with Granular Base/Subbase	1.35
Flexible (Semirigid) Pavements with Cement Treated Base/Subbase	1.20
Composite Pavement Structures (Asphalt over PCC)	1.05

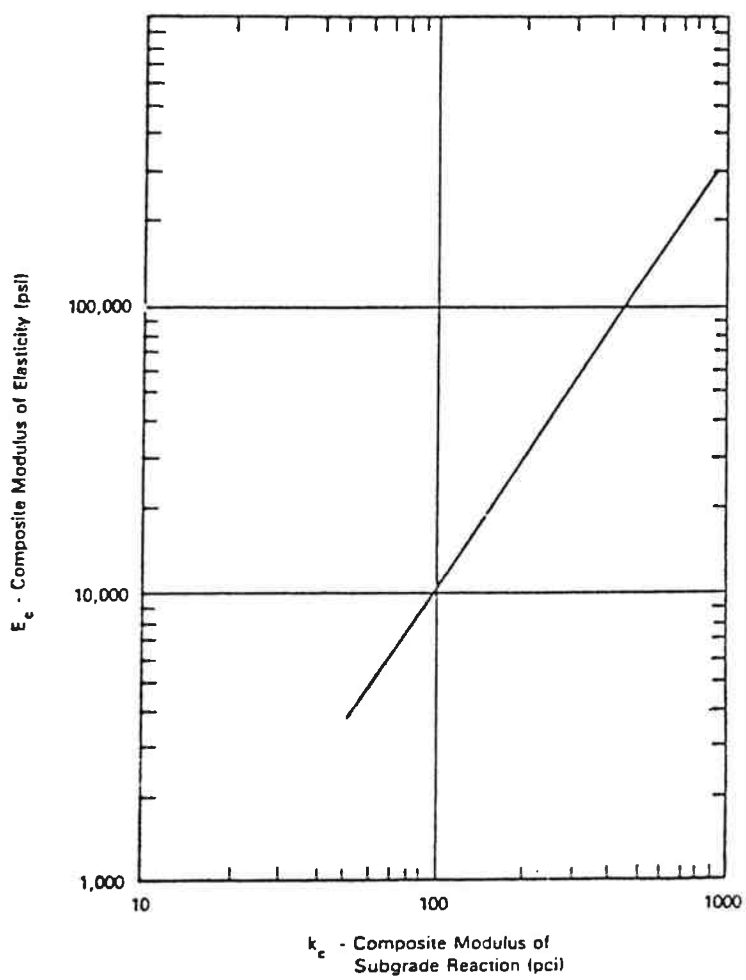


Figure 4.8. Relationship Between Composite Modulus of Elasticity and Reaction (3).

3. Knowing E_{PCC} and D_o, find D_{xeff} from Figure 4.5.

4. Determine D_y from Figure 2.3.

5. Determine R_{LX} from Step 8 in AC/PCC.

6. Determine R_{LY} from Step 9 in AC/PCC.

7. Find F_{RL} from Figure 2.7.

8. Use appropriate equation from Table 2.2.

5.0 GUIDELINES FOR USE

5.1 Procedure Selection

Both NDT Method 1 and NDT Method 2 can be employed for determining an existing pavement structural capacity. For higher volume roads involving significant funding levels, NDT Method 1 is recommended. For lower volume roads with lower funding levels, NDT Method 2 is suggested.

The computer program BISDEF is recommended for implementing the NDT Method 1. Evaluation of this program may be found in references (2) and (4). Since subgrade modulus plays an important role in determining the future overlay structural number (SN_y), a reasonably accurate value should be determined by all means. This value may be calculated using either AASHTO equation or from the program itself. The reasonable subgrade modulus thus determined may then be used as a fixed value to determine other layer moduli, such as base and surface, or used directly for overlay design.

5.2 Cautions with the Procedures

There are some cautions with the proposed design procedures. These include:

1. The predicted modulus from backcalculation needs to be verified with laboratory determined values.
2. The layer coefficients should be determined with care particularly for materials with extremely high or low modulus values.
3. Different backcalculation programs may not always give the same results; considerable engineering judgment is required in analyzing these results. Comparisons with prior experience should help to ensure reasonable results.

6.0 REFERENCES

1. Eichhorn, C.L., R.G. Hicks, R. Noble, and H. Zhou, "Development of an Improved Overlay Design Procedure for Oregon," Vol. I. TRR-87-33, Transportation Research Institute, Oregon State University, January 1987.
2. Zhou, H., R.G. Hicks, T. Rwebangira, and R. Noble, "Development of an Improved Overlay Design Procedure for Oregon," Vol. II, TRR-87-34, Transportation Research Institute, Oregon State University, December 1987.
3. American Association of State Highway and Transportation Officials, "AASHTO Guide for Design of Pavement Structures 1986," 1986.
4. Rwebangira, T., R.G. Hicks, and M. Truebe, "Sensitivity Analysis of Selected Backcalculation Procedures," TRR-86-23, Transportation Research Institute, Oregon State University, December 1986.
5. Bush III, A.J., "Nondestructive Testing of Light Aircraft Pavements, Phase II, Development of the Nondestructive Evaluation Methodology," Final Report No. FAA-RD-80-9-II, Federal Aviation Authority, November 1980.
6. Lytton, R.L., R.L. Roberts, and S. Stoffels, "Determination of Asphaltic Concrete Pavement Structural Properties by Nondestructive Testing," NCHRP Report No. 10-27, Texas A & M University, 1985.
7. Irwin, L.H., User's Guide to MODCOMP2, Version 2.1, Cornell University, Local Roads Program, Ithaca, NY, November 1983.
8. Van Til, C.J., B.F. McCullough, B.A. Vallerga, and R.G. Hicks, "Evaluation of AASHTO Interim Guides for Design of Pavement Structures," NCHRP Report 128, Transportation Research Board, 1972.

APPENDIX A

OVERLAY DESIGN USING NDT METHOD 1

1.0 INTRODUCTION

1.1 Background

In the past, overlay design procedures did not accurately take into account the remaining life of the existing pavement because of the difficulties in evaluating the existing pavement capacity. Although destructive testing, such as coring, provides some information to determine the pavement strength, it is an inefficient way of evaluating an existing pavement. In addition, destructive testing requires a large amount of laboratory testing; therefore, a well-equipped laboratory is necessary.

Two nondestructive testing methods were proposed in the 1986 AASHTO Guide to determine the structural capacity of an existing pavement (1). They include the pavement layer moduli prediction technique (NDT Method 1) and the direct structural capacity prediction technique (NDT Method 2). NDT Method 1 uses deflection basin data from the NDT testing devices to backcalculate the existing pavement moduli and, consequently, the structural capacity. NDT Method 2, on the other hand, relies on outer deflection values to estimate the subgrade moduli and the maximum measured NDT deflection to predict the effective structure pavement capacity.

1.2 Purpose

This appendix describes the AASHTO overlay design procedure using NDT Method 1 and three backcalculation programs for evaluating the existing pavement strength. Appendix B, of this report, describes NDT Method 2.

2.0 EVALUATION OF THE EXISTING PAVEMENT

2.1 Concepts

NDT Method 1 is a technique used to determine the structural capacity of an existing pavement. This technique uses measured deflection basin data from a NDT device to backcalculate the in-situ layer elastic moduli. This method is applicable for both flexible and rigid pavement systems. The fundamental premise of this solution is that a unique set of layer moduli exist such that theoretically predicated deflection basin is equivalent to the measured deflection basin. The backcalculation can be conducted by using computer programs such as ELSDEF, BISDEF, and MODCOMP2. The results of the backcalculation procedure are predicted layer elastic moduli of the existing pavement. The effective structural capacity of the pavement can be determined based upon the predicated elastic moduli.

2.2 Computer Program Descriptions

There are a number of computer programs available to backcalculate the layer elastic moduli (2). This section describes three of those programs, BISDEF, ELSDEF, and MODCOMP2.

2.2.1 BISDEF

The BISDEF program was developed by the U.S. Army Corps of Engineers at the Waterways Experiment Station. This program uses the deflection basin data from nondestructive testing (NDT) results to predict the elastic moduli of up to four pavement layers. BISDEF utilizes the BISAR program as its subroutine to compute the deflections, stresses, and strains of the structure under investigation. To determine the layer moduli, the following data are required:

1) Deflection basin data. These include measured deflection readings and their corresponding offset positions.
2) Thickness of each pavement layer.
3) Range of available modulus for each layer.
4) Initial estimate of modulus for each layer.
5) Poisson's ratio for each layer.
6) NDT device load and radius of the loading plate.

A users guide for the BISDEF program is presented in Appendix AA.

2.2.2 ELSDEF

The ELSDEF program was developed by B.R.E., Inc., using an approach similar to that for BISDEF (3). The program uses an elastic layered system computer program (ELSYM5), developed at the University of California at Berkeley. The input data are basically the same as those required by BISDEF. A users guide for the ELSDEF program is presented in Appendix AB.

2.2.3 MODCOMP2

MODCOMP2 was developed at Cornell University (4). This program utilizes the Chevron elastic layer computer program for determining the stresses, strains, and deformation in the pavement system. The data required to run the program include the following:

1) "Seed" modulus for each layer of the pavement system.
2) Poisson's ratio for each layer.
3) Thickness of each pavement layer.
4) Deflection basin data. These include measured deflection readings and their corresponding offset positions.
5) NDT device load and radius of the loading plate.

A users guide for MODCOMP2 is presented in Appendix AC.

2.2.4 Summary

This section briefly described three backcalculation procedures and their required input data. A summary of input data for the three programs are presented in Table 1. For each program, there is no closed-form solution for determining layer moduli from surface deflection data; iterative approaches are used in the computation. With the same data values, the final predicted moduli may vary for each program. This may be caused by the use of different assumptions and algorithms in developing the programs. It may be necessary for the user to exercise judgment in analyzing the calculated moduli. In other words, the layer moduli predicted from the NDT deflection basin analysis should be compared to the agency's prior experience with similar materials to ensure that the results are reasonable. The use of limited destructive tests/sampling is encouraged to provide spot verification of NDT-derived moduli and values.

2.3 Determination of Existing Pavement Strength

The final layer moduli determined from backcalculation programs are then used to compute the effective in situ structural pavement capacity. Slightly different approaches are required for flexible and rigid pavements as discussed below.

2.3.1 Flexible Pavement

For flexible pavements, the structural capacity of the existing pavement is determined by the following relationship:

$$SN_{xeff} = \sum_{i=1} a_i \ h_i$$

Table 1. Summary of Input Data for Three Programs.

Type of Data	Programs		
	BISDEF	ELSDEF	MODCOMP2
Deflection data	√	√	√
Range of modulus values	√	√	
Poisson's ratio	√	√	√
Thickness of layer	√	√	√
Seed or estimated modulus	√	√	√
NDT device load and radius of load plate	√	√	√
Tolerance	√	√	√
Number of iterations	√	√	√

where:

SN_{xeff} = structural number of existing pavements

a_i = layer coefficient of layer i

h_i = thickness of layer i

The thickness of each layer can be determined from original design records or by coring. The a_i values can be determined from Figures 2.1 to 2.5 (for asphalt concrete surface, use Figure 2.1; for granular base layers, use Figure 2.2; for granular subbase layers, use Figure 2.3; for cement-treated bases, use Figure 2.4; and for bituminous-treated bases, use Figure 2.5). Engineering judgment has to be used if a modulus value exceeds the range of the chart.

2.3.2 Rigid Pavement

For rigid pavements, the structural capacity of the existing pavement can be determined using the following relationships:

1) For normal structural overlay,

$$SN_{xeff} = 0.8\ D_{xeff} + SN_{xeff\text{-}rp}$$

2) For break-seat overlays, two methods can be used,

a) Estimating nominal cracking spacing

$$SN_{xeff} = 0.4\ D_o + SN_{xeff\text{-}rp}$$

b) Post cracking NDT method 1

$$SN_{xeff} = a_{bs}D_o + SN_{xeff\text{-}rp}$$

where:

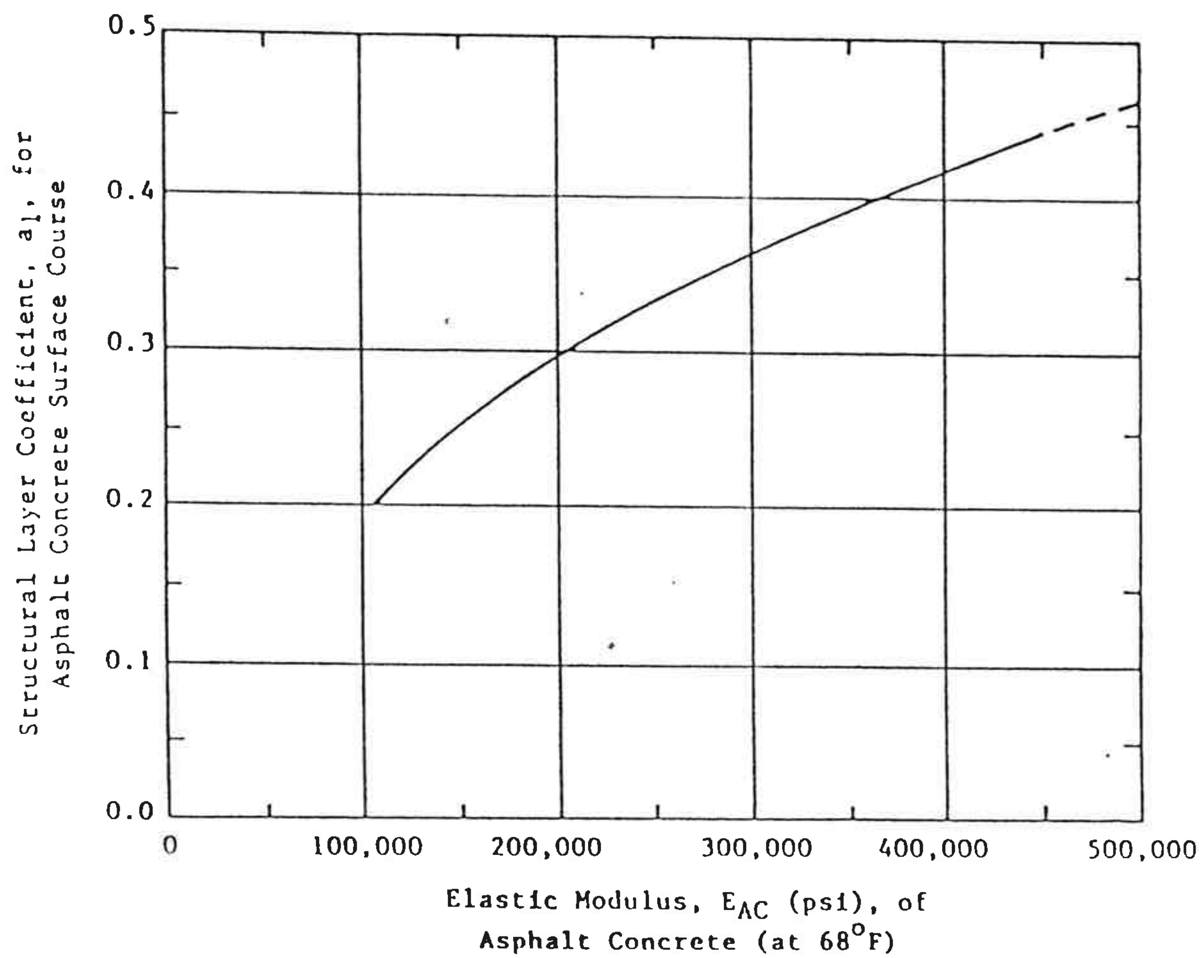
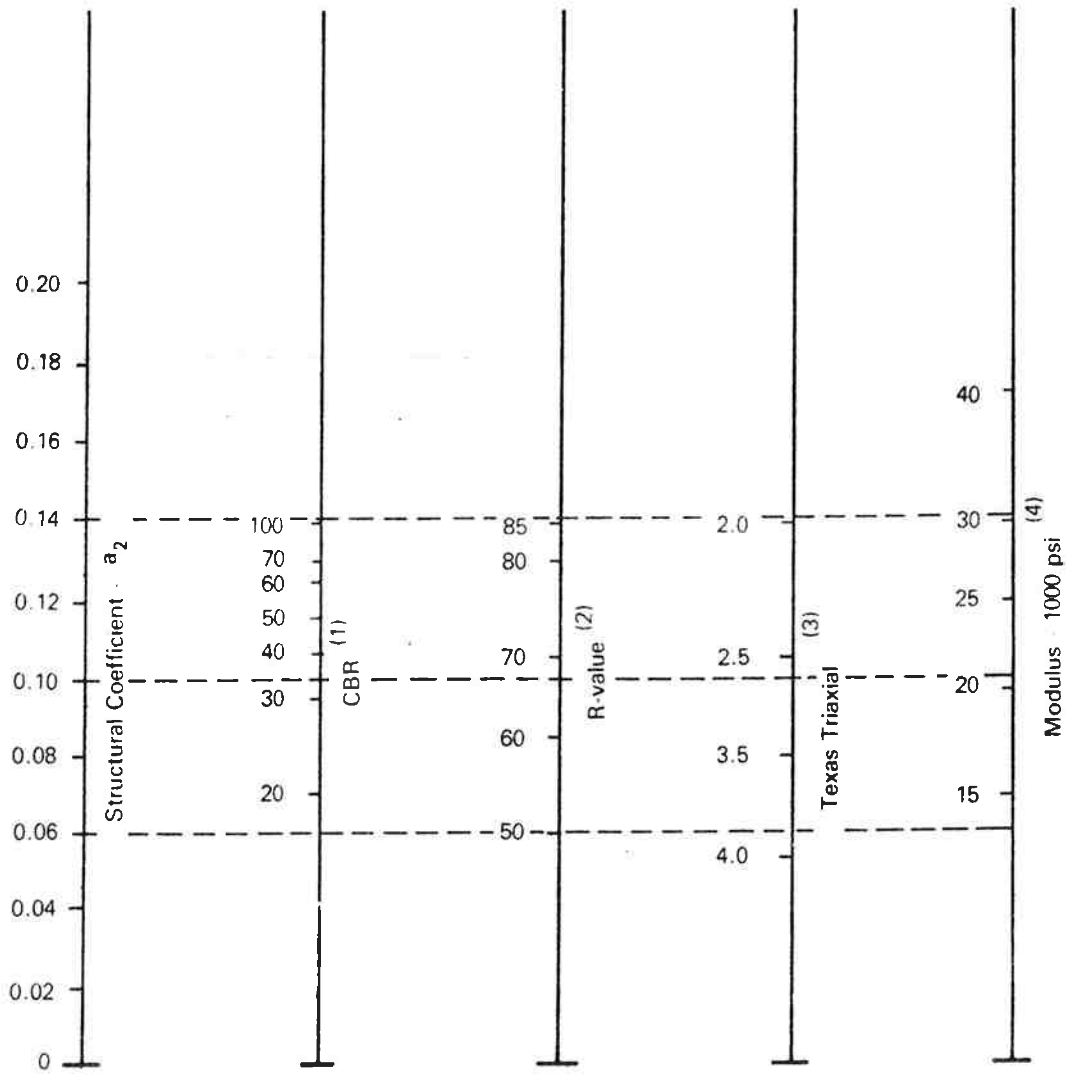
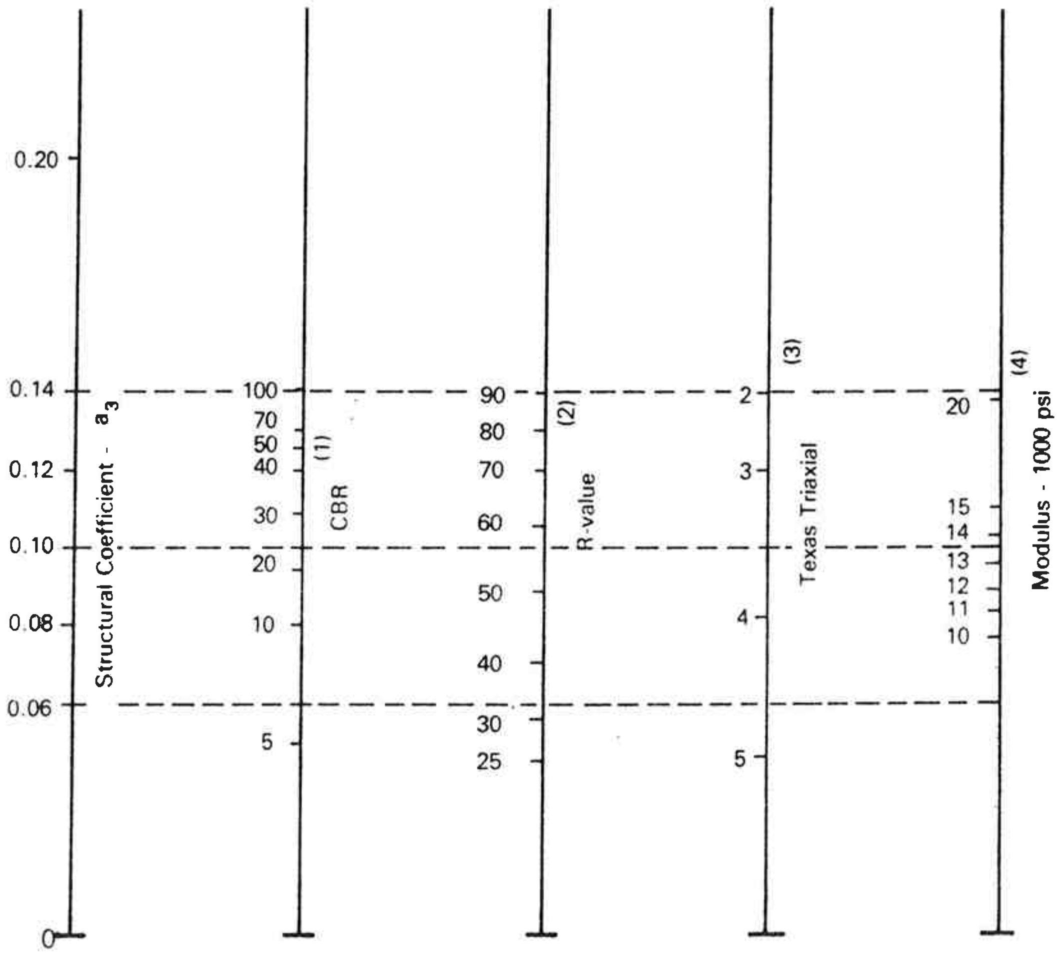


Figure 2.1. Chart for Estimating Structural Layer Coefficient of Dense-Graded Asphalt Concrete Based on Elastic Modulus (5).



(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 (5)

Figure 2.2. Variation in Granular Base Layer Coefficient (a_2) with Various Base Strength Parameters (5).



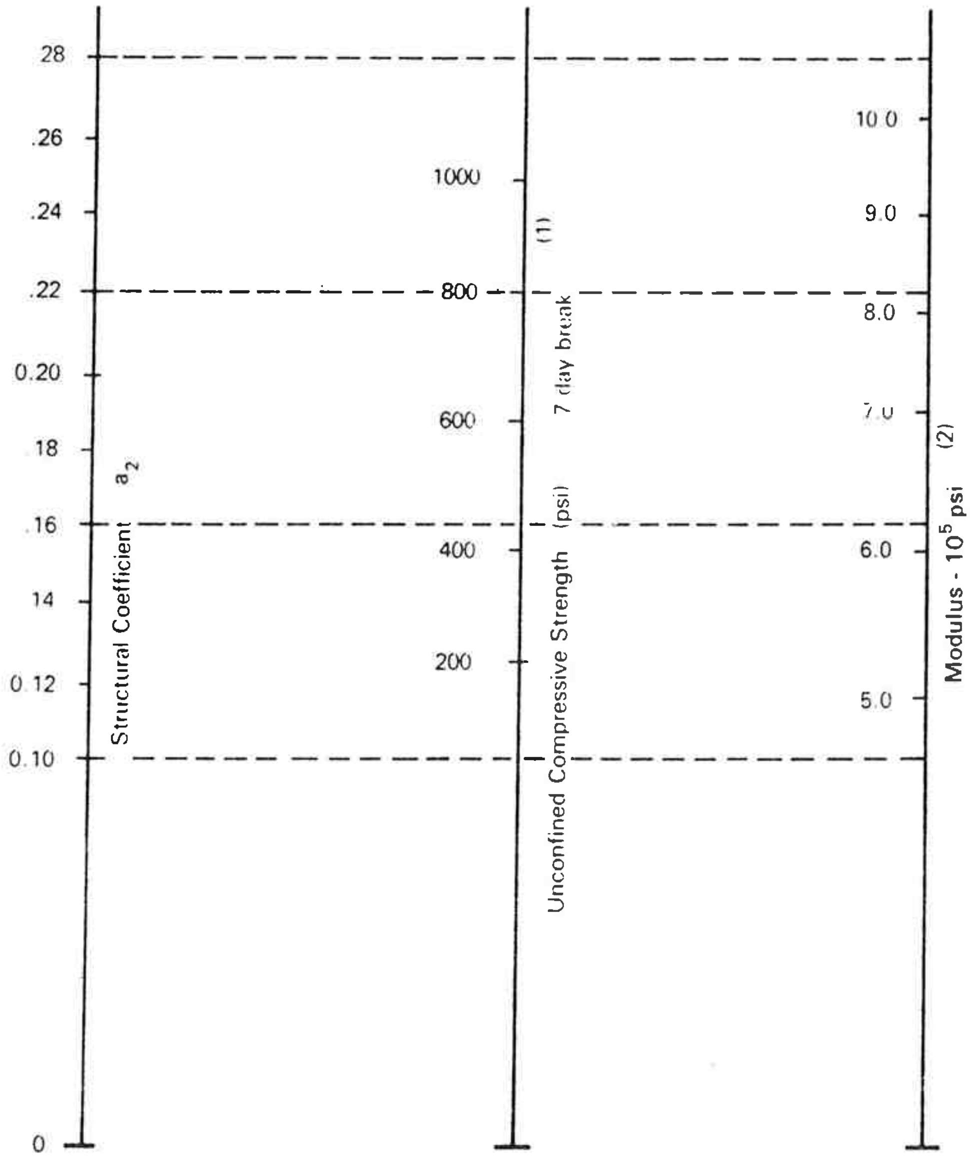
(1) Scale derived from correlations from Illinois.

(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 (5)

Figure 2.3. Variation in Granular Subbase Layer Coefficient (a_3) with Various Subbase Strength Parameters (5).



(1) Scale derived by averaging correlations from Illinois, Louisiana and Texas.

(2) Scale derived on NCHRP project (5)

Figure 2.4. Variation in a for Cement-Treated Bases with Base Strength Parameter (5).

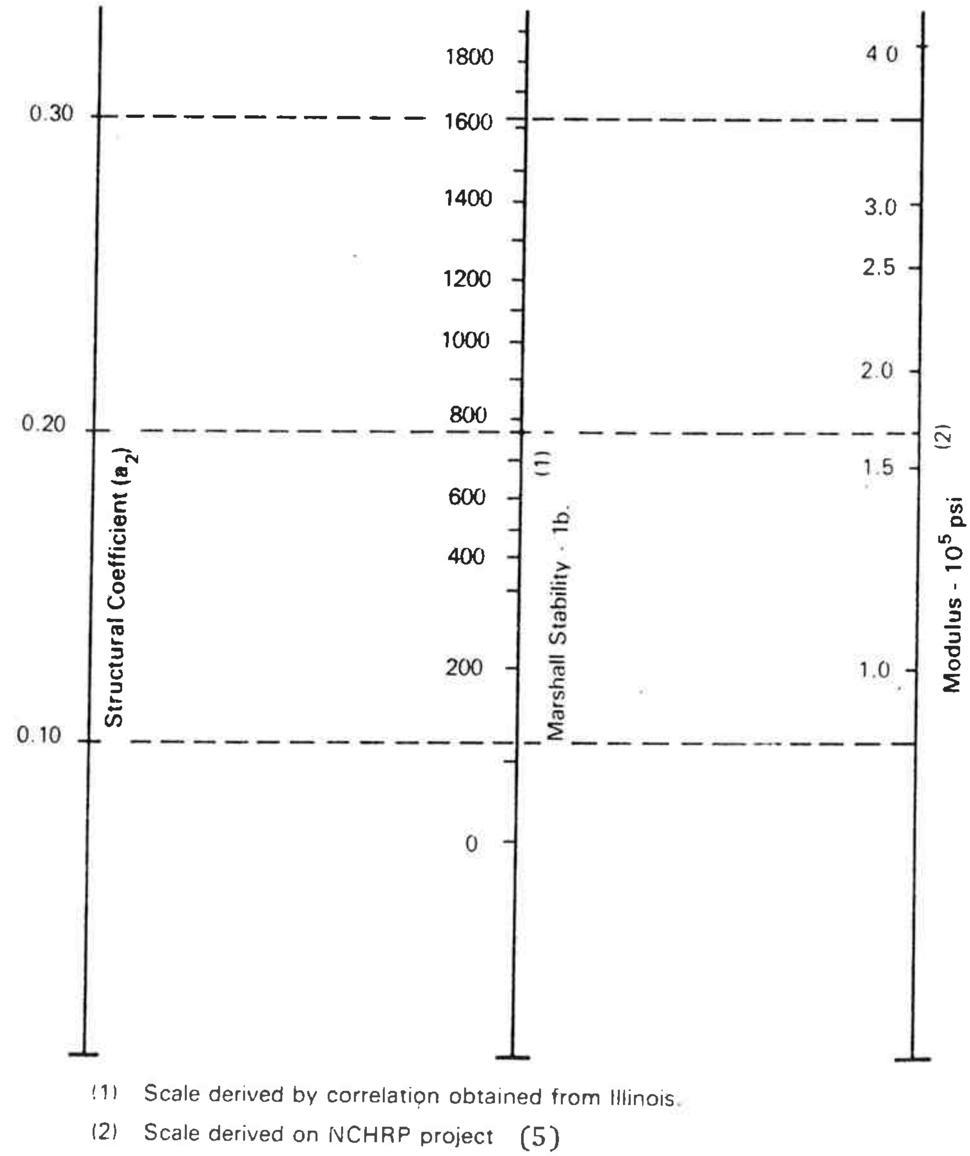


Figure 2.5. Variation in a_2 for Bituminous-Treated Bases with Base Strength Parameter (5).

SN_{xeff} = the total effective structural number of the existing pavement structure above the subgrade,

D_{xeff} = effective thickness of the in situ (cracked) PCC layer reflecting its reduced modulus value,

$SN_{xeff-rp}$ = the effective (in situ) structural capacity of all remaining pavement layers above the subgrade except for the existing PCC layer,

D_o = existing PCC layer thickness, and

a_{bs} = the structural layer coefficient of the PCC pavement layer after it has been broken (cracked) during the break-seat approach. This value is related to the in situ (broken) PCC modulus.

D_{xeff} can be determined with the use of Figure 2.6 from a knowledge of E_{pcc} from the NDT analysis and the total PCC thickness of the existing pavement, D_o. $SN_{xeff-rp}$ can be determined as described in the previous section.

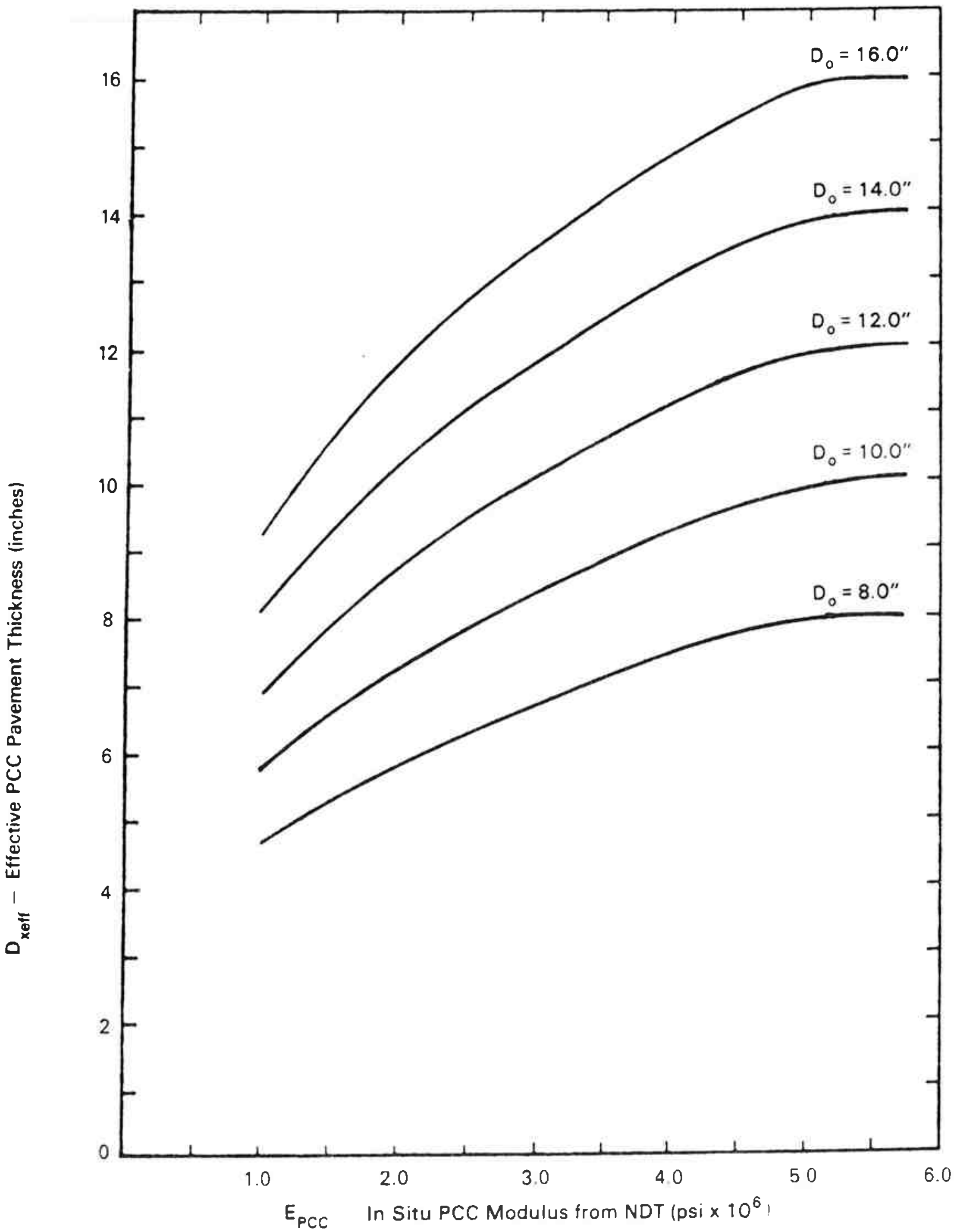


Figure 2.6. Determination of Effective PCC Structural Capacity (Thickness) from NDT-Derived PCC Modulus (1).

3.0 OVERLAY DESIGN PROCEDURE

The previous section described the methodology for determining the structural capacity of an existing pavement. With this value and a knowledge of the future structural capacity and remaining life of the pavement structure, the thickness of an overlay can be determined. This section discusses the analysis of future structural capacity, remaining life of the pavement structure, and the determination of an overlay thickness.

3.1 Analysis of Future Structural Capacity (SC_y)

3.1.1 Flexible Pavements

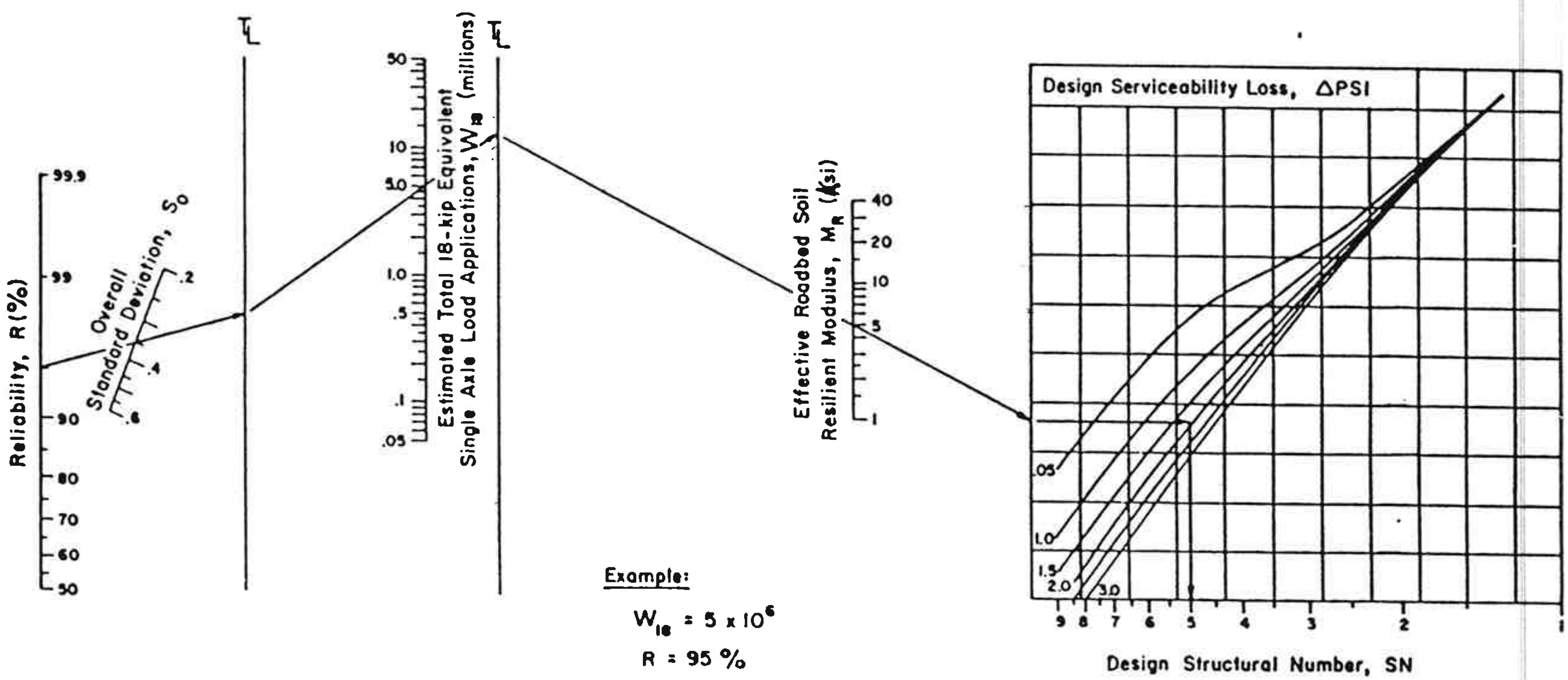
For flexible pavements, the SC_y (SN_y) value can be determined using Figure 3.1, knowing the expected number of 18-kips equivalent single axle load repetitions (W_{18}), design serviceability loss (Δpsi), subgrade modulus (M_R), reliability level (R), and overall standard deviation (S_o). An example of the use of the chart is also contained in Figure 3.1.

3.1.2 Rigid Pavements

For rigid pavements, the SC_y (D_y) value can be determined using Figure 3.2, knowing effective modulus of subgrade reaction (k), concrete elastic modulus (E_c), mean concrete modulus of rupture (S_c), load transfer coefficient (J), drainage coefficient (C_d), design serviceability loss (Δpsi), future total 18-kip equivalent single axle load applications (W_{18}), reliability level (R), and overall standard deviation (S_o). A complete description of each of the above parameters can be found in the 1986 AASHTO Guide (1).

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

ΔPSI = 1.9

Solution: SN = 5.0

Figure 3.1. Design Chart for Flexible Pavements Based on Using Mean Values for Each Input (1).

NOMOGRAPH SOLVES:

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

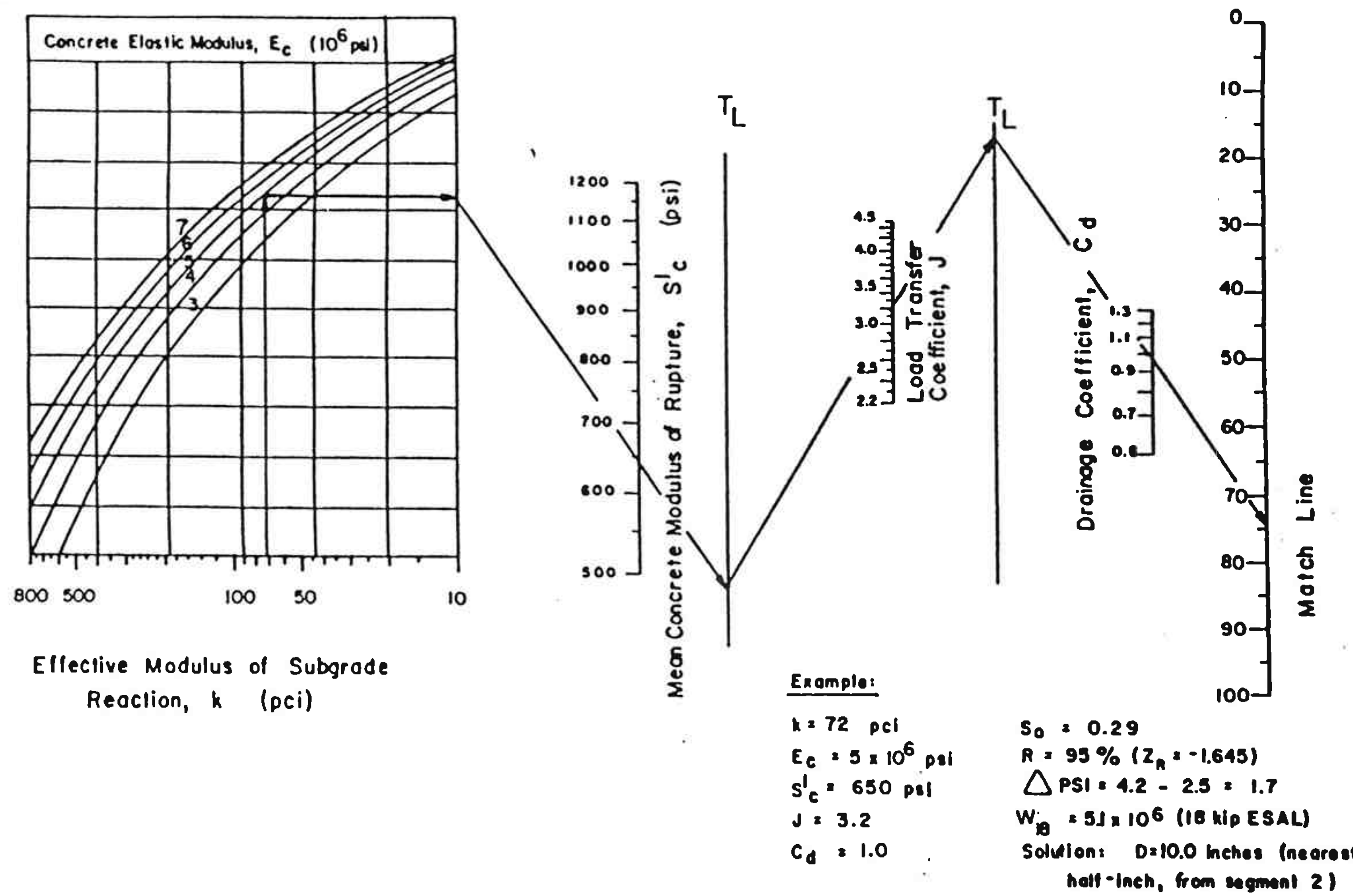


Figure 3.2a. Design Chart for Rigid Pavement Based on Using Mean Values for Each Input Variable (Segment 1) (1).

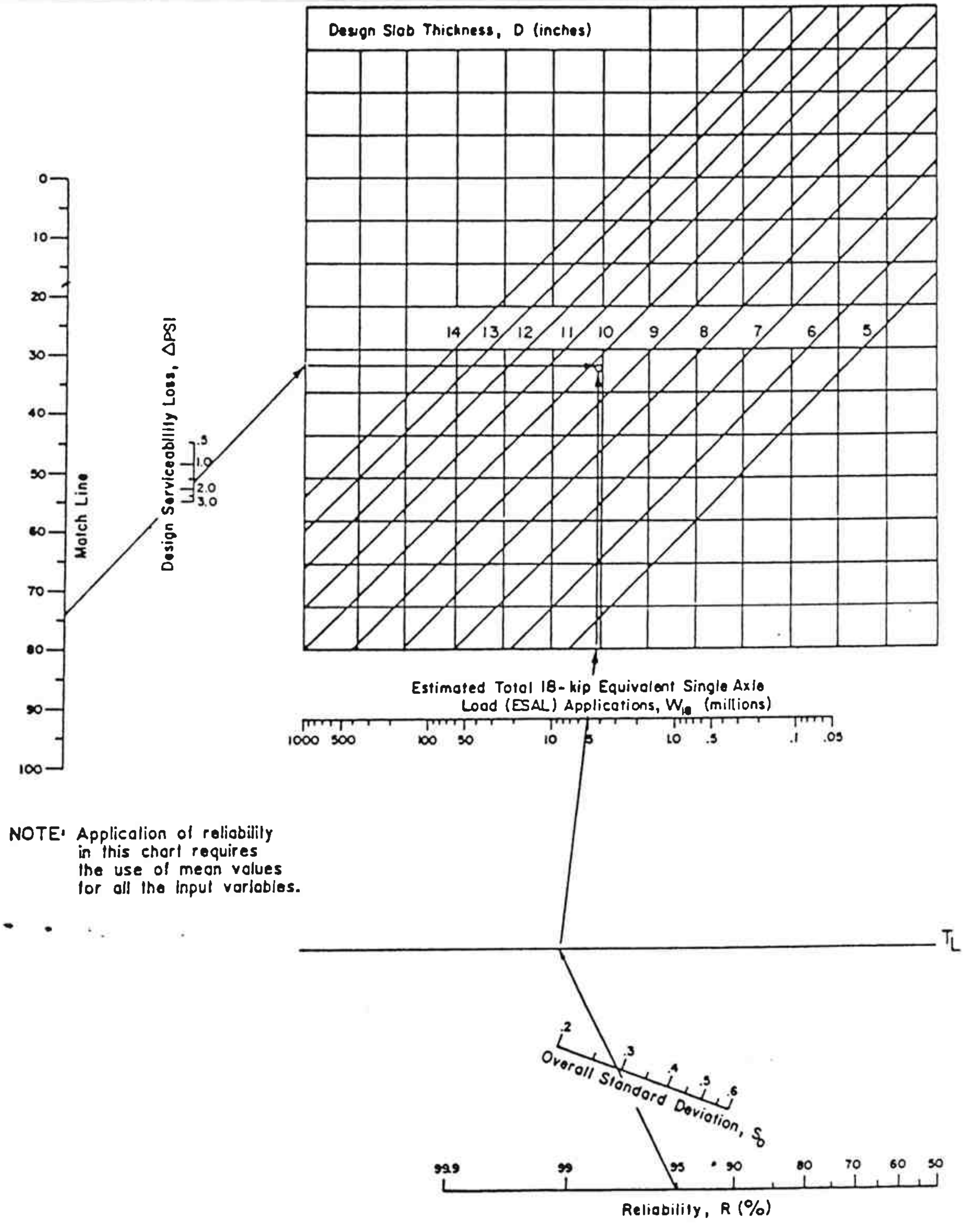


Figure 3.2b. Design Chart for Rigid Pavements Based on Using Mean Values for Each Input Variable (Segment 2) (1).

3.2 Determination of Remaining Life of Pavement Structure

The objective of this step is to determine the remaining life factor (F_{RL}) which is necessary in computing the thickness of an overlay. Two parameters, remaining life of an existing pavement (R_{LX}) and remaining life of an overlaid pavement (R_{LY}), must be determined before the F_{RL} can be estimated.

The R_{LX} can be found by five alternatives: NDT approach, traffic approach, time approach, serviceability approach, and visual condition survey approach. The NDT approach is based on the variation of the pavement structural capacity. The traffic approach relies on accurate historical traffic repetitions. The time approach requires information on the length of time that a particular highway section has been in service and how long its pavement type typically lasts before an overlay is needed. The serviceability approach requires the pavement serviceability index and initial structural capacity. The visual condition survey approach depends on visual inspection of a pavement condition. Although each of these approaches is theoretically equivalent, rarely will they yield the same value. The designer may use any of these approaches depending on the information available.

The remaining life of an overlaid pavement (R_{LY}) can be determined using the equation,

$$R_{LY} = (N_{fy} - Y)/N_{fy}$$

in which:

N_{fy} = the number of repetitions to failure ($P_f = 2.0$) for the overlaid pavement, and

Y = the number of repetitions for an overlaid pavement to reach P_{t2}.

Knowing both R_{LX} and R_{LY}, the remaining life factor F_{RL} may be determined using Figure 3.3.

3.3 Determination of Overlay Thickness

An overlay thickness may be determined by the following general structural capacity form:

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

where:

SC_{OL} = structural capacity required by an overlay,

SC_{y} = future overlay structural capacity (determined in Section 3.1),

F_{RL} = remaining life factor (determined in Section 3.2),

SC_{xeff} = structural capacity of an existing pavement (determined in Section 2.3), and

n = constant, depending on the type of overlay (see Table 3.1 for n values).

For different types of overlay over different existing pavement, corresponding equations should be used as summarized in Table 3.1.

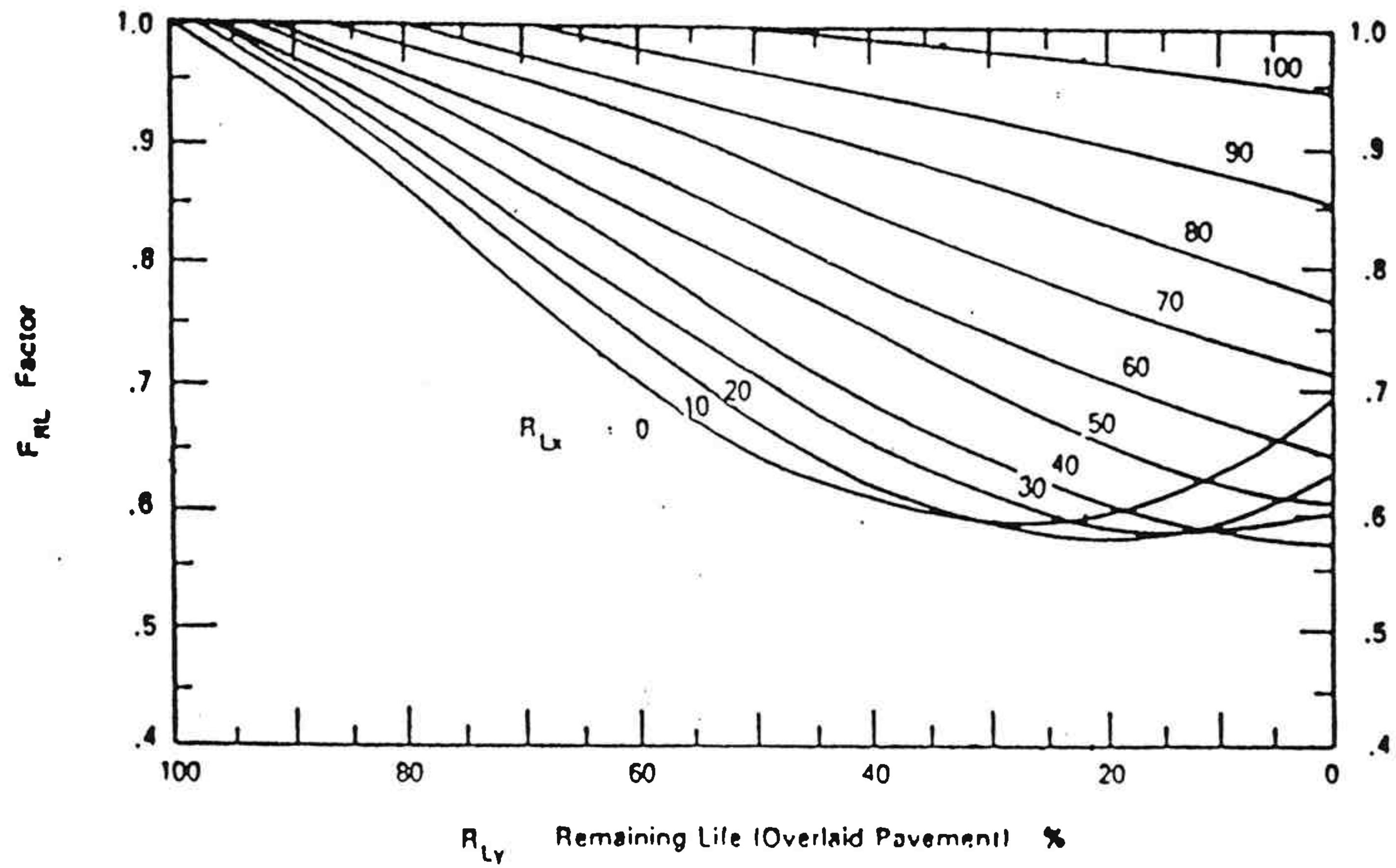


Figure 3.3. Remaining Life Factor as a Function of Remaining Life of Existing and Overlaid Pavements (1).

Table 3.1. Specific Overlay Equation Form Utilized (1).

Type Overlay	Type Existing Pavement	Specific Equation	Conditions/Remarks
Flexible	Flexible	$SN_{oL} = SN_y - F_{RL}\ SN_{xeff}$	SC = SN; n = 1.0
Flexible	Rigid	$SN_{oL} = SN_y - F_{RL}\ SN_{xeff}$	SC = SN; n = 1.0 (see Table 3.2 for equations used)
Rigid	Flexible	$D_{oL} = D_y$ (see remarks)	Treat overlay analysis as new rigid pavement design using existing flexible pavement as new foundation (subgrade)
Rigid	Rigid	$D_{oL} = D_y - F_{RL}\ (D_{xeff})$	SC = D; n = 1.0 (Bonded Overlay)
		$D_{oL}^{1.4} = D_y^{1.4} - F_{RL}\ (D_{xeff})^{1.4}$	SC = D; n = 1.4 (Partial Bond Overlay)
		$D_{oL}^{2} = D_y^{2} - F_{RL}\ (D_{xeff})^{2}$	SC = D; n = 2.0 (Unbonded Overlay)

General Structural Capacity Form: $SC_{oL}^{n} = SC_y^{n} - F_{RL}\ (SC_{xeff})^{n}$

Table 3.2. Summary of Overlay Equations Used in Flexible Overlay Over Existing Rigid Pavement Analysis (1).

Major Overlay Condition	Specific Method Used	SN_{oL} Equation
Normal Structural Overlay	NDT Method 1	$SN_{oL} = SN_y - F_{RL}\ (0.8\ D_{xeff} + SN_{xeff-rp})$
	NDT Method 2	$SN_{oL} = SN_y - F_{RL}\ SN_{xeff}$
	Visual Condition Factor	$SN_{oL} = SN_y - F_{RL}\ (A_{2r}D_o + SN_{xeff-rp})$
Break-Seat Overlay	Estimating Nominal Crack Spacing	$SN_{oL} = SN_y - 0.7\ (0.4\ D_o + SN_{xeff-rp})$*
	Post-Cracking NDT	
	a. NDT Method 1	$SN_{oL} = SN_y - 0.7\ (a_{bs}D_o + SN_{xeff-rp})$
	b. NDT Method 2	$SN_{oL} = SN_y - 0.7\ SN_{xeff}$

*Special Note: The coefficient of D_o (i.e., 0.4) actually varies from 0.35 for a nominal crack spacing of approximately 2.0 ft to a value of 0.45 for a nominal crack spacing of approximately 3.0 ft.

4.0 CONCLUSIONS AND RECOMMENDATIONS

4.1 Conclusions

This appendix described an overlay design procedure using NDT Method 1 and three backcalculation programs for evaluating an existing pavement structural capacity.

With the NDT method, an existing pavement structure can be evaluated quantitatively without damaging its structure. The three backcalculation programs have a lot of similarity with deflection basin data as their major input and predicted layer moduli as their output. The predicted layer moduli can be determined for each pavement layer and can also be calculated for particular layers.

4.2 Recommendations

The three backcalculation programs provide means of evaluating a pavement structure nondestructively. However, because the programs were developed using different algorithms, the final predicted moduli may vary for each program; it is, therefore, necessary to use engineering judgment to ensure the moduli calculated are reasonable.

In the case of very high or very low moduli for each layer, the layer coefficient may not be determined directly from the charts provided and judgment is also required.

5.0 REFERENCES

1. American Association of State Highway and Transportation Officials, "AASHTO Guide for Design of Pavement Structures 1986," 1986.
2. Yapp, M. and R.G. Hicks, "Development of an Improved Overlay Design Procedure for the State of Alaska," Department of Civil Engineering, Oregon State University, May 1987.
3. Lytton, R.L., F.L. Roberts, and S. Stoffels, "Determination of Asphaltic Concrete Pavement Structural Properties by Nondestructive Testing," final report, Texas Transportation Institute, Texas, April 1986.
4. Irwin, L.H., User's Guide to MODCOMP2, Version 2.1, Cornell University, Local Roads Program, Ithaca, NY, November 1983.
5. Van Til, C.J. B.F. McCullough, B.A. Vallerga, and R.G. Hicks, "Evaluation of AASHO Interim Guides for Design of Pavement Structures," NCHRP Report 128, Transportation Research Board, 1972.

APPENDIX AA

USERS GUIDE FOR BISDEF

USER GUIDE FOR BISDEF

Bisdef program was developed by the U.S. Army Corps of Engineers, Waterways Experiment Station. It uses a deflection basin from nondestructive testing (NDT) results to predict the elastic moduli of up to four pavement layers. This is accomplished by matching the calculated deflection basin to the measured deflection basin.

To determine the layer moduli, the basic inputs for analysis include the elastic layer pavement characteristics as well as deflection basin values. The inputs for each layer are:

1) Poisson's ratio,
2) Thickness of each layer,
3) Range of allowable modulus, and
4) Initial estimate of modulus.

For the deflection basin the required input includes:

1) Deflection at a number of sensor location (ND), and
2) Maximum acceptable error in deflections

The modulus of any surface layer may be assigned or computed. If assigned, the value will be based on the type of material or properties of the material at the time of the testing. The number of layers with unknown modulus values cannot exceed the number of measured deflections. Best results are obtained when not more than three layers are allowed to vary.

INPUT GUIDE

Line 1

LINENU NPROB

NPROB = Number of data sets

Line 2

Title 72 characters

Line 3

LINENU ND RRD(1) RRD(2) RRD(3) RRD(4)

ND = Number of deflection readings

RRD(1) = Measured deflections in mils

Line 4

LINENU NL TOL MAXIT

NL = Number of variable layers for which the modulus is to be determined (not to exceed the number of deflections)

TOL = Tolerance in percent for stopping program (usually = 10)

MAXIT = Maximum number of iterations (usually = 3)

Line 5

LINENU NW EMIN(i) EMAX(i)

NW = System layer number for unknown modulus value

EMIN(i) = Minimum allowable modulus for unknown modulus, psi

EMAX(i) = Maximum allowable modulus for unknown modulus, psi

Line 6

LINENU NSYS

NSYS = Number of systems

Line 7

LINENU NLAYS ISMO IRED

NLAYS = Number of layers

ISMO = 0 Request for Rough computational procedure.

= 1 Request for smooth computational procedure.

IRED = 0 if AK is input, = 1 if ALK is input.

NOTE: Smooth computational procedure is used for systems with frictionless slip between the layers.

Line 8

LINENU E NU THICK AK

E = Moduli of layer i

NU = Poisson's Ratio of layer i

THICK = thickness of layer i

AK = interface compliance

ALK = reduced interface compliance

AK values are generally very small thus it may be more desirable to use ALK(i) where ALK(i) = E1/(1+v2) * AK(i) For complete adhesion between layers i and i+1, set AK = ALK = 0. For almost frictionless slip between layers set:

Ei/(1+vi) * AK(i) = ALK(i) >= 1000

Line 9

LINENU E NU

E = moduli of the last layer

NU = Poisson's ratio of the last layer.

Line 10

LINENU NLOAD

NLOAD = Number of loaded areas.

Line 11

LINENU LDSTRS RADIUS X Y HOSTR PSI

LDSTRS = Vertical stress for loaded area i.
RADIUS = Radius of loaded area i.
X = Abscissa of center of loaded area.
Y = Ordinate of center of loaded area.
HOSTR = Horizontal stress for loaded area i.
PSI = Angle of HOSTR with respect to positive X-axis in degrees.

Line 12

LINENU NPOS

NPOS = The number of positions for which deflections have been input.

Line 13

LINENU LAYER AX AY DEPTH ETA

LAYER = Layer number of position i.
AX = Abscissa of position i.
AY = Ordinate of position i.
DEPTH = Depth from pavement surface to position.
ETA = Angle from which position is observed with respect to the direction of the tangential loading.

Line 14

LINENU NPOS

NPOS = The number of positions for which stress, strain and displacements are to be computed.

Line 15

LINENU LAYER AX AY DEPTH ETA

LAYER = Layer number of position i.
AX = Abscissa of position i.
AY = Ordinate of position i.
DEPTH = Depth from pavement surface to position.
ETA = Angle from which position is observed with respect to the direction of the tangential loading.

BISDEF Data File Structure

```
Line 1 :                1
Line 2 : DYNAFLECT 10-1
Line 3 :   4    0.62  0.42  0.30  0.22
Line 4 :   4 10.  3
Line 5 :   1      100000.    2000000.
Line 6 :   2       15000.     200000.
Line 7 :   3       15000.     200000.
Line 8 :   4        5000.      50000.
Line 9 :   1
Line 10:   4  1  1
Line 11:   500000. 0.35     1.00     0.
Line 12:    50000. 0.35    12.00     0.
Line 13:    50000. 0.40     4.00     0.
Line 14:    10000. 0.50
Line 15:   2
Line 16:    500.00    1.600     0.00    10.00 0. 0.
Line 17:    500.00    1.600     0.00   -10.00 0. 0.
Line 18:   4
Line 19:   1     0.00     0.00 0.  0.
Line 20:   1    12.00     0.00 0.  0.
Line 21:   1    24.00     0.00 0.  0.
Line 22:   1    36.00     0.00 0.  0.
```

BISDEF Data Interpretation

Line 1 : Number of Problem (1)

Line 2 : Title

Line 3 : Number of Deflections(4), Deflection Readings(1-4)

Line 4 : Number of Layers(4), Tolerance (10), Number of Iterations (3)

Line 5 : Layer 1, Minimum Modulus, Maximum Modulus

Line 6 : Layer 2, Minimum Modulus, Maximum Modulus

Line 7 : Layer 3, Minimum Modulus, Maximum Modulus

Line 8 : Layer 4, Minimum Modulus, Maximum Modulus

Line 9 : Number of Systems (1)

Line 10: Number of Layers(4), Rough Computation (procedure (0)), Reduced interface compliance

Line 11: Estimated Modulus of Layer 1, Poisson's Ratio of Layer 1, Thickness of Layer 1, Interface Compliance

Line 12: Estimated Modulus of Layer 2, Poisson's Ratio of Layer 2, Thickness of Layer 2, Interface Compliance

Line 13: Estimated Modulus of Layer 3, Poisson's Ratio of Layer 3, Thickness of Layer 3, Interface Compliance

Line 14: Estimated Modulus of Layer 4, Poisson's Ratio of Layer 4, Thickness of Layer 4, Interface Compliance

Line 15: Number of Loaded Areas (2)

Line 16: Vertical Stress for Loaded Area 1, Radius of Loaded Area 1, Abscissa of Center of Loaded Area 1, Ordinate of Center of Loaded Area 1, Horizontal Stress for Loaded Area 1, Angle of HOSTR with respect to positive X-axis in Degrees

Line 17: Same as Line 16, but for Loaded Area 2

Line 18: Number of Positions for which deflections have been input

Line 19: Layer Number of Position1, Abscissa of Position 1, Ordinate of Position 1, Ordinate of Position 1, Depth of Pavement Surface to Position, Angle from which Position is observed with respect to direction of the tangential

Line 20: Same as Line 19

Line 21: Same as Line 19

Line 22: Same as Line 19

```
* # ** # ** # ** # ** # ** # ** # ** # ** # ** # *
           P R O B L E M   N U M B E R  =   1
* # ** # ** # ** # ** # ** # ** # ** # ** # ** # *
```

DYNAFLECT 10-1

DEFLECTION READINGS IN MILS
****

POSITION NUMBER	1	2	3	4
DEFLECTIONS	0.62	0.42	0.30	0.22
WEIGHTING FACTOR:	1.6129	2.3810	3.3333	4.5455

NUMBER OF VARIABLE LAYERS AND TARGET DEFLECTIONS = 4

VARIABLE LAYER NO	SYSTEM LAYER NO	VALUE OF MAXIMUM MODULUS	VALUE OF MINIMUM MODULUS
1	1	2000000.0	100000.0
2	2	200000.0	15000.0
3	3	200000.0	15000.0
4	4	50000.0	5000.0

INITIAL PAVEMENT PARAMETERS
****

LAYER NUMBER	CALCULATION METHOD	YOUNG'S MODULUS	POISSON'S RATIO	THICKNESS	REDUCED SPRINGCOMPL
1	ROUGH	0.5000E+06	0.3500E+00	0.1000E+01	0.0000E+00
2	ROUGH	0.5000E+05	0.3500E+00	0.1200E+02	0.0000E+00
3	ROUGH	0.5000E+05	0.4000E+00	0.4000E+01	0.0000E+00
4		0.1000E+05	0.5000E+00		

LOAD INFORMATION
****

LOAD NUMBER	NORMAL STRESS	SHEAR STRESS	RADIUS OF LOADED AREA	LOAD - POSITION X	LOAD - POSITION Y	SHEAR DIRECTION
1	0.6217E+02	0.0000E+00	0.1600E+01	0.0000E+00	0.1000E+02	0.0000E+00
2	0.6217E+02	0.0000E+00	0.1600E+01	0.0000E+00	-0.1000E+02	0.0000E+00

DEFLECTIONS COMPUTED FOR INITIAL MODULUS VALUES

POSITION	OFFSET	DEFLECTION	MEASURED	DIFFERENCE	% DIFF.
********	******	**********	********	**********	*******
1	0.00	1.6088	0.6200	-0.9888	-159.5
2	12.00	1.3086	0.4200	-0.8886	-211.6
3	24.00	0.9672	0.3000	-0.6672	-222.4
4	36.00	0.7228	0.2200	-0.5028	-228.6
			ABSOLUTE SUM:	3.0473	821.9865
			ARITHMETIC SUM:		-821.9865
			AVERAGE:	0.7618	205.4966

************************BISDEF OUTPUT SUMMARY************************

PREDICTED E'S FOR ITERATION NO.: 3

PREDICTED E DISREGARDING BOUNDRY CONDITIONS

LAYER NO.	MODULUS
*********	**********
1	24.
2	12545.
3	537596416.
4	32124.

PREDICTED E WITH BOUNDARY CONDITIONS CONSIDERED

LAYER NO.	MODULUS
*********	**********
1	100000.
2	68015.
3	1071908.
4	32568.

PREDICTED E WITH BOUNDARY CONDITIONS CONSIDERED

LAYER NO.	MODULUS
*********	**********
1	100000.
2	184438.
3	200000.
4	33682.

DEFLECTIONS COMPUTED FOR FINAL MODULUS VALUES

POSITION	OFFSET	DEFLECTION	MEASURED	DIFFERENCE	% DIFF.
********	******	**********	********	**********	*******
1	0.00	0.5025	0.6200	0.1175	18.9
2	12.00	0.4107	0.4200	0.0093	2.2
3	24.00	0.2997	0.3000	0.0003	0.1
4	36.00	0.2187	0.2200	0.0013	0.6
			ABSOLUTE SUM:	0.1283	21.8236
			ARITHMETIC SUM:		21.8236
			AVERAGE:	0.0321	5.4559

FINAL MODULUS VALUES
****

LAYER NO.:	1	2	3	4
MODULUS:	100000.	184438.	200000.	33682.

REACHED MAX NO OF ITERATIONS

ABSOLUTE SUM OF % DIFF. NOT WITHIN TOLERANCE

CHANGE IN MODULUS VALUES NOT WITHIN TOLERANCE

APPENDIX AB

USERS GUIDE FOR ELSDEF

MODIFIED ELSDEF USERS GUIDE

REFERENCED FROM

DETERMINATION OF ASPHALTIC CONCRETE PAVEMENT STRUCTURAL PROPERTIES BY NONDESTRUCTIVE TESTING

FINAL REPORT

Prepared for

National Cooperative Highway Research Program

Transportation Research Board

National Research Council

By

R.L. Lytton, F.L. Roberts and S. Stoffels

TEXAS TRANSPORTATION INSTITUTE
The Texas A&M University System
College Station, Texas

Research Foundation Project RF7026

Revision
APRIL 1986

ELSDEF USERS GUIDE

ELSDEF was modified from the program BISDEF, developed by the Corps of Engineers at the Pavement Systems Division, Geotechnical Laboratory, Waterways Experiment Station. The modification was done by Peter Jordahl at Brent Rauhut Engineers. The BISAR sub-routine was replaced by ELSYM5, adapted from the ELSYM5 computer program written by Gale Ahlborn, ITTE, University of California at Berkeley. ELSYM5 is based on LAYER, the original elastic layer program, which was developed by Chevron. ELSYM5, and therefore ELSDEF, incorporated several improvements, including the capability to input multiple equal loads.

ELSDEF has been compiled with the Microsoft Fortran Compiler Version 3.31 to run on IBM-compatible microcomputers. Two compiled versions are available. ELSDEF.EXE is the standard version and should run on any IBM-compatible microcomputer. ELSDEF87.EXE was compiled requiring the computer in use to be configured with a 8087 math coprocessor chip.

ELSDEF is a batch-type program; it does not interactively prompt the user for data input. A separate file must be created for the data. Build this file as for any file on the computer in use. Input the data according to the formats in this users guide. Save the data file under any name you wish.

In order to run the program, type:

program, data, output

where

program = name of the program you wish to run

data = name of the saved data set you wish to analyze

output = the name under which you want to output file to be stored

Alternatively, if you only input:

program

the computer will prompt you for the appropriate input and output units. These are specified in both programs with UNIT 5 as input and UNIT 6 as output. Therefore, when the machine prompts as follows, respond with:

UNIT 5? data

UNIT 6? output

INPUT GUIDE

Line 1

LINENU NPROB

NPROB = Number of data sets

Line 2

TITLE 72 characters

Note: Lines 2-4 are repeated for each data set.

Line 3

LINENU ND RRD (i) -- -- -- -- -- -- RRD (ND)

ND = Number of deflection readings (max. 10)

RRD(i) = Measured deflection in mils

i = 1 to ND

Line 4

LINENU NL TOT MAXIT

NL = Number of variable layers for which the modulus is to be determined (not to exceed the number of deflections)

TOL = Tolerance in percent for stopping program (usually = 10)

MAXIT = Maximum number of iterations (usually = 3)

Line 5-1 through 5-NL (one line for each unknown modulus)

LINENU ILV(i) EMIN(i) EMAX(i)

ILV(i) = System layer number for unknown modulus value

EMIN(i) = Minimum allowable modulus for unknown modulus, psi

EMAX(i) = Maximum allowable modulus for unknown modulus, psi

Line 6

COL 1-8	COL 9-10(I2)	COL 11-20(F10.0)
"PROBLEM"	0.0	1.0 if line 7 is desired, 0 otherwise

Line 7 (optional)

TITLE (20A9)

Line 8

COL 1-8	COL 9-10(I2)	COL 11-20(F10.0)	COL 21-25(F5.0)
"LOADS"	No. of Loads	Load Magnitude (lbs)	Tire pressure (psi)

Line 9

x, y pairs for load coordinates (16F5.0)

Line 10

COL 1-8	COL 9-10 (I2)
"NLAYER"	No. of layers

Line 11-1 through 11-NLAYER (one line for each layer)

COL 1-8	COL 9-10(I2)	COL 11-20(F10.0)	COL 21-25(F5.0)
"LAYER"	Layer No.	"Seed" Modulus	Thickness (in.)

COL 26-30 (F5.0)	COL 31-32 (Last layer only)
Poisson's ratio	Friction condition (see note)

NOTE: If the bottom layer is given a thickness of zero, the program assumes the layer is infinite. If a depth is given, a rigid layer is assumed at that depth. The friction condition is either "FF" for full friction with the rigid layer of "NF" for no friction with the rigid layer. Leave the friction condition blank for an infinite bottom layer.

<u>Line 12</u>

COL 1-8 COL 9-10 (I2)

"XYOUT" The no. of x,y points for output

<u>Line 13</u>

The x,y coordinates for output (16F5.2). The output point should correspond to the deflection sensors used.

<u>Line 14</u>

COL 1-8 COL 9-10 (I2)

"ZOUT" 1.0

<u>Line 15</u>

Blank or zero

<u>Line 16</u>

"END"

Supplement to ELSDEF Users Guide

ELSDEF was revised to provide the user with an option that calculates initial moduli estimates within the program. Both ELSDEF.EXE and ELSDEF87.EXE include this option. If the option is invoked, the estimates will be calculated for each layer except the surface layer. A value for the surface layer will need to be provided by the user. The purpose of the estimate option is to reduce convergence time and the amount of iterations required for calculation of actual values. This option should be used when the user does not have enough information to formulate the estimates required.

To invoke the option, an additional line of information is required in the datafile between lines 15 and 16 (as in the Users Guide). The format for line 15a is as follows:

COL 1-8	COL 9-10 (i2)
"ESTOPT"	10

If the option is not to be invoked, Columns 9-10 must contain the value of 20 or the line must be left out.

Dummy values should be included in place of the "seed" moduli for lines 11-2 through 11-NLAYER which will be replaced by the estimated values (except for the surface layer).

ELSCRN User Guide

The Elscrn program is a screen edit program which allows the user to input data with an ability to edit the input numbers without having to use any word processors. The user is allowed to move to any fields using [LEFT], [RIGHT], [UP], and [DOWN] arrow keys. The other important key is the [ESC] key which allows the user to exit the program. There is a message line at the bottom of the screen which will display the message to the user to follow. The keys are explain as below:

[ESC]	-	To save the data and exit the program
[LEFT]	-	To move one space to the left or to left field
[RIGHT]	-	To move one space to the right or to right field
[UP]	-	To move to next left field
[DOWN]	-	To move to next right field

ELSDEF Data File Structure

```
Line 1 : 010 1
Line 2 : 020 TH 20 MP 216
Line 3 : 030 7,18.41, 9.41, 5.45, 3.66, 2.57, 2.00, 1.60
Line 4 : 040 3, 10 , 3
Line 5 : 050 1, 200000 , 2000000
Line 6 : 060 2, 15000 , 200000
Line 7 : 070 3, 4000 ,, 50000
Line 8 : PROBLEM
Line 9 : LOADS     1    10608.  97.
Line 10:   0.  0.
Line 11: NLAYER    3
Line 12: LAYER     1   500000.    5. 0.35
Line 13: LAYER     2    80000.   18. 0.40
Line 14: LAYER     3    10000.  200. 0.50FF
Line 15: XYOUT     7
Line 16: 0.   0.   0.   12.  0.   24.   0.   36.   0.   48.   0.   60.   0.   72.
Line 17: ZOUT      1
Line 18: 0.
Line 19: END
```

ELSDEF Data file Interpretation

Line 1 : Problem Number
Line 2 : Title
Line 3 : Number of Deflection, Deflection Readings (1-7)
Line 4 : Number of layers, Tolerance, Max. Iterations
Line 5 : Layer 1, Minimum Modulus, Maximum Modulus
Line 6 : Layer 2, Minimum Modulus, Maximum Modulus
Line 7 : Layer 3, Minimum Modulus, Maximum Modulus
Line 8 : PROBLEM
Line 9 : Loads, Number of Load, Load Magnitude, Load Pressure
Line 10: Abscissa of Load Position, Ordinate of Load Position
Line 11: NLAYER, Number of Layers
Line 12: LAYER 1, Estimated modulus, Thickness, Poisson's Ratio
Line 13: LAYER 2, Estimated modulus, Thickness, Poisson's Ratio
Line 14: LAYER 3, Estimated modulus, Thickness, Poisson's Ratio
Line 15: XYOUT, Number of Deflection Positions
Line 16: Abscissa of Position(i), Ordinate of Position(i)
Line 17: ZOUT 1
Line 18: 0.
Line 19: END

THE NUMBER OF PROBLEMS TO BE SOLVED IS 1

PROBLEM NUMBER 1

020 IH 20 MP216
NUMBER OF VARIABLE LAYERS AND TARGET DEFLECTIONS = 3

DEFLECTION READINGS IN MILS

POSITION NO:	1	2	3	4	5	6	7
DEFLECTIONS:	18.410	9.410	5.450	3.660	2.570	2.000	1.600
WEIGHTING FACTOR:	.054	.106	.183	.273	.389	.500	.625

VARIABLE LAYER NO	SYSTEM LAYER NO	VALUE OF MAXMUM MODULUS	VALUE OF MINIMUM MODULUS
1	1	2000000.0	200000.0
2	2	200000.0	15000.0
3	3	50000.0	4000.0

ELSYM5 - FIVE LAYERED ELASTIC SYSTEM - VERSION 4.5
LATEST REVISION: 81/02/07 - P. R. JORDAHL BRENT RAUHUT ENGINEERING, INC.

SYSTEM NUMBER 0

NUMBER OF ELASTIC LAYERS = 3
NUMBER OF LOAD LOCATIONS = 1
NUMBER OF OUTPUT LOCATIONS= 7
NUMBER OF OUTPUT DEPTHS = 1

LAYER	ELASTIC MODULUS	POISSONS RATIO	THICKNESS (IN.)
1	500000.	.350	5.000
2	80000.	.400	18.000
3	10000.	.500	200.000

LOAD DESCRIPTION:

LOAD FORCE = 10608.
TIRE PRESSURE = 97.
LOAD RADIUS = 5.90

LOADS LOCATED AT:

LOAD	X	Y
1	.000	.000

RESULTS REQUESTED FOR SYSTEM LOCATION(S)

X-Y POINT(S)

X	Y
.00	.00
.00	12.00
.00	24.00
.00	36.00
.00	48.00
.00	60.00
.00	72.00

DEPTHS = .00

POSITION	DEFLECTION	MEASURED	DIFFERENCE	% DIFF.
1	14.2040	18.4100	4.2060	22.8
2	8.5957	9.4100	.8143	8.7
3	6.6008	5.4500	-1.1508	-21.1
4	4.8949	3.6600	-1.2349	-33.7
5	3.6515	2.5700	-1.0815	-42.1
6	2.7158	2.0000	-.7158	-35.8
7	1.9899	1.6000	-.3899	-24.4
		ABSOLUTE SUM:	9.5932	188.5957
		ARITHMETIC SUM:		-125.5949

DATA FOR DEVELOPING EQUATIONS FOR ITERATION NO. 1

LAYER NO.	INITIAL MODULUS	CHANGED MODULUS	OFFSET DISC.	DEFLECTIONS INITIAL	DEFLECTIONS CHANGED	READINGS
1	500000.	2000000.	.00	14.204	11.248	18.410
			12.00	8.596	7.554	9.410
			24.00	6.601	6.214	5.450
			36.00	4.895	4.662	3.660
			48.00	3.651	3.513	2.570
			60.00	2.716	2.653	2.000
			72.00	1.990	1.977	1.600
2	80000.	200000.	.00	14.204	10.220	18.410
			12.00	8.596	5.827	9.410
			24.00	6.601	5.242	5.450
			36.00	4.895	4.175	3.660
			48.00	3.651	3.306	2.570
			60.00	2.716	2.597	2.000
			72.00	1.990	2.000	1.600
3	10000.	50000.	.00	14.204	7.853	18.410
			12.00	8.596	3.704	9.410
			24.00	6.601	1.890	5.450
			36.00	4.895	1.136	3.660
			48.00	3.651	.741	2.570
			60.00	2.716	.499	2.000
			72.00	1.990	.341	1.600

PREDICTED E DISREGARDING BOUNDARY CONDITIONS
2674272. 11004. 27638.

PREDICTED E RESPECTING BOUNDARY CONDITIONS
2000001. 15450. 24205.

POSITION	DEFLECTION	MEASURED	DIFFERENCE	% DIFF.
1	11.9421	18.4100	6.4679	35.1
2	8.4542	9.4100	.9558	10.2
3	5.2232	5.4500	.2268	4.2
4	2.9453	3.6600	.7147	19.5
5	1.6586	2.5700	.9114	35.5
6	.9793	2.0000	1.0207	51.0
7	.6152	1.6000	.9848	61.5
		ABSOLUTE SUM:	11.2822	217.0276
		ARITHMETIC SUM:		217.0276
		AVERAGE:	31.0039	31.0039

DATA FOR DEVELOPING EQUATIONS FOR ITERATION NO. 2

LAYER NO.	INITIAL MODULUS	CHANGED MODULUS	OFFSET DISC.	DEFLECTIONS INITIAL	CHANGED	READINGS
1	2000001.	1414214.	.00	11.942	13.529	18.410
			12.00	8.454	9.195	9.410
			24.00	5.223	5.303	5.450
			36.00	2.945	2.833	3.660
			48.00	1.659	1.558	2.570
			60.00	.979	.930	2.000
			72.00	.615	.602	1.600
2	15450.	15336.	.00	11.942	11.966	18.410
			12.00	8.454	8.474	9.410
			24.00	5.223	5.235	5.450
			36.00	2.945	2.951	3.660
			48.00	1.659	1.660	2.570
			60.00	.979	.979	2.000
			72.00	.615	.615	1.600
3	24205.	19405.	.00	11.942	12.967	18.410
			12.00	8.454	9.317	9.410
			24.00	5.223	6.016	5.450
			36.00	2.945	3.557	3.660
			48.00	1.659	2.096	2.570
			60.00	.979	1.277	2.000
			72.00	.615	.810	1.600

PREDICTED E DISREGARDING BOUNDARY CONDITIONS
554966. 34557. 14958.

POSITION	DEFLECTION	MEASURED	DIFFERENCE	% DIFF.
1	16.3138	18.4100	2.0962	11.4
2	9.8565	9.4100	-.4465	-4.7
3	5.9896	5.4500	-.5396	-9.9
4	3.7895	3.6600	-.1295	-3.5
5	2.5266	2.5700	.0434	1.7
6	1.7274	2.0000	.2726	13.6
7	1.1867	1.6000	.4133	25.8
		ABSOLUTE SUM:	3.9410	70.7167
		ARITHMETIC SUM:		34.3480
		AVERAGE:	10.1024	10.1024

DATA FOR DEVELOPING EQUATIONS FOR ITERATION NO. 3

LAYER NO.	INITIAL MODULUS	CHANGED MODULUS	OFFSET DISC.	DEFLECTIONS INITIAL	CHANGED	READINGS
1	554966.	429989.	.00	16.314	17.341	18.410
			12.00	9.856	10.049	9.410
			24.00	5.990	5.976	5.450
			36.00	3.790	3.781	3.660
			48.00	2.527	2.526	2.570
			60.00	1.727	1.728	2.000
			72.00	1.187	1.187	1.600
2	34557.	28257.	.00	16.314	17.590	18.410
			12.00	9.856	10.690	9.410
			24.00	5.990	6.287	5.450
			36.00	3.790	3.846	3.660
			48.00	2.527	2.508	2.570
			60.00	1.727	1.693	2.000
			72.00	1.187	1.156	1.600
3	14958.	10757.	.00	16.314	18.579	18.410
			12.00	9.856	11.667	9.410
			24.00	5.990	7.691	5.450
			36.00	3.790	5.122	3.660
			48.00	2.527	3.528	2.570
			60.00	1.727	2.465	2.000
			72.00	1.187	1.718	1.600

PREDICTED E DISREGARDING BOUNDARY CONDITIONS

509037. 34684. 15236.

POSITION	DEFLECTION	MEASURED	DIFFERENCE	% DIFF.
1	16.5186	18.4100	1.8914	10.3
2	9.8182	9.4100	-.4082	-4.3
3	5.8952	5.4500	-.4452	-8.2
4	3.7200	3.6600	-.0600	-1.6
5	2.4786	2.5700	.0914	3.6
6	1.6936	2.0000	.3064	15.3
7	1.1631	1.6000	.4369	27.3
		ABSOLUTE SUM:	3.6395	70.6045
		ARITHMETIC SUM:		42.3133
		AVERAGE:	10.0864	10.0864

THE FINAL MODULUS VALUES ARE

509037. 34684. 15236.

CHANGE IN MODULUS VALUES ARE IN TOLERANCE

***** END OF PROGRAM *****

APPENDIX AC

USERS GUIDE FOR MODCOMP2

AC.1 Input Data File

AC.1.1 Data File Structure

Line									
1 :	TRIAL PROBLEM				JUNE 22, 1983				
2 :	ENGL,BRIEF								
3 :	0.15,10								
4 :	4								
5a:	1	0	200000.0	0.35	145.0	1.0	5.0	0.0	0.0
5b:	1	1	15000.0	0.35	135.0	1.0	4.5	0.0	0.0
5c:	1	1	12000.0	0.45	130.0	1.0	4.5	0.0	0.0
5d:	0	0	7500.0	0.45	130.0	1.0	0.0	0.0	0.0
6 :	4								
7a:	0.0,	50.0,	6.0						
7b:	0.0,	72.0,	6.0						
7c:	0.0,	100.0,	6.0						
7d:	0.0,	145.0,	6.0						
8 :	7								
9 :	0.00	7.87	11.81	17.72	25.590	35.430	47.240		
10a:	21.20	17.29	14.72	11.54	8.457	5.925	4.242		
10b:	30.09	24.55	20.93	16.46	12.130	8.545	6.118		
10c:	41.27	33.68	28.73	22.65	16.790	11.840	8.514		
10d:	59.02	48.17	41.12	32.49	24.240	17.280	12.380		

AC.1.2. Interpretation

See Tables 1, 2, and 3.

Table 1. MODCOMP 2 Input File Description.

Line	Variable Names	Comments
1	TITLE	Descriptive title for problem (Format:20A4)
2	UNITS, OUTPUT	UNITS: either 'METR' for SI metric input, or 'ENGL' for English customary units (see Table 2 for further information). Default units are metric. OUTPUT: either 'BRIE' for brief (i.e., only the final iteration results are tabulated), or 'LONG' if the results of each iteration are desired, or 'ALL ' if intermediate calculations are also of interest. Default output is brief. (Format: A4,1X,A4)
3	TOL, MAXITN	TOL: tolerance desired for maximum difference between input and calculated deflections, given in percent. MAXITN: the maximum allowed number of iterations in the main program loop.
4	NS	Number of layers in the pavement system, counting the subgrade as one layer. (Maximum NS=8).
5a 5b 5c 5d etc.	TYPE(I), MODEL(I), E(I), V(I), DEN(I), KØ(I), THKNES(I), K1(I), K2(I) where I = layer number	(One line for each layer) TYPE: (see Table 3 for description) MODEL: (see Table 3 for description) E(I): a seed modulus (i.e., a starting point for the computations) for nonlinear (MODEL>0), known (TYPE=0) layers and for all unknown (TYPE=1) layers. For linear, known layers this modulus will be used for all calculations. V(I): Poisson's ratio for the layer. DEN(I): Unit weight of layer material (can be input as 0.0 if all layers in the system are linear (MODEL=0)). KØ(I): At-rest lateral earth pressure coefficient (can be input as 0.0 for each linear layer (MODEL=0)). THKNES(I): Layer thickness (can be input as 0.0 for the bottom layer). K1(I): Coefficient in nonlinear models for the form $E=k_1 S^{k_2}$, where S may be any stress-strain parameter. (See Table 3 for further information.) (Required only for known (TYPE=0), nonlinear (MODEL>0) layers; can be input as 0.0 for all others.) K2(I): Exponent in nonlinear models. (See Table 3 for further information.) (Required only for known, nonlinear layers; can be input as 0.0 for all others.)

Table 1, continued.

Line	Variable Names	Comments
6	NLOADS	Number of load levels (maximum NLOADS=6).
7a 7b 7c 7d etc.	LOAD(J), PRESUR(J), LDRAD(J) where J=load number	(One line for each load level.) LOAD(J): Load force on plate PRESUR(J): Plate pressure LDRAD(J): Plate radius (only two of these three parameters must be input. If the third is input as 0.0 it will be computed, assuming a circular plate.)
8	NDEF	Number of surface deflections (maximum NDEF=8).
9	INPRAD(K) where K = deflection number	Radial distance measured from the center of the load plate to each deflection sensor.
10a 10b 10c 10d etc.	INPDEF(J,K) where J=load number and K=deflection number	(One line for each load level.) Surface deflection data.

Except on line 1 and line 2 where the alphanumeric input format is specified, all input is format-free. Each item of input may be separated by a comma or one or more blank spaces. See Table 2 for further information regarding variable types and required units.

Table 2. MODCOMP 2 Input Variable Types and Required Units.

Variable Name	Parameter	Variable Type	Required Units: English System	Required Units: Metric System
DEN(I)	Density	Real	pounds/cu. ft.	kilograms/cu. m.
E(I)	Elastic Modulus	Real	pounds/sq. in.	megapascals
INPDEF(J,K)	Measured Deflections	Real	mils (10^{-3} in.)	microns (10^{-6} m.)
INPRAD(K)	Deflection Radii	Real	inches	meters
KØ(I)	Earth Pressure Coefficient	Real	dimensionless	dimensionless
K1(I)	Nonlinear Model Coefficient	Real	pounds/sq. in.	megapascals
K2(I)	Nonlinear Model Exponent	Real	dimensionless	dimensionless
LOAD(J)	Load Force	Real	pounds	kilonewtons
LDRAD(J)	Plate Radius	Real	inches	meters
MAXITN	Iteration Limit	Integer	---	---
MODEL(I)	Layer Model	Integer	---	---
NDEF	Number of Deflections	Integer	---	---
NLOADS	Number of Load Levels	Integer	---	---
NS	Number of Layers	Integer	---	---
OUTPUT	Output Format	Alphanumeric	---	---
PRESUR(J)	Plate Pressure	Real	pounds/sq. in.	kilopascals
THKNES(I)	Layer Thickness	Real	inches	meters
TITLE	Problem Title	Alphanumeric	---	---
TOL2	Tolerance for Calculation	Real	percent	percent
TYPE(I)	Layer Type	Integer	---	---
UNITS	Input Units	Alphanumeric	'ENGL'	'METR'
V(I)	Poisson's Ratio	Real	dimensionless	dimensionless

Table 3. Layer TYPE and MODEL Descriptions.

TYPE	DESCRIPTION
0	Constitutive relationship is known. If linear, the seed modulus will be assigned to the layer for all calculations. If nonlinear, the input K_1 and K_2 parameters will be assigned to the layer for the MODEL specified.
1	Constitutive relationship is unknown. MODCOMP 2 will determine either a linear modulus or the nonlinear parameters K_1 and K_2, according to the MODEL specified.

MODEL	DESCRIPTION
0	Linear layer of the form: E = constant. In general, most asphalt concrete, portland cement concrete, and treated (i.e., stabilized) soil materials conform to this constitutive relationship.
1	Nonlinear bulk stress model of the form: $E = k_1 S^{k_2}$, where $S = \sigma_z + \sigma_t + \sigma_r$. Some coarse-grained untreated base and subbase gravels have been found to conform to this relationship.
2	Nonlinear deviatoric stress model of the form: $E = k_1 S^{k_2}$, where $S = \sigma_1 - \sigma_3$, the difference between the major principal stress and the minor principal stress. Note that this exponential model differs from the more customary linear model ($E = k_1 S + k_2$) which is a popular relationship for fine-grained, untreated materials.
3	Nonlinear stress model of the form: $E = k_1 S^{k_2}$, where $S = J_2/\tau_{oct}$. The parameter J_2 is the second stress invariant $(J_2 = \sigma_z\sigma_t + \sigma_t\sigma_r + \sigma_r\sigma_z + \tau_{rz}^2$ and τ_{oct} is the octahedral shear stress $\tau_{oct} = 1/3\left((\sigma_z - \sigma_t)^2 + (\sigma_t - \sigma_r)^2 + (\sigma_r - \sigma_z)^2 + 6\,\tau_{rz}^2)^{1/2}\right)$. This constitutive relationship has been found to be useful for both base course and subgrade materials, and the coefficient k_1 appears to be primarily a function of material density and soil moisture tension.
4	Nonlinear stress model of the form: $E = k_1 S^{k_2}$, where $S = \tau_{oct}$, as defined for MODEL = 3. This relationship has been found to be useful for frozen soils, and the coefficient k_1 appears to be a function of soil temperature and moisture content.

AC.2 Output

```
*   *  *****  ***    *****  *****  *   *  *****      *****  *****
** **  *   *  *  *   *      *   *  ** **  *   *        *      *
* * *  *   *  *   *  *      *   *  * * *  *   *        *      *
*   *  *   *  *   *  *      *   *  *   *  *****        *      *
*   *  *   *  *   *  *      *   *  *   *  *            *      *
*   *  *   *  *  *   *      *   *  *   *  *            *      *
*   *  *****  ***    *****  *****  *   *  *          *****  *****
```

(VERSION 2.4; 28 FEBRUARY 1986)

********** TRIAL PROBLEM JUNE 22, 1983 **********

*** L O A D / D E F L E C T I O N   P A R A M E T E R S ***

LOAD NUMBER	LOAD (LB)	PRESSURE (PSI)	LOAD RADIUS (IN)	INPUT DEFLECTIONS (MILS) 1<RADIUS>1 0.000	2<RADIUS>2 7.870	3<RADIUS>3 11.810	4<RADIUS>4 17.720	5<RADIUS>5 25.590	6<RADIUS>6 35.430	7<RADIUS>7 47.240
1	5654.86	50.0	6.000	21.200	17.290	14.720	11.540	8.457	5.925	4.242
2	8143.00	72.0	6.000	30.090	24.550	20.930	16.460	12.130	8.545	6.118
3	11309.72	100.0	6.000	41.270	33.680	28.730	22.650	16.790	11.840	8.514
4	16399.10	145.0	6.000	59.020	48.170	41.120	32.490	24.240	17.280	12.380

*** L A Y E R E D   S Y S T E M   P A R A M E T E R S ***

LAYER NUMBER	TYPE	MODEL	SEED MODULUS (PSI)	POISSON'S RATIO	THICKNESS (INCHES)	KO	DENSITY (LB/CU FT)	NON-LINEAR CHARACTERISTICS K1 (PSI)	K2
1	1	0	200000.00	0.350	5.00	1.00	145.000	0.0	0.000
2	1	1	15000.00	0.350	4.50	1.00	135.000	0.0	0.000
3	1	1	12000.00	0.450	4.50	1.00	130.000	0.0	0.000
4	0	0	7500.00	0.450	INFINITE	1.00	130.000	0.0	0.000

DEFLECTION MATCH TOLERANCE: 0.150 %
MAXIMUM NUMBER OF ITERATIONS TO ACHIEVE TOLERANCE: 10

*** WARNING: MODCOMP2 -- NO CORRESPONDING INPUT DEFLECTION FOR LAYER NUMBER 3. USING INTERPOLATED DEF. FOR CALCULATION. ***

*** I N T E R P O L A T E D   D E F L E C T I O N S ***

LOAD NUMBER	1<RADIUS>1 0.000	2<RADIUS>2 7.415	3<RADIUS>3 14.088	4<RADIUS>4 20.761
1	21.20	17.61	13.40	10.21
2	30.09	25.00	19.07	14.59
3	41.27	34.30	26.20	20.13
4	59.02	49.05	37.52	28.93

*** D E F L E C T I O N   A S S I G N M E N T S ***

LAYER NUMBER 1: ASSIGNED INPUT DEFLECTION NUMBER 1 AT RADIUS = 0.000
LAYER NUMBER 2: ASSIGNED INPUT DEFLECTION NUMBER 2 AT RADIUS = 7.870
LAYER NUMBER 3: ASSIGNED AN INTERPOLATED DEFLECTION AT RADIUS = 14.088

*** SUMMARY OF RESULTS OF MODCOMP II EXECUTION ***

ITERATION NUMBER: 5

LAYER	TYPE	MODEL	COEFF. (R)	COMMENTS
1	UNKNOWN	E (PSI) = 256246.74	--	
2	UNKNOWN	E (PSI) = 16256.90 * S ** 0.177	0.999	S = BULK STRESS DETERMINED OVER THE RANGE: 4.711 < S < 10.081
3	UNKNOWN	E (PSI) = 2420.06 * S ** 0.817	0.999	S = BULK STRESS DETERMINED OVER THE RANGE: 6.014 < S < 8.764
4	KNOWN	E (PSI) = 7500.00	--	

CALCULATED/SUPPLIED DEFLECTION AGREEMENT FOR LOAD NUMBER: 4

RADIUS		CALCULATED DEFLECTION	MEASURED/INTERPOLATED DEFLECTION	PERCENT DIFFERENCE	ASSIGNED TO LAYER
0.000	MEASURED	59.019	59.020	0.00	1
7.870	MEASURED	48.187	48.170	0.04	2
11.810	MEASURED	41.167	41.120	0.12	
14.088	INTERPOLATED	37.570	37.521	0.13	3
17.720	MEASURED	32.541	32.490	0.16	
25.590	MEASURED	24.222	24.240	-0.07	
35.430	MEASURED	17.339	17.280	0.34	
47.240	MEASURED	12.354	12.380	-0.21	

ROOT MEAN SQUARE ERROR = 0.171 PERCENT
(MEASURED DEFLECTIONS ONLY)

ELAPSED TIME: 3028.12 SEC.

TABLE OF MODULI

MODULI OF SYSTEM FOR LOAD LEVEL 4

LAYER	1 <RADIUS> 1	2 <RADIUS> 2	3 <RADIUS> 3	4 <RADIUS> 4	5 <RADIUS> 5	6 <RADIUS> 6	7 <RADIUS> 7
1	256246.74	256246.74	256246.74	256246.74	256246.74	256246.74	256246.74
2	25473.90	24489.83	23807.41	23017.57	22111.08	20984.49	19754.78
3	14394.62	14455.92	14395.40	14014.16	12621.65	9930.48	7364.70
4	7500.00	7500.00	7500.00	7500.00	7500.00	7500.00	7500.00

COMPUTATION TERMINATED BECAUSE TOLERANCE WAS SATISFIED AFTER 5 ITERATIONS.

APPENDIX B

OVERLAY DESIGN WITH AASHTO NDT METHOD 2: A COMPUTER APPROACH

1.0 INTRODUCTION

1.1 Background

In the design of overlays for flexible pavements, the determination of the structural capacity of the existing pavement is a vital factor. With this value, together with future traffic data and other design factors, the overlay thickness may be computed.

The 1986 AASHTO Guide (1) presents two nondestructive methods to determine the structural capacity of the existing pavement (SN_{xeff}). NDT Method 1 uses the deflection basin data from the NDT testing device to backcalculate the structural capacity of the existing pavement. NDT Method 2 uses the measured maximum deflection to determine SN_{xeff}. Although this method does not require backcalculation procedures such as ELSDEF (3), it involves a trial-and-error approach in computing SN_{xeff}.

1.2 Purpose

The purpose of this appendix is to present a calculation procedure for NDT Method 2 using computerized approach. Two major sections are included in this appendix. Section 2.0 presents the background information on overlay design for flexible pavements with emphasis on NDT Method 2. Section 3.0 describes the implementation of the computer approach. The appendices include a sample input data file and its corresponding output, a users guide for the computer program (OVERLAY), and the program listing.

2.0 BACKGROUND OF FLEXIBLE OVERLAY DESIGN

2.1 Overlay Design Concepts

The proposed AASHTO overlay design method (1) is based on the serviceability-traffic and structural capacity-traffic relationships developed at the AASHTO Road Test. The basic design concept is illustrated in Figure 2.1, where the following definitions apply:

P_o = the initial serviceability of the original pavement,

P_{t1} = terminal serviceability of the existing pavement immediately prior to the overlay,

P_{t2} = terminal serviceability desired with the overlaid pavement after the overlay traffic has been applied, and

P_f = the ultimate failure serviceability corresponding to a completely damaged pavement.

In the proposed AASHTO method, the P_f value has been set as 2.0, while P_{t1} and P_{t2} are input by the designer. The designation "x" is the cumulative equivalent 18 KSAL repetitions up to the overlay and "y" is the cumulative equivalent 18 KSAL repetitions anticipated on the future overlaid pavement. The N_{fx} represents the total number of repetitions of the existing pavement prior to the overlay and N_{fy} represents the number of repetitions for the overlaid pavement to reach failure ($P_f = 2.0$).

The structural capacity of a pavement system is proportional to its serviceability, as shown in Figure 2.1. The initial structural capacity is noted by SC_o which gradually reduces to an "effective capacity" (SC_{xeff}) prior to the overlay. The initial structural capacity SC_o and effective capacity SC_{xeff} are related by a condition factor "C_x" as follows:

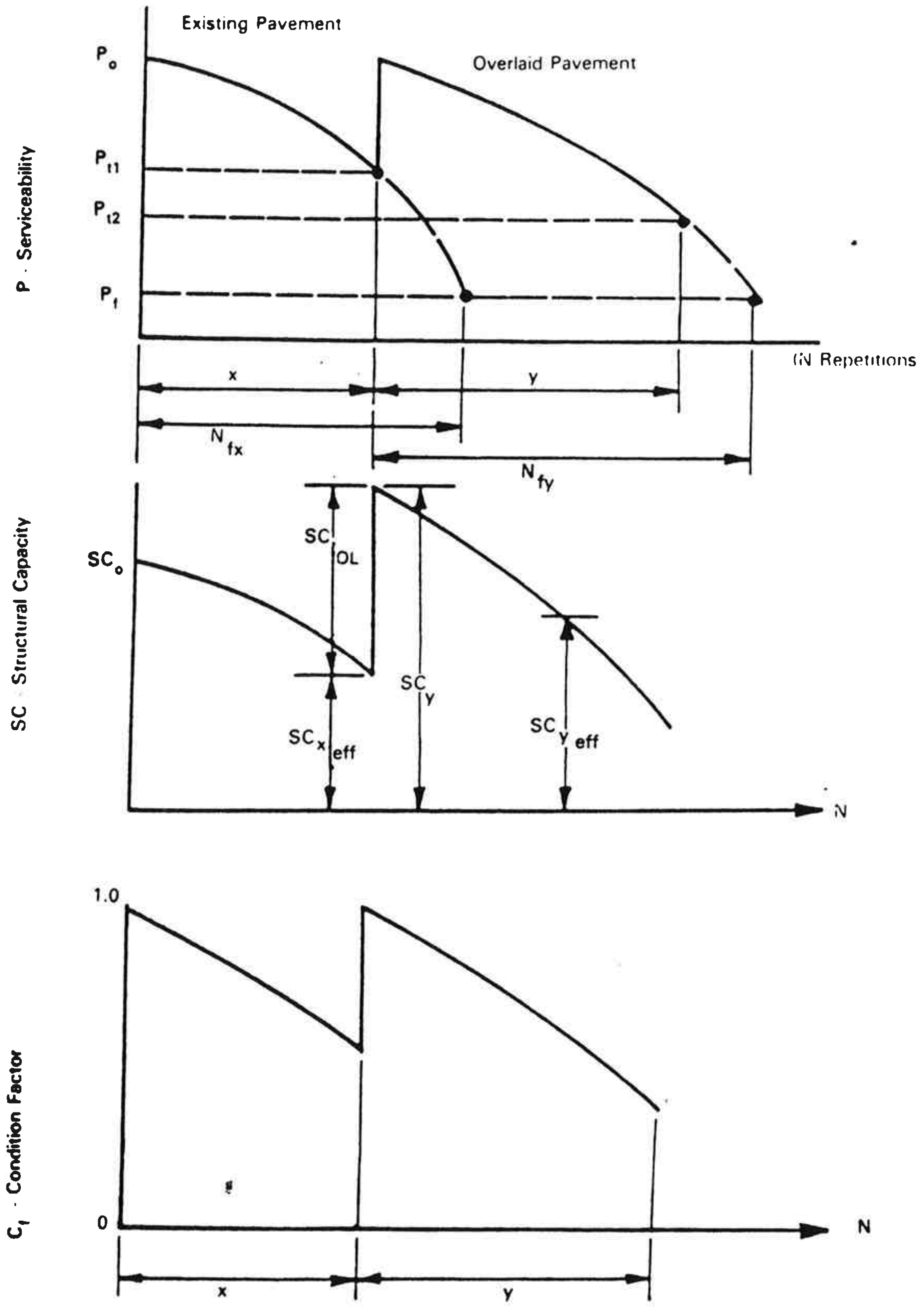


Figure 2.1. Relationship Between Serviceability-Capacity Condition Factor and Traffic (1).

$$SC_{xeff} = C_x SC_o \tag{2-1}$$

The structural capacity required in an overlay is noted by SC_{OL}. This capacity can be represented mathematically by the following form:

$$SC_{OL}^n = SC_y^n - F_{RL}(SC_{xeff})^n \tag{2-2}$$

where:

SC_y = the total structural capacity required to support the overlay traffic over existing subgrade conditions,

SC_{xeff} = effective structural capacity of existing pavement,

F_{RL} = the remaining life factor accounting for damage in the existing pavement and the desired degree of damage at the end of the overlay traffic (≤ 1.0),

SC_{OL} = structural capacity required in overlay thickness for overlay traffic, and

n = constant dependent upon the type of pavement system used (rigid versus flexible).

The structural capacity (SC) represents a strength parameter for all types of pavement. For flexible pavements, the structural number (SN) is used in place of SC.

2.2 AASHTO Overlay Design Procedures

Several steps are involved in the AASHTO overlay design. These are discussed below:

2.2.1 Data Collection

2.2.1.1. Historical Data. If accurate data are not available, NDT deflection testing should be conducted. The testing should normally be done in the outer wheel path of the lane adjacent to the shoulder with deflection taken at equal intervals of 300 to 500 feet for a construction unit, approximately 0.5 mile in length.

If accurate data are available, NDT deflection testing may be conducted to verify or modify the preliminary units selected. Ten to 15 test points are randomly selected within each unit.

2.2.1.2 Traffic Data. Traffic data consists of two components: 1) the cumulative equivalent 18 KSAL repetitions up to the overlay, and 2) the cumulative equivalent 18 KSAL repetitions anticipated on the future overlaid pavement. The historical traffic data are helpful in determining the remaining life of the existing pavement. These data are not required if the condition factor "C_x" can be found using the NDT approach. However, the anticipated future repetitions data are essential in determining the SN_y value.

2.2.2 Materials and Environmental Study

The primary concern regarding materials properties is the determination of layer modulus. The elastic modulus can be determined from destructive testing or by backcalculation. The latter technique uses results of NDT deflection basin measurements and with a multilayer elastic computer program, such as ELSDEF (3), to solve for the layer moduli.

Two NDT methods have been proposed in the AASHTO Guide. NDT Method 1 determines the modulus for each layer through backcalculation using the NDT deflection basin. These elastic moduli are then evaluated to obtain the structural layer coefficients (a_i) and subsequently the SN_{xeff}.

NDT Method 2 does not require backcalculation. It requires a knowledge of subgrade modulus and maximum deflection (temperature adjusted) to determine the effective structural capacity. This subgrade modulus can be estimated directly from the AASHTO equation,

$$E_{sg} = (PS_f)/(d_r r) \tag{2-3}$$

where:

E_{sg} = in situ modulus of elasticity of the subgrade, psi;

P = dynamic load of the NDT device, lbs;

d_r = the measured NDT deflection at a radial distance of r from the NDT plate load center, mils;

r = radial distance from plate load center to point of d_r measurement, inches; and

S_f = the subgrade modulus prediction factor.

For a given nondestructive test, the load (P), outer deflection (d_r), and radial distance (r), are known values. The S_f factor, which can be determined from Figure 2.2, is a function of Poisson's ratio (u) and radial offset ratio r/a_e. As can be seen in Figure 2.2, the S_f values are constants for $r/a_e \geq 1.0$. The a_e is the effective radius of the subgrade stress zone which can be determined by the following:

$$a_e = a_c/F_b \tag{2-4}$$

where:

a_c = the radius of the NDT load plate, and

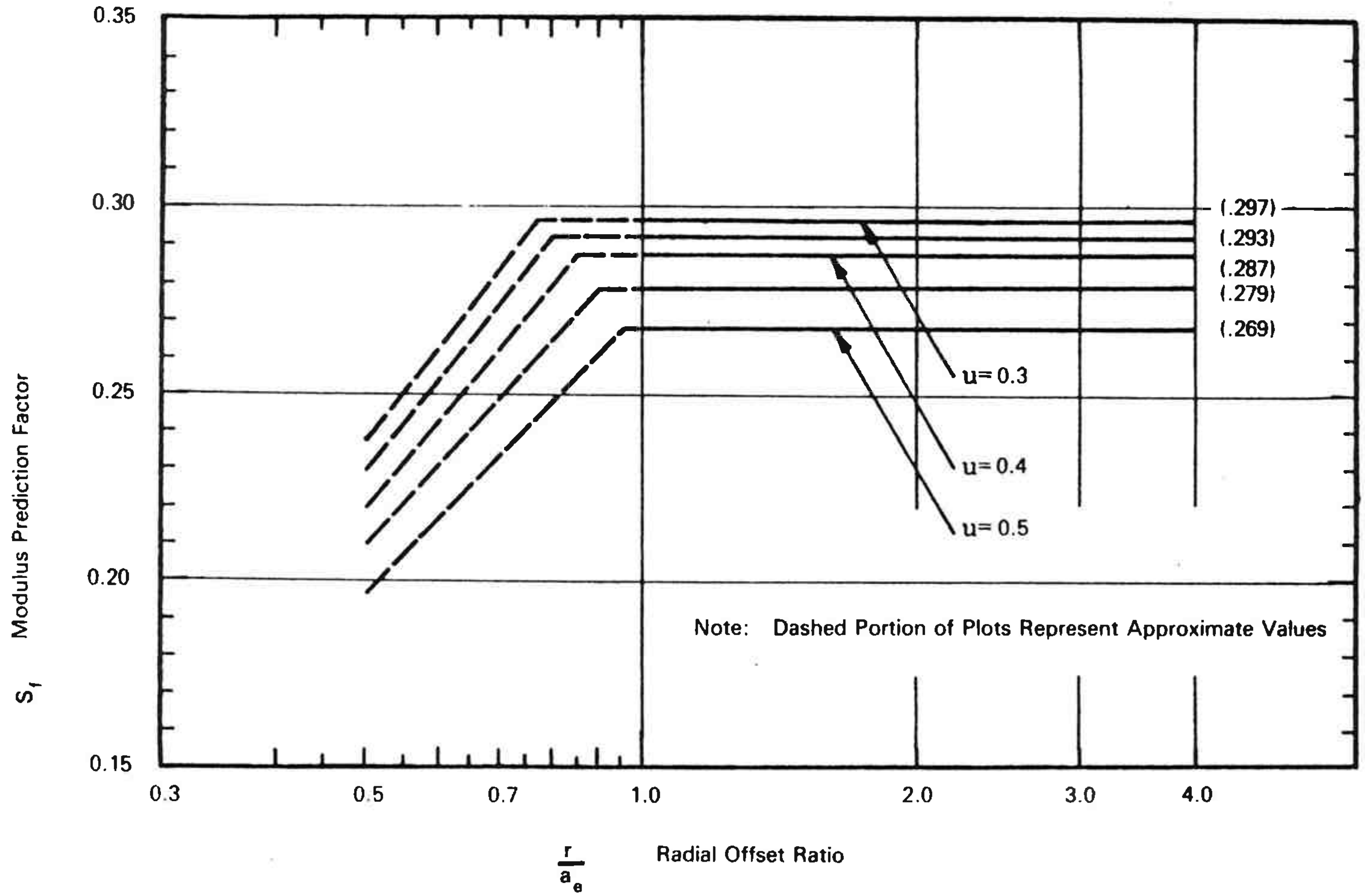


Figure 2.2. Subgrade Modulus Prediction Factor Versus Radial Offset Ratio.

F_b = the deflection factor which is a function of the subgrade Poisson's ratio and the pavement's effective thickness plate radius ratio (H_e/a_c ratio).

H_e, the effective pavement thickness is computed from

$$H_e = 0.9 \sum_{i=1} h_i \; [[E_i(1-u_{sg}^2)]/[E_{sg}(1-u_i^2)]]^{1/3} \qquad (2\text{-}5)$$

where:

h_i = the thickness of layer i (in.),

E_i = the elastic modulus of layer i (psi), and

u_i = Poisson's ratio of layer i.

As can be seen in the above equation, in order to determine the a_e value, assumed values of the individual pavement layer properties (E_i, u_i) are necessary. If $r/a_e < 1.0$, then the S_f factor is a function of r/a_e. After the value for S_f is determined, the subgrade modulus can be computed. This modulus is then used to determine the existing pavement strength SN_{xeff} as described in the next section.

2.2.3 Effective Structural Capacity Analysis (SN_{xeff})

The effective structural capacity (SN_{xeff}) can be determined by either NDT Method 1 or Method 2. With NDT Method 1, the deflection basin data are used to backcalculate layer moduli which are then used to determine the layer coefficient a_i. SN_{xeff} is then computed using the relationship:

$$SN_{xeff} = \sum a_i \, h_i \qquad (2\text{-}6)$$

With NDT Method 2, the maximum measured deflection is utilized to determine SN_{xeff} as shown below:

$$d_o = \left[\frac{2\ p\ (.0043 \cdot h_t)^3}{3.1416\ a_c SN^3}\right] \left[1 + F_b\left[\frac{SN^3(1 - \mu_{sg}^2)}{E_{sg}\ (.0043 \cdot h_t)^3} - 1\right]\right] \qquad (2\text{-}7)$$

where:

d_o	=	deflection value
p	=	NDT device load (in pounds)
h_t	=	total layer thickness (above subgrade)
μ_{sg}	=	subgrade Poisson ratio
E_{sg}	=	subgrade modulus
SN	=	SN_{xeff}
F_b	=	Boussinesq one-layer deflection factor, and is given by

$$F_b = \left[\left[1 + \left[\frac{h_e}{a_c}\right]^2\right]^{.5} - \frac{h_e}{a_c}\right] \left[1 + \frac{(h_e/a_c)}{2(1 - \mu_{sg})[1 + (h_e/a_c)^2]^{.5}}\right] \qquad (2\text{-}8)$$

h_e = equivalent transformed thickness, and is given by

$$h_e = 0.9\ h_t \left[\frac{E_e\ (1 - \mu_{sg}^2)}{E_{sg}\ (1 - \mu_e^2)}\right]^{1/3} \qquad (2\text{-}9a)$$

μ_e can be selected to have any value so if it is assumed that μ_e is equal to μ_{sg}, then

$$E_e = \left[\frac{E_e}{E_{sg}}\right]^{1/3} \qquad (2\text{-}9b)$$

E_e = equivalent pavement modulus, and is given by:

$$E_e = \left[\frac{SN}{0.0043 \cdot h_t}\right]^3 (1 - \mu_{sg}^2) \qquad (2\text{-}10)$$

The SN_{xeff} value for a particular pavement structure can be determined by a trial-and-error process. This is done by assuming an SN_{xeff} and computing the deflection d_o. If the calculated d_o does not agree with the maximum measured deflection, a new SN_{xeff} is assigned until calculated deflection matches the maximum measured deflection.

2.2.4 Future Structural Capacity Analysis (SN_y)

SN_y is the capacity required to carry future traffic repetitions in the overlay period to a terminal serviceability P_{t2} which is selected by the designer. The following equation is utilized to determine the SN_y.

$$\log_{10}W_{18} = Z_R \cdot S_o + 9.35 \cdot \log_{10}(SN+1) - 0.20 + \frac{\log_{10}\left[\frac{\Delta PSI}{4.2-1.5}\right]}{0.40 + \frac{1094}{(SN+1)^{5.19}}} + 2.32 \cdot \log_{10}M_R - 8.07 \qquad (2\text{-}11)$$

where:

W_{18} = predicted number of 18-kip equivalent single axle load repetitions;

Z_R = standard normal deviate;

S_o = combined standard error of the traffic prediction and performance prediction;

ΔPSI = difference between the initial design serviceability index, P_o, and the design terminal serviceability index, P_t; and

M_R = subgrade resilient modulus (PSI).

2.2.5 Remaining Life Factor Determination (F_{RL})

The remaining life factor, F_{RL}, is an adjustment factor applied to the effective capacity parameter (SN_{xeff}) to reflect a more realistic assessment of the weighted effective capacity during the overlay period. This factor is dependent upon the remaining life value of the existing pavement prior to overlay (R_{LX}) and the remaining life of the overlaid pavement after the design traffic (and subsequent serviceability) has been reached (R_{LY}).

The remaining life of the existing pavement prior to overlay is a difficult parameter to accurately determine, but an approximate R_{LX} value can be estimated using five possible methods as indicated in the AASHTO Guide: NDT approach, traffic approach, time approach, serviceability approach, and visual condition survey approach. While each of these approaches is theoretically equivalent, rarely will all approaches yield the same value. In this study, only the NDT approach is considered. This method does not require historical traffic data, which are often difficult to obtain. The existing pavement condition is related by a condition factor "C_x" as follows:

$$SN_{xeff} = C_x \, SN_o \quad \text{or} \quad C_x = SN_{xeff}/SN_o \qquad (2\text{-}12)$$

where SN_o is the initial structural capacity. Once the C_x value is determined, the remaining life R_{LX} can be estimated from Figure 2.3.

The remaining life of an overlaid pavement R_{LY} can be determined using the following equation:

$$R_{LY} = (N_{fy} - Y)/N_{fy} \qquad (2\text{-}13)$$

where:

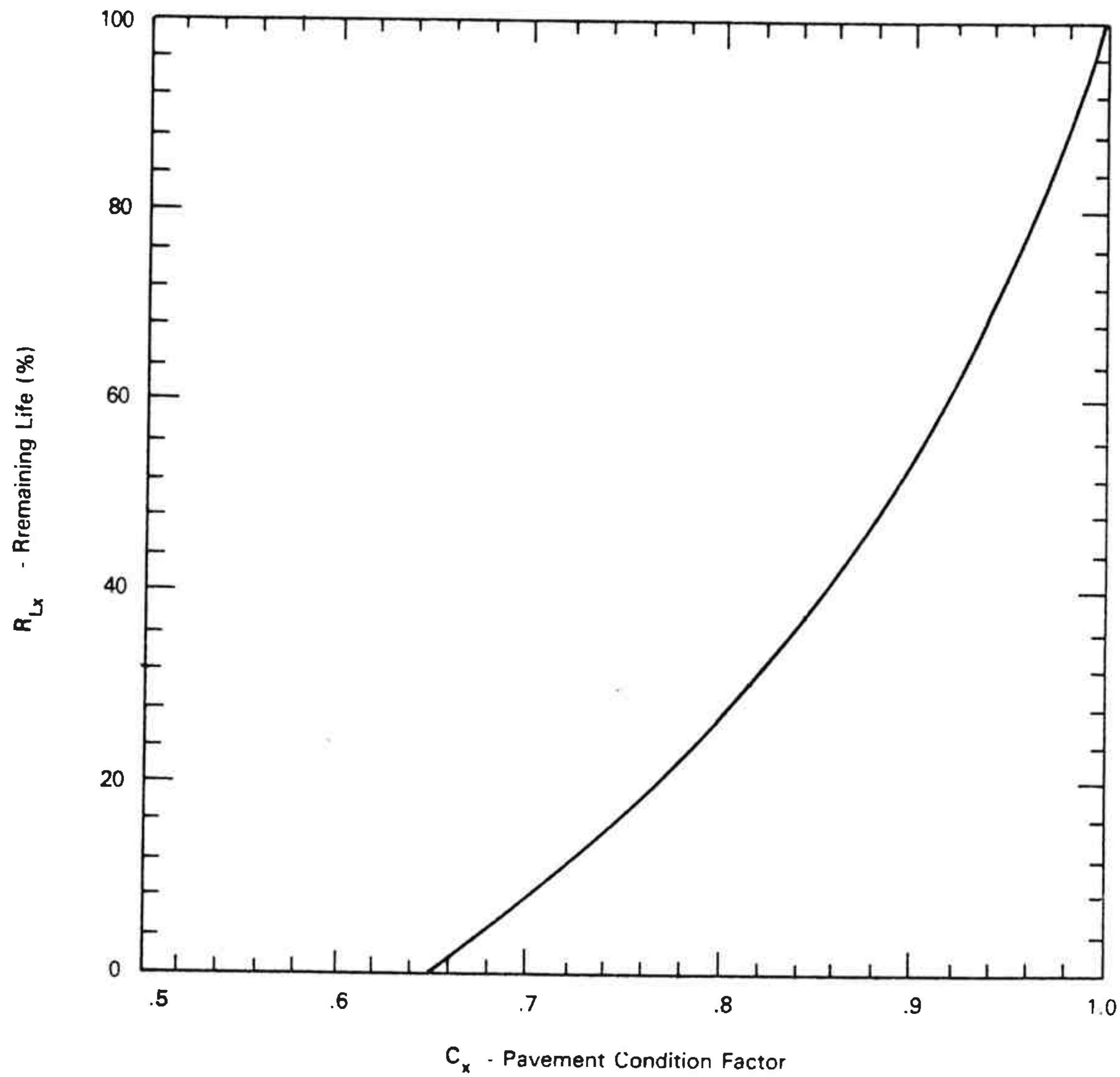


Figure 2.3. Remaining Life Estimate Predicted from Pavement Condition Factor (1).

N_{fy} = the ultimate number of repetitions for overlaid pavement to failure (p_f = 2.0), and

Y = the number of repetitions for overlaid pavement to reach P_{t2}.

Knowing both R_{LX} and R_{LY}, the remaining life factor F_{RL} can be estimated from Figure 2.4.

2.2.6 Determine Overlay Thickness

For a flexible overlay over an existing flexible pavement, the required thickness can be found from,

$$h_{oL} = SN_{oL}/a_{oL} = (SN_y - F_{RL}SN_{xeff})/a_{oL} \quad (2\text{-}14)$$

where:

a_{oL} = the structural layer coefficient of the overlay material, and

SN_{oL} = structural capacity required for overlay.

If the SN_{oL} is less than or equal to zero, no overlay is required.

2.3 Summary

This section summarized the AASHTO overlay design concepts and design procedures. It can be seen that designing an overlay pavement requires a considerable effort to find a solution. With NDT Method 1, backcalculation is necessary to determine the elastic moduli. With NDT Method 2, trial-and-error computation is required to find the existing pavement strength. The remainder of this document presents overlay design using NDT Method 2.

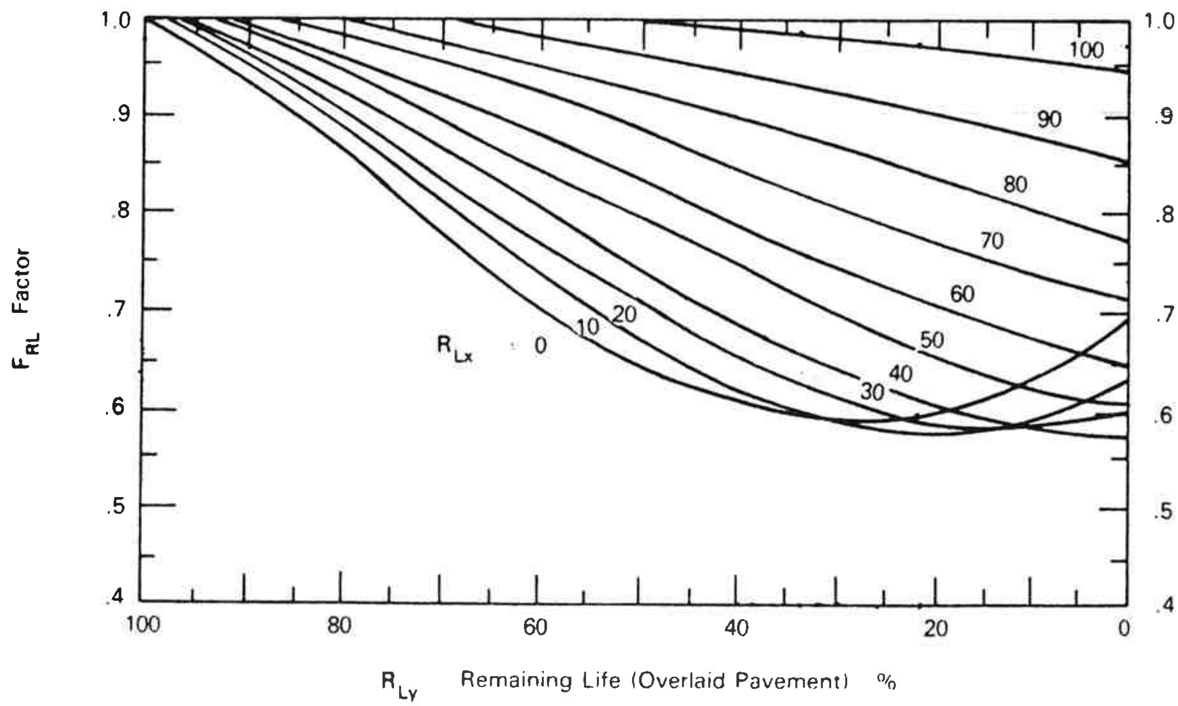


Figure 2.4. Remaining Life Factor as a Function of Remaining Life of Existing and Overlaid Pavements (1).

3.0 DESCRIPTION OF NDT METHOD 2 COMPUTER PROGRAM

This section presents a computerized approach for a flexible overlay over an existing flexible pavement using AASHTO NDT Method 2. The significant contribution of this program (OVERLAY) is to computerize the procedure discussed in the previous section so that the overlay design can be accomplished easily and in a very short time.

3.1 Flow Chart of the Program

Figure 3.1 shows a flow chart of the program. As can be seen, the chart basically represents the steps described in Section 2.0.

3.2 Design Input Data

The program requires the following data:

1. number of layers of pavement system,
2. thickness of each layer,
3. modulus of each layer,
4. Poisson's ratio of each layer,
5. layer coefficients of the original pavement,
6. deflection data,
7. load and radius of NDT testing device,
8. desire serviceability loss,
9. anticipated future traffic repetitions, and
10. reliability level and standard deviation.

The layer thickness and layer coefficients data are used to determine the initial pavement strength (SN_o) and structural number (SN_{xeff}) of the existing pavement.

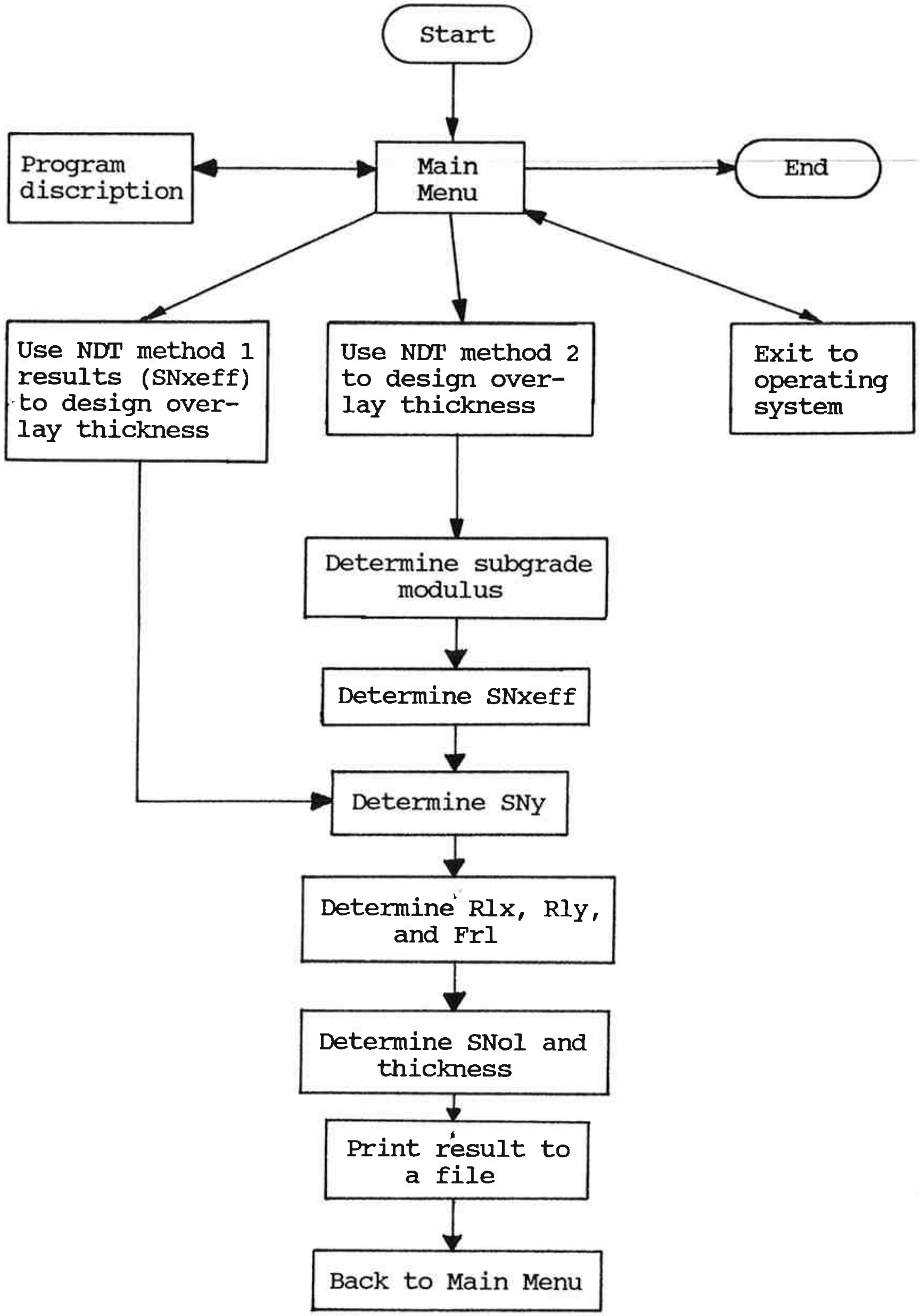


Figure 3.1. Flow Chart of the Program.

If an overlay is required, the program utilizes the same layer coefficient used in the initial pavement design to determine the thickness of the overlay.

The deflection data, together with the load and radius of the NDT testing device, are used to determine the subgrade modulus and, subsequently, SN_{xeff}. The distance to the outermost sensor of the NDT device and its corresponding deflection reading are required to find the subgrade modulus while the maximum deflection reading is used to compute the SN_{xeff}.

The desired serviceability loss and anticipated future traffic repetitions data are utilized to determine the SN_y value for the overlay; knowing SN_y, the remaining life factor (F_{RL}), the overlay thickness can be determined.

The reliability level and standard deviation allow the designer to take into account the reliability of his overlay in handling the design period traffic with serviceability $P \geq P_t$. For example, an overlay design with 95% reliability level would provide a thicker overlay than with 70% reliability level, other conditions being the same.

3.3 Program Output

The output of the program includes the following:

1. subgrade modulus,
2. location using milepost
3. calculated deflection
4. SN_{xeff}, SN_o, SN_y, and SN_{oL}
5. R_{LX}, R_{LY}, and F_{RL}, and
6. overlay thickness required.

The subgrade modulus is a calculated value using the deflection data. The calculated deflections indicate how close they are to the measured deflections in the process of determining the SN_{xeff} value. The SN_{xeff} indicates the structural capacity of the existing pavement. The SN_o is the initial structural capacity of the pavement. The SN_y is the structural capacity required for anticipated future traffic. The SN_{oL} is the structural number required for overlay. The R_{LX}, R_{LY}, and F_{RL} are the percentage of the remaining life for the existing pavement, overlay, and future remaining life factor, respectively. The final value is the overlay thickness required for a particular test site.

3.4 User Information

The flexible overlay pavement design program (OVERLAY) is written in Quick BASIC (4). Unlike BASICA or GWBASIC, which are interpretive languages, Quick BASIC is a complier. This makes the execution speed much faster than with interpretive BASIC. The computation of an overlay design involves iterations and trial and error; a fast execution would be a great benefit to the user.

The program has two options. Option 1 allows the user to design an overlay using the results (SN_{xeff}) obtained from NDT Method 1. Option 2 allows the user to design a flexible overlay using NDT Method 2. A full screen editor for the NDT Method 2 is provided. The deflection test data generated by the Falling Weight Deflectometer (FWD) or Dynaflect and recorded on a floppy disk can be read directly by the program. Deflection data for a single test location can also be analyzed with this program.

The program is straightforward and user-friendly. On IBM AT computers, one dataset with deflection measurements at five locations may take about 10 seconds. During execution, a small window is displayed on the monitor which shows the location of the deflection data that the computer is processing.

The OVERLAY program can be run on any IBM compatible microcomputer with minimum memory of 256 KB. There is no installation procedure required. To run the program, simply type in OVERLAY followed by a carriage return. A menu screen will then be displayed; the instructions are self-explanatory. A guideline on the use of the program is provided in Appendix BB.

3.5 Example Application

This section presents an example application of the overlay design program using the FWD. Dynaflect data may also be used. The design data are given below:

1) Existing pavement:

   Surface: 6 inches asphalt concrete

   Base: 12 inches granular base

   Subgrade: infinite sandy clay

2) Material properties:

   Surface: estimated modulus 200,000 psi, Poisson's ratio .35

   Base: estimated modulus 15,000 psi, Poisson's ratio .40

   Subgrade: estimated modulus 5,000 psi, Poisson's ratio .45

3) Initial design layer coefficients:

   Surface: 0.40

   Base: 0.07

4) Traffic data

   Repetitions to data (x=?) unknown

   Future overlay design repetitions (y $=2\times10^6$ 18 KSAL)

5) NDT device:

Equipment: FWD device

Dynamic load: 9,000 lbs

Load plate: 5.91-inch plate radius

6) Deflection basin data:

Offset (in.)	Location 1	2	3	4	5
0	31.73	26.34	36.57	43.82	28.77
12	21.03	18.63	22.65	27.36	19.16
24	10.70	10.14	10.39	11.18	9.36
36	4.56	4.73	4.47	4.93	4.18

Figure 3.2 shows the deflection measured along the test locations.

7) Others:

Design serviceability loss: 2.0

Reliability level: 90%

Standard deviation: 0.35

The format of this input data file and its output is presented in Appendix BA.

The results of the design data are illustrated in Figures 3.2 to 3.6.

Figure 3 shows the calculated subgrade modulus along the test locations. Figure 4 shows initial pavement structural number (SN_o), existing pavement structural capacity (SN_{xeff}), and structural number required for an overlay (SN_{ol}). The required overlay thickness for each test location is presented in Figure 5.

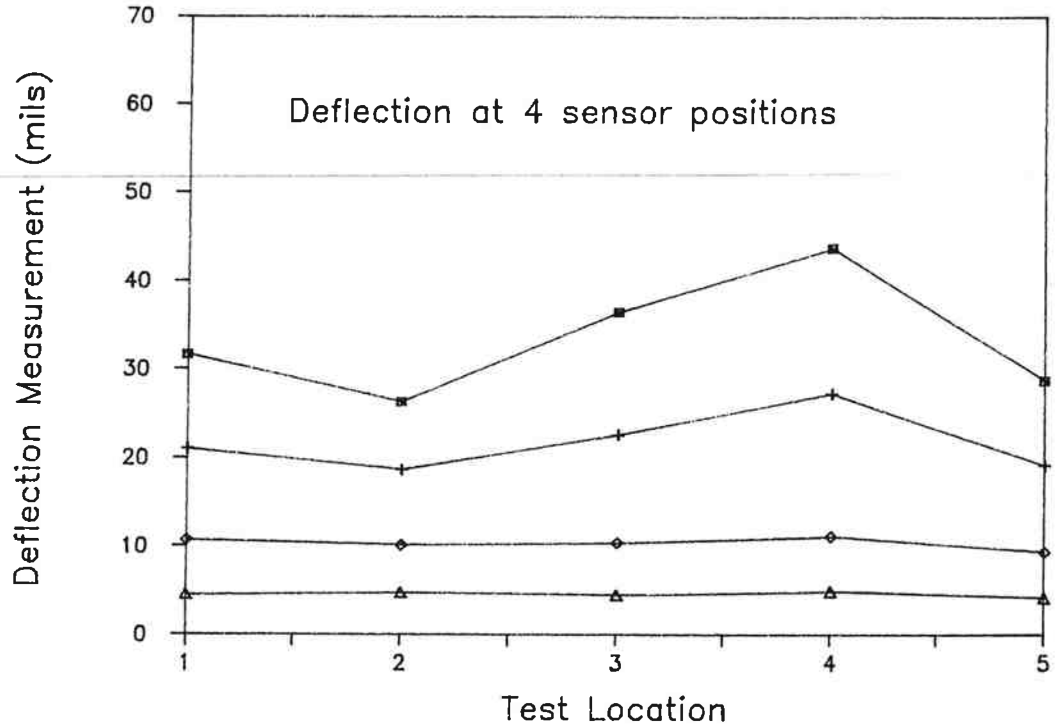


Figure 3.2. Deflection Readings Along Test Locations.

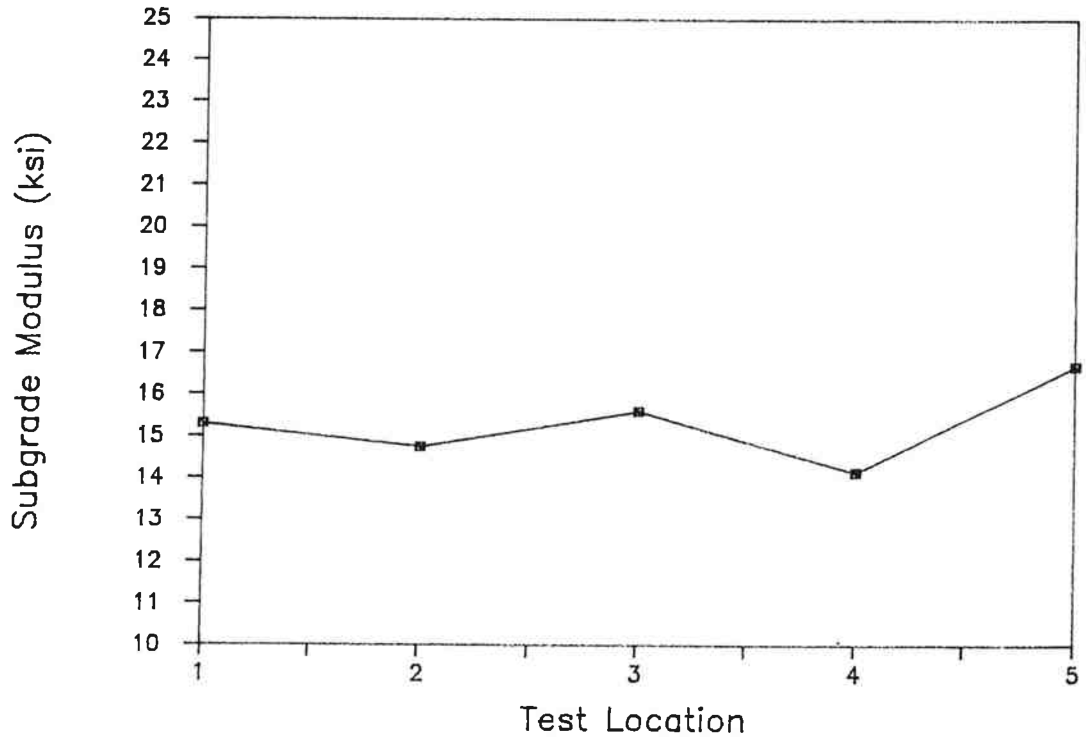


Figure 3.3. Subgrade Modulus Along Test Locations.

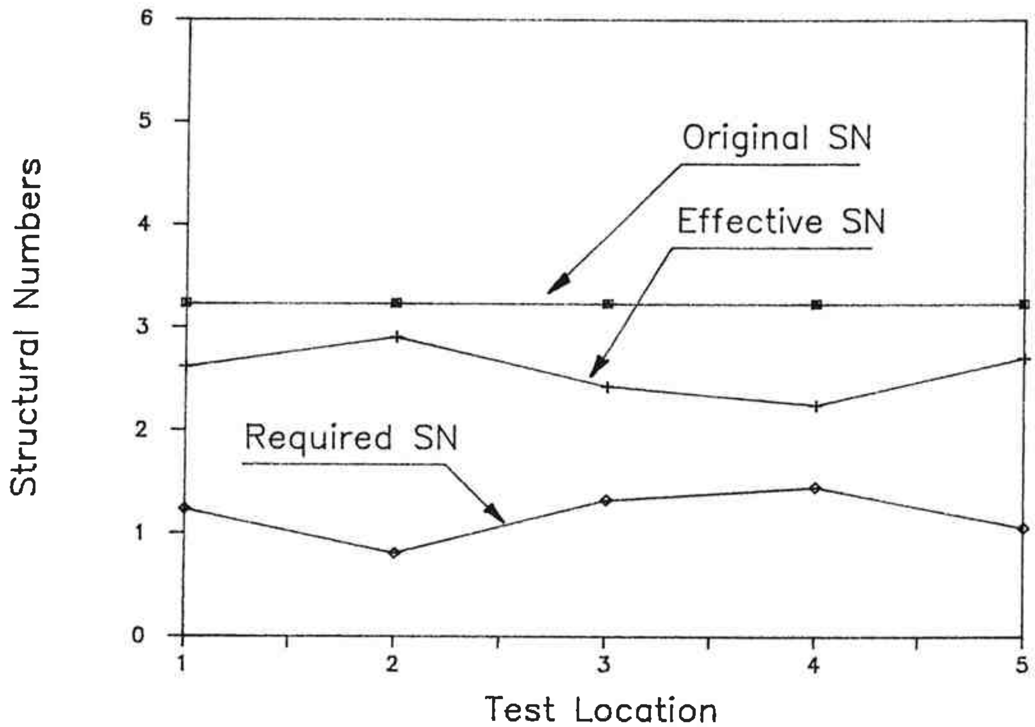


Figure 3.4. Structural Capacities Along Test Locations.

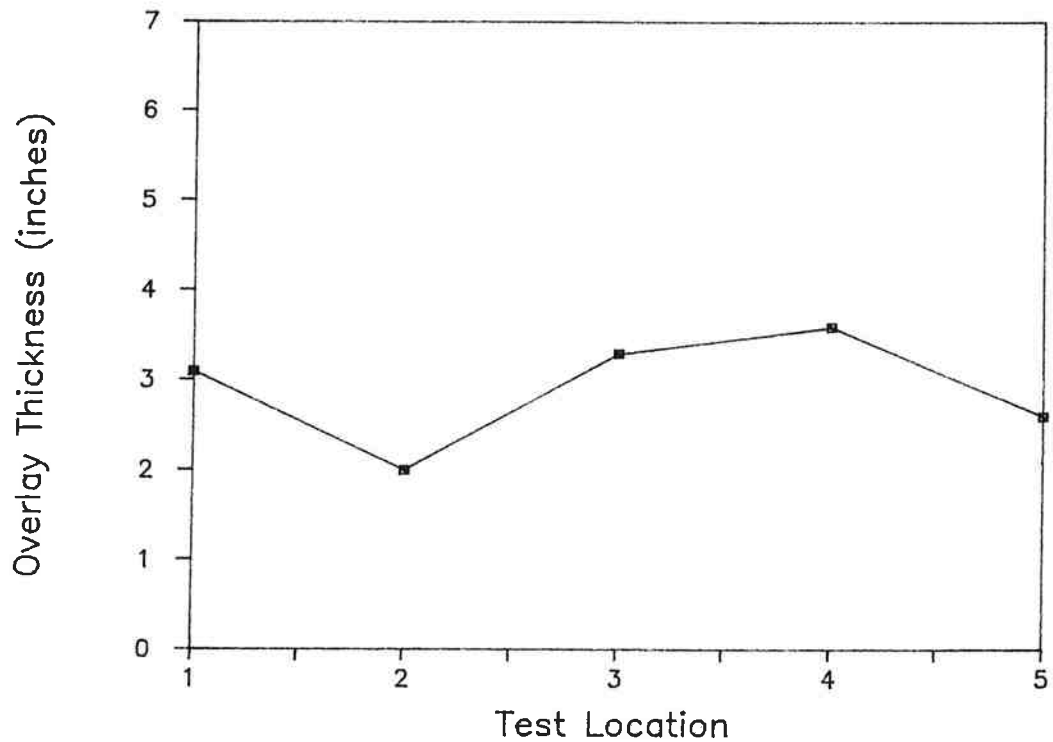


Figure 3.5. Required Overlay Thickness Along Test Locations.

4.0 CONCLUSIONS AND RECOMMENDATIONS

4.1 Conclusions

This appendix presents a computerized approach of designing a flexible overlay with NDT Method 2. The use of this program permits the flexible overlay design to be accomplished easily and in a few seconds. This approach does not require the user to have any knowledge of backcalculation. Therefore, the overlay design procedure is greatly simplified. The theoretical background behind this method is also described.

4.2 Recommendations

This program is developed to design a flexible overlay over existing flexible pavement. It can also be used to develop relationships among different variables, such as maximum deflection versus SN_{xeff} as presented in Appendix PP of the AASHTO 1986 Guide (1). Sensitivity analysis with different parameters can also be conducted with this program.

5.0 REFERENCES

1. American Association of State Highway and Transportation Officials, "AASHTO Guide for Design of Pavement Structures 1986."

2. Eichhorn, C.L. et al., "Development of an Improved Overlay Design Procedure for Oregon," Transportation Research Report: TRI-87-33, Oregon State University, January 1987.

3. Lytton, R.L., F.L. Roberts, and S. Stoffels, "Determination of Asphaltic Concrete Pavement Structural Properties by Nondestructive Testing," final report, Texas Transportation Institute, Texas, April 1986.

4. "Quick BASIC," Microsoft, 1987.

APPENDIX BA

DATA FILES

BA.1 Data File Format

Line No.	Data
Line 1:	FWD
Line 2:	IndividualTest
Line 3:	3
Line 4:	6.0, 200000, 0.35, 0.40
Line 5:	12.0, 15000, 0.40, 0.07
Line 6:	5000, 0.45
Line 7:	4, 0.00, 12.00, 24.00, 36.00
Line 8:	5.91, 2.00, 2000000, 90.0, 0.35
Line 9:	1 , 9000 , 31.73 , 21.08 , 10.7 , 4.56
Line 10:	2 , 9000 , 26.34 , 18.63 , 10.14, 4.73
Line 11:	3 , 9000 , 36.57 , 22.65 , 10.39, 4.47
Line 12:	4 , 9000 , 43.82 , 27.36 , 11.18, 4.93
Line 13:	5 , 9000 , 28.77 , 19.16 , 9.36 , 4.18

	Interpretation
Line 1:	NDT device name
Line 2:	Data type
Line 3:	Number of layers
Line 4:	Thickness, Modulus, Poisson's ratio, Layer coefficient (Layer 1)
Line 5:	Thickness, Modulus, Poisson's ratio, Layer coefficient (Layer 2)
Line 6:	Subgrade modulus, Poisson's ratio (Layer 3)
Line 7:	Number of deflections, Sensor locations
Line 8:	NDT radius, Design serviceability loss, Future traffic repetitions, Reliability, Standard deviation
Line 9:	Location 1, NDT load, Deflection readings at corresponding sensor locations
Line 10:	Location 2, NDT load, Deflection readings at corresponding sensor locations
Line 11:	Location 3, NDT load, Deflection readings at corresponding sensor locations
Line 12:	Location 4, NDT load, Deflection readings at corresponding sensor locations
Line 13:	Location 5, NDT load, Deflection readings at corresponding sensor locations

BA.2 Output Format

Project: ndt2pp

Location	Subgrade Modulus	Deflect (mils)	SN_o	SN_{xeff}	SN_y	SN_{ol}	Thickness (in.)	R_{Lx} %	R_{Ly} %	F_{rl} %
1	15307	31.73	3.24	2.62	2.77	1.24	3.1	0.28	0.06	0.58
2	14757	26.34	3.24	2.81	2.81	0.81	2.0	0.54	0.06	0.69
3	15615	36.57	3.24	2.75	2.75	1.33	3.3	0.16	0.06	0.58
4	14158	43.82	3.24	2.85	2.85	1.46	3.6	0.06	0.07	0.62
5	16699	28.77	3.24	2.68	2.68	1.06	2.6	0.36	0.06	0.60

APPENDIX BB

USER GUIDE FOR THE OVERLAY PROGRAM

INTRODUCTION

OVERLAY is a computer program developed for flexible overlay design with nondestructive method. The program has two functions. Function 1 allows the user to design an overlay with the result determined from nondestructive Method 1 (NDT Method 1). Function 2 allows the user to design an overlay with NDT Method 2. A theoretical description of these two methods can be found in Appendices A and B.

PROGRAM DESCRIPTION AND EXECUTION

OVERLAY is an executable program. This allows a user to run the program in the DOS environment. To execute the program, simply type in OVERLAY followed by a carriage return. A menu screen as shown in Fig. BB1 will be displayed. The six options which can be selected are described below. The user may use up or down arrow keys to select the desired option and press carriage return to activate it.

Selection 1 provides a program description in which data required to run the program are described. Some useful information, such as the selection of modulus range, Poisson's ratio, and layer coefficient, is presented.

Selection 2 designs an overlay with the results obtained from the NDT Method 1 analysis. The process of entering data is interactive. The input data include the following:

1. the existing pavement structural capacity (SN_{xeff}),
2. the initial or original design structural number (SN_o),
3. layer coefficient of the asphalt concrete,
4. in situ subgrade modulus,
5. estimated future total 18 kips ESAL applications,

Program Main Menu

Program Description
Overlay Design with NDT Method 1
Overlay Design with NDT Method 2
Print Result
Operating System
Quit

Figure BB1. OVERLAY Program Main Menu.

Menu for NDT Method 2

Create a Data File
Edit a Data File
Analyze a Data File

Figure BB2. Submenu for NDT Method 2.

6. design serviceability loss,

7. reliability level, and

8. overall standard deviation.

The output will be saved in an ASCII text file. The user will be asked to specify a name to save the output results. If the output file name is not given, the results will be stored in a file named NDT1.OUT.

Selection 3 designs an overlay with NDT Method 2. By selecting this option, a submenu as shown in Fig. BB2 will be displayed. This submenu includes three choices: Choice 1 allows the user to create a data file for analysis; Choice 2 allows the user to edit an existing data file; Choice 3 analyzes a file created beforehand. A file must be created before choice 3 can be selected.

Choice 1: This choice creates a data file for analysis. By selecting this choice, an input data screen as shown in Fig. BB3 will be displayed. The required inputs include file name to store the data, number of pavement layers, layer thickness, estimated modulus, Poisson's ratio, layer coefficient, estimated future 18 KSAL applications, design serviceability loss, reliability level, and standard deviation.

The deflection data are those generated either by a FWD or Dynaflect testing device. The program is designed to read the deflection data directly from a floppy disk with data recorded by FWD or Dynaflect. The program also allows the user to analyze a single testing location. Other inputs include NDT load force, loading plate radius, and sensor locations. If the filename and number of layers are not specified, the program will not save anything and simply returns to the submenu. Once the required

NDT METHOD 2 DATA INPUT/EDIT

Filename:

For subgrade, both thickness and layer coefficient are not required

Number of Layers: 0

Layer No.	Thick (in.)	Assumed Modulus	Poisson Ratio	Layer Coefficient
1 .	0.0	0	0.00	0.00
2 .	0.0	0	0.00	0.00
3 .	0.0	0	0.00	0.00
4 .	0.0	0	0.00	0.00
5 .	0.0	0	0.00	0.00
6 .	0.0	0	0.00	0.00

Est. Future Total 18Kips ESAL Applications:	0
Design Serviceability Loss (0.05-3.0) :	2.00
Reliability Level (ranges 50-100) :	90.0
Overall Standard Deviation (ranges .2-.6) :	.40

PRESS Esc TO EXIT/SAVE DATA

Figure BB3. NDT Method 2 Data Input/Edit Screen.

inputs are filled up on the screen, the user may press Esc key to save the data to a disk under a given filename.

Choice 2: This choice allows the user to edit a file created with choice 1. With this choice, the data are retrieved and displayed on the input screen (Fig. BB3). The deflection data read from either FWD or Dynaflect floppy disk are not intended to be edited. However, the deflection data for a single testing location may be changed by entering new information.

Choice 3: This choice analyzes a data file generated previously. The user needs to specify a file name to be analyzed and a file name in which the output will be stored. If no file name is given, the output will be sent to a file named "NDT2.OUT". During execution, a message window shows the number of data record that is being processed.

Selection 4 allows the user to print the result on the screen or to a printer. By specifying either S (screen) or P (Printer), the output will be sent to the selected destination.

Selection 5 allows the user to go to the operating system (or DOS) while the program is still in memory. The user may return to the program by typing EXIT followed by a carriage return. The advantage of this selection is that the user does not have to reload the program which may take a little longer than by using EXIT.

Selection 6 terminates the program.

APPENDIX BC

OVERLAY PROGRAM LISTING

```
DECLARE SUB PrintResult (Outfile$)
DECLARE SUB TempAdjust (TempAdj!)
DECLARE SUB Box2 ()
DECLARE SUB Box1 ()
DECLARE SUB BottomMsg ()

     ' Flexible overlay pavement design program
     ' Developed by Haiping Zhou and R. G. Hicks
     ' Department of Civil Engineering
     ' Oregon State University
     ' July 1987

     COLOR 7, 0
     CLS
     LOCATE 5, 10: PRINT STRING$(60, 205)
     LOCATE 5, 10: PRINT STRING$(1, 201)
     LOCATE 5, 70: PRINT STRING$(1, 187)
     FOR I = 6 TO 21
     LOCATE I, 10: PRINT STRING$(1, 186)
     LOCATE I, 70: PRINT STRING$(1, 186)
     NEXT I
     LOCATE 21, 10: PRINT STRING$(60, 205)
     LOCATE 21, 70: PRINT STRING$(1, 188)
     LOCATE 21, 10: PRINT STRING$(1, 200)

     LOCATE 7, 25: PRINT "Flexible Overlay Design Program"
     LOCATE 8, 25: PRINT "            with"
     LOCATE 9, 25: PRINT "  Non-Destructive Test Method "
     LOCATE 10, 25: PRINT "  Based on 1986 AASHTO Guide "
     LOCATE 11, 25: PRINT "        Developed for"
     LOCATE 12, 23: PRINT "Oregon Department of Transportation"
     LOCATE 13, 25: PRINT "              by"
     LOCATE 14, 25: PRINT "Haiping Zhou       R.G. Hicks"
     LOCATE 15, 25: PRINT "  Graduate         Professor"
     LOCATE 16, 25: PRINT " Civil Engineering Department"
     LOCATE 17, 25: PRINT "   Oregon State University"
     LOCATE 18, 25: PRINT "     Corvallis, OR 97331"
     LOCATE 19, 25: PRINT "         Version 1.0"

     LOCATE 25, 26: COLOR 0, 7: PRINT " PRESS ANY KEY TO CONTINUE "; : COLOR 7, 0
PressAKey:
     K$ = INKEY$: IF K$ = "" THEN GOTO PressAKey
Menu:
     ' Main menu display
     COLOR 7, 0: CLS
     LOCATE 6, 20: PRINT STRING$(40, 205)
     LOCATE 6, 20: PRINT STRING$(1, 201)
     LOCATE 6, 60: PRINT STRING$(1, 187)
     FOR I = 7 TO 18
     LOCATE I, 20: PRINT STRING$(1, 186)
     LOCATE I, 60: PRINT STRING$(1, 186)
     NEXT I
     LOCATE 18, 20: PRINT STRING$(40, 205)
     LOCATE 18, 60: PRINT STRING$(1, 188)
```

```
     LOCATE 18, 20: PRINT STRING$(1, 200)

     DEFSTR V
     DIM VCHOICE(6), Ai(10), Ai$(10)
     VCHOICE(1) = "Program Description            "
     VCHOICE(2) = "Overlay Design with NDT Method 1"
     VCHOICE(3) = "Overlay Design with NDT Method 2"
     VCHOICE(4) = "Print Result                   "
     VCHOICE(5) = "Operating System               "
     VCHOICE(6) = "Quit                           "
     GOSUB 100
     ON X GOTO Description, OverlayDesign1, OverlayDesign2, PResult, OperSys, Quit
     END
100  COLOR 7, 0
     LOCATE 8, 32: PRINT "Program Main Menu"
     LOCATE 9, 21: PRINT STRING$(39, 196): LOCATE 9, 20: PRINT STRING$(1, 199)
     LOCATE 9, 60: PRINT STRING$(1, 182)
     LOCATE 25, 20: COLOR 0, 7: PRINT " USE "; CHR$(24); " OR "; CHR$(25); " TO SELECT";
     PRINT "  USE "; CHR$(17); CHR$(217); " TO ACTIVATE ";
     COLOR 7, 0: FOR X = 1 TO 6: LOCATE X + 10, 25: PRINT VCHOICE(X); : NEXT
     X = 1: KEY(11) ON: KEY(14) ON:
     ON KEY(11) GOSUB 150
     ON KEY(14) GOSUB 160
110  LOCATE X + 10, 25: COLOR 0, 7: PRINT VCHOICE(X); : COLOR 7, 0: IF X = 1 THEN GOSUB 170: GOTO
120
     COLOR 7: LOCATE X + 9, 25: PRINT VCHOICE(X - 1): IF X = 6 THEN GOSUB 180: GOTO 130
120 COLOR 7: LOCATE X + 11, 25: PRINT VCHOICE(X + 1)
130  A$ = INKEY$
      IF A$ = CHR$(13) THEN GOTO 140
      IF A$ = CHR$(32) THEN GOSUB 160 ELSE GOTO 130
140 KEY(11) OFF: KEY(14) OFF: KEY OFF: RETURN
150 ' key up.
     IF X = 1 THEN X = 6 ELSE X = X - 1
     RETURN 110
160 ' key down.
     IF X = 6 THEN X = 1 ELSE X = X + 1
     RETURN 110
170 LOCATE 16, 25: PRINT VCHOICE(6); : RETURN
180 LOCATE 11, 25: PRINT VCHOICE(1); : RETURN
190 A$ = INKEY$: IF A$ = "" THEN 190 ELSE RETURN

PResult:
     CALL Box2
     XY = 3
     LOCATE 3, 5: INPUT "Enter filename: ", Outfile$
     ON ERROR GOTO ErrorHandler1
     CALL PrintResult(Outfile$)
     GOTO Menu

OperSys:
     CLS
     SHELL
     GOTO Menu
```

```
Description:
     ' Description of the program
     CALL Box2
     OPEN "README" FOR INPUT AS #1
     xcount = 1
     WHILE NOT EOF(1)
     LINE INPUT #1, massage$
     LOCATE xcount + 1, 2: PRINT massage$
     xcount = xcount + 1
     IF xcount = 21 THEN
          xcount = 1
          LOCATE 25, 14: COLOR 0, 7: PRINT " PRESS Esc TO EXIT, PRESS SPACE BAR TO GO TO NEXT PAGE
"; : COLOR 7, 0
WT1: ky$ = INKEY$
     IF ky$ = "" THEN GOTO WT1
     IF ky$ = CHR$(27) THEN CLOSE #1: GOTO Menu
     FOR t = 2 TO 22
     LOCATE t, 2: PRINT SPACE$(78)
     NEXT t
     LOCATE 25, 1: PRINT SPACE$(80);
     END IF
     WEND
     CLOSE #1
     LOCATE xcount + 1, 5: PRINT "End of description"
     LOCATE 25, 28: COLOR 0, 7: PRINT "  PRESS ANYKEY TO CONTINUE "; : COLOR 7, 0
WT2:
     IF INKEY$ = "" THEN GOTO WT2
     GOTO Menu

OverlayDesign1:
     CALL Box2
     LOCATE 3, 5: PRINT "This procedure uses the backcalculation results together with the"
     LOCATE 4, 5: PRINT "traffic data to design an overlay."
     LOCATE 5, 5: PRINT "The following data are needed to perform the analysis:"
     LOCATE 6, 5: PRINT "The existing Structure Number (SNxeff)"
     LOCATE 7, 5: PRINT "The original Structure Number (SNo)"
     LOCATE 8, 5: PRINT "The layer coefficient for AC surface and subgrade modulus"
     LOCATE 9, 5: PRINT "Est. future total 18kips ESAL applications"
     LOCATE 10, 5: PRINT "Design serviceability loss"
     LOCATE 11, 5: PRINT "Reliability level and overall standard deviation."
     LOCATE 2, 20: PRINT " NDT METHOD 1 FOR OVERLAY DESIGN"
EXIT DRCBREK250 PREVIOUSRQUESTIONRINT:"CPRESS7;Q0
     LOCATE 12, 2: PRINT STRING$(78, 196)
     LOCATE 12, 1: PRINT CHR$(195)
     LOCATE 12, 80: PRINT CHR$(180)
Q1:     LOCATE 13, 61: PRINT "          "
     LOCATE 13, 14: INPUT "Enter the existing Structural Number (SNxeff): ", SNx$
     IF SNx$ = "" THEN GOTO Menu ELSE SNx = VAL(SNx$)
Q2:     LOCATE 14, 58: PRINT "          "
     LOCATE 14, 14: INPUT "Enter the original Structural Number (SNo): ", SNo$
     IF SNo$ = "" THEN GOTO Q1 ELSE SNo = VAL(SNo$)
Q3:     LOCATE 15, 53: PRINT "          "
     LOCATE 15, 14: INPUT "Enter layer coefficient for AC surface: ", Ai$(1)
     IF Ai$(1) = "" THEN GOTO Q2 ELSE Ai(1) = VAL(Ai$(1))
```

```
Q4:    LOCATE 16, 44: PRINT "            "
    LOCATE 16, 14: INPUT "Enter subgrade modulus (psi): ", E$
    IF E$ = "" THEN GOTO Q3 ELSE E = VAL(E$)
Q5:    LOCATE 17, 58: PRINT "            "
    LOCATE 17, 14: PRINT "Est. future total 18kips ESAL applications: ";
    INPUT "", Y$: IF Y$ = "" THEN GOTO Q4 ELSE Y = VAL(Y$)
Q6:    LOCATE 18, 60: PRINT "            "
    LOCATE 18, 14: PRINT "Design serviceability loss (ranges 0.05-3.0): ";
    INPUT "", DSL$: IF DSL$ = "" THEN GOTO Q5 ELSE DSL = VAL(DSL$)
Q7:    LOCATE 19, 49: PRINT "            "
    LOCATE 19, 14: PRINT "Reliability level (ranges 50-100): "; : INPUT "", ReL$
    IF ReL$ = "" THEN GOTO Q6 ELSE ReL = VAL(ReL$)
Q8:    LOCATE 20, 59: PRINT "            "
    LOCATE 20, 14: PRINT "Overall standard deviation (ranges 0.2-0.6): ";
    INPUT "", SD$: IF SD$ = "" THEN GOTO Q7 ELSE SD = VAL(SD$)
    GOTO DetermineSNy

OverlayDesign2:
    CLS : COLOR 7, 0
    DIM choice$(3)
    LOCATE 5, 23: PRINT STRING$(34, 196)
    LOCATE 5, 23: PRINT STRING$(1, 218)
    LOCATE 5, 57: PRINT STRING$(1, 191)
    FOR I = 6 TO 12
    LOCATE I, 23: PRINT STRING$(1, 179)
    LOCATE I, 57: PRINT STRING$(1, 179)
    NEXT I
    LOCATE 13, 23: PRINT STRING$(34, 196)
    LOCATE 13, 57: PRINT STRING$(1, 217)
    LOCATE 13, 23: PRINT STRING$(1, 192)

    choice$(1) = "Create a Data File "
    choice$(2) = "Edit a Data File   "
    choice$(3) = "Analyze a Data File"
    GOSUB 200
    LOCATE 25, 1: PRINT SPACE$(80);
    ON G GOTO NewDesign, EditData, UseExistingFile
200 COLOR 7, 0
    LOCATE 6, 30: PRINT "Menu for NDT Method 2"
    LOCATE 7, 24: PRINT STRING$(33, 196): LOCATE 7, 23: PRINT STRING$(1, 195)
    LOCATE 7, 57: PRINT STRING$(1, 180)
    LOCATE 25, 11: COLOR 0, 7: PRINT " USE "; CHR$(24); " OR "; CHR$(25); " TO SELECT";
    PRINT "  USE "; CHR$(17); CHR$(217); " TO ACTIVATE ";
    PRINT "  USE Esc TO EXIT ";
    COLOR 7, 0: FOR G = 1 TO 3: LOCATE G + 8, 31: PRINT choice$(G); : NEXT
    G = 1: KEY(11) ON: KEY(14) ON:
    ON KEY(11) GOSUB 250:
    ON KEY(14) GOSUB 260
210 : LOCATE G + 8, 31: COLOR 0, 7: PRINT choice$(G); : COLOR 7, 0: IF G = 1 THEN GOSUB 270: GOTO
220
    COLOR 7: LOCATE G + 7, 31: PRINT choice$(G - 1): IF G = 3 THEN GOSUB 280: GOTO 230
220 : COLOR 7: LOCATE G + 9, 31: PRINT choice$(G + 1)
230 : A$ = INKEY$
    IF A$ = CHR$(13) THEN GOTO 240
```

```
      IF A$ = CHR$(27) THEN GOTO Menu
      IF A$ = CHR$(32) THEN GOSUB 260 ELSE GOTO 230
240 : KEY(11) OFF: KEY(14) OFF: KEY OFF: RETURN
250 : ' key up.
     IF G = 1 THEN G = 3 ELSE G = G - 1
     RETURN 210
260 : ' key down.
     IF G = 3 THEN G = 1 ELSE G = G + 1
     RETURN 210
270 : LOCATE 11, 31: PRINT choice$(3); : RETURN
280 : LOCATE 9, 31: PRINT choice$(1); : RETURN
290 : A$ = INKEY$: IF A$ = "" THEN GOTO 290 ELSE RETURN


UseExistingFile:
     CALL Box1
     DIM DefRead(300), DefRead$(300), Thick(10), modulus(10), U(10), Offset(10)
     DIM Offset$(10)
Reinput:
     LOCATE 25, 29: COLDK UQ EXIPRINT:"CBRERS7;Q0
     LOCATE 16, 25: INPUT "File name: ", InputFile$
     IF InputFile$ = "" THEN GOTO OverlayDesign2
          ON ERROR GOTO ErrorHandler2
          OPEN InputFile$ FOR INPUT AS #1
     LOCATE 17, 25: INPUT "Output name: ", Outfile$
          IF Outfile$ = "" THEN Outfile$ = "NDT2.out"
          Accu = 1
          OPEN Outfile$ FOR OUTPUT AS #2
          PRINT #2, "Project: "; InputFile$
     PRINT #2, "Location Subgrade Deflect  SNo  SNxeff  SNy  SNol  Thickness  RLx  RLy  Frl"
     PRINT #2, "          modulus  (mils)                              (inches)   %    %    %"
          LINE INPUT #1, DevNam$
          LINE INPUT #1, Ttl$
          INPUT #1, NumLayer
          Ht = 0
          FOR I = 1 TO NumLayer - 1
          INPUT #1, Thick(I), modulus(I), U(I), Ai(I)
          Ht = Ht + Thick(I)
          NEXT I
          INPUT #1, modulus(NumLayer), U(NumLayer)
          INPUT #1, NumDeflection
          FOR I = 1 TO NumDeflection
          INPUT #1, Offset(I)
          NEXT I
          INPUT #1, Radius, DSL, Y, ReL, SD, TempAdj

ReadNewData:
          ON ERROR GOTO ErrorHandler2
          IF EOF(1) THEN GOTO CloseDataFile
          INPUT #1, Location, NDTLoad
          FOR J = 1 TO NumDeflection
          INPUT #1, DefRead(J)
          DefRead(J) = DefRead(J) * TempAdj
          NEXT J
```

```
    GOTO DetermineSNxeff

NewDesign:
    ' New overlay design
    ' Data input routine
     COLOR 7, 0
     chk = 0
10000 DIM VL.SS$(30), LO.SS%(30, 2), LE.SS%(30), TY.SS$(30), PIC.SS$(30), RG.SS(30, 2), CL.SS%(30,
2), SPECCHR.SS%(30), DT(10)
     KEY OFF: SD.SS% = 1: NUMSCR.SS% = 1: BLNK.SS$ = SPACE$(78)
     IF chk = 1 THEN INIT.SS% = 0 ELSE INIT.SS% = -1
     SCR.SS% = 1: SAME.SS% = 0: EXIT.SS% = 0
     WHILE NOT EXIT.SS%
     GOSUB 60000
     LOCATE , , 0, 4, 7
     IF chk = 0 THEN GOSUB Start
     IF chk = 1 THEN RETURN
     GOTO OverlayDesign2
     WEND
     END
30005 ' ***   Variables Section   ***
     VL.SS$(1) = SAVETOFILE$: VL.SS$(2) = STR$(NumLayer):
     VL.SS$(3) = STR$(Thick(1)): VL.SS$(4) = STR$(modulus(1)):
     VL.SS$(5) = STR$(U(1)): VL.SS$(6) = STR$(Ai(1)): VL.SS$(7) = STR$(Thick(2)):
     VL.SS$(8) = STR$(modulus(2)): VL.SS$(9) = STR$(U(2)):
     VL.SS$(10) = STR$(Ai(2)): VL.SS$(11) = STR$(Thick(3)):
     VL.SS$(12) = STR$(modulus(3)): VL.SS$(13) = STR$(U(3)):
     VL.SS$(14) = STR$(Ai(3)): VL.SS$(15) = STR$(Thick(4)):
     VL.SS$(16) = STR$(modulus(4)): VL.SS$(17) = STR$(U(4)):
     VL.SS$(18) = STR$(Ai(4)): VL.SS$(19) = STR$(Thick(5)):
     VL.SS$(20) = STR$(modulus(5)): VL.SS$(21) = STR$(U(5)):
     VL.SS$(22) = STR$(Ai(5)): VL.SS$(23) = STR$(Thick(6)):
     VL.SS$(24) = STR$(modulus(6)): VL.SS$(25) = STR$(U(6)):
     VL.SS$(26) = STR$(Ai(6)): VL.SS$(27) = STR$(Y): VL.SS$(28) = STR$(DSL):
     VL.SS$(29) = STR$(ReL): VL.SS$(30) = STR$(SD):
     RETURN
30095 '***    Assign VL.SS$ Array to the variables   ***
     SAVETOFILE$ = VL.SS$(1): NumLayer = VAL(VL.SS$(2)): Thick(1) = VAL(VL.SS$(3)):
     modulus(1) = VAL(VL.SS$(4)): U(1) = VAL(VL.SS$(5)): Ai(1) = VAL(VL.SS$(6)):
     Thick(2) = VAL(VL.SS$(7)): modulus(2) = VAL(VL.SS$(8)): U(2) = VAL(VL.SS$(9)):
     Ai(2) = VAL(VL.SS$(10)): Thick(3) = VAL(VL.SS$(11)):
     modulus(3) = VAL(VL.SS$(12)): U(3) = VAL(VL.SS$(13)): Ai(3) = VAL(VL.SS$(14)):
     Thick(4) = VAL(VL.SS$(15)): modulus(4) = VAL(VL.SS$(16)): U(4) = VAL(VL.SS$(17)):
     Ai(4) = VAL(VL.SS$(18)): Thick(5) = VAL(VL.SS$(19)):
     modulus(5) = VAL(VL.SS$(20)): U(5) = VAL(VL.SS$(21)): Ai(5) = VAL(VL.SS$(22)):
     Thick(6) = VAL(VL.SS$(23)): modulus(6) = VAL(VL.SS$(24)): U(6) = VAL(VL.SS$(25)):
     Ai(6) = VAL(VL.SS$(26)): Y = VAL(VL.SS$(27)): DSL = VAL(VL.SS$(28)):
     ReL = VAL(VL.SS$(29)): SD = VAL(VL.SS$(30)):
     RETURN
30170 '***    Section To Initialize Variables To Initial Values ***
     SAVETOFILE$ = "": NumLayer = 0: Thick(1) = 0!: modulus(1) = 0: U(1) = 0!:
     Ai(1) = 0!: Thick(2) = 0!: modulus(2) = 0: U(2) = 0!: Ai(2) = 0!:
     Thick(3) = 0!: modulus(3) = 0: U(3) = 0!: Ai(3) = 0!: Thick(4) = 0!:
     modulus(4) = 0: U(4) = 0!: Ai(4) = 0!: Thick(5) = 0!: modulus(5) = 0:
```

```
      U(5) = 0!: Ai(5) = 0!: Thick(6) = 0!: modulus(6) = 0: U(6) = 0!:
      Ai(6) = 0!: Y = 0: DSL = 2!: ReL = 90!: SD = .4:
      RETURN
30220 '     **** List DATA statements & Print DISPLAY Only Variables ****
      'Lin,Col,Len,Picture,Low Range,High Range,Foreground,Background,# of Edit
      DATA 22,5,12,"C","XXXXXXXXXXXX",,,0,7,0
      DATA 31,7,1,"N","#",0,6,0,7,0
      DATA 22,11,5,"N","###.#",0.0,999.9,0,7,1
      DATA 32,11,9,"N","#########",0,999999999,0,7,0
      DATA 47,11,5,"N","##.##",0.00,0.50,0,7,1
      DATA 60,11,5,"N","##.##",0.00,1.00,0,7,1
      DATA 22,12,5,"N","###.#",0.0,999.9,0,7,1
      DATA 32,12,9,"N","#########",0,999999999,0,7,0
      DATA 47,12,5,"N","##.##",0.00,0.50,0,7,1
      DATA 60,12,5,"N","##.##",0.00,1.00,0,7,1
      DATA 22,13,5,"N","###.#",0.0,999.9,0,7,1
      DATA 32,13,9,"N","#########",0,999999999,0,7,0
      DATA 47,13,5,"N","##.##",0.00,0.50,0,7,1
      DATA 60,13,5,"N","##.##",0.00,1.00,0,7,1
      DATA 22,14,5,"N","###.#",0.0,999.9,0,7,1
      DATA 32,14,9,"N","#########",0,999999999,0,7,0
      DATA 47,14,5,"N","##.##",0.00,0.50,0,7,1
      DATA 60,14,5,"N","##.##",0.00,1.00,0,7,1
      DATA 22,15,5,"N","###.#",0.0,999.9,0,7,1
      DATA 32,15,9,"N","#########",0,999999999,0,7,0
      DATA 47,15,5,"N","##.##",0.00,0.50,0,7,1
      DATA 60,15,5,"N","##.##",0.00,1.00,0,7,1
      DATA 22,16,5,"N","###.#",0.0,999.9,0,7,1
      DATA 32,16,9,"N","#########",0,999999999,0,7,0
      DATA 47,16,5,"N","##.##",0.00,0.50,0,7,1
      DATA 60,16,5,"N","##.##",0.00,1.00,0,7,1
      DATA 56,18,10,"N","##########",0,9999999999,0,7,0
      DATA 61,19,5,"N","##.##",0.05,3.00,0,7,1
      DATA 61,20,5,"N","###.#",50.0,100.0,0,7,1
      DATA 61,21,5,"N","##.##",0.20,0.60,0,7,1
      RETURN
30395 '***    Screen Display Initialization Statements   ***
      NUMFLDS.SS% = 30:
      EXITCHR.SS$ = CHR$(27) + ""
      RESTORE 30220
      RETURN
60000 IF SAME.SS% THEN 60200
      IF SCR.SS% = SCRLST.SS% THEN 60140
      ON SCR.SS% GOSUB 30395
      GOSUB 60550
      GOSUB SCRDISP
60140 IF INIT.SS% THEN ON SCR.SS% GOSUB 30170
      ON SCR.SS% GOSUB 30005
      GOSUB 60590
      ON SCR.SS% GOSUB 30220
      F.SS% = 1: SCRLST.SS% = 0' SCR.SS%
60200 IF NUMFLDS.SS% = 0 THEN RETURN
      LOCATE , , , 4, 7
      EXSCR.SS% = 0
```

```
60220 WHILE NOT EXSCR.SS%
      GOSUB 60740
      WEND
      FOR F.SS% = 1 TO NUMFLDS.SS%
      GOSUB 62500
      IF ERR.MSG% = -1 THEN EXSCR.SS% = 0: GOTO 60220
      NEXT F.SS%
      F.SS% = FLDLST.SS%
      ON SCR.SS% GOSUB 30095
      RETURN
      ' **** Read Field Data For This Screen ****
60550 FOR F.SS% = 1 TO NUMFLDS.SS%
      READ LO.SS%(F.SS%, 2), LO.SS%(F.SS%, 1), LE.SS%(F.SS%), TY.SS$(F.SS%), PIC.SS$(F.SS%),
RG.SS(F.SS%, 1), RG.SS(F.SS%, 2), CL.SS%(F.SS%, 1), CL.SS%(F.SS%, 2), SPECCHR.SS%(F.SS%)
      NEXT F.SS%
      RETURN
      '*** Pad Fields With Blanks, Insert Special Characters, and Display Flds
60590 FOR F.SS% = 1 TO NUMFLDS.SS%
      IF TY.SS$(F.SS%) = "N" THEN 60655
      IF LEN(VL.SS$(F.SS%)) > LE.SS%(F.SS%) THEN VL.SS$(F.SS%) = LEFT$(VL.SS$(F.SS%),
LE.SS%(F.SS%)): GOTO 60610
      VL.SS$(F.SS%) = VL.SS$(F.SS%) + MID$(BLNK.SS$, 1, LE.SS%(F.SS%) - LEN(VL.SS$(F.SS%)))
60610 IF INSTR("CD", TY.SS$(F.SS%)) = 0 OR SPECCHR.SS%(F.SS%) = 0 THEN 60690
      CNT.SS% = 0
      FOR J.SS% = 1 TO LE.SS%(F.SS%)
      IF INSTR("ULX#89", MID$(PIC.SS$(F.SS%), J.SS%, 1)) = 0 THEN MID$(VL.SS$(F.SS%), J.SS%, 1) =
MID$(PIC.SS$(F.SS%), J.SS%, 1): CNT.SS% = CNT.SS% + 1
      IF CNT.SS% = SPECCHR.SS%(F.SS%) THEN 60690
      NEXT J.SS%
      GOTO 60690
60655 NUMDEC% = LE.SS%(F.SS%) - INSTR(PIC.SS$(F.SS%), ".")
      IF LEFT$(VL.SS$(F.SS%), 1) = " " THEN VL.SS$(F.SS%) = RIGHT$(VL.SS$(F.SS%),
LEN(VL.SS$(F.SS%)) - 1)
      IF NUMDEC% = LE.SS%(F.SS%) THEN NUMDEC% = 0: NUMINT% = LE.SS%(F.SS%) ELSE NUMINT% =
LE.SS%(F.SS%) - NUMDEC% - 1
      IF VAL(VL.SS$(F.SS%)) = 0 THEN VL.SS$(F.SS%) = LEFT$(MID$(BLNK.SS$, 1, NUMINT% - 1) + "0." +
STRING$(NUMDEC%, "0"), LE.SS%(F.SS%)): GOTO 60690
      DEC.VL% = INSTR(VL.SS$(F.SS%), "."): IF DEC.VL% = 0 THEN DEC.VL% = LE.SS%(F.SS%) + 1
      VL.SS$(F.SS%) = LEFT$(RIGHT$(MID$(BLNK.SS$, 1, NUMINT%) + LEFT$(VL.SS$(F.SS%), DEC.VL% - 1),
NUMINT%) + "." + MID$(VL.SS$(F.SS%), DEC.VL% + 1) + STRING$(NUMDEC%, "0"), LE.SS%(F.SS%))
60690 GOSUB 62340
      NEXT F.SS%
      RETURN
      '          *** Accept Input Data For The Current Field ***
60740 IF TY.SS$(F.SS%) <> "N" THEN A.SS% = 1: GOTO 60790
      NEWNUM% = -1: NUMED.SS% = 0
      DECPOS% = INSTR(PIC.SS$(F.SS%), "."): IF DECPOS% = 0 THEN DECPOS% = LE.SS%(F.SS%) + 1
      A.SS% = DECPOS% - 1
60790 WHILE INSTR("ULX#98", MID$(PIC.SS$(F.SS%), A.SS%, 1)) = 0: A.SS% = A.SS% + 1: WEND
      CURCOL% = LO.SS%(F.SS%, 2) + A.SS% - 1
      LOCATE LO.SS%(F.SS%, 1), CURCOL%, 1
      FLDLST.SS% = F.SS%
      EXFLD.SS% = 0
      WHILE NOT EXFLD.SS%
```

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60860 X.SS$ = INKEY$: IF X.SS$ = "" THEN 60860
      IF ERR.MSG% THEN ERR.MSG% = 0: LOCATE 25, 1: COLOR 7, 0: PRINT SPACE$(80);
      LOCATE , , 0
      CALL BottomMsg
      IF LEN(X.SS$) > 1 OR INSTR(CHR$(8) + CHR$(13) + CHR$(27), X.SS$) <> 0 THEN X.SS$ =
RIGHT$(X.SS$, 1) ELSE 60960
      IF TY.SS$(F.SS%) <> "N" THEN 60920
      IF INSTR("GO", X.SS$) <> 0 THEN 61030
      IF INSTR("RKM" + CHR$(8), X.SS$) <> 0 THEN NUMED.SS% = -1: NEWNUM% = 0
60920 IF INSTR(EXITCHR.SS$, X.SS$) <> 0 THEN EXFLD.SS% = -1: EXSCR.SS% = -1: GOTO 61040'Check CODE
to EXIT SCREEN
      ON INSTR("MKHPGRSO" + CHR$(8) + CHR$(13), X.SS$) GOSUB 61110, 61140, 61210, 61260, 61650,
61440, 61300, 61600, 61140, 61260: GOTO 61020
      GOTO 61030
60960 IF TY.SS$(F.SS%) = "N" AND X.SS$ = "." THEN NEWNUM% = 0: NUMED.SS% = -1: GOTO 61010
      IF ASC(X.SS$) < 32 OR ASC(X.SS$) > 126 THEN 61030
      GOSUB 61750: IF ERR.MSG% THEN 61030
      GOSUB 62230
      GOSUB 62340
61010 GOSUB 62380
61020 IF ERR.MSG% THEN 60740
61030 WEND
61040 LASTCHR.SS$ = X.SS$
      RETURN
      '*** Cursor right ***
61110 GOSUB 62380
      RETURN
      '*** Cursor left or backspace ***
61140 IF CURCOL% = LO.SS%(F.SS%, 2) THEN 61210
      IF TY.SS$(F.SS%) = "N" AND INSTR(" +-", MID$(VL.SS$(F.SS%), A.SS%, 1)) <> 0 THEN RETURN
      CURCOL% = CURCOL% - 1: A.SS% = A.SS% - 1
      IF INSTR("ULX#89", MID$(PIC.SS$(F.SS%), A.SS%, 1)) = 0 THEN 61140
      LOCATE LO.SS%(F.SS%, 1), CURCOL%, 1
      RETURN
      '*** Cursor up ***      Move to next field left
61210 GOSUB 62500
      IF ERR.MSG% THEN RETURN
      EXFLD.SS% = -1
      IF F.SS% > 1 THEN F.SS% = F.SS% - 1 ELSE F.SS% = NUMFLDS.SS%
      RETURN
      '*** Cursor down or carriage return - Advance to next field ***
61260 GOSUB 62500
      IF ERR.MSG% THEN RETURN
      EXFLD.SS% = -1
      IF F.SS% = NUMFLDS.SS% AND INSTR(EXITCHR.SS$, CHR$(127)) <> 0 THEN EXSCR.SS% = -1
      IF F.SS% < NUMFLDS.SS% THEN F.SS% = F.SS% + 1 ELSE F.SS% = 1                    ' Increment
fld num to next fld
      RETURN
61300 ' **** Del key pressed ******
      IF TY.SS$(F.SS%) = "N" AND A.SS% < DECPOS% THEN MID$(VL.SS$(F.SS%), 1) = " " +
LEFT$(VL.SS$(F.SS%), A.SS% - 1) + RIGHT$(VL.SS$(F.SS%), LE.SS%(F.SS%) - A.SS%): GOTO 61420
      IF TY.SS$(F.SS%) = "N" THEN MID$(VL.SS$(F.SS%), 1) = LEFT$(VL.SS$(F.SS%), A.SS% - 1) +
MID$(VL.SS$(F.SS%), A.SS% + 1, LE.SS%(F.SS%) - A.SS%) + "0": GOTO 61420
      IF SPECCHR.SS%(F.SS%) = 0 THEN MID$(VL.SS$(F.SS%), 1) = LEFT$(VL.SS$(F.SS%), A.SS% - 1) +
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MID$(VL.SS$(F.SS%), A.SS% + 1, LE.SS%(F.SS%) - A.SS%) + " ": GOTO 61420
      CNT.SS% = 0
      WHILE INSTR("ULX#89", MID$(PIC.SS$(F.SS%), A.SS% + 1 + CNT.SS%, 1)) <> 0 AND CNT.SS% <
LE.SS%(F.SS%) - A.SS%: CNT.SS% = CNT.SS% + 1: WEND
      VL.SS$(F.SS%) = LEFT$(VL.SS$(F.SS%), A.SS% - 1) + MID$(VL.SS$(F.SS%), A.SS% + 1, CNT.SS%) +
" " + RIGHT$(VL.SS$(F.SS%), LE.SS%(F.SS%) - A.SS% - CNT.SS%)
61420 CURCOL% = CURCOL% - 1: A.SS% = A.SS% - 1: GOSUB 62340: GOSUB 62380
      RETURN
61440 ' ***** Ins key pressed ***
      IF TY.SS$(F.SS%) = "N" AND A.SS% < DECPOS% THEN MID$(VL.SS$(F.SS%), 1) = MID$(VL.SS$(F.SS%),
2, A.SS% - 1) + "0" + RIGHT$(VL.SS$(F.SS%), LE.SS%(F.SS%) - A.SS%): GOTO 61580
      IF TY.SS$(F.SS%) = "N" THEN VL.SS$(F.SS%) = LEFT$(VL.SS$(F.SS%), A.SS% - 1) + "0" +
MID$(VL.SS$(F.SS%), A.SS%, LE.SS%(F.SS%) - A.SS%): GOTO 61580
      IF SPECCHR.SS%(F.SS%) = 0 THEN VL.SS$(F.SS%) = LEFT$(VL.SS$(F.SS%), A.SS% - 1) + " " +
MID$(VL.SS$(F.SS%), A.SS%, LE.SS%(F.SS%) - A.SS%): GOTO 61580
      NEWVL$ = LEFT$(VL.SS$(F.SS%), A.SS% - 1) + " ": NEXTCHR$ = MID$(VL.SS$(F.SS%), A.SS%, 1)
      FOR I% = A.SS% + 1 TO LE.SS%(F.SS%)
      X.SS$ = MID$(PIC.SS$(F.SS%), I%, 1): IF INSTR("ULX#89", X.SS$) = 0 THEN NEWVL$ = NEWVL$ +
X.SS$: GOTO 61570
      NEWVL$ = NEWVL$ + NEXTCHR$: NEXTCHR$ = MID$(VL.SS$(F.SS%), I%, 1)
      NEXT I%
61570 VL.SS$(F.SS%) = NEWVL$ + MID$(VL.SS$(F.SS%), I% + 1, LE.SS%(F.SS%))
61580 CURCOL% = CURCOL% - 1: A.SS% = A.SS% - 1: GOSUB 62340: GOSUB 62380
      RETURN
61600 ' ***** END key pressed *****
      CURCOL% = LO.SS%(F.SS%, 2) + LE.SS%(F.SS%) - 1: A.SS% = LE.SS%(F.SS%)
      WHILE INSTR("ULX#89", MID$(PIC.SS$(F.SS%), A.SS%, 1)) = 0: A.SS% = A.SS% - 1: CURCOL% =
CURCOL% - 1: WEND
      LOCATE LO.SS%(F.SS%, 1), CURCOL%, 1
      RETURN
61650 ' **** HOME key pressed ****  put cursor at beginning of field
      A.SS% = 1
      WHILE INSTR("ULX#89", MID$(PIC.SS$(F.SS%), A.SS%, 1)) = 0: A.SS% = A.SS% + 1: WEND
      CURCOL% = LO.SS%(F.SS%, 2) + A.SS% - 1
      LOCATE LO.SS%(F.SS%, 1), CURCOL%, 1
      RETURN
      '***Check for special character type conversion***
61750 ON INSTR("ND", TY.SS$(F.SS%)) GOTO 61800, 62100
      ON INSTR("ULX#89", MID$(PIC.SS$(F.SS%), A.SS%, 1)) GOTO 61890, 61920, 62130, 61800, 62060,
62100
      PRINT "EDIT PICTURE TYPE "; MID$(PIC.SS$(F.SS%), A.SS%, 1); " NOT FOUND": STOP
      '*** Numeric values; "."; "-"; "+"; " "
61800 ' NOTE: The decimal point is trapped in the"Accept input data" routine
      IF X.SS$ >= "0" AND X.SS$ <= "9" THEN RETURN
      IF X.SS$ <> "+" AND X.SS$ <> "-" AND X.SS$ <> " " THEN 61850
      IF TY.SS$(F.SS%) = "C" THEN RETURN
      IF LEFT$(VL.SS$(F.SS%), A.SS% - 1) = SPACE$(A.SS% - 1) OR A.SS% = 1 THEN RETURN
61850 MSG.SS$ = " Only numeric values can be entered here. Please re-enter. "
      GOSUB 62180: RETURN
      '*** Upper case or any other character***
61890 IF ASC(X.SS$) > 96 AND ASC(X.SS$) < 123 THEN X.SS$ = CHR$(ASC(X.SS$) - 32)
      GOTO 62130
      '*** Lower case or any other character***
61920 IF ASC(X.SS$) > 65 AND ASC(X.SS$) < 91 THEN X.SS$ = CHR$(ASC(X.SS$) + 32)
```

```
      GOTO 62130
      ' *** Numeric values only ****
62060 IF (ASC(X.SS$) > 47 AND ASC(X.SS$) < 58) THEN GOTO 62130
      MSG.SS$ = " Only numeric values can be entered here. Please re-enter. "
      GOTO 62180
      ' *** Numeric values and " " only ***
62100 IF (ASC(X.SS$) > 47 AND ASC(X.SS$) < 58) OR X.SS$ = " " THEN GOTO 62130
      MSG.SS$ = " Only numeric values or blanks can be entered here. Please re-enter. "
      GOTO 62180
62130 RETURN
      ' **** Print Error Messages ******
62180 ERR.MSG% = -1: SOUND 500, SD.SS% * 1:
      LOCATE 25, 8: PRINT SPACE$(65);
      LOCATE 25, INT(81 - LEN(MSG.SS$)) / 2, 0:
      PRINT MSG.SS$; : LOCATE LO.SS%(F.SS%, 1), CURCOL%, 1
      WHILE INKEY$ <> "": WEND
      RETURN
62230 ' **** Add character to current field *****
      IF TY.SS$(F.SS%) = "N" AND NEWNUM% THEN MID$(VL.SS$(F.SS%), 1) = MID$(BLNK.SS$, 1, A.SS% -
1) + X.SS$ + "." + STRING$(LE.SS%(F.SS%), "0"): NEWNUM% = 0: RETURN
62260 IF TY.SS$(F.SS%) <> "N" OR NUMED.SS% = -1 THEN MID$(VL.SS$(F.SS%), A.SS%, 1) = X.SS$: RETURN

      IF LEFT$(VL.SS$(F.SS%), 1) = " " THEN MID$(VL.SS$(F.SS%), 1, A.SS%) = MID$(VL.SS$(F.SS%), 2,
A.SS% - 1) + X.SS$ ELSE NUMED.SS% = -1: GOTO 62260
      RETURN
      '*** Print new value of field ***
62340 COLOR CL.SS%(F.SS%, 1), CL.SS%(F.SS%, 2)
      LOCATE LO.SS%(F.SS%, 1), LO.SS%(F.SS%, 2), 0: PRINT VL.SS$(F.SS%);
      RETURN
62380 '**** Move cursor to new location ****
      IF TY.SS$(F.SS%) <> "N" OR NUMED.SS% <> 0 THEN 62420
      IF LEFT$(VL.SS$(F.SS%), 1) <> " " THEN NUMED.SS% = -1 ELSE A.SS% = DECPOS% - 1: CURCOL% =
LO.SS%(F.SS%, 2) + A.SS% - 1: LOCATE LO.SS%(F.SS%, 1), CURCOL%, 1: RETURN
62420 IF A.SS% < LE.SS%(F.SS%) THEN A.SS% = A.SS% + 1: CURCOL% = CURCOL% + 1 ELSE GOSUB 61260:
RETURN
      IF INSTR("ULX#89", MID$(PIC.SS$(F.SS%), A.SS%, 1)) = 0 THEN 62420
      LOCATE LO.SS%(F.SS%, 1), CURCOL%, 1
      RETURN
      ' ***  Edit check final field result ***
62500 IF TY.SS$(F.SS%) <> "N" THEN 62720
      IF VAL(VL.SS$(F.SS%)) > RG.SS(F.SS%, 2) THEN MSG.SS$ = " The maximum value allowed in this
field is " + STR$(RG.SS(F.SS%, 2)): GOSUB 62180: RETURN
      IF VAL(VL.SS$(F.SS%)) < RG.SS(F.SS%, 1) THEN MSG.SS$ = " The minimum value allowed in this
field is " + STR$(RG.SS(F.SS%, 1)): GOSUB 62180: RETURN
62720 RETURN

SCRDISP:
    CLS
    LOCATE 3, 7: PRINT STRING$(66, 196)
    LOCATE 3, 7: PRINT STRING$(1, 218)
    LOCATE 3, 73: PRINT STRING$(1, 191)
    FOR I = 4 TO 23
    LOCATE I, 7: PRINT STRING$(1, 179)
    LOCATE I, 73: PRINT STRING$(1, 179)
```

```
     NEXT I
     LOCATE 23, 7: PRINT STRING$(66, 196)
     LOCATE 23, 73: PRINT STRING$(1, 217)
     LOCATE 23, 7: PRINT STRING$(1, 192)

     LOCATE 3, 25: PRINT " NDT METHOD 2 DATA INPUT/EDIT "
     LOCATE 5, 12: PRINT "Filename:"
     LOCATE 5, 37: PRINT "For subgrade, both thickness and "
     LOCATE 6, 37: PRINT "layer coefficient are not required"
     LOCATE 7, 12: PRINT "Number of Layers:"
     LOCATE 8, 12: PRINT "Layer    Thick     Assumed     Poisson     Layer"
     LOCATE 9, 12: PRINT " No.     (in.)     Modulus      Ratio    Coefficient"
     LOCATE 10, 12: PRINT "          . . .     . . . .  FOR.I.=.1.TO 6
     LOCATE I + 10, 12: PRINT I; "."
     NEXT I
     LOCATE 18, 12: PRINT "Est. Future Total 18Kips ESAL Applications:"
     LOCATE 19, 12: PRINT "Design Serviceability Loss (0.05-3.0)     :"
     LOCATE 20, 12: PRINT "Reliability Level (ranges 50-100)         :"
     LOCATE 21, 12: PRINT "Overall Standard Deviation (ranges .2-.6) :"
     CALL BottomMsg
     RETURN

Start:
     IF ASC(SAVETOFILE$) = 32 OR NumLayer = 0 THEN COLOR 7, 0: RETURN
     CALL Box2
     LOCATE 25, 30: COLOR 0O EXIPRINT:"CBREES7;Q0
     LOCATE 3, 5: PRINT "Which NDT Device used"
     LOCATE , 5: PRINT ". .LOCATE , 5:.PRINT
     LOCATE , 5: PRINT "1.  Dynaflect"
     LOCATE , 5: PRINT "2.  Falling Weight Deflectometor (FWD) "
     LOCATE , 5: PRINT
     LOCATE , 5: INPUT "Choice  ", Ch
     ON Ch GOTO Dynaflect, FWD
     GOTO OverlayDesign2

Dynaflect:
     DevNam$ = "DYNAFLECT"
     LOCATE 11, 5: PRINT "For Dynaflect, do you want to"
     LOCATE , 5: PRINT ". . . . . . . . . . . . .
     LOCATE , 5: PRINT "1. have computer to read Dynaflect data"
     LOCATE , 5: PRINT "2. input deflection from keyboard"
     LOCATE , 5: PRINT
     LOCATE , 5: INPUT "Choice  ", Choi
     ON Choi GOSUB DynaA, PreIndTest
     GOTO OverlayDesign2

DynaA:
     XY = 1
     CALL Box2
EXIT DRCBEEK2TO PREVIOUSRQUESTIONRINT:"CBREES7;Q0
QD1:    LOCATE 3, 5: PRINT "For Dynaflect, (type D for directory)"
     LOCATE 4, 45: PRINT "                 "
     LOCATE 4, 5: INPUT "Enter file name of your Dynaflect test: ", filename$
     IF filename$ = "" THEN GOTO OverlayDesign2
```

```
     IF filename$ = "D" OR filename$ = "d" THEN GOTO DirDisk
     ON ERROR GOTO ErrorHandler1
     OPEN filename$ FOR INPUT AS #2
     LOCATE 22, 21: PRINT "                                          "
QD2:    LOCATE 5, 44: PRINT "          "
     LOCATE 5, 5: INPUT "Enter radius of the NDT loading plate (in.): ", Radius$
     IF Radius$ = "" THEN CLOSE #2: GOTO QD1 ELSE Radius = VAL(Radius$)
QD3:    LOCATE 6, 51: PRINT "        "
     LOCATE 6, 5: INPUT "Enter number of deflections at each location: ", NumDeflection$
     IF NumDeflection$ = "" THEN GOTO QD2 ELSE NumDeflection = VAL(NumDeflection$)
     FOR J = 1 TO NumDeflection
     LOCATE 7, 47: PRINT SPACE$(3)
     LOCATE 7, 5: PRINT "Offset distance (from loading center) ";
          COLOR 0, 7: PRINT J; : COLOR 7, 0
          INPUT ": ", Offset$(J): Offset(J) = VAL(Offset$(J))
          IF Offset$(J) = "" THEN GOTO QD3
     NEXT J
     CALL TempAdjust(TempAdj)
     LINE INPUT #2, F3$
     GOSUB WriteData

ReadDynaData:
     ON ERROR GOTO ErrorHandler1
     IF EOF(2) THEN GOTO CloseDynaFile
     LINE INPUT #2, Ck$
     IF LEFT$(Ck$, 1) = "H" OR LEFT$(Ck$, 1) = "C" THEN GOTO ReadDynaData ELSE IF NumDeflection =
4 THEN WRITE #1, VAL(MID$(Ck$, 35, 7)), 1000, VAL(MID$(Ck$, 6, 3)) / 100, VAL(MID$(Ck$, 10, 3)) /
100, VAL(MID$(Ck$, 14, 4)) / 100, VAL(MID$(Ck$, 18 _
, 3)) / 100
      IF NumDeflection = 5 THEN WRITE #1, VAL(MID$(Ck$, 35, 7)), 1000, VAL(MID$(Ck$, 6, 3)) / 100,
VAL(MID$(Ck$, 10, 3)) / 100, VAL(MID$(Ck$, 14, 4)) / 100, VAL(MID$(Ck$, 18, 3)) / 100,
VAL(MID$(Ck$, 22, 3)) / 100
     GOTO ReadDynaData
CloseDynaFile:
     CLOSE #1, #2
     RETURN

FWD:
     DevNam$ = "FWD"
     LOCATE 11, 5: PRINT "For FWD, do you want to"
     LOCATE , 5: PRINT ". . . . . . . . . . .
     LOCATE , 5: PRINT "1. have computer to read FWD data"
     LOCATE , 5: PRINT "2. input deflection from keyboard"
     LOCATE , 5: PRINT
     LOCATE , 5: INPUT "Choice  ", Choi
     ON Choi GOSUB FWDA, PreIndTest
     GOTO OverlayDesign2

FWDA:
     XY = 2
     CALL Box2
EXIT DRCBTEK2TO PREVIOUSRQUESTIONRINT:"CBREES7;Q0
QQ1:    LOCATE 3, 5: PRINT "For FWD, (type D for Directory)"
     LOCATE 4, 39: PRINT SPACE$(15)
```

```
    LOCATE 5, 5: PRINT SPACE$(44)
    LOCATE 4, 5: INPUT "Enter file name of your FWD test: ", filename$
    IF filename$ = "" THEN GOTO OverlayDesign2
    IF filename$ = "D" OR filename$ = "d" THEN GOTO DirDisk
    ON ERROR GOTO ErrorHandler1
    OPEN filename$ FOR INPUT AS #2
    LOCATE 22, 21: PRINT "                                      "
QQ2:   LOCATE 5, 44: PRINT "          "
    LOCATE 5, 5: INPUT "Enter radius of the NDT loading plate (in.): ", Radius$
    IF Radius$ = "" THEN CLOSE #2: GOTO QQ1 ELSE Radius = VAL(Radius$)
QQ3:   LOCATE 6, 51: PRINT "        "
    LOCATE 6, 5: INPUT "Enter number of deflections at each location: ", NumDeflection$
    IF NumDeflection$ = "" THEN GOTO QQ2 ELSE NumDeflection = VAL(NumDeflection$)
    FOR J = 1 TO NumDeflection
    LOCATE 7, 47: PRINT SPACE$(3)
    LOCATE 7, 5: PRINT "Offset distance (from loading center) ";
         COLOR 0, 7: PRINT J; : COLOR 7, 0
         INPUT ": ", Offset$(J): Offset(J) = VAL(Offset$(J))
         IF Offset$(J) = "" THEN GOTO QQ3
    NEXT J
    CALL TempAdjust(TempAdj)
    INPUT #2, F1$, F2$
    LINE INPUT #2, F3$
    GOSUB WriteData

ReadFWDFile:
    ON ERROR GOTO ErrorHandler1
    IF EOF(2) THEN GOTO CloseFWDFile
    LINE INPUT #2, Ck$
    IF LEFT$(Ck$, 10) = " TEST  LOC" THEN
ReadInData:
         IF EOF(2) THEN GOTO CloseFWDFile
         LINE INPUT #2, C$
         IF NumDeflection = 4 THEN
         WRITE #1, VAL(MID$(C$, 8, 3)), VAL(MID$(C$, 26, 5)), VAL(MID$(C$, 35, 5)), VAL(MID$(C$,
43, 5)), VAL(MID$(C$, 51, 5)), VAL(MID$(C$, 59, 5))
         END IF
         IF NumDeflection = 5 THEN
         WRITE #1, VAL(MID$(C$, 8, 3)), VAL(MID$(C$, 26, 5)), VAL(MID$(C$, 35, 5)), VAL(MID$(C$,
43, 5)), VAL(MID$(C$, 51, 5)), VAL(MID$(C$, 59, 5)), VAL(MID$(C$, 67, 5))
         END IF
         IF NumDeflection = 6 THEN
         WRITE #1, VAL(MID$(C$, 8, 3)), VAL(MID$(C$, 26, 5)), VAL(MID$(C$, 35, 5)), VAL(MID$(C$,
43, 5)), VAL(MID$(C$, 51, 5)), VAL(MID$(C$, 59, 5)), VAL(MID$(C$, 67, 5)), VAL(MID$(C$, 75, 5))
         END IF
         GOTO ReadInData
    END IF
    GOTO ReadFWDFile

CloseFWDFile:
    CLOSE #1, #2
    RETURN

PreIndTest:
```

```
     comp = 0
IndTest:
     CALL Box2
EXIT DRCBMEK2TO PREVIOUSRQUESTIONRINT:"CPRESS7;Q0
QI1:    LOCATE 2, 26: PRINT "            "
     LOCATE 2, 5: PRINT "Enter load of the "; DevNam$; " : "; : INPUT "", NDTL$
     IF NDTL$ = "" AND comp = 0 THEN CLOSE : RETURN
     IF NDTL$ = "" AND comp = 1 THEN CLOSE : GOTO OverlayDesign2
     NDTL = VAL(NDTL$)
QI2:    LOCATE 3, 44: PRINT SPACE$(10)
     LOCATE 3, 5: INPUT "Enter radius of the NDT loading plate: ", Radius$
     IF Radius$ = "" THEN GOTO QI1 ELSE Radius = VAL(Radius$)
QI3:    LOCATE 4, 51: PRINT SPACE$(8)
     LOCATE 4, 5: PRINT "Enter number of deflections at each location: ";
     INPUT "", NumDeflection$
     IF NumDeflection$ = "" THEN GOTO QI2 ELSE NumDeflection = VAL(NumDeflection$)
     FOR J = 1 TO NumDeflection
     LOCATE 5, 26: PRINT SPACE$(4): LOCATE 5, 54: PRINT SPACE$(4)
     LOCATE 5, 5: PRINT "Offset distance "; : COLOR 0, 7: PRINT J; : COLOR 7, 0: INPUT " : ",
Offset$(J)
          Offset(J) = VAL(Offset$(J))
     IF Offset$(J) = "" THEN GOTO QI3
     LOCATE 5, 35: INPUT "Deflection (mils): ", DefRead$(J)
          DefRead(J) = VAL(DefRead$(J))
          IF DefRead$(J) = "" THEN
          FOR K = 2 TO 20
          LOCATE K, 14: PRINT SPACE$(54)
          NEXT K
          GOTO QI3
          END IF
     NEXT J
     CALL TempAdjust(TempAdj)
     F3$ = "IndividualTest"
     GOSUB WriteData
     PRINT #1, 0, ; ","; NDTL; ",";
     FOR L = 1 TO NumDeflection
     PRINT #1, DefRead(L);
     IF L <> NumDeflection THEN PRINT #1, ",";
     NEXT L
     CLOSE #1
     IF comp = 0 THEN RETURN ELSE GOTO OverlayDesign2


WriteData:
     ' Write data to a file
     COLOR 7, 0
     LOCATE 23, 28: PRINT " Writing data to the file "
     OPEN SAVETOFILE$ FOR OUTPUT AS #1
          PRINT #1, DevNam$
          PRINT #1, F3$
          PRINT #1, NumLayer
          FOR I = 1 TO NumLayer - 1
          PRINT #1, USING "###.#\\########\\#.##\\#.##"; Thick(I); ","; modulus(I); ","; U(I);
","; Ai(I)
```

```
        NEXT I
        PRINT #1, USING "#######\\#.##"; modulus(NumLayer); ","; U(NumLayer)
        PRINT #1, USING "#\\"; NumDeflection; ",";
        FOR I = 1 TO NumDeflection
        PRINT #1, USING "###.##"; Offset(I);
        IF I <> NumDeflection THEN PRINT #1, ",";
        NEXT I
        PRINT #1,
        PRINT #1, USING "###.##\\#.##\\#########\\##.#\\#.##\\#.###"; Radius; ","; DSL; ","; Y;
","; ReL; ","; SD; ","; TempAdj
        RETURN

DirDisk:
    LOCATE , 14: INPUT "Which drive (eg. A:) ", Dir$
    CLS
    IF Dir$ = "a:" OR Dir$ = "A:" OR Dir$ = "b:" OR Dir$ = "B:" OR Dir$ = "c:" OR Dir$ = "C:"
THEN FILES Dir$ ELSE GOTO DirDisk
WaitKey:
    LOCATE 25, 5: PRINT SPACE$(70);
    LOCATE 25, 26: COLOR 0, 7: PRINT " PRESS ANY KEY TO CONTINUE "; : COLOR 7, 0
WaitAKey:
    W$ = INKEY$: IF W$ = "" THEN GOTO WaitAKey
    ON XY GOTO DynaA, FWDA, Menu

ErrorHandler1:
    IF ERR = 62 THEN RESUME 0
    IF ERR = 53 THEN
        LOCATE 22, 33: BEEP: PRINT "File not found   "
        RESUME WaitKey
    END IF
    IF ERR = 71 THEN
        SOUND 300, .8
        LOCATE 17, 25: PRINT "Disk not ready             ":
        IF XY = 1 THEN RESUME Dynaflect
        IF XY = 2 THEN RESUME FWD
        IF XY = 3 THEN RESUME Menu
    END IF

EditData:
    CLEAR
    CALL Box1
EditData1:
    LOCATE 25, 29: COLOX UQ EXIPRINT:"CBRERS7;Q0
    LOCATE 16, 25: PRINT "                              "
    LOCATE 16, 25: LINE INPUT "File name: "; SAVETOFILE$
    IF SAVETOFILE$ = "" THEN GOTO OverlayDesign2
    ON ERROR GOTO ErrorHandler3
    LOCATE 17, 25: PRINT "Reading data ...   "
    OPEN SAVETOFILE$ FOR INPUT AS #1
        LINE INPUT #1, DevNam$
        LINE INPUT #1, F3$
        INPUT #1, NumLayer
        FOR I = 1 TO NumLayer - 1
        INPUT #1, Thick(I), modulus(I), U(I), Ai(I)
```

```
        NEXT I
        INPUT #1, modulus(NumLayer), U(NumLayer)
        INPUT #1, NumDeflection
        FOR I = 1 TO NumDeflection
        INPUT #1, Offset(I)
        NEXT I
        INPUT #1, Radius, DSL, Y, ReL, SD, TempAdj
        OPEN "WORKFILE" FOR OUTPUT AS #2
ReDat1:
        IF EOF(1) THEN GOTO CloseEdit1
        FOR I = 1 TO NumDeflection + 2
        INPUT #1, DT(I)
        WRITE #2, DT(I)
        NEXT I
        GOTO ReDat1
CloseEdit1:
        CLOSE #1, #2
        chk = 1
        GOSUB 10000
        IF F3$ = "IndividualTest" THEN comp = 1: GOTO IndTest
        GOSUB WriteData
        OPEN "WORKFILE" FOR INPUT AS #2
ReDat2:
        IF EOF(2) THEN GOTO CloseEdit2
        INPUT #2, RDT1: PRINT #1, USING "######\\"; RDT1; ",";
        INPUT #2, RDT2: PRINT #1, USING "#####\\"; RDT2; ",";
        FOR I = 1 TO NumDeflection
        INPUT #2, DT(I)
        PRINT #1, USING "###.##"; DT(I);
        IF I <> NumDeflection THEN PRINT #1, ",";
        NEXT I
        PRINT #1,
        GOTO ReDat2
CloseEdit2:
        CLOSE #1, #2
        KILL "WORKFILE"
    GOTO OverlayDesign2

DetermineSNxeff:
    LOCATE 20, 23: PRINT STRING$(34, CHR$(196))
    LOCATE 20, 23: PRINT STRING$(1, CHR$(218))
    LOCATE 20, 57: PRINT STRING$(1, CHR$(191))
    FOR I = 21 TO 22
    LOCATE I, 23: PRINT STRING$(1, CHR$(179))
    LOCATE I, 57: PRINT STRING$(1, CHR$(179))
    NEXT I
    LOCATE 22, 23: PRINT STRING$(34, CHR$(196))
    LOCATE 22, 57: PRINT STRING$(1, CHR$(217))
    LOCATE 22, 23: PRINT STRING$(1, CHR$(192))

    LOCATE 25, 1: PRINT SPACE$(80);
    LOCATE 21, 27: PRINT "Now working on location     "
    LOCATE 21, 52: PRINT Accu
    HH = 0: Ht = 0
```

```
    FOR I = 1 TO NumLayer - 1
    Ht = Ht + Thick(I)
    Hz1 = modulus(I) * (1 - U(NumLayer) ^ 2)
    Hz2 = modulus(NumLayer) * (1 - U(I) ^ 2)
    HH = HH + Thick(I) * (Hz1 / Hz2) ^ (1 / 3)
    NEXT I
    He = .9 * HH
    HeRatio = He / Radius
    IF HeRatio < 3 THEN
        IF U(NumLayer) >= .3 AND U(NumLayer) < .4 THEN
        FbCoef = .525 * HeRatio ^ (-.543)
        END IF
        IF U(NumLayer) >= .4 AND U(NumLayer) <= .5 THEN
        FbCoef = .5987 * HeRatio ^ (-.49394)
        END IF
    END IF
    IF HeRatio >= 3 THEN
        IF U(NumLayer) >= .3 AND U(NumLayer) < .4 THEN
        FbCoef = .7687586 * HeRatio ^ (-.9837)
        END IF
        IF U(NumLayer) >= .4 AND U(NumLayer) <= .5 THEN
        FbCoef = .91831145# * HeRatio ^ (-.98372)
        END IF
    END IF

    Ae = Radius / FbCoef
    FurthestOffset = Offset(NumDeflection)
    FurthestRead = DefRead(NumDeflection)
    IF NumDeflection = 1 THEN
        FurthestOffset = 48: FurthestRead = DefRead(1)
    END IF

DetermineSf:
    r = FurthestOffset
    Ra = r / Ae
    IF Ra >= 1 THEN
      IF U(NumLayer) >= .3 AND U(NumLayer) < .35 THEN Sf = (U(NumLayer) - .35) * (.2969 - .2933)
/ (.3 - .35) + .2933
      IF U(NumLayer) >= .35 AND U(NumLayer) < .4 THEN Sf = (U(NumLayer) - .4) * (.2933 - .2874) /
(.35 - .4) + .2874
      IF U(NumLayer) >= .4 AND U(NumLayer) < .45 THEN Sf = (U(NumLayer) - .45) * (.2874 - .2792)
/ (.4 - .45) + .2792
      IF U(NumLayer) >= .45 AND U(NumLayer) <= .5 THEN Sf = (U(NumLayer) - .5) * (.2792 - .2686)
/ (.45 - .5) + .2686
    END IF

    IF Ra < 1 THEN
      Remind$ = "*"
      IF Ra > .95 AND U(NumLayer) >= .45 THEN U(NumLayer) = .5: Sf = .2686
      IF Ra < .95 AND U(NumLayer) >= .45 THEN U(NumLayer) = .5: Sf = .196 + (.269 - .196) / (.95
- .5) * (Ra - .5)
      IF Ra > .9 AND (U(NumLayer) > .4 AND U(NumLayer) <= .45) THEN U(NumLayer) = .45: Sf = .279

      IF Ra < .9 AND (U(NumLayer) > .4 AND U(NumLayer) <= .45) THEN U(NumLayer) = .45: Sf = .21 +
```

```
(.279 - .21) / (.9 - .5) * (Ra - .5)
        IF Ra > .85 AND (U(NumLayer) > .35 AND U(NumLayer) <= .4) THEN U(NumLayer) = .4: Sf = .287

        IF Ra < .85 AND (U(NumLayer) > .35 AND U(NumLayer) <= .4) THEN U(NumLayer) = .4: Sf = .22 +
(.287 - .22) / (.85 - .5) * (Ra - .5)
        IF Ra > .8 AND (U(NumLayer) > .3 AND U(NumLayer) <= .35) THEN U(NumLayer) = .35: Sf = .293

        IF Ra < .8 AND (U(NumLayer) > .3 AND U(NumLayer) <= .35) THEN U(NumLayer) = .35: Sf = .23 +
(.293 - .23) / (.8 - .5) * (Ra - .5)
        IF Ra > .77 AND (U(NumLayer) = .3) THEN Sf = .297
        IF Ra < .77 AND (U(NumLayer) = .3) THEN Sf = .236 + (.297 - .236) / (.77 - .5) * (Ra - .5)

     END IF

     IF DevNam$ = "DYNAFLECT" THEN
     NDTLoad = NDTLoad / 2
     FurthestRead = FurthestRead / 2
     FurthestOffset = SQR(FurthestOffset * FurthestOffset + 100)
     DefRead(1) = DefRead(1) / 2
     END IF

     E = (NDTLoad * Sf) / (FurthestRead / 1000 * FurthestOffset)
     Deflection! = DefRead(1) / 1000
     PI = 3.141592
     SNx = 2

Iteration:
     HC = 209.3 * SNx / Radius * ((1 - U(NumLayer) ^ 2) / E) ^ (1 / 3)
     FB = ((1 + HC * HC) ^ .5 - HC) * (1 + HC / (2 * (1 - U(NumLayer)) * (1 + HC * HC) ^ .5))
     SSS = (2 * NDTLoad * (.0043 * Ht) ^ 3 / (PI * Radius * SNx ^ 3))
     DN! = SSS * (1 + FB * (SNx ^ 3 * (1 - U(NumLayer) * U(NumLayer)) / (E * (.0043 * Ht) ^ 3) -
1))

     IF (DN! > Deflection!) THEN
     SNx = SNx + 1 / (SNx * 2): GOTO Iteration
     END IF
     IF (Deflection! > DN!) THEN
     IF (Deflection! - DN!) > .001 THEN SNx = SNx - .01: GOTO Iteration
     IF (Deflection! - DN!) > .0001 THEN SNx = SNx - .001: GOTO Iteration
     IF (Deflection! - DN!) > .00001 THEN SNx = SNx - .0001: GOTO Iteration
     IF (Deflection! - DN!) > .000001 THEN SNx = SNx - .00001: GOTO Iteration
     IF (Deflection! - DN!) <= .000001 THEN GOTO DetermineSNy
     END IF

DetermineSNy:
     SNy = 3
          IF ReL = 50 THEN Zr = 0: GOTO IterationSNy
          IF ReL = 60 THEN Zr = -.253: GOTO IterationSNy
          IF ReL = 70 THEN Zr = -.524: GOTO IterationSNy
          IF ReL = 75 THEN Zr = -.674: GOTO IterationSNy
          IF ReL = 80 THEN Zr = -.841: GOTO IterationSNy
          IF ReL = 85 THEN Zr = -1.037: GOTO IterationSNy
          IF ReL = 90 THEN Zr = -1.282: GOTO IterationSNy
          IF ReL = 91 THEN Zr = -1.34: GOTO IterationSNy
```

```
        IF ReL = 92 THEN Zr = -1.405: GOTO IterationSNy
        IF ReL = 93 THEN Zr = -1.476: GOTO IterationSNy
        IF ReL = 94 THEN Zr = -1.555: GOTO IterationSNy
        IF ReL = 95 THEN Zr = -1.645: GOTO IterationSNy
        IF ReL = 96 THEN Zr = -1.751: GOTO IterationSNy
        IF ReL = 97 THEN Zr = -1.881: GOTO IterationSNy
        IF ReL = 98 THEN Zr = -2.054: GOTO IterationSNy
        IF ReL = 99 THEN Zr = -2.327: GOTO IterationSNy
        IF ReL = 99.9 THEN Zr = -3.09: GOTO IterationSNy
        IF ReL = 99.99 THEN Zr = -3.75: GOTO IterationSNy
        Zr = -1.282      'Default ReL=90%

IterationSNy:
        ZZ = LOG(10)
        F = .4 + 1094 / (SNy + 1) ^ 5.19
        Gcoeff = LOG(DSL / (4.2 - 1.5)) / ZZ
        A = 10 ^ ((1 / 9.36) * LOG(Y) / ZZ)
        AA = 10 ^ (-Zr * SD / 9.36)
        B = 10 ^ ((.2 / 9.36))
        BB = 10 ^ ((-Gcoeff / F) / 9.36)
        C = E ^ (-2.32 / 9.36)
        D = 10 ^ (8.07 / 9.36)
        S1y = A * AA * B * BB * C * D - 1
        IF ABS(S1y - SNy) <= 1E-10 THEN GOTO DetermineThickness
        IF S1y = 1 OR S1y >= 15 THEN SNy = S1y: GOTO DetermineThickness
        SNy = S1y
    GOTO IterationSNy

DetermineThickness:
    IF X = 2 THEN GOTO NDTapproach
    SNo = 0
    FOR I = 1 TO NumLayer - 1
    SNo = SNo + Thick(I) * Ai(I)
    NEXT I
NDTapproach:
    Cx = SNx / SNo
    IF Cx > .97715 THEN Rlx = 1: GOTO DetermineNfy
    IF Cx < .66 THEN Rlx = 0: GOTO DetermineNfy
    Rlx = SQR(LOG(.7 / (1 - Cx))) - .85
    IF Rlx < 0 THEN Rlx = 0
    IF Rlx > 1 THEN Rlx = 1
DetermineNfy:
    Accu = Accu + 1
    T1 = 9.36 * LOG(SNy + 1) / ZZ - .2
    T2 = LOG(2.2 / (4.2 - 1.5)) / ZZ
    T3 = .4 + 1094 / ((SNy + 1) ^ 5.19)
    T4 = 2.32 * LOG(E) / ZZ - 8.07
    T5 = Zr * SD
    LW18 = T1 + T2 / T3 + T4 + T5
    Nfy = 10 ^ (LW18)
    Rly = (Nfy - Y) / Nfy
    IF Rly < 0 THEN Rly = 0
    X1 = EXP((Rlx + Rly - .15) * (Rlx + Rly - .15))
    X2 = EXP((Rly + .85) * (Rly + .85))
```

```
     X3 = EXP((Rlx + .85) * (Rlx + .85))
     X1 = 1 - .7 * (1 / X1)
     X2 = 1 - .7 * (1 / X2)
     X3 = 1 - .7 * (1 / X3)
     Frl = X1 / (X2 * X3)
     IF Frl > 1 THEN Frl = 1
     SNol = SNy - Frl * SNx
     IF SNol <= 0 THEN SNol = 0
     Hol = SNol / Ai(1)

PrintToFile:
     IF X = 2 THEN
     LOCATE 22, 25: PRINT "Output file name: "; : INPUT "", Outfile$
          IF Outfile$ = "" THEN Outfile$ = "NDT1.OUT"
          OPEN Outfile$ FOR OUTPUT AS #2
          PRINT #2, "Project: "; Outfile$
     PRINT #2, "Subgrade   SNo  SNxeff   SNy    SNol   Thickness  RLx   RLy   Frl"
     PRINT #2, "modulus                                (inches)    %     %     %"
     PRINT #2, USING "#######   ##.## ##.## ##.##   ##.##   ###.#      #.## #.## #.## "; E,
SNo, SNx, SNy, SNol, Hol, Rlx, Rly, Frl;
     IF Ra < 1 THEN PRINT #2, Remind$ ELSE PRINT #2,
     GOTO CloseDataFile
     END IF
     IF DevNam$ = "DYNAFLECT" THEN DN! = DN! * 2
     PRINT #2, USING "###### ###### ###.## ##.## ##.## ##.## ##.## ###.# #.## #.## #.##
"; Location, E, DN! * 1000, SNo, SNx, SNy, SNol, Hol, Rlx, Rly, Frl;
     IF Ra < 1 THEN PRINT #2, Remind$ ELSE PRINT #2,
     GOTO ReadNewData

CloseDataFile:
     CLOSE #1, #2
     SOUND 150, 1
     CALL Box2
     CALL PrintResult(Outfile$)
     IF X = 3 THEN GOTO OverlayDesign2
     GOTO Menu

ErrorHandler2:
     IF ERR = 53 THEN
          SOUND 200, .8
          LOCATE 17, 25: PRINT "File not found           ":              RESUME UseExistingFile
     END IF
     IF ERR = 71 THEN
          SOUND 300, .8
          LOCATE 17, 25: PRINT "Disk not ready           ":              RESUME UseExistingFile
     END IF
     IF ERR = 62 THEN RESUME CloseDataFile

ErrorHandler3:
     IF ERR = 53 THEN
          SOUND 200, .8
          LOCATE 17, 25: PRINT "File not found     ":              RESUME EditData1
     END IF
     IF ERR = 71 THEN
```

```
          SOUND 300, .8
          LOCATE 17, 25: PRINT "Disk not ready     ":              RESUME EditData1
     END IF
Quit:
     CLS
     END

SUB BottomMsg STATIC
     LOCATE 25, 26: COLOR 0, 7: PRINT " PRESS Esc TO EXIT/SAVE DATA "; : COLOR 7, 0
END SUB

     SUB Box1 STATIC
     LOCATE 15, 23: PRINT STRING$(34, 196)
     LOCATE 15, 23: PRINT STRING$(1, 218)
     LOCATE 15, 57: PRINT STRING$(1, 191)
     FOR I = 16 TO 18
     LOCATE I, 23: PRINT STRING$(1, 179)
     LOCATE I, 57: PRINT STRING$(1, 179)
     NEXT I
     LOCATE 18, 23: PRINT STRING$(34, 196)
     LOCATE 18, 57: PRINT STRING$(1, 217)
     LOCATE 18, 23: PRINT STRING$(1, 192)
     LOCATE 16, 25: PRINT "                              "
     END SUB

SUB Box2 STATIC
     COLOR 7, 0: CLS
     LOCATE 1, 1: PRINT STRING$(79, 196)
     LOCATE 1, 1: PRINT STRING$(1, 218)
     LOCATE 1, 80: PRINT STRING$(1, 191)
     FOR I = 2 TO 23
     LOCATE I, 1: PRINT STRING$(1, 179)
     LOCATE I, 80: PRINT STRING$(1, 179)
     NEXT I
     LOCATE 23, 1: PRINT STRING$(79, 196)
     LOCATE 23, 80: PRINT STRING$(1, 217)
     LOCATE 23, 1: PRINT STRING$(1, 192)
END SUB

SUB PrintResult (Outfile$) STATIC
     OPEN Outfile$ FOR INPUT AS #1
     LOCATE 3, 5: INPUT "Do you want to print results on Screen or Printer (S/P) "; OutDevice$
     IF UCASE$(OutDevice$) = "P" THEN OPEN "O", #3, "LPT1:" ELSE OPEN "O", #3, "SCRN:"
     Row = 5
     WHILE NOT EOF(1)
     LINE INPUT #1, ResultIn$
     LOCATE Row, 3: PRINT #3, ResultIn$
     Row = Row + 1
     IF Row > 21 THEN
     LOCATE 25, 21: COLOR 0, 7: PRINT "PRESS ANY KEY TO CONTINUE OR Esc TO EXIT"; : COLOR 7, 0
     anykey$ = INPUT$(1)
          IF anykey$ = CHR$(27) THEN CLOSE : EXIT SUB
          FOR I = 8 TO 21
               LOCATE I, 3: PRINT SPACE$(76)
```

```
        NEXT I
        Row = 8
    END IF
    WEND
    CLOSE #1, #3
    LOCATE , 3: PRINT "- END -"
    LOCATE 25, 28: COLOR 0, 7: PRINT "PRESS ANY KEY TO CONTINUE"; : COLOR 7, 0
    anykey$ = INPUT$(1)
END SUB

SUB TempAdjust (TempAdj) STATIC
    LOCATE 8, 2: PRINT STRING$(78, 196)
    LOCATE 8, 1: PRINT CHR$(195)
    LOCATE 8, 80: PRINT CHR$(180)
    LOCATE 9, 5: INPUT "Enter pavement temperature at test site (Default 70 F): ", Tempe
    IF Tempe = 0 THEN Tempe = 70
    LOCATE , 5: PRINT "Curve ID (Base Thickness (inch)       Base Material"
    LOCATE , 5: PRINT "────────────────────────────         ──────────────"
    LOCATE , 5: PRINT "A. (all Thickness)                    Asphalt (Full Depth)"
    LOCATE , 5: PRINT "B. (4-in of Granual Subbase)          Asphalt (Deep Strength)"
    LOCATE , 5: PRINT "C. (6-in); D (12-in); E (20-in);"
    LOCATE , 5: PRINT "F. (25-in)                            Granular (Nonstabilized)"
    LOCATE , 5: PRINT "G.                                    Portland Cement Concrete"
    LOCATE , 5: PRINT "Cement Treated Base"
    LOCATE , 5: PRINT "D. (4-in); E (8-in)                   Sound"
    LOCATE , 5: PRINT "C. (4-in); D (8-in)                   Cracked"
    LOCATE , 5: PRINT
    LOCATE , 5: INPUT "Select Curve Identification (A, .., G) => ", Curve$
    IF Curve$ = "" THEN Curve$ = "A"
    IF UCASE$(Curve$) = "A" THEN
        TempAdj = 8.907039 - .3132037 * Tempe + 4.809102E-03 * Tempe ^ 2 - 3.429334E-05 * Tempe
^ 3 + 9.19731E-08 * Tempe ^ 4
    END IF
    IF UCASE$(Curve$) = "B" THEN
        TempAdj = 4.253685 - 9.139152E-02 * Tempe + 5.032298E-04 * Tempe ^ 2 + 7.927465E-06 *
Tempe ^ 3 - 1.119466E-07 * Tempe ^ 4 + 3.884587E-10 * Tempe ^ 5
    END IF
    IF UCASE$(Curve$) = "C" THEN
        TempAdj = 4.59491 - .1431501 * Tempe + 2.217366E-03 * Tempe ^ 2 - 1.599463E-05 * Tempe ^
3 + 4.358037E-08 * Tempe ^ 4
    END IF
    IF UCASE$(Curve$) = "D" THEN
        TempAdj = 3.70286 - .1064016 * Tempe + 1.617305E-03 * Tempe ^ 2 - 1.139606E-05 * Tempe ^
3 + 3.018599E-08 * Tempe ^ 4
    END IF
    IF UCASE$(Curve$) = "E" THEN
        TempAdj = 3.157851 - 8.274735E-02 * Tempe + 1.221044E-03 * Tempe ^ 2 - 8.363603E-06 *
Tempe ^ 3 + 2.157132E-08 * Tempe ^ 4
    END IF
    IF UCASE$(Curve$) = "F" THEN
        TempAdj = 3.40264 - .1063771 * Tempe + 1.806766E-03 * Tempe ^ 2 - 1.383258E-05 * Tempe ^
3 + 3.912249E-08 * Tempe ^ 4
    END IF
    IF UCASE$(Curve$) = "G" THEN
```

```
        TempAdj = 1.824984 - 2.531542E-02 * Tempe + 2.591468E-04 * Tempe ^ 2 - 9.324547E-07 *
Tempe ^ 3
    END IF
END SUB
```

APPENDIX C

EXAMPLES OF OVERLAY DESIGN

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EXAMPLES OF OVERLAY DESIGN

Example calculations for the overlay design procedure are contained in this appendix.

<u>Asphalt Concrete over Asphalt Concrete</u>

A. <u>Salem Parkway</u>

1) Pavement layer thicknesses

   3.5" AC (asphalt concrete)

   10" CTB (cement-treated base)

   6" CTS (cement-treated subbase)

2) Future traffic in 20 years = 3.2×10^6 ESAL's

3) $P_o = 4.2$, $P_t = 2.5$, $\Delta PSI = 1.7$

4) Calculate SN_o from standard coefficients from AASHO road test

   $SN_o = (3.5")(.44) + (10")(.26) + (6")(.17)$

   $= 5.16$

5) Using NDT Method 1, find SN_{xeff}

   $E_{AC} = 863{,}000$ psi (from core testing)

   $E_{CTB} = 2{,}280{,}000$ psi (from core testing)

   ↓

   BISDEF

   ↓

   $E_{CTS} = 100{,}000$ psi (lower bound value)

   $E_{SG} = 14{,}000$ psi

   $SN_{xeff} = (3.5")(.44) + (10")(.28) + (6")(.12)$

   $= \underline{5.06}$

Layer coefficients for the base and subbase are estimated values.

6) Determine SN_y from Figure 2.2

Reliability = 95%

S_o = .35 (standard deviation)

Future traffic = $3.2x10^6$ ESAL's

E_{SG} = 14,000 psi

ΔPSI = 1.7

From Figure 2.2, SN_y = 3.5

7) Remaining Life Factor

a) NDT Approach

$C_x = SN_{xeff}/SN_o = 5.06/5.16 = 0.98$

R_{LX} = 0.89 from Figure 2.4

b) Using Figure 2.2 to find N_{FY} and thus R_{LY}

SN_y = 3.5

ΔPSI = 2.2 (P_o = 4.2 P_f = 2.0)

E_{SG} = 14,000 psi

↓

N_{FY} = $4.9x10^6$ ESAL's (from Figure 2.2)

$$R_{LY} = \frac{N_{FY}-Y}{N_{FY}} = \left(\frac{4.9-3.2}{4.9}\right) = .35$$

Using Figure 2.7 (R_{LX} = 0.89 and R_{LY} = .35)

F_{RL} = .98

8) $SN_{OL} = SN_y - F_{RL} (SN_{xeff})$

$SN_{OL} = 3.5 - .98 (5.06)$

$SN_{OL} < 0$ ∴ no overlay required

B. Lancaster Blvd.

1) Pavement layer thicknesses

3.5" AC (asphalt concrete)

18" Base (aggregate base)

2) Future traffic in 20 years = 1.0×10^6 ESAL's

3) $P_o = 4.2$, $P_t = 2.5$ $\Delta PSI = 1.7$

4) Calculate SN_o from layer coefficients from AASHO road test

$$SN_o = (3.5")(.44) + (18")(.14)$$

$$= 4.06$$

5) Using NDT Method 2, find SN_{xeff} (from Ullidtz equation rather than AASHTO equations)

a) Equivalent thickness of pavement for AC and base

Assume $E_{AC} = 200,000$ psi

$E_{base} = 40,000$ psi

$E_{sg} = 19,000$ psi

AC: $$H_e = .9\,(3.5)\sqrt[3]{\frac{200,000\,(1-.45^2)}{19,000\,(1-.35^2)}}$$

$$= 6.7"$$

Base: $$H_e = .9\,(18)\sqrt[3]{\frac{40,000\,(1-.45^2)}{19,000\,(1-.35^2)}}$$

$$= 20.1"$$

$H_e = 6.7" + 20.1" = 26.8" < 36"$ (maximum h_e for furthest sensor at 36")

b) Ullidtz equation

$$E_{SG} = \frac{(1-\mu^2)P_o a^2}{r d_r}$$

u = Poisson's ratio

P_o = loading pressure

a = radius loading plate

r = radial distance to furthest sensor

d_r = deflection at furthest sensor

$$E_{SG} = \frac{(1-.45^2)\ \frac{9000}{\pi a^2}\ a^2}{36"\ (d_r)}$$

using $d_r = 5.08$

E_{SG} = 12,493 psi (use 14,000 psi for the remainder of calculations)

Substitute E_{SG} in above equation for equivalent thickness to see if H_e changes.

c) h_t = 3.5" + 18" = 21.5"

d) Max deflection = 28.40×10^{-3} in. from deflection test

e) Using AASHTO regression equations, find

SN_{xeff} = 3.31

6) Solve SN_y from Figure 2.2

Reliability = 95%

Standard deviation = .35

Traffic = 1.0×10^6 ESAL

E_{SG} = 14,000 psi

ΔPSI = 1.7

SN_y = 2.8

7) Remaining Life Factor

a) NDT Approach

$C_x = SN_{xeff}/SN_o$ = 3.3/4.06 = .81

R_{LX} = .32 from Figure 2.4

b) Using Figure 2.2 to find N_{fy}

$SN_y = 2.8$

$\Delta PSI = 2.2$

$E_{SG} = 14{,}000$ psi

↓

$N_{FY} = 1.5x10^6$

$$R_{LY} = \frac{N_{FY}-y}{N_{FY}} = \frac{1.5-1.0}{1.5} = .32$$

c) Using Figure 2.7 to find F_{RL}

8) $SN_{OL} = SN_y - F_{RL}\ (SN_{xeff})$

$= 2.8 - .67\ (3.3)$

$= .589$

$h_{OL} = SN_{OL}/a_i$

$h_{OL} = \frac{.589}{.44}$ (for asphalt)

$h_{OL} = 1.34"$ use 1.5"

Asphalt Concrete over Portland Cement Concrete

Interstate 5

1) Pavement layer thickness

D_o = 8" PCC (portland cement concrete)

D_{Sb} = 12" base (aggregate base)

2) Future expected traffic = 20 years ($47x10^6$ ESAL's)

3) $P_o = 4.2$, $P_t = 2.5$

$\Delta PSI = 1.7$

4) Calculate SN_o

$SN_o = (8")(.50) + (12")(.14)$

$= 5.68$

5) Using NDT Method 1, find SN_{xeff}

$E_{PCC} = 2,869,000$ psi (from core testing)

↓

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↓

$E_{base} = 30,000$ psi

$E_{SG} = 17,000$ psi

$D_{xeff} = 6.6$ from Figure 4.5

$SN_{xeff-rp} = D_{Sb}\ a_{Sb} = (.20)(12") = 2.4"$

$SN_{xeff} = SN_{xeff-rp} + 0.8\ D_{xeff}$

$= 2.4 + 0.8\ (6.6)$

$SN_{xeff} = 7.68$

6) Solve SN_y from Figure 2.2

Reliability = 95%

Standard deviation = .35

Traffic = 47×10^6 ESAL

$E_{SG} = 17,000$

$\Delta PSI = 2.0$

↓

$SN_y = 4.7$

7) Remaining Life Factor

a) NDT Approach

$C_x = SN_{xeff}/SN_o = 7.68/5.68 > 1.0$

$R_{LX} = 1.0$ from Figure 2.4

b) Using Figure 2.2, find N_{FY} and thus R_{LY}

$SN_y = 4.7$

$\Delta PSI = 2.2 \qquad (P_o = 4.2,\ P_f = 2.0)$

$E_{SG} = 17{,}000$ psi

$\downarrow$

$N_{FY} = 85x10^6$ from Figure 2.2

$$R_{LY} = \frac{N_{FY}-y}{N_{FY}} = \frac{85-47}{85} = .45$$

Using Figure 2.7 to find F_{RL}

$F_{RL} = .99$

8) $SN_{OL} = SN_y - F_{RL}\ (SN_{xeff})$

$= 4.7 - (.99)\ (7.68)$

$SN_{OL} < 0$

$\therefore$ No overlay needed

Portland Cement Concrete over Portland Cement Concrete

Interstate 5

1) Pavement layer thicknesses

D_o = 8" PCC

D_{Sb} = 12" Base

2) Future expected traffic in 30 years = $78.95x10^6$ ESAL's

3) $P_o = 4.5,\ P_t = 2.5$

$\therefore \Delta PSI = 2.0$

4) Choose bonding option (bonded overlay)

5) Using NDT Method 1, find D_{xeff}

E_{PCC} = 2,869,000 psi (from core testing

$\downarrow$

BISDEF

↓

E_{Base} = 30,000 psi

E_{SG} = 17,000

D_{xeff} = 6.6 from Figure 4.5

6) Solve for k as outlined in AASHTO guide (k = 600 pci)

7) Solve for D_y

Reliability = 95%

Standard deviation = 3.5

ΔPSI = 2.0

Traffic = 78.95×10^6 ESAL's

Assume:

C_d = 1.0

J = 3.2 for CRCP

S_c' = 650 psi

E_c = 5×10^6 psi

↓

D_y = 13.5"

8) Remaining Life Factor

a) NDT Approach

$C_x = D_{xeff}/D_o = 6.6/8 = .82$

b) Using Figure 2.3, find N_{fy} and thus R_{LY}

$N_f = 100 \times 10^6$

$$R_{LY} = \frac{N_{FY}-y}{N_{FY}} = \frac{100-78.95}{100} = .21$$

Using Figure 2.7

F_{RL} = .85

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

$D_{OL} = 13.5 - (.85)(6.6)$

$= 7.89$ use 8"

Portland Cement Concrete over Asphalt Concrete

A. Find k value for:

Salem Parkway (Pavement temperature = 76°F)

$k_d = F_d \times C_d$

$C_d = 1.2$ (from Table 4.2)

$F_d = .99$ (from Figure 4.7)

$\therefore k_d = 1.188$

$d_{oc} = d_o K_d$

$d_o = 5.22$ (deflection from NDT test)

$d_{oc} = (5.22)(1.188) = 6.201 \times 10^{-3}$ in.

$E_c = P/(D_p)(d_{oc})$

$P = 9000$ lbs

$D_p = 5.91$ in.

$E_c = 9000/(5.91)(6.201 \times 10^{-3}) = 245{,}600$

$k = 890$ pci from Figure 4.8 (design value) put directly into equation

$D_y = 7.5"$ from Figure 2.3

B. Find k value for

Lancaster Drive (Pavement temperature = 108°F)

$k_d = F_d \times C_d$

$C_d = 1.35$ (from Table 4.2)

$F_d = .90$ (from Figure 4.7)

$\therefore k_d = 1.215$

d_o = 24.80 (deflections $x10^{-3}$ from NDT test)

d_{oc} = (1.215)(24.80) = 30.13

E_c = $P/(D_p)(d_{oc})$, $d_{oc} = d_o K_d$

P = 9000 lbs

D_p = 5.91 in. = radius

E_c = $9000/(5.91)(30.13x10^{-3})$ = 50,542

k = 280 pci from Figure 4.8

D_y = 7" from Figure 2.3