DESIGN OF ASPHALT CONCRETE OVERLAY TO MITIGATE REFLECTIVE CRACKING

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CHAPTER 1

INTRODUCTION

This report is prepared for the Florida Department of Transportation on the development and design of "asphalt concrete overlay design equations and design procedures to address reflective cracking".

Design equations were developed using Fracture Mechanics criteria. They were developed for flexible overlays of both flexible and rigid pavements with the 'Stress Absorbing Membrane Interlayer' (SAMI) and Reinforcing Grid. A complete package of computer programs have been assembled to design overlays capable of resisting or retarding reflective cracking. The program is designed for use on Microsoft Windows (95, 98, NT).

Objective

This user manual outlines a procedure for the design of asphaltic concrete overlays on existing asphalt concrete and Portland cement concrete pavement surfaces. It is intended to guide the user on the type and form of information required and contains all elements necessary for the user to design overlays with and without SAMIs and reinforcing grids. This manual also covers in detail the theory and logic underlying the procedure.

Summary of Procedure

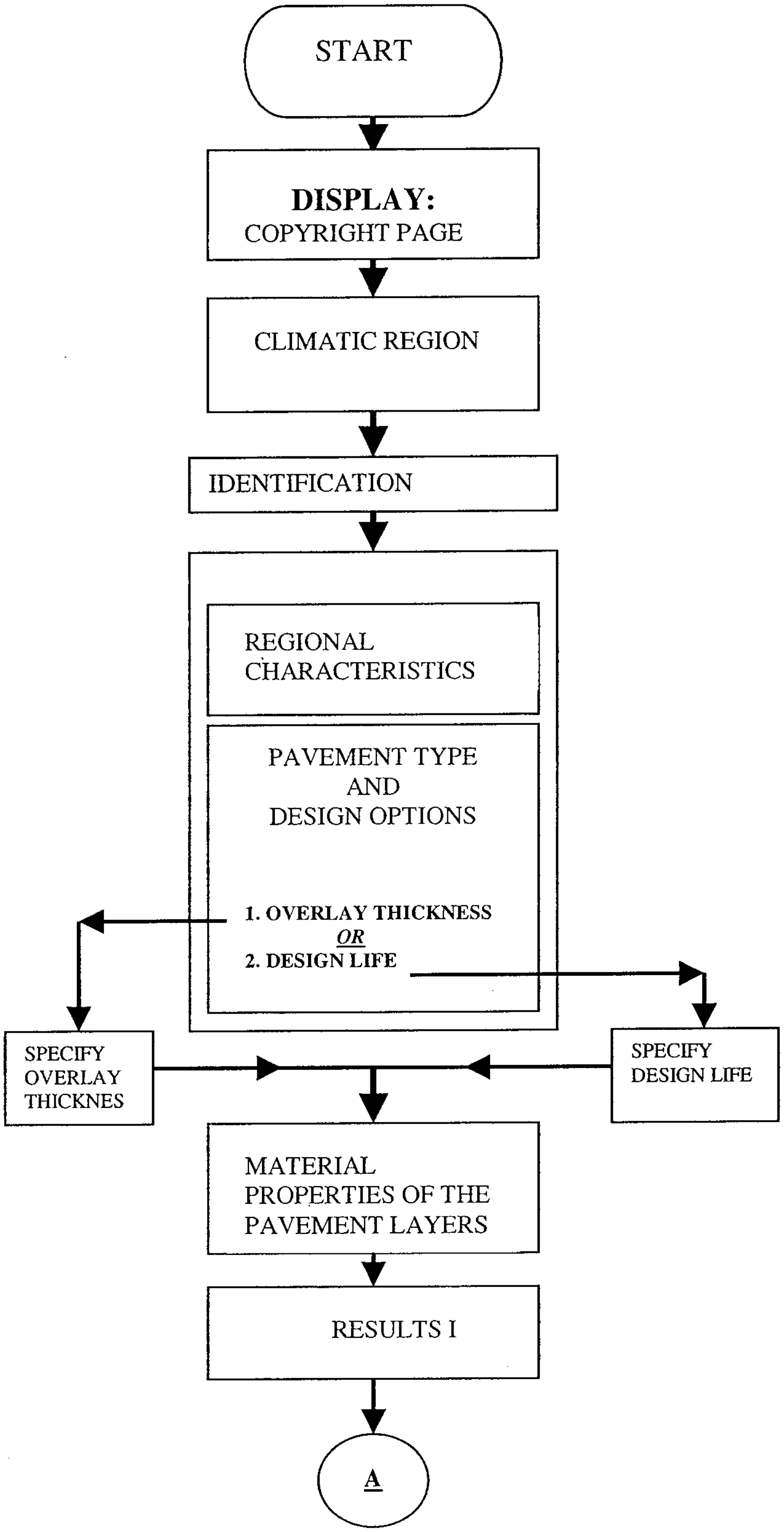
The overlay design procedure is mechanistic-empirical in concept. Mechanistic equations were developed to represent the existing pavement as a beam on elastic foundation. Basic asphalt concrete properties are used with fracture mechanics concepts to calculate the rate at which cracks in the existing pavement will propagate through the overlay due to traffic and thermal action. These mechanistic equations were calibrated with in-service data from Florida Department of Transportation.

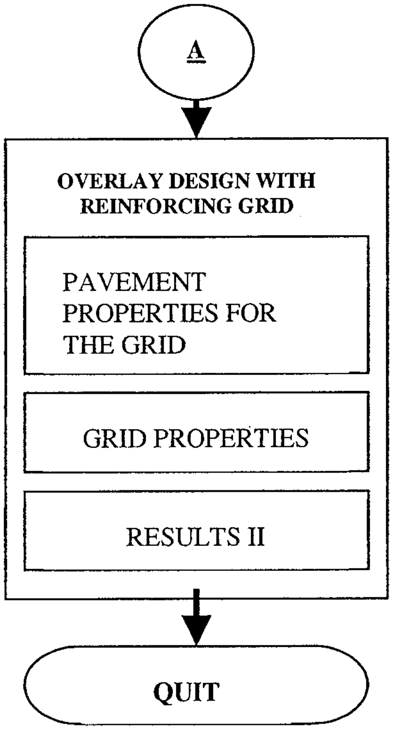
To use these equations, the design engineer supplies information on the types and thicknesses of layers in the pavement, the material properties of the asphalt concrete being considered for use in the overlay and the traffic to which the overlay is expected to be subjected. The program then provides an estimate of the time to failure by reflective cracking. Failure can be at three different levels of damage.

Outline of Report

Figure 1 is a simplified flow chart illustrating the steps required to use the program. Chapter 2 provides guidance on how to use the design concepts included in this procedure. Chapter 3 provides guidance on how to run the computer program, which was developed as a part of this project. A tutorial is included in Chapter 3. Program listings and data acquired from the Florida Department of Transportation are provided in the Appendices.

Simplified Reflection Cracking Design Flow Chart




A
OVERLAY DESIGN WITH REINFORCING GRID
PAVEMENT PROPERTIES FOR THE GRID
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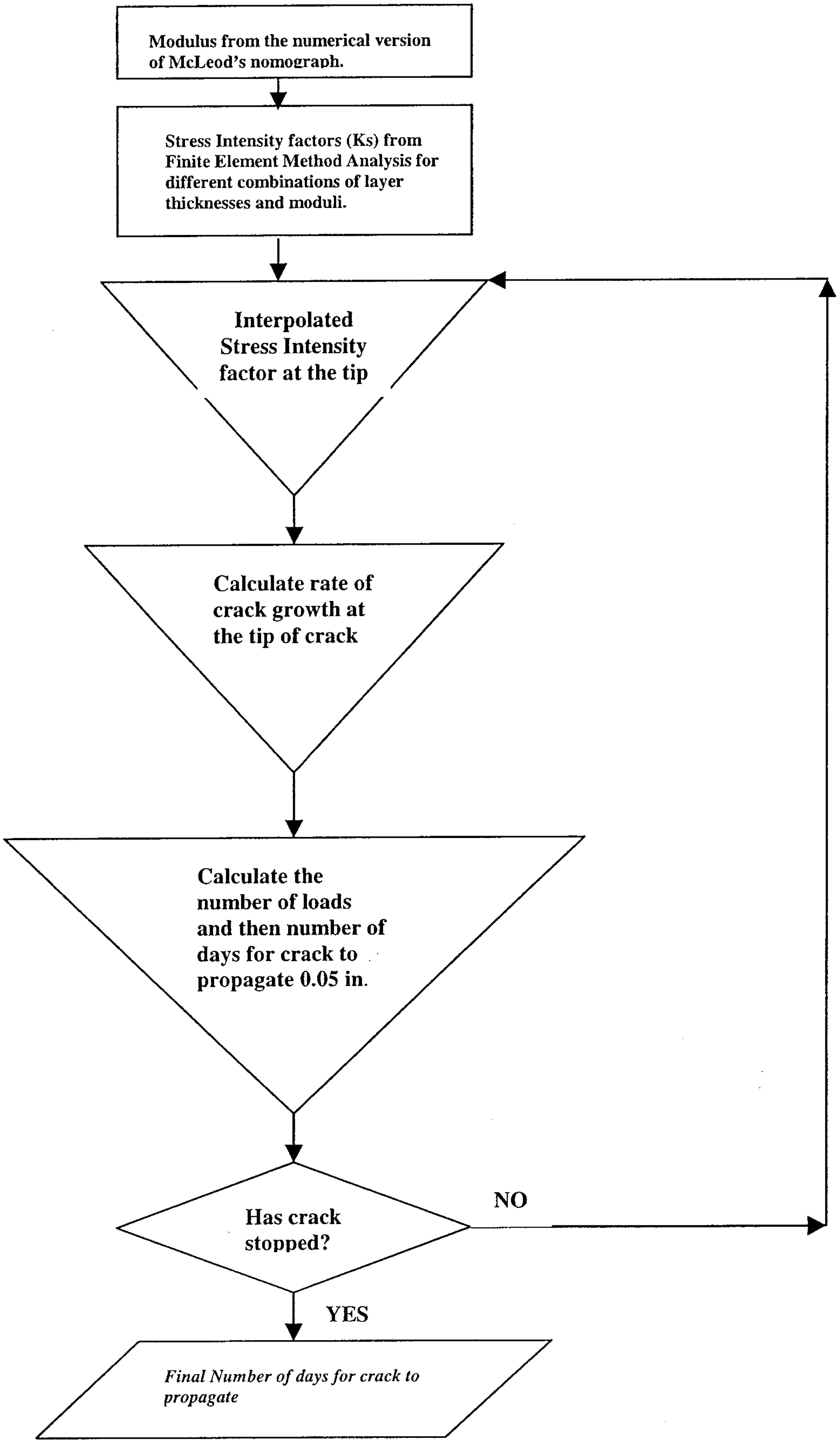


CHAPTER 2

CONCEPTS OF THE FRACTURE MECHANICS FOR REFLECTION CRACKING AND PROGRAM STRUCTURE

Introduction

Many pavements which are considered to be structurally sound after the construction of an overlay prematurely exhibit a cracking pattern similar to that, which existed in the old pavement. The cracking in the new overlay surface is due to the inability of the overlay to withstand shear and tensile stresses created by movements of the underlying pavement. This movement may be due to traffic loading causing differential deflections in the underlying pavement layers, expansion or contraction of subgrade soils, or expansion or contraction of pavement itself due to changes in the temperature. Pavement movement, induced by any of the above causes, creates shear or tensile stresses in the overlay. When these stresses become greater than the shear or tensile strength of the asphaltic concrete, a crack develops in the new overlay. This propagation of an existing cracking pattern from the old pavement into and through a new overlay is known as "reflection crack".

The occurrence of a reflection crack may take place several years after overlay construction or only a few months. This form of cracking, together with its accompanying effects, is the primary cause of overlay deterioration. When a reflection crack occurs, the continuity of the overlay surface is destroyed, the structural strength of the pavement is decreased, and water is allowed to enter the pavement system, leading to further deterioration. Thus the occurrence of a reflection crack prematurely shortens the useful life of asphalt overlays by extending the same problems which weakened the original pavement into the new overlay.

Reinforcing grids reduce the amount of water that enters the sublayers of a pavement by reinforcing the overlay. Reinforcing delays the appearance of the reflection crack and reduces the width of cracks that develop. Various engineering reinforcing grids have been used in recent years to provide reinforcing for overlay in attempting to prevent or delay the occurrence of reflection crack and the subsequent penetration of water into the sublayers. Reinforcing grids made of fiberglass or polypropylene have been used for this purpose.

Other treatments that have been used with greater or less success include fabric strips placed on the cracks in the old pavement surface or on a one inch leveling course before the overlay is placed; fibers mixed in with the asphalt concrete overlay; and stress or strain absorbing membrane interlayers (Stress Absorbing Membrane Interlayers) between the old pavement and the new overlay.

Pretreatments include undersealing or replacing joints or cracks in the old pavement to restore load transfer prior to placing the overlay; milling the old surface to restore a level surface, to remove aged or stripped surface material, or to preserve drainage characteristics; and in some cases, cracking and sealing the old pavement prior to overlay.

All of these treatments have been attempted and observed under a variety of traffic and weather conditions. Some work and others don't, raising questions of what causes a reflection crack and, more to the point, whether it is possible to design an overlay to prevent, retard, or mitigate reflection cracking. Successful design always requires an understanding of the cause so that a successful strategy can be devised to eliminate or at least to lessen the cause or causes. With reflection cracking, the strategy involves the selection and placement of materials, together with an appropriate pre-treatment.

CAUSE OF REFLECTION CRACKING

Both traffic loads and temperature changes cause cracks in an old pavement to reflect through the overlay. Everytime a load passes over a crack in the old pavement, three pulses of high stress concentration occur at the tip of a crack as it grows up through the overlay, as illustrated in Figure 1. With each pulse of high stress concentration, the crack grows a little bit more. The first stress pulse that the crack feels is a maximum shear stress pulse as shown at Point A in Figure 1. The second stress pulse is a maximum bending stress pulse as shown at point B in Figure 1. The third stress pulse is again a maximum shear stress pulse, except that it is in the opposite direction to the previous shear stress pulse. Also, because there is void beneath the old surface at this point, the maximum shearing stress at point C is larger than at point A. These stress pulses occur in a very short period of time, on the order of 0.05 seconds. The stiffness of the asphaltic concrete in the overlay and in the old pavement at these high loading rates is fairly high.

The change of temperature in an overlaid pavement can also cause a reflection crack to grow. The thermal stresses in the overlay are due to temperature changes at the surface as shown

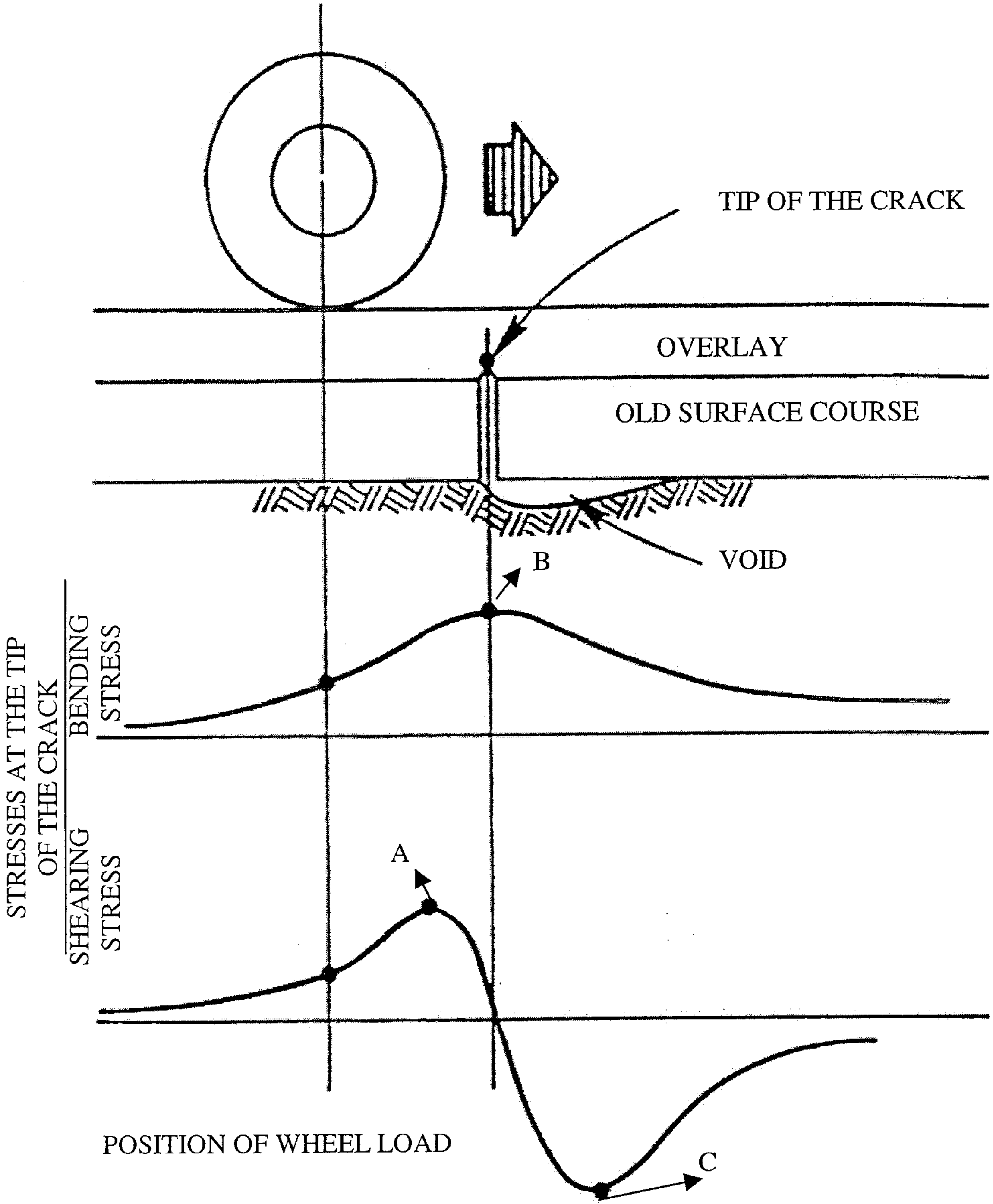


Figure 1. Stresses and Crack Growth in Overlays Due to Traffic.

at point A in Figure 2, and to the contraction and curling of the underlying old pavement surface as shown at point B in the same Figure. It is observed that thermal stresses can cause cracks to propagate both from the top and the bottom of the overlay. The contraction and curling of the old pavement surface layer applies a shear stress along the bottom of the overlay and produces a concentration of tensile stress at point B. The change of temperature in a pavement occurs very slowly, over a period of several hours or even the major part of a day. The stiffness of the asphaltic concrete in the overlay and in the old pavement is very low, as much as 1000 to 10,000 times lower than the modulus that these same materials exhibit under traffic loads.

Every time a load passes and every time the temperature decreases in an overlaid pavement the reflection crack grows a little more. The major hope that engineers have of retarding the growth of such reflection crack is in the selection of the thickness and material properties of the overlay and of the pretreatment of the old pavement so as to reduce, as much as possible, the growth of these cracks. This is the purpose of the design..

Design requires the use of relatively simple tests which determine the "fracture properties" of an overlay due to one of the three major means by which a crack propagates through the overlay: bending, shear, and thermal contraction of the underlying pavement. The " fracture properties" are material properties of the overlay and depend upon the properties of the asphaltic concrete mixture, the reinforcing grid, fabric, SAMI, or other interlayer, its position within the overlay, and its tack coat or adhesive application rate. The "fracture properties" for fracture due to bending, shear, and contraction are then put into a simple computer program along with the data on traffic, daily temperature change, crack spacing and overlay thickness to calculate the number of load applications and temperature cycles that a given overlay can withstand. The advantage of this approach is that more of the simple tests can be made for each mode of fracture separately to permit a more careful investigation of the best grid, or SAMI properties and positions within an overlay and the best tack coat application rate to reduce as much as possible the rate of crack growth through an overlay. These tests can show clearly the contribution of the overlay treatment to the reflection crack in each fracture mode separately and can lead directly to rules, guidelines, and specification limits on the use and application of reinforcing grids, fabrics, and Stress and Strain Absorbing Membrane Interlayers in overlays.

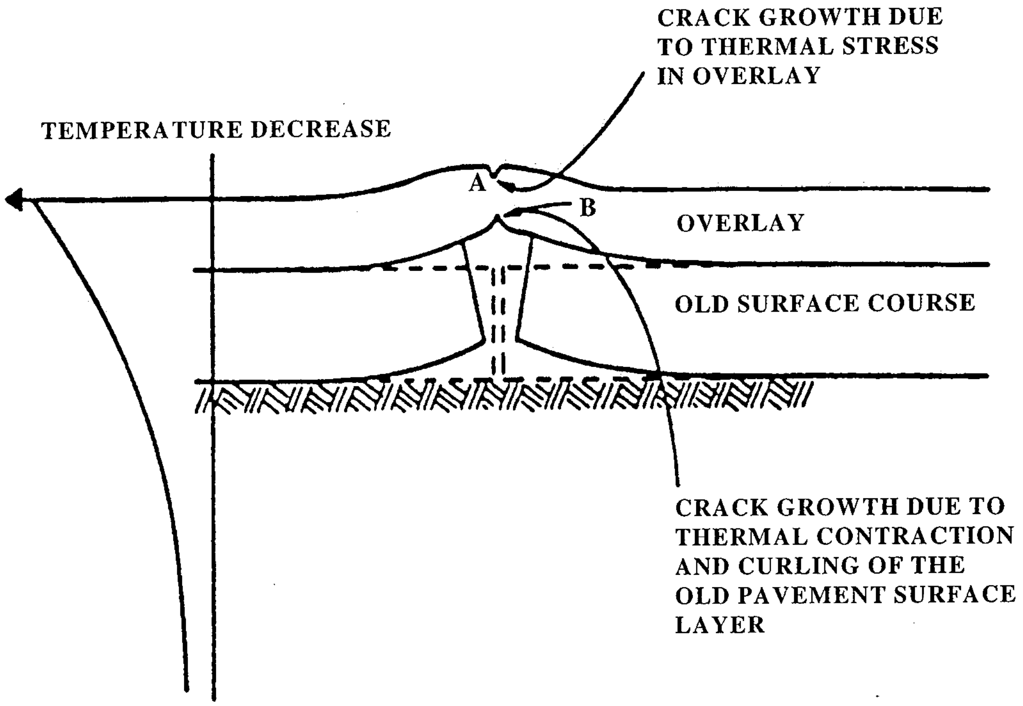


Figure 2. Temperature Changes and Consequent Crack Growth in Overlays.

Fracture Mechanics Analysis for Reflection Cracking

The reflection cracking life of an asphalt overlay can be predicted by Paris' law.

$$\frac{dC}{dN} = A(K)^{n} \qquad (1)$$

A, n = Fracture parameters of the material

K= stress intensity factors (K_b, K_s, or K_t)

N= number of load cycles

C= crack length

A and n are determined from overlay beam test data. The value of n is calculated internally in the program from the calculated slope of the log stiffness versus log (loading time) curve, m. The relation between m and n is

$$n = g_0 + \frac{g_1}{m} \qquad (2)$$

where the values of g_0 and g_1 are taken as follows for different climatic zones (Ref 5). These values are based on Backcalculation Asphalt Moduli.

	CLIMATIC ZONES			
COEFFICIENTS	***Wet–Freeze***	***Wet-No Freeze***	***Dry-Freeze***	***Dry-No Freeze***
g_0	-2.090	-1.615	-2.121	-1.992
g_1	1.952	1.98	1.707	1.984

for bending and shearing reflection cracking and

$$n = \frac{2}{m} \qquad (3)$$

for thermal reflection cracking.

The relationship between log A and n for bending and shear reflection cracking is

$$\mathbf{A = 10^{(-2.19 - 2.38 * n)}} \qquad (4)$$

and for thermal reflection cracking,

$$\mathbf{A = 10^{(-1.32421 - 1.43707 * n)}} \qquad (5)$$

This is for Wet-NoFreeze region (Florida) (Ref 5)

The stress intensity factors (K) for in service pavements are determined using finite element technique by P.W. Jaywickrama and R. L. Lytton for bending, shearing and thermal reflection cracking (Ref 7).

Analysis for Reinforcing Grid:

Stress Distribution in Overlay:

Stress distribution in a beam with a vertical crack is assumed as in Figure

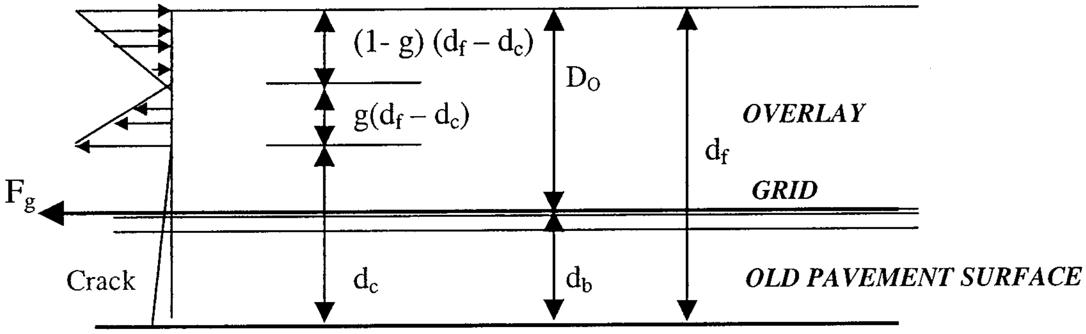


Figure 3: Stress Distribution in the beam with vertical crack.

Total force in the Grid

Total grid force is calculated as follows using E_g and M_g

$$M_g = \frac{n\pi t_g}{4s} E_g \qquad (6)$$

where

n = number of strand in each grid spacing
t_g = thickness of the grid
s = spacing of strands
E_g = modulus of elasticity of the grid material.

M_g, the equivalent modulus of elasticity of the grid is calculated as in the Equation (6). It is used in equation (7) to determine the force in the grid.

$$F_g = \frac{M_g t_g 12 S_t \sqrt{3d_f}\,[g(1-\frac{d_c}{d_f}) + (\frac{d_c}{d_f} - \frac{d_b}{d_f})]\frac{1}{4} e^{-\beta * L} \sin(\beta L)}{\sqrt{3E_o(1-\frac{d_c}{d_f})^3 E_{old}}} \tag{7}$$

"g" and "β" are calculated as follows in the above equations:

$$g = \frac{2 + \frac{d_c}{d_f} - 3\frac{d_b}{d_f}}{3(1 + \frac{d_c}{d_f} - 2\frac{d_b}{d_f})} \tag{8}$$

$$\beta = [\frac{3E_{old}}{E_o d_f^{\,3}(1-\frac{d_c}{d_f})^3}]^{1/4} \tag{9}$$

where,

F_g = Force in the grid
S_t = Average Tire Pressure in psi (80)
D_o = Depth of Overlay above the grid
d_c = Depth of Crack
d_b = Depth of overlay below the grid
d_f = Depth of overlay
L = Length of tire contact
E_o = Modulus of Overlay
E_{old} = Modulus of Old Pavement
τ_s = Friction stress below the grid

Friction in Grid (τ_s)

There are three kinds of failure modes in an overlay test (Figure 4)

Mode I and III failures are called the bonding modes, and mode II failure is called the debonding mode. In the bonding modes and debonding modes, the shear stress distribution is different.

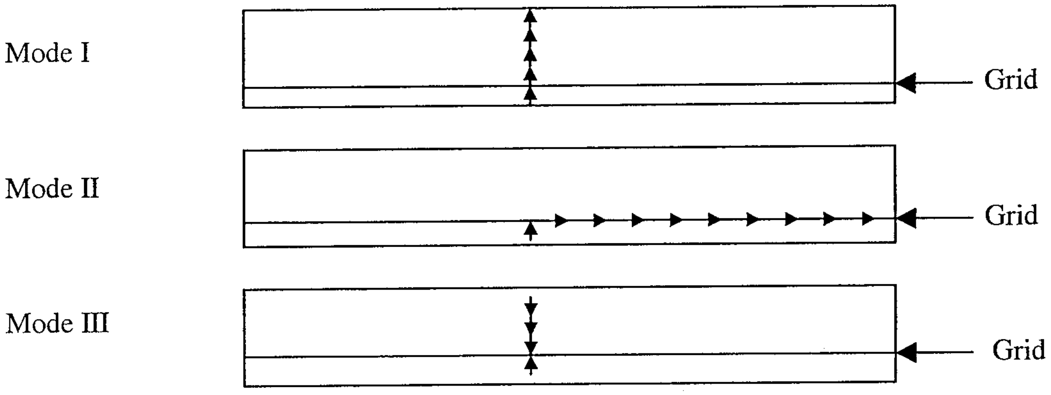


Figure. 4 Modes of Failure in the Overlay

In each case, the shear stress distribution is assumed as follows (Figure 5):

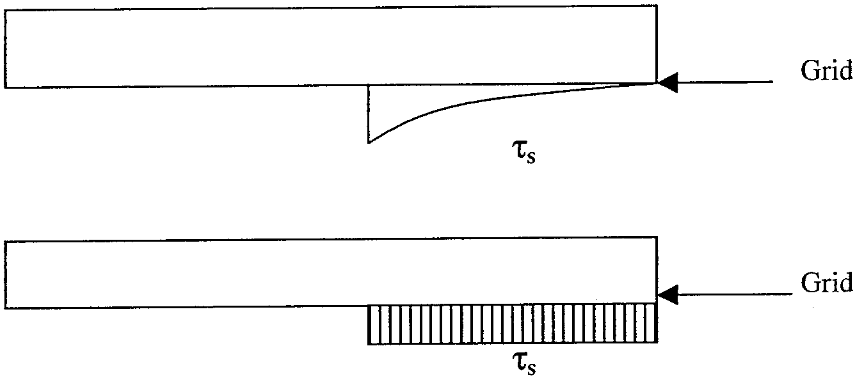


Figure. 5 Shear Stress Distribution

<u>Bonded case:</u>

$$\tau_s = \frac{k_0}{\beta_f \sinh(\frac{\beta_f w}{2})}[\cosh(\frac{\beta_f w}{2}) - 1] \tag{10}$$

where,

$$\beta_f = [\frac{k_0}{E_u d_u}]^{1/2} \tag{11}$$

E_u = modulus of the material below the grid

k_0 = initial slope of the shear stress versus shear displacement curve

d_u = depth of the material below the grid

Debonded case

$$\tau_s = \tau_{\min} * \frac{w}{2} \tag{12}$$

where,

w = length of the overlay test sample

The variables E_u, k_0, and $\tau_{\min}$ are determined from overlay data.

Phases of Reflection Cracking Program:

1. Analysis of the beam on elastic foundation

This analysis was done in computer program ABAQUS. Nearly 55,000 runs were made on this program. The output of this program is the stress intensity factors for various ratios of the crack length/ layer thickness. The output is obtained for many combinations of the moduli of three layers of the pavement. (Old Pavement/ Interlayer /Overlay). This is read in the design program with a tertiary tree algorithm.

2. Calculation of Stiffness by numerical version of McLeod's Nomograph.

The Falling Weight deflectometer data from Florida DOT was used in the program Modulus to find the moduli of the three layers in the pavements. These moduli were then again cross-checked from McLeod's nomograph.

A numerical version of McLeod's Nomograph which was developed at Texas A&M was then incorporated in the program to find the moduli of all layers and the creep compliance. These moduli are then used to interpolate the stress intensity factors from the data obtained from the ABAQUS analysis. The Stress intensity factors were found out at every 0.05-inch of crack depth during the crack propagation.

3. Calculation crack Length

The rate of crack growth is calculated from Equation (1). This procedure is repeated till the crack either stops growing, in the case of bending stresses, or reaches the surface of the overlay in the case of thermal tensile or shearing stresses. In this way the number of days for a crack to propagate in bending, shear and thermal mode is calculated. These are the inputs of the Calibrated models.

4. Calibration of Models

The model was calibrated including SAMI, to the Florida data, in the following steps a,b, and c.

a. The number of days required to start and stop the reflection cracking due to bending mode, shearing mode and thermal mode were found out separately using the above stress intensity factors. Then the models for old asphalt pavement and jointed cement concrete were calibrated using the observed number of days for reflection cracking to occur and the number of days using the stress intensity factors.

b. An S shape curve through the existing reflection crack data for each section of pavement separately was fitted. This curve relates the percent area cracked to the number of days required for the crack to break through the overlay.

Using the curves found in step b determine the number of days to reach standard amounts of cracking, such as 0.17, 0.33, 0.50 which corresponds to the different levels of severity of cracking (Low/ Medium/High). Low severity is when the crack first appears. Medium severity is when the crack opens up more than ¼ inch and allows water into sublayers. High severity is when the reflection crack is spalled. The numerical values for low medium and high severity are 0.17, 0.33 and 0.50 respectively. It was assumed that the observed number of days for a crack to reflect through an overlay corresponded to a low level of severity.

c. The regression coefficients were determined α_p I=1 to 5, combining bending, shear and thermal modes of crack propagation. The number of days required for each mode to break through the overlay were calculated separately and then were combined linearly to predict the actual number of days the overlay will last.

The model used was:

$$N = N_{T1}(\alpha 1 - \alpha 2 * \frac{N_{T1}}{N_b} - \alpha 3 * \frac{N_{T1}}{N_{S1}}) + N_{T2}(\alpha 4 - \alpha 5 * \frac{N_{T2}}{N_{S2}}) \qquad (13)$$

Where,

N = Actual number of days to reflection crack.

N_{T1}, N_{T2} = Number of days for thermal reflection cracking to reach the neutral axis (N_{T1}) and the additional number of days for thermal reflection cracking to break through the overlay. (N_{T2})

N_b = Number of days for bending reflection cracking to reach the neutral axis. The "neutral axis " is the point where bending stresses no longer cause crack propagation. Its location depends upon the level of load transfer.

N_{S1}, N_{S2} = number of days for shearing reflection cracking to reach the neutral axis (N_{S1}), and from there to breakthrough (N_{S2}).

The Regression Coefficients are different for progressively higher levels as seen in the accompanying tables for asphalt overlays over cracked asphalt pavement and over jointed pavement. These regression coefficients were obtained after several runs of the data in the Statistical Analysis Software.

Table 1. Regression Coefficient for Damage Levels 0.17, 0.33, 0.50 for Old Asphalt Pavement.

α_I	**0.17**	**0.33**	**0.50**
α_1	2.92371	3.91662	5.44858
α_2	0.26246	0.40307	0.59267
α_3	7.61638	9.79696	13.0214
α_4	2.21993	2.75224	3.43166
α_5	2.82208	3.64735	4.48650

Table 2. Regression Coefficient for Damage Levels 0.17, 0.33, 0.50 for Old Jointed Cement Concrete Pavements.

α_I	**0.17**	**0.33**	**0.50**
α_1	0.0012	0.0130	0.1346
α_2	2.8E-7	3.3E-6	3.5E-5
α_3	-1.1E-7	-1.3E-6	-1.4E-5
α_4	0.8102	8.7601	83.1091
α_5	0.8541	9.3573	114.850

5. Calculation of number of days for pavement to fail in reflection cracking:

After getting the number of days for failure in three different modes from step 4 above these are used in the calibrated models above to get the final number of days to failure with the specified severity.

CHAPTER 3

DESIGN GUIDE

This chapter provides the user with a ready reference of procedures and a guide to the input information required in the program, Reflection Cracking Design.

Selection of Input Data

In this design procedure, the data required are from the following areas:

1. Regional Data
2. Past Construction History
3. Traffic Data
4. Material Characterization

Regional Data

Climatic factors influence performance. Pavements are expected to perform differently and exhibit different types of predominant distress as the climate changes from a warm, wet climate to a dry climate with a hard freeze every winter. The 24-hour temperature Drop for the pavement location is needed. The 24-hour temperature drop is calculated as the monthly maximum temperature minus the monthly minimum temperature. This is

24-Hour Temp Drop = Max. Temp –Min. Temp

The thermal stress intensity factor is directly dependent on the 24- hour Temperature Drop. The 24 hour Temperature Drop can be obtained from the publication titled, "Climatography of the United States No. 81 (By State) Monthly Normals of Temperature, precipitation, and Heating and Cooling Degree days 1951- 1990," Asheville, N.C. 28801 –2696. Or this can be obtained from software LTPPBIND version 2.0 Developed by Pavement Systems (PaveSys).

Past Construction History.

The construction history data listed below is required:

1. Thickness of last layer or layers of asphalt concrete,
2. Thickness of PCC slab,
3. Type of Overlay,
4. Degree of aggregate Interlock.

The degree of aggregate interlock is considered to be the effect of aggregate interlock (grain interlock) on load transfer across the cracks and/or joints in the existing pavements. This load transfer must be measured during the deflection testing. By placing the deflection equipment plate on one side of a crack or joint and the second deflection sensor on the other side of the crack joint, the amount of load transfer can be calculated using the following equation:

$$\%LT = \frac{dU}{dL}100 \qquad (14)$$

where:

$\%LT$ = percent load transfer

dU = deflection of the pavement on the unloaded side of the crack or the joint, and

dL = deflection of the pavement on the loaded side of the crack or joint.

Traffic Data:

The amount of 18 kip (80 kN) single axle loads (ESAL) expected to occur in each lane is necessary to determine the life of the overlay. This information is typically is collected from the traffic bureau, W-4 tables, or traffic maps published by highway agencies. Traffic is expressed in terms of 18-kip (80 kN) single axle load (ESAL) per day.

Material Characterization:

Both the existing materials and the materials in the overlay affect the life of the overlay. The program uses a numerical version of the McLeod's Nomographs to calculate the stiffness of the asphalt concrete.

The modulus of elasticity of the asphalt overlay is determined by one of the two nomographic procedures using basic material properties of the bitumen and asphalt concrete. The choice of nomographic procedure is governed by available material data.

One of the methods for determining the modulus of asphalt concrete was by Van der Poel (Ref 6) based upon the results of the experimental research carried out by Shell Oil Company. This method utilizes some basic properties of the bitumen and the mix to calculate the stiffness of the mix and is commonly used in the form of nomograph.

To use Van der Poel's method, the following properties of the bitumen and mix are required:

1. Penetration at 77^0 F,
2. Ring and ball softening point,
3. Asphalt % by weight of aggregate,
4. Time of loading ,
5. Age of mix in service,
6. Service Temperature,
7. CV (volume concentration of mineral aggregates)

The second method of determining the modulus of asphalt concrete developed by N.W. McLeod (Ref 6) McLeod developed a different quantitative measure for temperature susceptibility, the PEN-VIS number, viscosity in centistokes at 275 ^{0}F (135 ^{0} C). To use McLeod's method the following properties of the bitumen and mix are required.

1. Penetration at 77^0F (25^0C),
2. Viscosity in centistokes,
3. Asphalt % in the mix,
4. Time of loading,
5. Service Temperature,
6. CV (Volume concentration of mineral aggregate).

CV can be calculated as follows:

$$CV = \frac{\text{Volume of mineral aggregate}}{\text{Vol. of mineral agg. + Vol. of bitumen}}$$

$$CV = \frac{100 - VMA}{100 - \%\ Air} \qquad (15)$$

where:

VMA = voids in the mineral aggregate (%)

% Air = % air voids.

If the percentage of asphalt in the mix is known, the following approximate formula can be used:

$$CV = 1/[1 + ((\%\ Asphalt/100)\ 2.65)] \qquad (16)$$

It assumes an aggregate specific gravity of 2.65 and an asphalt specific gravity of 1.0.

The program uses this data to determine the slope of the log mix stiffness versus log loading time curves at different temperatures.

The program McLeod uses the data mentioned above and follows N.W.Mcleod's nomographic approach to compute the stiffness of asphalt concrete mixes.

Reinforcing Grid Properties:

Following data provided by the manufacturer of the reinforcing grid should be available if the user wants to use the Reinforcing grid in the program.

1. Whether the grid is to be used with or without tack coat.
2. Modulus of Elasticity of the Grid. If the manufacturer does not directly provide this then it should be calculated from the other properties given like the strain and the applied load at that strain.
3. Number of filaments in each strand. If there are more than one filament in each strand in the grid. If the grid does not consist of the filaments then just "1": can be specified in this input box.
4. Strand Spacing. This is the center to center spacing (in inches) between two consecutive and parallel strands.
5. Grid Width.
6. Grid thickness in inches.

7. Actual tack coat used during installation. This is not required if the user has previously specified the "Grid without Tack Coat".
8. Density of the material. This might be provided by the manufacturer or can be calculated from the weight and the geometric specifications of the grid.

Design Procedure:

This section provides the user with a ready reference of procedures required in the design program. The steps used in the overlay design procedure are shown schematically in the flow chart in chapter 2 of this report which describes the mechanistic concepts behind this program. Chapter 4 of this report provides details for using the program.

Program Description:

The program computes the number of years to reach damage levels of reflective cracking of an asphalt concrete overlay or the required thickness of an concrete overlay when the number of years to reach the damage levels of reflective cracking is specified. This process is based on :

1. The use of mechanistic model which indicates the influence of layer thicknesses, material stiffnesses, and the amount of subgrade support, and
2. Use of finite element analysis, which determines the magnitudes of stress intensity factors occurring within an actual pavement structure and variation with crack length and different levels of aggregate interlock action.

The following major steps are used in the design process:

1. Selection of input data according to section " Selection of Input Data", in this chapter, and
2. Determination of stiffness of overlay and slope m, described in the "Material Characterization" of this chapter. Determination of stress intensity factors at the tip of the crack by interpolating between the stress intensity factor values from the Abacus output. These stress intensity factors are calculated at the tip of the propagating crack in each layer. (The program is discussed in the Appendix)
3. Calculation of number of cycles to failure of the overlay, using integration of Paris' crack growth law. This integration is carried out numerically within the program by considering each crack growth mechanism equations based on fracture mechanics described in chapter 2 of this report. After calculating the number of cycles for failure these are converted into the number of days by using user's AADT data.

4. Selection of the input data for the Reinforcing grid.
5. Calculation of number of cycles to failure of the overlay when Reinforcing Grid is use.

Output Description and Data Interpretation:

The output formats of the Reflection Cracking Design program has been designed to inform the engineer of anticipated reflection cracking problems. The output is designed in two different ways according to the user's option for the design. If the user has specified the overlay thickness then the output shows the number of days to reach failure of the pavement with all severities (Low/ Medium/High). The user can go back from here to the previous screens and use more thickness to increase the life of the pavement. This output screen also gives the final depths of all three layers excluding the thickness of the old pavement which was milled.

On the other hand, if the user has specified the designed life with a particular severity then the ouput screen gives the calculated depths of the three layers of the pavement at which the overlay will fail at that specified level of severity. The user has still the option to go back to the previous screens and enter the new design life and get the revised section of the pavement.

When the user uses the reinforcing grid in the same section, the program calculates the life and thicknesses for the same specified material but with the reinforcing grid. The output screens for this section (with the reinforcing grid) are similar to the previous discussion according to the user's specified option of the design.

Sample Design:

The following example is provided to illustrate the design of an asphaltic concrete overlay on an existing asphalt or jointed concrete pavement.

The **first data set** required from the user is the data listed below:

Climatic Region

Climatic Region: Region 1

The **second data set** required from the user is the data listed below:

Identification Information

Highway Name : 610 S
Milepost Start : 0.0
Project Number : 1001

County : Brazos

The **third data set** required from the user is listed below:

Regional Characteristics

Temperature (^{0}C) : 25
Wind Velocity (mph) : 10
AADT (veh/day) : 1000
Average Daily Temperature Change(^{0}F) : 8.5

The **fourth data set** required from the user is listed below:

Pavement Type and Design Option

Old Pavement Type :Asphalt
Mill
    Mill old pavement? : Yes
    Milling Thickness(in) : 1.5
Layer Thicknesses
    Old Pavement : 5.0
    SAMI : 0.8
Design Option : Specify Overlay thickness in inches

The **fifth data set** required from the user is listed below:

Specify Overlay Thickness: **4.0 inches**

The **sixth data set** required from the user is listed below:

Material Properties

Overlay:
    Want to use SHRP grade Asphalt: : YES
    SHRP Grade : 54^{0}F –12^{0}F(54 DF –12DF)
    Volume Concentration of Aggregates : 95 (%)

Interlay (SAMI):
    Want to use the SHRP grade asphalt : NO
    Volume concentration of aggregates : 95 (%)
    Viscosity Test Temperature : 140 ^{0}F
    Viscosity in centistokes : 3500 Centistokes

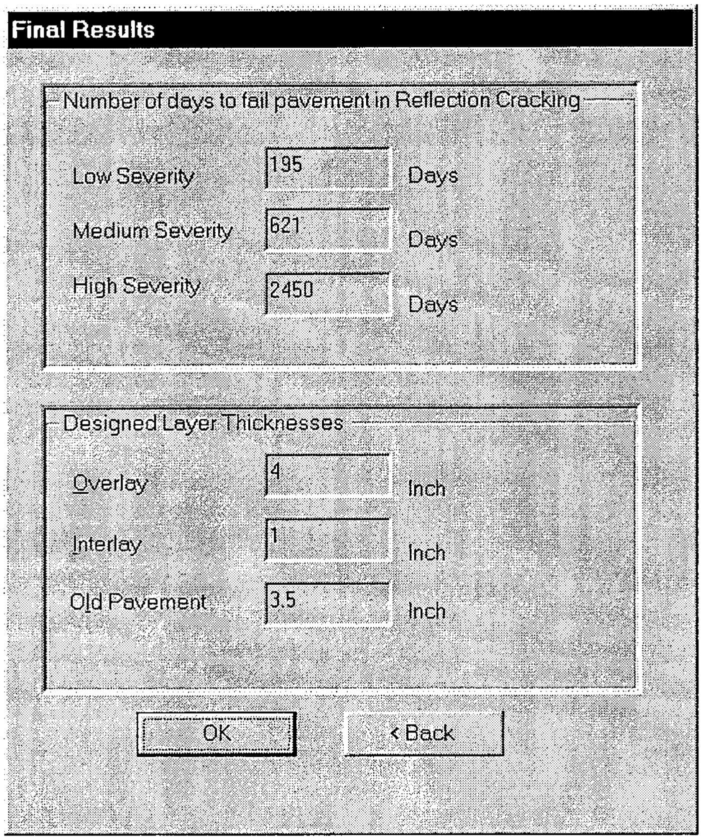
Penetration at 77^0F : 70 dmm

Old Pavement:

Want to use SHRP grade Asphalt : YES
SHRP Grade : 64^0 F – 10^0F (64 DF –10DF)
Volume Concentration of Aggregates : 95 (%)

In the above sample example, Interlay asphalt grade specifications are given by the user. To illustrate the type of input required for the user. The specifications for the SHRP grade asphalt are directly fed into the program, which calculates the other parameters required for the numerical method of McLeod's Nomographs. (See 'Material Characterization' in this chapter above). The following is a brief discussion about how SHRP grades are converted into the required parameters:

FINAL RESULTS:



Final Results

Number of days to fail pavement in Reflection Cracking

Low Severity: 195 Days
Medium Severity: 621 Days
High Severity: 2450 Days

Designed Layer Thicknesses

Overlay: 4 Inch
Interlay: 1 Inch
Old Pavement: 3.5 Inch

In the above figure (directly from the program) there are two input boxes:

1) Number of days for failure with different severities. This gives:

Low : 195
Medium:621
High :2450

2) This box gives the final thicknesses of the three layers.

Overlay : 5.0
Interlay (SAMI):0.80
Old Pavement :3.5

The **seventh data set** required from the user is listed below:

Want to use the Reinforcing Grid: **YES** (The first radio Button)

The **eighth data set** required from the user is listed below:

Pavement Properties for the Reinforcing Grid:

Depth of the Overlay below Grid(in)	:0.0
Average Tire Contact Pressure(psi)	:80.0
Aggregate Interlocking Factor	:Medium

Here the first input is 0 since the grid is directly laid on the old Pavement.

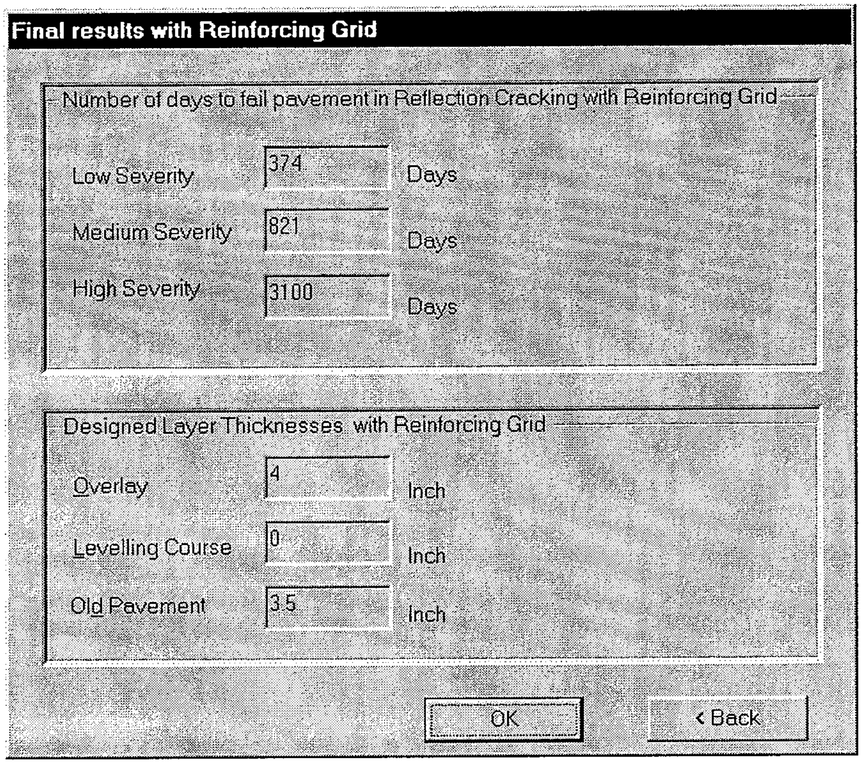
The **ninth data set** required from the user is listed below:

Reinforcing Grid properties:

Modulus of Elasticity (psi)	: 6E06 (6000000)
Number of filaments in each strand	: 2
Strand Spacing (in)	: 1.5
Grid Width (in)	: 6
Grid Thickness (in)	: 0.03
Actual tack coat used during installation(gallon/yard^2)	: 0.3
Density of the material (lb/ft^3)	: 146

Final Results with the reinforcing grid:

This output dialog box shows again the life of the overlay with all severities and the section specifications.


Final results with Reinforcing Grid

Number of days to fail pavement in Reflection Cracking with Reinforcing Grid

Low Severity 374 Days
Medium Severity 821 Days
High Severity 3100 Days

Designed Layer Thicknesses with Reinforcing Grid

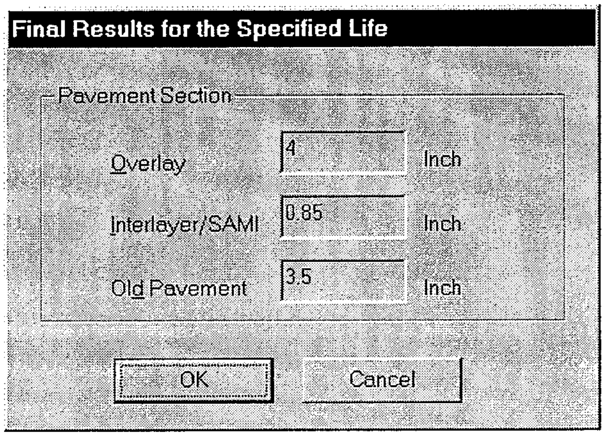
Overlay 4 Inch
Levelling Course 0 Inch
Old Pavement 3.5 Inch

Design Sample when the design option is "Specify Design Life in the third data set above:

Assuming other input data cards (1st, 2nd & 3rd) are entered the same as before. The fourth data set will be:

Design life in years	: 10
Severity level	: Medium

The FINAL RESULT output box will give the results:

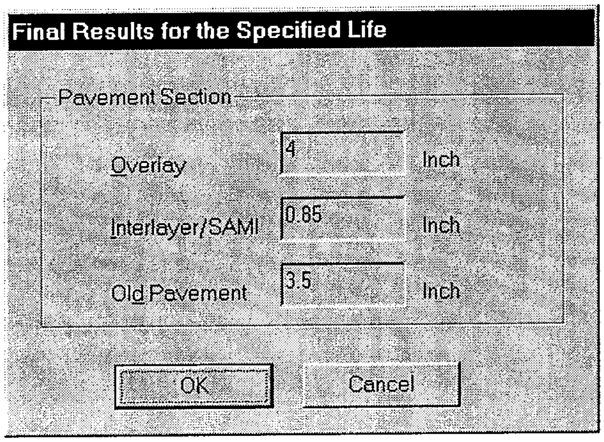

Final Results for the Specified Life

Pavement Section

Overlay 4 Inch
Interlayer/SAMI 0.85 Inch
Old Pavement 3.5 Inch

This shows that for this pavement to last for ten years the above section should have 0.85 inches of the old pavement surface and then a SAMI of 0.8 inches and an overlay of 4 inches placed on it.

Final results with the reinforcing grid:



Final Results for the Specified Life

Pavement Section

Overlay 4 Inch

Interlayer/SAMI 0.85 Inch

Old Pavement 3.5 Inch

CHAPTER 4

COMPUTER USERS GUIDE

The design program, developed as a part of this project, is collection of three programs. An umbrella program was prepared to allow data entry and program interaction. It connects different modules of the program and provides the final report.

Computer System Requirements

The 'Reflection Cracking Design' program is written in Visual C++ version 6.0 (Visual C++ is a trademark of Microsoft Corporation). It is developed to run in Windows 95, 98 and NT. The program requires at least 16 Mb of random Access Memory and a zip disk drive. The program occupies 5.44 Mb of memory

Getting Started

The following section specifies skills required to install and start the program. This manual assumes that the user is familiar with Windows and can perform the following skills: Unzip, copy, create.

If the user wants to run this program from disk then double click the icon in the respective drive by opening it in windows explorer. To save this program on the hard disk, copy all files including the text files and the dll (the files with .dll extension) files in one directory and then double click the icon of "Reflection" to start the program. Do not delete any text or dll file from the directory any time, these are the supporting data and systems files for the program. To start running the program, press the left mouse button. The first window will appear which gives a short description of the program. The program is self-intuitive in the following screens.

INTERACTION WITH THE PROGRAM

The following sections describe maneuvering through the program and entering data.

Getting around in the program.

The program is designed to be simple to use. The whole program takes the different input through different dialog boxes. Each dialog box has a 'next' and a 'back' button (except the starting and ending screens). This will allow user to go back and forth in the dialog boxes. The input data has been grouped in the different dialog boxes.

Entering Data in the program

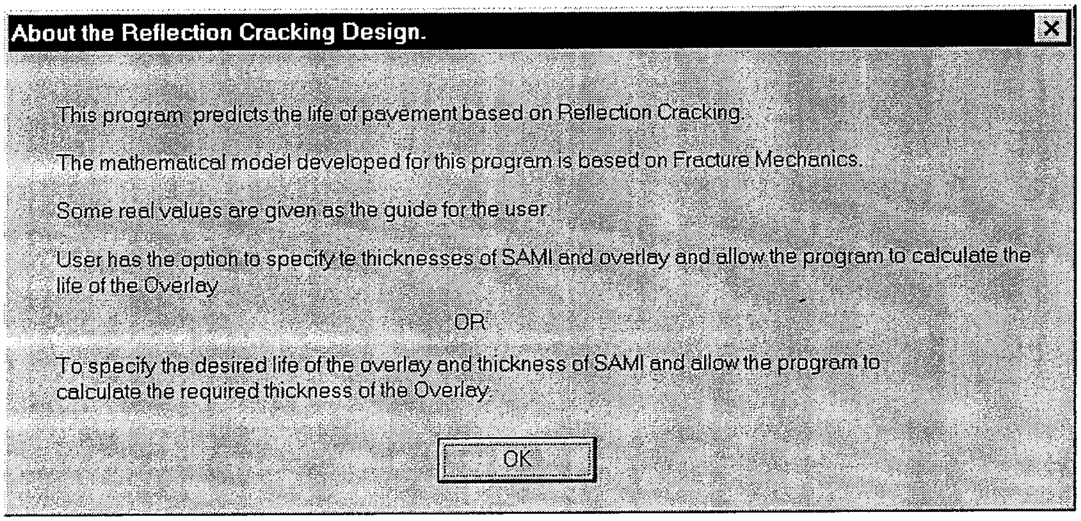
Entering the data in the program is very simple. The data should be entered in the boxes provided in front of their description. Some of the default values have already been provided in the program. The user can keep the same default values or he can enter his values. If the user enters any invalid data then the program will automatically prompt him about that. Thew user can move to the next data input box by just pressing the TAB button on the keyboard or using the Alt-key combination for specific input. To move back to the previous input box in the same dialog box, press Shift-Tab or the Alt-Key combination of the previous input box.

Data Input Screens by Classification

The following shows each screen of input with different classifications of data. The data is shown with the unit (English). The default data is also shown in the screen.

SCREEN 1: - About the Reflection Cracking Design Program

This screen contains general description of the program to give broad outline of the philosophy of the program. To go to the next screen click on "OK".



About the Reflection Cracking Design.

This program predicts the life of pavement based on Reflection Cracking.

The mathematical model developed for this program is based on Fracture Mechanics.

Some real values are given as the guide for the user.

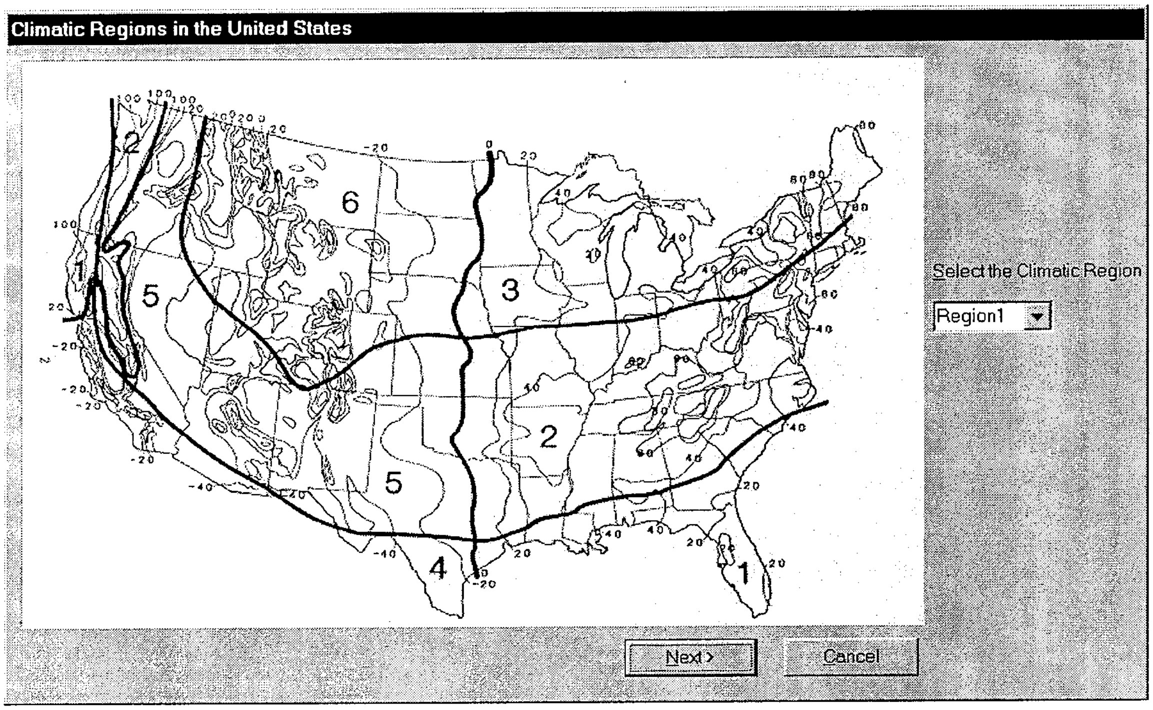
User has the option to specify te thicknesses of SAMI and overlay and allow the program to calculate the life of the Overlay

OR

To specify the desired life of the overlay and thickness of SAMI and allow the program to calculate the required thickness of the Overlay.

SCREEN 2:- Climatic Region in the United States

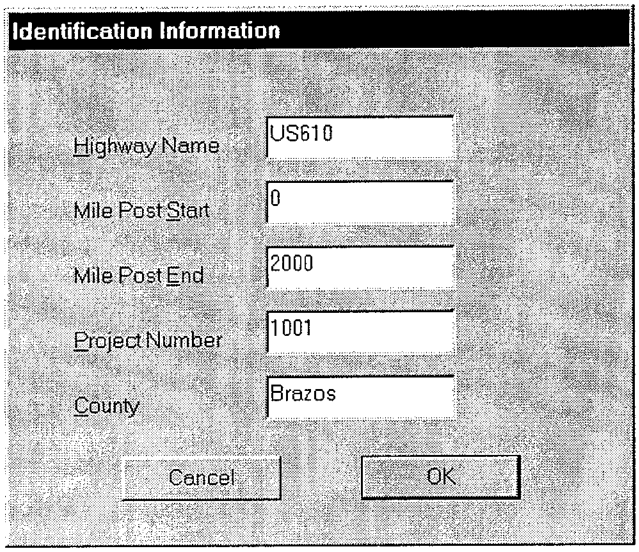
This screen provides the United States map with the six climatic regions. From these regions the user can select the region in which the overlay is placed or to be placed.



Select the Climatic Region: Region1

SCREEN 3:- Identification Information

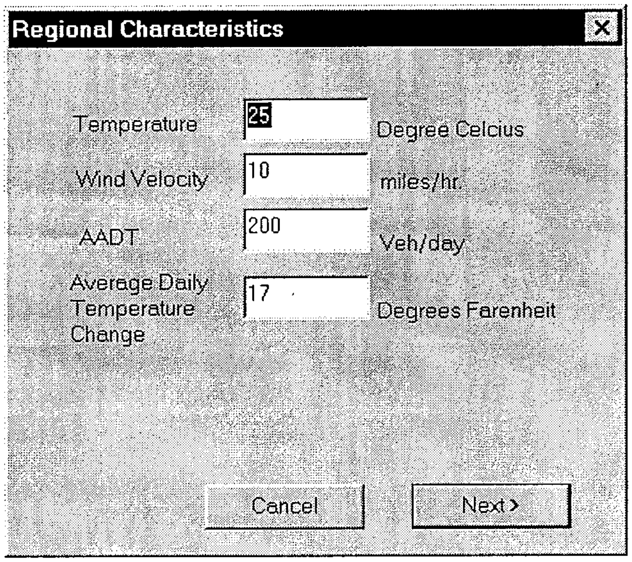
This screen contains the information about the project. This information is stored for the identification in the saved file.



Highway Name: US610
Mile Post Start: 0
Mile Post End: 2000
Project Number: 1001
County: Brazos

SCREEN 4: Regional Characteristics

This screen contains the input boxes for the climatic and traffic characteristics of the region.



Temperature: 25 Degree Celcius
Wind Velocity: 10 miles/hr.
AADT: 200 Veh/day
Average Daily Temperature Change: 17 Degrees Farenheit

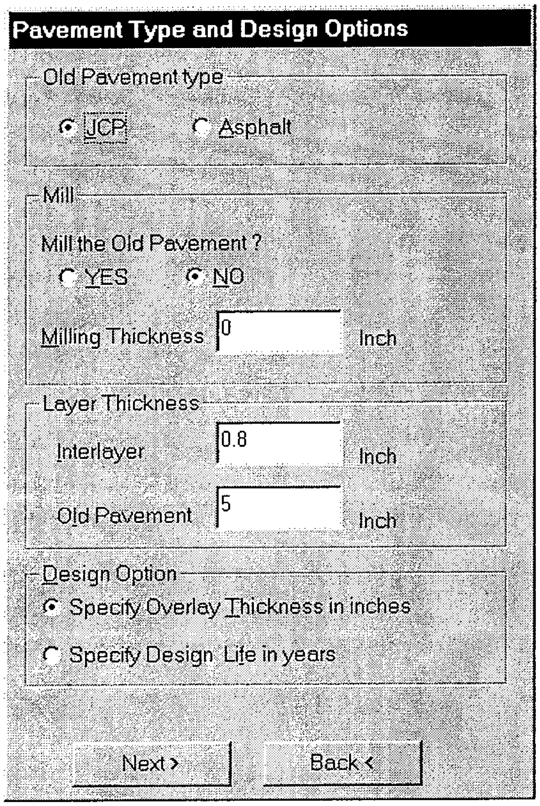
Temperature: This is the average temperature of the region in which the pavement is placed.

Wind Velocity: This is the average annual wind velocity in the region.

AADT: (Annual Average Daily traffic): The average daily traffic on the placed pavement.

Average Daily Temperature Change: This is the change between the Daytime temperature and Night temperature.

SCREEN 5: Pavement type and Design Options



Pavement Type and Design Options

Old Pavement type

● JCP ○ Asphalt

Mill

Mill the Old Pavement ?

○ YES ● NO

Milling Thickness 0 Inch

Layer Thickness

Interlayer 0.8 Inch

Old Pavement 5 Inch

Design Option

● Specify Overlay Thickness in inches

○ Specify Design Life in years

This screen shows the input for the old pavement and design options:

- The 'Old Pavement Type' box asks for the type of the old pavement. The default option is JPC (Jointed Plain Concrete). The user has the option to select the Asphalt Pavement also.
- The 'Mill Thickness' box asks whether user wants to mill the old pavement and if yes, how much.
- The 'Layer Thickness' box asks for the thickness of the Old pavement and how much interlayer (SAMI: Stress Absorption Membrane Interlayer) thickness the user wants to put in.

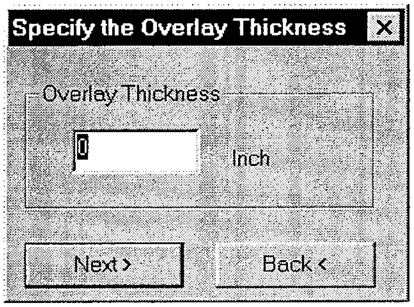
- In the 'Design Option' box, user has the option to either specify the overlay thickness and ask the program to calculate the life of the pavement for three severity levels OR to specify the life of the pavement he wants to last, and ask the program to calculate the thickness of the Overlay for the corresponding life. The user can anytime come back to this screen from the next screen and change this option.

SCREEN 6: Overlay Thickness or Design Life

This screen depends on the option in the 'Design Option' from the previous screen (screen 3). If the user has specified the thickness of the Overlay then the following screen will appear otherwise the next described screen will appear.

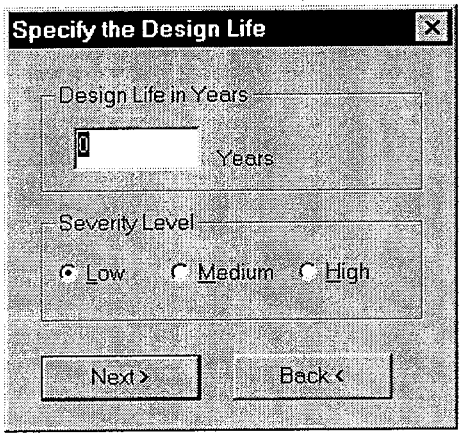
User specified the Overlay Thickness: -

This is a small input screen with just one input box for the overlay Thickness in inches. The user can change this option by going back to the previous screen and checking the option for the "Specified Life".



Overlay Thickness: 0 Inch

***User has specified the design life of the pavement*: -**



Specify the Design Life

Design Life in Years

0 Years

Severity Level

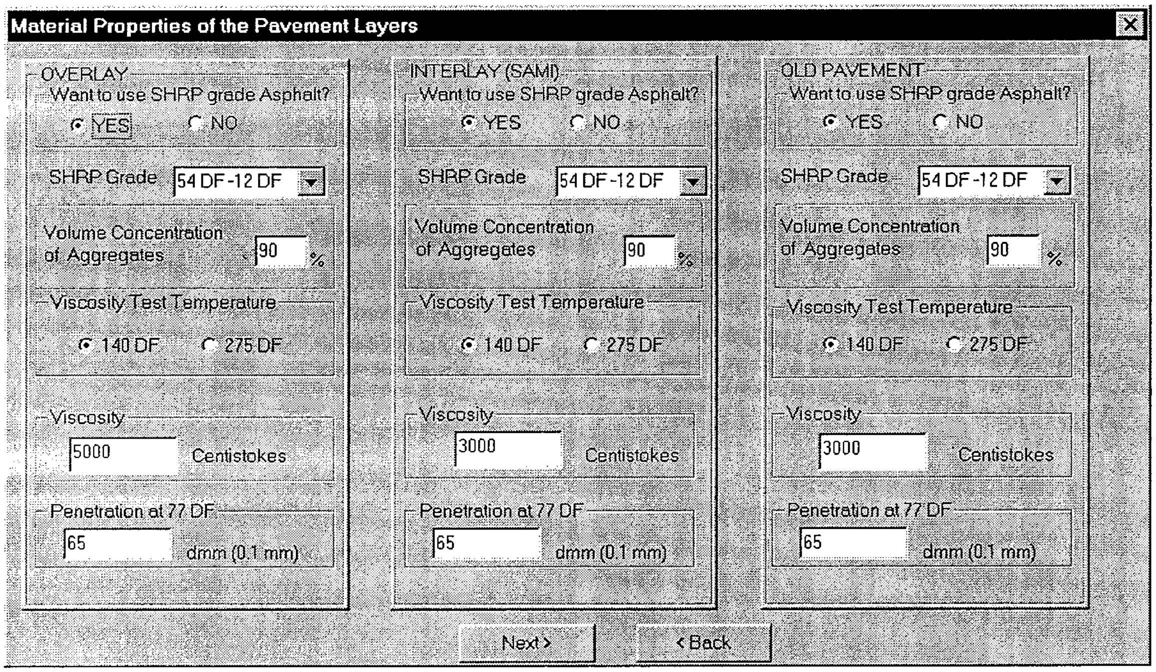
● Low ○ Medium ○ High

There are two input boxes in this screen. The first 'Design Life in Years' asks the user, how long he wants this pavement to last with the severity level in the next box 'Severity Level'.

SCREEN 7: Material Properties of the Pavement Layers

This is the screen which takes the material properties of all three layers of the pavement, with three distinguishable input boxes. All three boxes have the same input data but for three different layers, viz. Overlay, Interlayer (SAMI) and Old Pavement.

If the user wants to use the SHRP (Strategic Highway Research Program) type of asphalt, then he need not to specify the last three inputs in each box i.e. Viscosity test temperature, Viscosity and Penetration. Instead he will just have to select a SHRP grade asphalt from the pull down menu. The two digits in this box show the upper and lower test temperatures of the typical asphalt grade in Degrees Fahrenheit. Then the user should specify the Volume concentration of the aggregates in the particular asphalt layer.



Material Properties of the Pavement Layers

	OVERLAY	INTERLAY (SAMI)	OLD PAVEMENT
Want to use SHRP grade Asphalt?	● YES ○ NO	● YES ○ NO	● YES ○ NO
SHRP Grade	54 DF-12 DF	54 DF-12 DF	54 DF-12 DF
Volume Concentration of Aggregates	90 %	90 %	90 %
Viscosity Test Temperature	● 140 DF ○ 275 DF	● 140 DF ○ 275 DF	● 140 DF ○ 275 DF
Viscosity	5000 Centistokes	3000 Centistokes	3000 Centistokes
Penetration at 77 DF	65 dmm (0.1 mm)	65 dmm (0.1 mm)	65 dmm (0.1 mm)

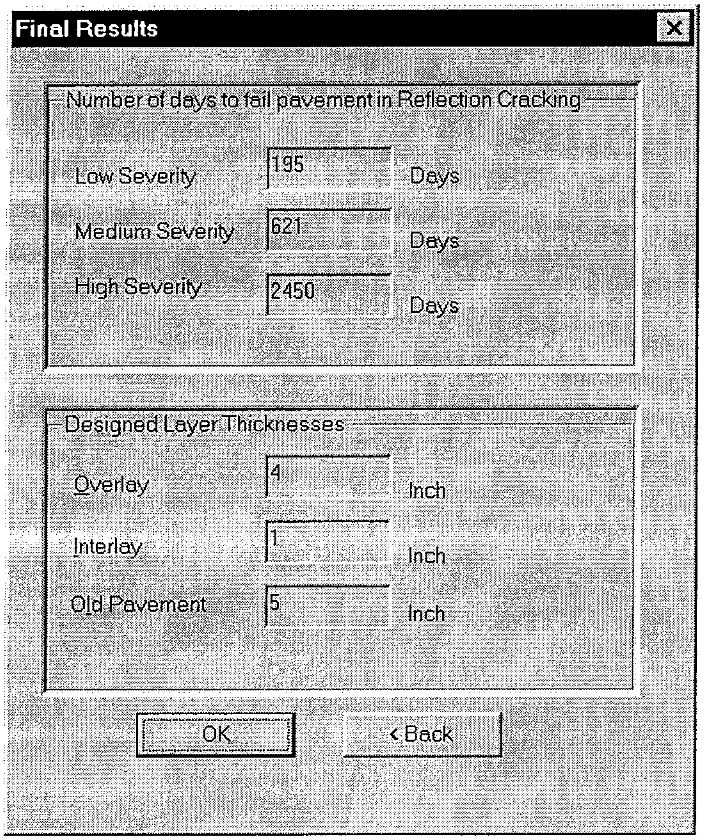
The next three inputs in each box is for the user specified asphalt type NOT for any SHRP grade asphalt. These input values are used in the numerical version of the McLeod's nomographs to calculate the stiffnesses of the layer and in turn the moduli of elasticity of the three layers. The user should specify at what standard temperature the viscosity of the Asphalt has been tested. The next input is the viscosity of the asphalt material at the above specified standard test temperature. Also the user should know what is the penetration at 77 degrees Fahrenheit in dmm i. e. one tenth of the mm.

The same input should be provided for all three layers of the pavement.

SCREEN 8: Computed Design Life or Overlay Thickness

This screen depends on the user specified design option in screen 5 (Overlay Thickness/Design Life).

If the user has given the Overlay Thickness option


Final Results

Number of days to fail pavement in Reflection Cracking

Low Severity 195 Days

Medium Severity 621 Days

High Severity 2450 Days

Designed Layer Thicknesses

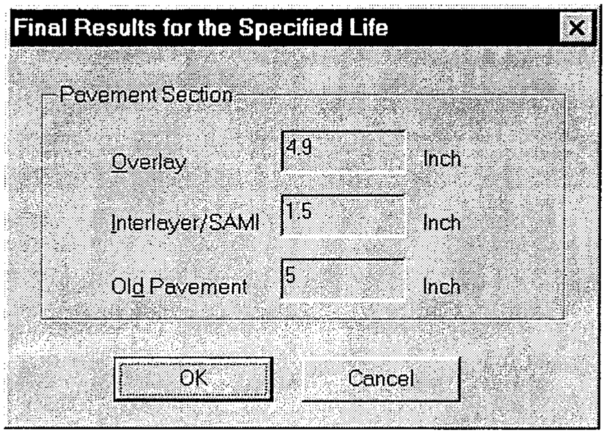
Overlay 4 Inch

Interlay 1 Inch

Old Pavement 5 Inch

This output screen shows the life of the pavement with user specified Overlay Thickness for different severity levels. The second box summarizes the thicknesses of the layers. These are the same as given by the user in screens 5 and 6.

If the user has given the specified design life option:


Final Results for the Specified Life

Pavement Section

Overlay 4.9 Inch

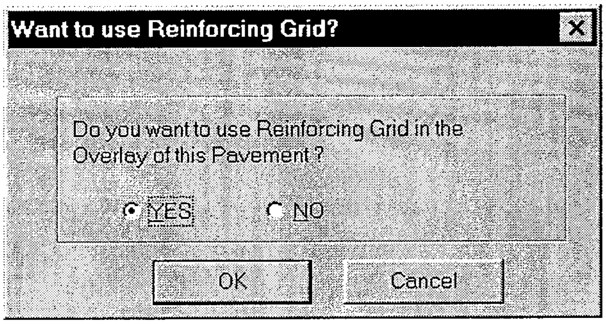
Interlayer/SAMI 1.5 Inch

Old Pavement 5 Inch

This is the Output for the program. This screen gives the thicknesses of the three layers of the pavement for the user specified design life in years in screen 2.

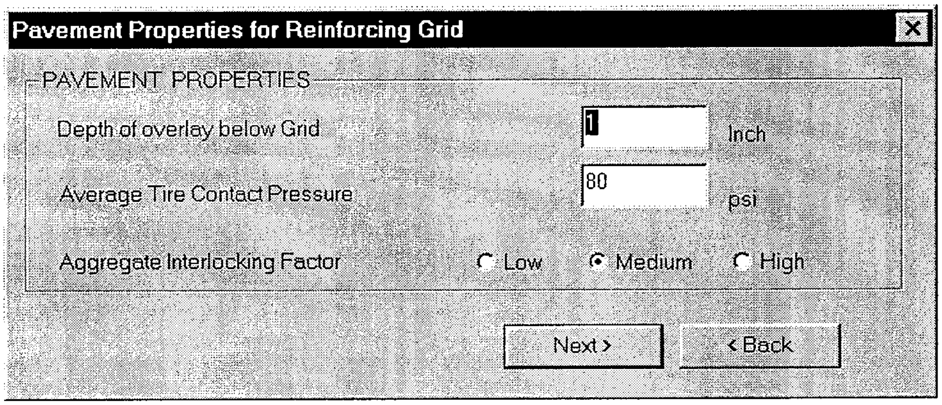
This is the end of first part of the program. The next part consists of the design of the overlay using the reinforcing grid in the Pavement.

SCREEN 9:Want to use the Reinforcing Grid?



This screen asks whether the user wants to a Reinforcing Grid in the pavement. If the user says "Yes" the next screen will appear. Otherwise the program is terminated here.

SCREEN 10: Pavement Properties for the Reinforcing Grid



Depth of overlay below Grid: 1 Inch

Average Tire Contact Pressure: 80 psi

Aggregate Interlocking Factor: ○ Low ● Medium ○ High

This screen has three input data. The depth of the overlay below grid, is when user wants to use the grid in the Overlay. User can specify zero (0 inches) if the Reinforcing grid is not used in the Overlay.

Average Tire Contact Pressure is the pressure exerted by the truck tire. Here the Average pressure is 105 psi.

Aggregate Interlocking Factor: This is the aggregate interlocking which contributes to a crack or joint in the old pavement surface.

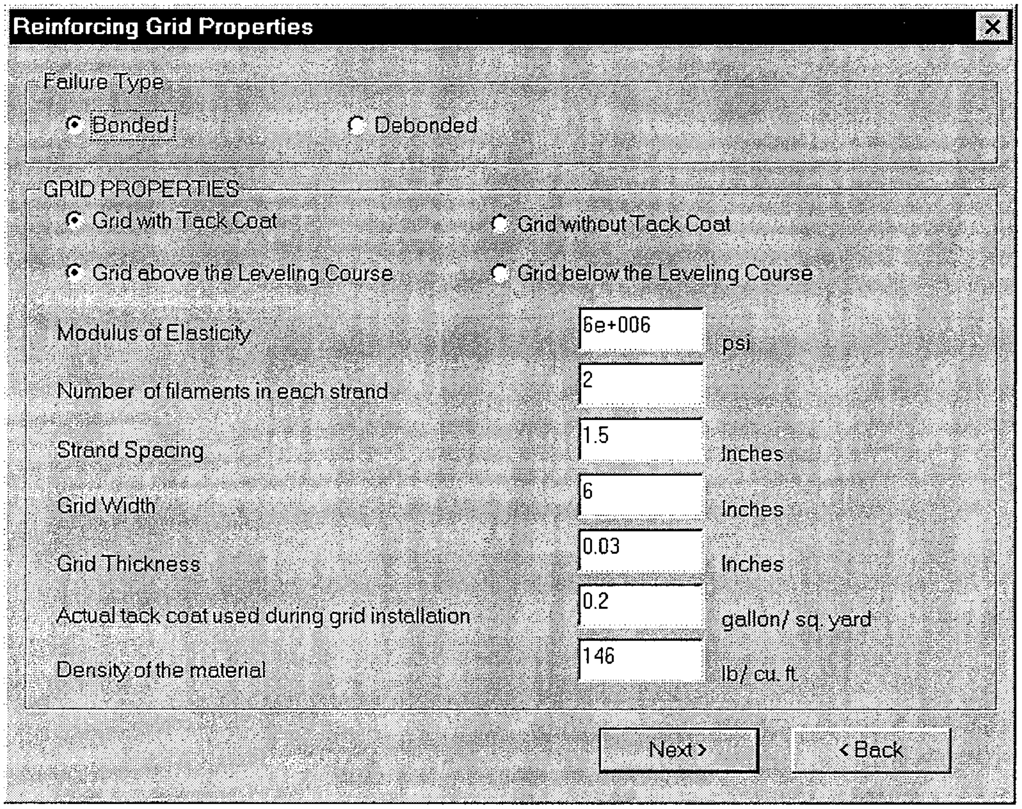
SCREEN 11: Reinforcing Grid properties

This screen takes the different physical properties of the reinforcing Grid.

Failure Type: These are the kinds of failure described in the previous section. This option gives the user option to test the life for both kinds of failure.

Modulus of Elasticity, this will be specified by the manufacturer of the typical grid or could also be calculated from the other specifications of the Grid provided by the manufacturer like elongation for particular load, and cross section of the strands.

Number of filaments in each strand, this gives the user the option of using as different number of the filaments in each strand. The user can specify '1' if the grid is not made up of filament strands.



Failure Type

● Bonded ○ Debonded

GRID PROPERTIES

● Grid with Tack Coat ○ Grid without Tack Coat

● Grid above the Leveling Course ○ Grid below the Leveling Course

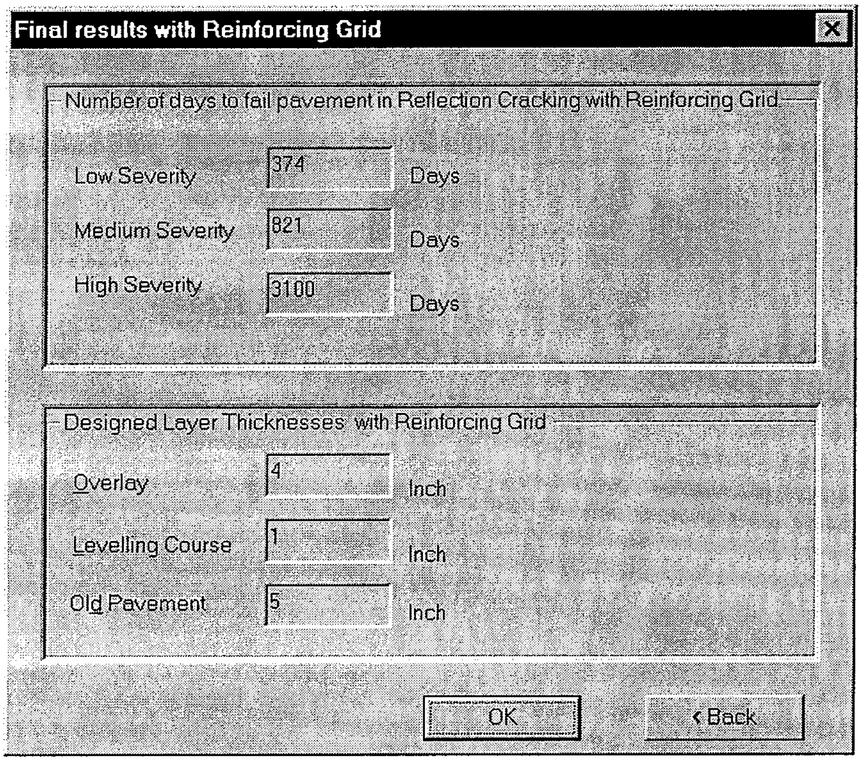
Modulus of Elasticity	6e+006	psi
Number of filaments in each strand	2	
Strand Spacing	1.5	Inches
Grid Width	6	Inches
Grid Thickness	0.03	Inches
Actual tack coat used during grid installation	0.2	gallon/ sq. yard
Density of the material	146	lb/ cu. ft

Strand Spacing, is the center to center spacing between two strands.

The other data, like the density of the reinforcing grid material is specified by the grid provider.

SCREEN 12: Final Results with the Reinforcing Grid.

This screen summarizes the output of the pavement after using the reinforcing grid in the pavement. The first output box summarizes the life of the pavement with the Reinforcing grid for all three severity. And the second output box shows the thicknesses of the layers in the pavement including the Reinforcing grid.



Number of days to fail pavement in Reflection Cracking with Reinforcing Grid

Low Severity: 374 Days
Medium Severity: 821 Days
High Severity: 3100 Days

Designed Layer Thicknesses with Reinforcing Grid

Overlay: 4 Inch
Levelling Course: 1 Inch
Old Pavement: 5 Inch

The above results with all the input data are stored in the file created by the program in the text format for user's future reference.

References:

1. J. N. Reddy, "An Introduction to the Finite Element Method", 1994.
2. David Broek, "Elementary Engineering Fracture Mechanics", *Third Edition, Martinus Nijhoff Publishers, The Hauge, Netherlands, 1984.*
3. Yang H. Huang, "Pavement Analysis and Design", *Prentice Hall, Englewood Cliffs, New Jersey, 1993.*
4. *The Asphalt Institute, "The Asphalt Handbook", College Park, Maryland.*
5. R. L. Lytton, J. Uzan, E.G. Fernando, R. Roque, D. Hiltunen, S. Stoffels, "Development and validation of Performance Prediction Models and Specifications for Asphalt Binders and Paving Mixes", *Strategic Highway Research Program, national Research Council, Washington, DC, 1993.*
6. N.W. McLeod, "Asphalt Cements. PEN-VIS Number and it's Application to Moduli Stiffness", *Journal of Testing and Evaluation ASTM, Vol. 4, No. 4, 1976.*
7. P. Jayawickrama, R. L. Lytton, "Methodology for Predicting Asphalt Concrete Overlay Life Against Reflection Cracking", *Proceedings, Sixth International Conference on Structural Design of Asphalt Pavements, Ann Arbor, University of Michigan, 1987,pp. 912.*
8. J.S. Milton and Jesse C. Arnold, "Principles and Application for Engineering and Computing Sciences", *McGraw-Hill, New York, 1997.*
9. Yashavant Kanetkar,"Let Us C", *BPB Publications, New Delhi, India, 1995.*
10. 10.David Bennett, et al., "Visual C++ 5.0 developer's guide", *Indianapolis, Ind.Sams Pub, c1997.*
11. Frank Crockeett, "MFC Developer's Workshop", *Microsoft Press, 1997.*