NC STATE UNIVERSITY

PB98-149222

CENTER FOR TRANSPORTATION ENGINEERING STUDIES

A COMPARATIVE STUDY OF PERFORMANCE OF DIFFERENT DESIGNS FOR FLEXIBLE PAVEMENTS

NCFLEX (ver 1.0) - MANUAL

by

N. Paul Khosla, Satish Sankaran,
Nakseok Kim, and Y. Richard Kim

DEPARTMENT OF CIVIL ENGINEERING

A COMPARATIVE STUDY OF PERFORMANCE OF DIFFERENT DESIGNS FOR FLEXIBLE PAVEMENTS

NCFLEX (ver 1.0) - MANUAL

by

N. Paul Khosla, Satish Sankaran,
Nakseok Kim, and Y. Richard Kim

A COMPARATIVE STUDY OF PERFORMANCE OF DIFFERENT DESIGNS FOR FLEXIBLE PAVEMENTS

By

N. Paul Khosla
Principal Investigator

Satish Sankaran
Graduate Research Assistant

Nakseok Kim
Graduate Research Assistant

Research Project 23241-87-1

Draft Copy of Final Report

in cooperation with the

North Carolina Department of Transportation

and

Federal Highway Administration
The United States Department of Transportation

CENTER FOR TRANSPORTATION ENGINEERING STUDIES
Department of Civil Engineering
North Carolina State University
Raleigh, NC 27695-7908

July 1996

Technical Report Documentation Page

1. Report No. FHWA/NC/97-004	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle A Comparative Study of Performance of Different Designs for Flexible Pavements		5. Report Date July 1996
		6. Performing Organization Code
		8. Performing Organization Report No.
7. Author(s) Dr. N. Paul Khosla, Satish Sankaran Nakseok Kim, and Dr. Y. Richard Kim		
9. Performing Organization Name and Address Center for Transportation Engineering Studies North Carolina State University Box 7908 Raleigh, NC 27695-7908		10. Work Unit No. (TRAIS)
		11. Contract or Grant No. 23241-87-1
12. Sponsoring Agency Name and Address North Carolina Department of Transportation Raleigh, NC 27611 The Federal Highway Administration Raleigh, NC 27611		13. Type of Report and Period Covered Final Report 7/1/86 - 6/30/96
		14. Sponsoring Agency Code
15. Supplementary Notes		

16. Abstract

The objective of this research was to conduct a comparative study of performance of different designs for flexible pavements. This objective was approached through extensive field and laboratory testing of test pavements. Also, a comprehensive computer-based design procedure for flexible pavements was developed based on results from the field and laboratory tests. Testing was carried out at a test facility constructed on US 421 Bypass near Siler City, North Carolina. The experimental stretch was about seven and one-half miles long and was composed of 12 pavement section types, two of each type in two directions of traffic (having different expected traffic loads), for a total of 48 sections. Of these, only 24 sections on the south-bound lane were instrumented. Response parameters were measured in the field using stress and strain gages embedded in the pavement structure, and an assembly of LVDT's were used to measure deflections at various layer interfaces. In addition, traffic volume and pavement distresses were monitored during the pavement life. Traffic measurements were made using a weigh-in-motion device.

Based on the nondestructive testing procedures, layer moduli for the various pavement layers were backcalculated. A comparison of predicted and measured responses were carried out based on measurements obtained from field instrumentation. Distress survey data, along with the measured responses, were used to compare the various designs employed in the study. In the laboratory testing, the mechanical properties of pavement layer materials were determined by subjecting specimens of the given materials to a series of dynamic load tests under environmental conditions representative of those experienced in the field. Performance prediction models for predicting fatigue cracking and rutting of the asphaltic concrete layers were developed. A study of the variability observed in the field data was performed. A reliability-based methodology to deal with the variability in pavement layer properties was developed. The application of the reliability-based methodology in pavement design computations has been demonstrated. Calibration factors for fatigue and rutting based on field and laboratory results were developed. In addition, a methodology for a calibrated mechanistic design, based on fatigue and rutting criteria, was developed. Also, based on the mechanistic principles developed, a computer program (NCFLEX) was created that could be used to analyze and design flexible pavement systems based on fatigue and rutting criteria. A comparative study of the various existing pavement design methods like AASHTO, VESYS, and the Asphalt Institute was carried out with respect to the US 421 field observed distress data.

17. Key Words flexible pavements, field study, base and subgrade stabilization, fatigue, rutting, distress survey, computer based design procedure		18. Distribution Statement No Restrictions 175 copies of this document were printed at a cost of $0.57 per copy	
19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages 19	22. Price

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

NCFLEX
VERSION 1.0, 1996

A PROGRAM FOR THE ANALYSIS AND DESIGN OF FLEXIBLE PAVEMENTS

NCFLEX (version 1.0, 1996)

The NCFLEX program is a microsoft windows-based program for analyzing and designing flexible pavements. The program is windows-based in that it accepts input through a graphical user interface (GUI). An input file called flexinp.dat is automatically created. The program then runs the FORTRAN program for calculating the design parameters. During this stage, the program runs in the full-screen DOS mode for optimum computing time. The program then reverts back to the Windows mode, opens up the windows application program called NOTEPAD, and displays the results. The results can be found in the file flexout.dat. Details regarding the nature of computation, specific models used, etc., can be found in other references (Khosla et. al., 1996).

Files :
NCFLEX31.EXE - Windows executable file (written in Visual C++)
SAT.EXE - Fortran program for design computation

1. Copy NCFLEX31.EXE and SAT.EXE to any directory on the hard drive.
2. To start the program, run the NCFLEX31.exe program from within the Windows environment.

Note: This program is compatible with Microsoft Windows version 3.1 and lower.

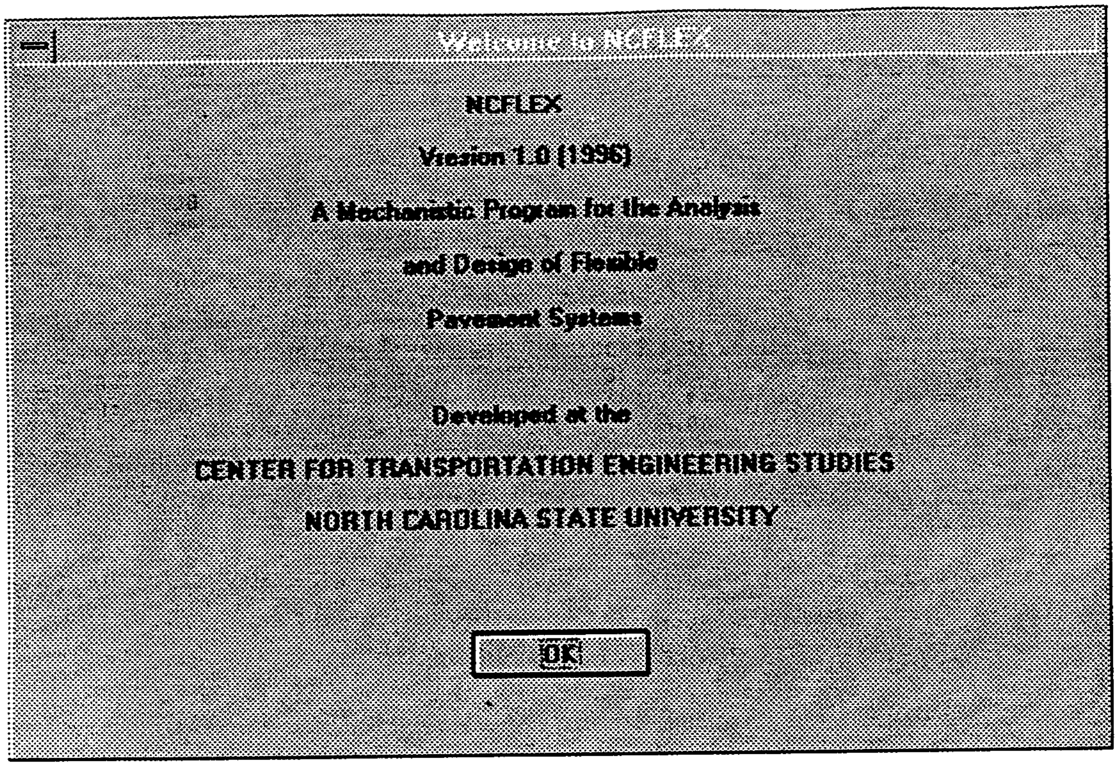
<u>To run the program from DOS prompt:</u>

Type win NCFLEX31.EXE <enter>

<u>To run the program from within windows:</u>

From the menu choose File and then Run
Type <directory>/NCFLEX31.EXE <return>

The user should see the first input screen of the NCFLEX program. This would be the "Welcome to NCFLEX" screen. The user would click on the "next " button to move to the next input screen. Also clicking on the "cancel" button, will allow the user to exit the program.



NCFLEX

There are six modules, or input screens, that the user will interact with during the course of running this program. They are:

1. Welcome to NCFLEX: Gives a welcome message
2. Layer Properties
3. Layer Stiffness
4. Design Traffic and Life
5. Fatigue Properties, and
6. Rutting Properties.

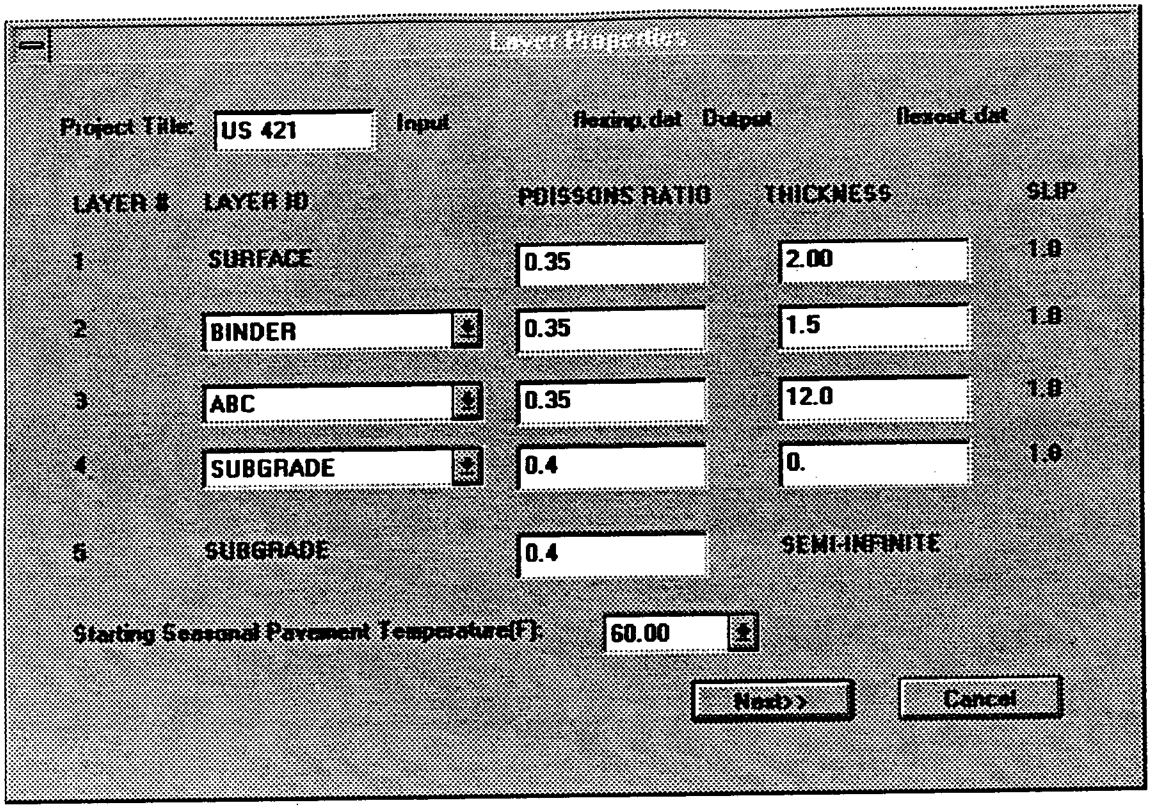
The modules are explained in detail in the following sections. To aid the user, actual printouts of the various input screens (as seen on the computer) are also included. The title of the input screen can be seen at the top of the screen or at the bottom right corner of each figure (screen) in the printout.

Also, a sample screen printout of the NOTEPAD containing the output file FLEXOUT.DAT is also shown.

Layer Properties

This module accepts the following input:

1. The input file is named flexinp.dat and the output file is named flexout.dat



NCFLEX - LAYER PROPERTIES

2. Layer ID:

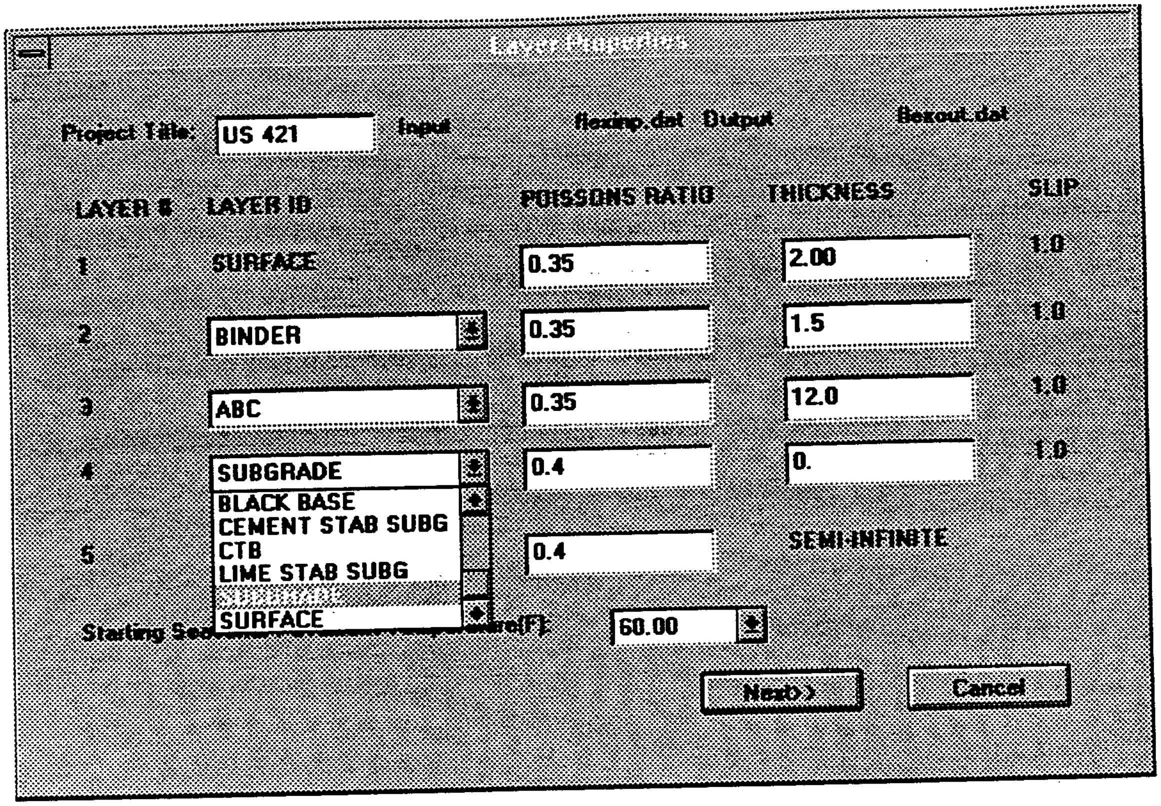
The user is prompted to choose the layer material for the 5 layers of the pavement system. The 5th layer is fixed to be a subgrade. For the remaining layers the user has the option of choosing from any of the following:

Table A-1. Layer Properties: Layer ID

Layer Properties	Layer ID
Surface	1
Binder	2
Black Base	3
Aggregate Base Course	4
Cement Treated Base Course	5
Lime Stabilized Subbase	6
Cement Stabilized Subbase	7
Subgrade	8

3. Poisson's Ratio:

Default values for the Poisson's ratio are provided in the table below. These default values are automatically filled in on selection of Layer ID. The user has an option of changing these values.



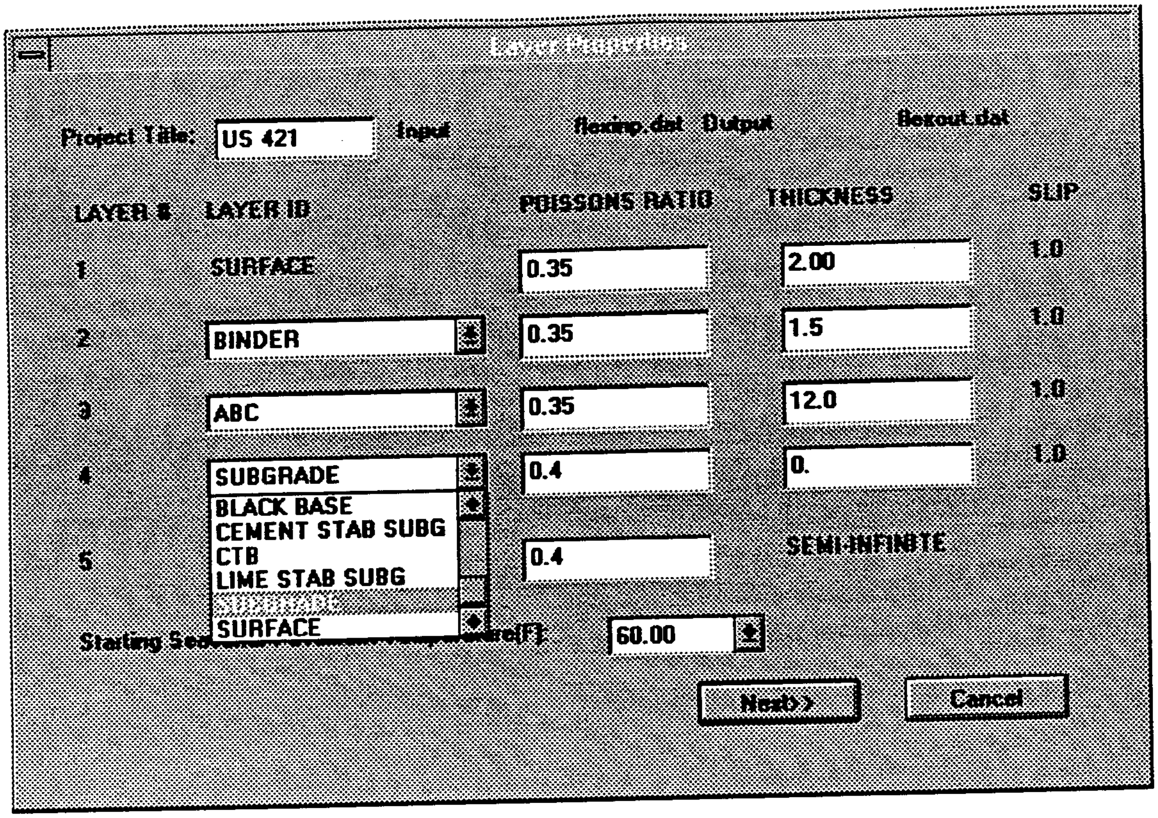
NCFLEX - LAYER PROPERTIES

Table A-2. Layer Properties: Poisson's Ratio

Layer Material	Poisson's Ratio
Surface	0.35
Binder	0.35
Black Base	0.35
Aggregate Base Course	0.35
Cement Treated Base Course	0.1
Lime Stabilized Subbase	0.2
Cement Stabilized Subbase	0.1
Subgrade	0.4

4. Thickness:
The thickness in inches of the 5 layers need to be input by the user. The 5th layer is considered semi-infinite. If any of the other layers are selected to be subgrades, the program automatically selects a thickness of 0 (zero) inches.

5. The slip values are always maintained at 1.0 (no slip condition). The user is not permitted to manipulate this.



NCFLEX - LAYER PROPERTIES

6. Starting Seasonal Pavement Temperature:

The computation is carried over 4 seasons. The drop-down box allows the selection of the starting pavement temperature in degrees Fahrenheit. This refers to temperature at the time the pavement is opened to traffic after construction. The user is allowed to choose from the following four temperatures.

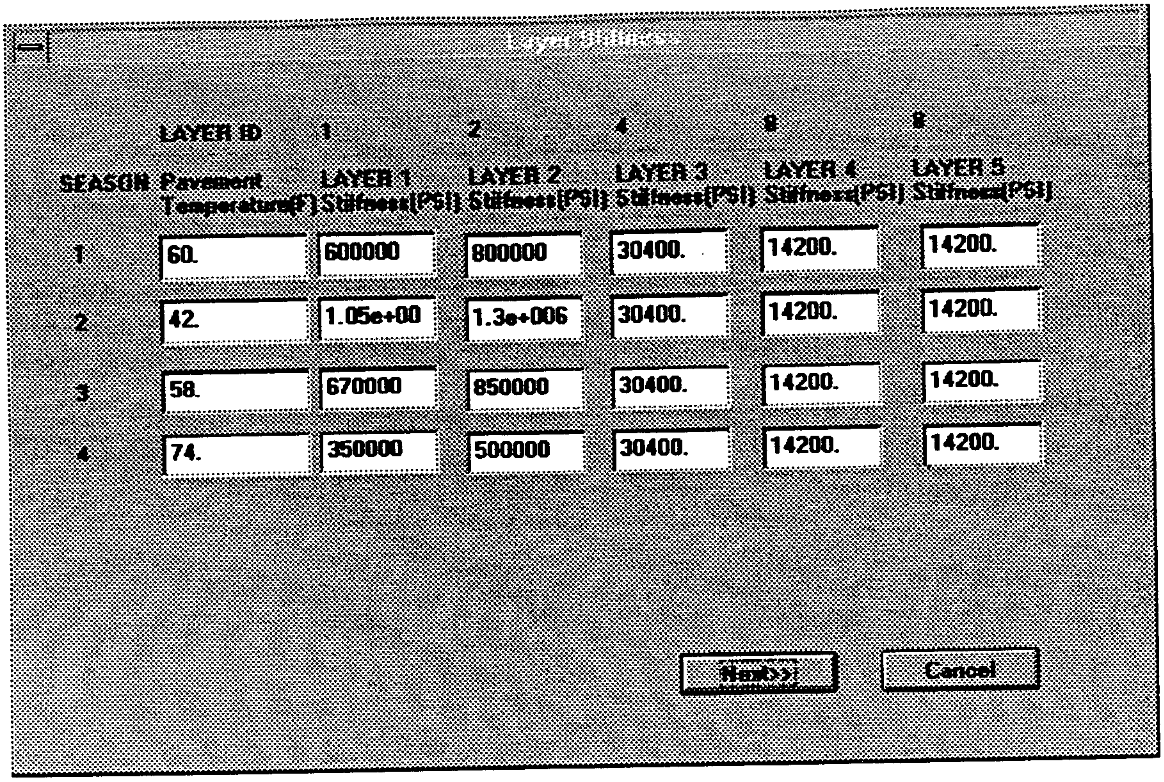
Table A-3. Default Starting Seasonal Pavement Temperatures(Fahrenheit)

Season	Temperature (^{0}F)
Season I	60
Season II	42
Season III	58
Season IV	74

The user is allowed to manipulate the four temperatures in the next module. Choosing the starting temperature fixes the temperatures for the successive seasons in the given order.

Layer Stiffness

This module uses default values for the stiffness of the various layers based on the Layer ID and the pavement temperature. The temperatures that appear in this module are based on the starting seasonal pavement temperature chosen in the previous module.



NCFLEX - LAYER STIFFNESS

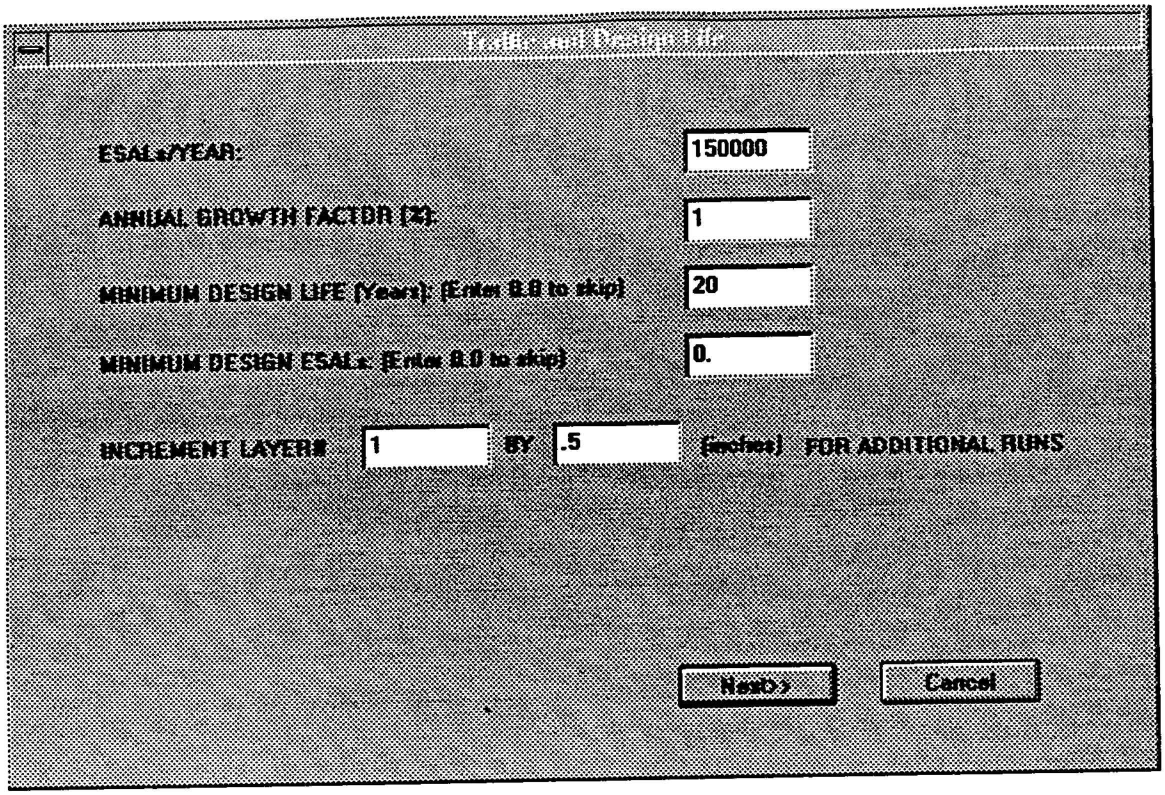
1. Temperature The user is allowed to change the pavement temperature for the 4 seasons in this module.
2. Stiffness Any changes in the temperature would necessarily mean a change in the stiffness values. The user should change the stiffness values based on his experience of the material types and temperatures. To aid the use, the following charts are provided:

- Resilient modulus versus temperature for the surface, binder and black base mixes. (Fig 1)
- Reliability based estimates of resilient modulus values for the aggregate base course and subgrades. (Figures 2a and 2b)

For example, in Figure 2b, to obtain a subgrade modulus value for the period of December - February at a reliability level of 80 percent, a subgrade modulus value that is approximately 30 percent of the maximum subgrade modulus would be used (30% of 23 = 6.9 KSI).

Design Traffic and Life

This module accepts the following as input:
1. Total ESALs / Year anticipated.
2. Annual Growth Factor - in percentage (ex. 1, 1.5, 2, ...)
3. Minimum design Life (years) (ex. 10 , 15, 20,...)
   Entering 0.0 would pass the control over to the minimum design ESALs criteria.



NCFLEX - TRAFFIC AND DESIGN LIFE

4. Minimum design ESALs

Entering 0.0 would pass the control over to the minimum design life criteria.

It is important that both criteria's (minimum design life and minimum design ESALs) are not zero.

5. The user is prompted to increment <u>any one layer</u> by a given amount of thickness (inches) so as to check a host of designs to arrive at one that actually satisfies the necessary criteria. The same thickness will be maintained for the other layers.

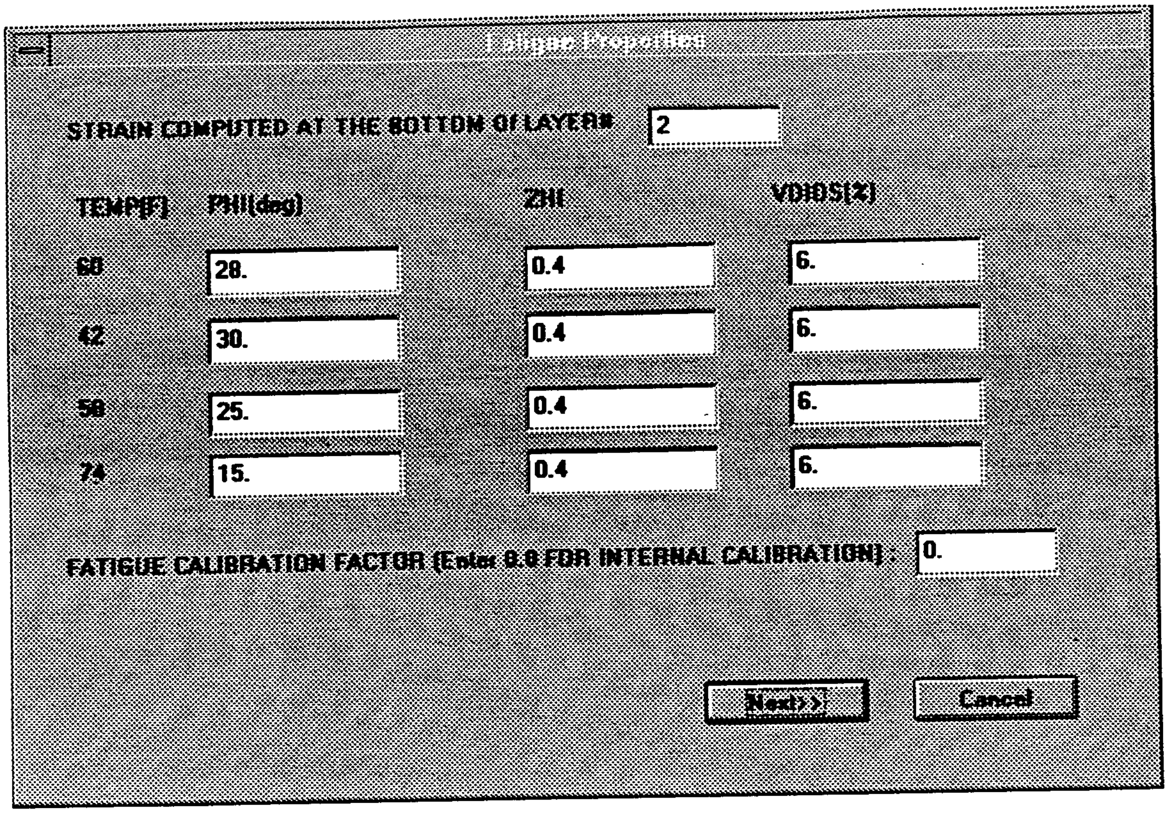
Fatigue Properties

1. This module determines the layer to be used in the fatigue computation (i.e., the lowermost asphaltic layer).

2. Also, based on temperature and the Layer ID (lowermost asphaltic layer), default values for the fatigue parameters for phase angle (PHI (degrees)), Energy Ratio (ZHI) and %Voids (V) are filled in. If the temperatures chosen in the earlier modules are not part of the default dataset, the program would fill in zero's, and the user would have to input values for the various fatigue parameters.

If different mixes need to be adopted, it may be necessary to carry out fatigue tests to arrive at the PHI, ZHI, and VOIDS estimates.

3. It is advisable to enter zero for fatigue calibration factor, so that the program would choose an appropriate value based on the pavement parameters. Essentially, entering zero forces the program to perform an internal calibration routine. The user can change the value of the calibration factor.



NCFLEX - FATIGUE PROPERTIES

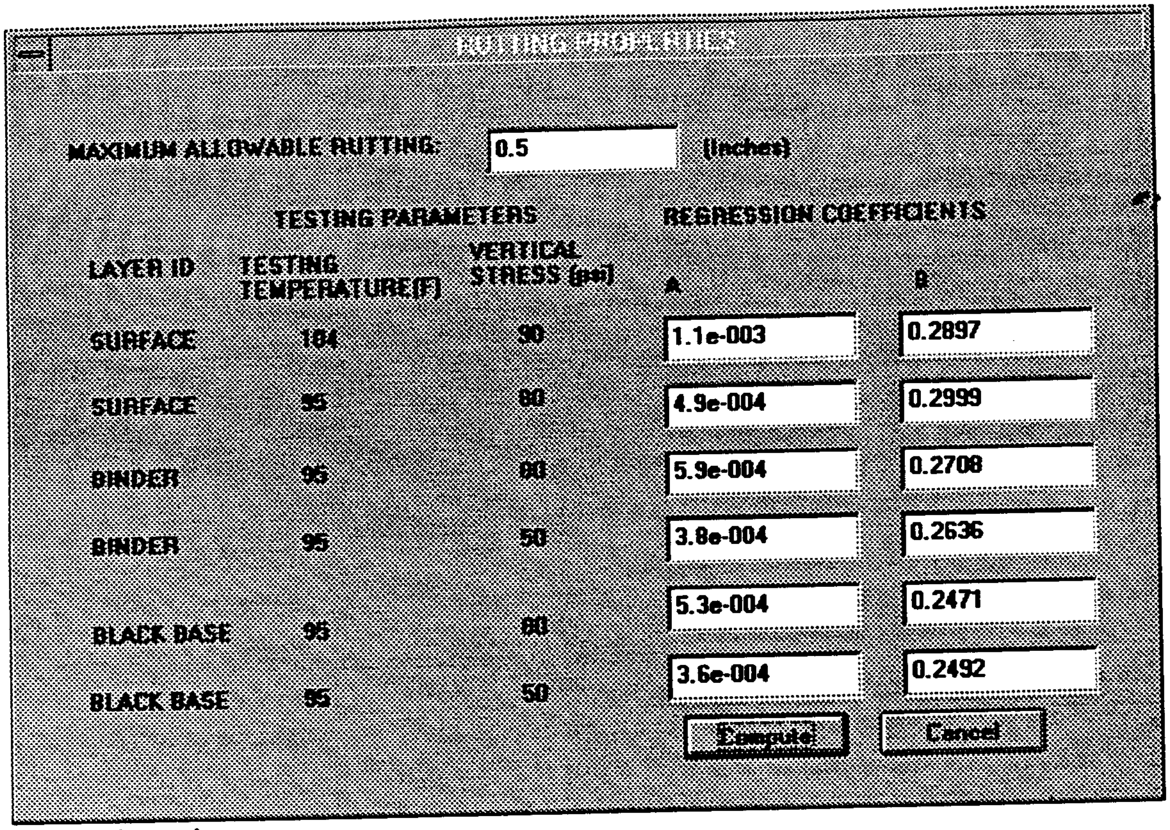
Rutting Properties

1. A default value of 0.5 inches is chosen for maximum allowable rutting. An option is given to the user for changing this.
2. Coefficients A and B for the various asphaltic layer mixtures tested under different conditions are shown as default values. If different mixes need to be adopted, it may be necessary to carry out rutting tests to obtain new coefficients A and B.

The primary rutting model used in the program NCFLEX is based on asphalt layer rutting only. This approach was adopted based on observed results. To make the rutting model more generic, the SHELL approach (Shook, J.F., 1982) on rutting, based on limiting subgrade strain has been added to the existing computer program. This method provides the number of ESALs the pavement can carry without causing excessive rutting (defined as greater than 0.5 inches). The results from this generic model are not supported by data from the research project used to develop the rutting model.

3. Click on the compute button to begin computation.

Computation time depends on the nature of the design calculations. The user would have to wait for a while, before the output is obtained. During the computation process, the program moves into the DOS mode, and a PLEASE WAIT sign will appear on the screen. The user will have to wait during this process.



Design Selection

Based on the output the user can select the appropriate design. The output provides the fatigue life and asphalt rutting estimates for the various combinations of design. The user can pick up the final combination shown in both the fatigue and rutting outputs and decide on the final design.

Also, provided are life to failure estimates based on SHELL subgrade rutting criteria.

Example Computation

Problem:

To design an aggregate base course pavement to last 5 years. The pavement is expected to experience a traffic level of 150000 ESALs in the first year with a 1 % increase every year. The requsite properties for the materials are provided.

Design :

Tables 1(a). and 1(b). show the input and output files respectively. Table 1(a). indicates the seed design used and the various parameters used in the design. The output from the program is shown in Table 1(b). From fatigue considerations the pavement (3" surface, 2" binder and 12' aggregate base course) fails in 72 months (which is greater than 5 years). From rutting considerations the same configuration experiences a rutting of 0.29 inches during the 5 year design period. This is lesser than the 0.5 inches criteria assumed for pavement failure due to rutting. Therefore in this case the pavement is designed based on the fatigue criteria. The SHELL criteria for rutting is also provided.

```
File  Edit  Search  Help
  4       8    .40     .000          1.
  5       8    .40
 ---------------
 LAYER MATERIAL -> ID
 HDS-> 1  HDB -> 2 HB -> 3 ABC -> 4 CTB -> 5
 LIME_SUBGRADE -> 6 CEMENT_SUBGRADE -> 7 SUBGRADE -> 8
 ---------------------------------------------------
            MODULI      MODULI      MODULI      MODULI
           SEASON 1    SEASON 2    SEASON 3    SEASON 4
 LAYER:1  600000.00  1050000.00   670000.00   350000.00
 LAYER:2  800000.00  1300000.00   850000.00   500000.00
 LAYER:3   30400.00    30400.00    30400.00    30400.00
 LAYER:4   14200.00    14200.00    14200.00    14200.00
 LAYER:5   14200.00    14200.00    14200.00    14200.00
 ---------------------------------------------------
 LAYER ID--> 1 2 4 8
   H1     H2     H3      H4    FAT.LIFE(MONTHS)   ESALS TO FAT.
 ------------------------------------------------------------
   2.00   1.50 12.00    .00      24                  .60E+06
   2.50   1.50 12.00    .00      36                  .89E+06
   3.00   1.50 12.00    .00      48                  .12E+07
   3.50   1.50 12.00    .00      72                  .18E+07
   4.00   1.50 12.00    .00      96                  .24E+07
   4.50   1.50 12.00    .00     138                  .35E+07
   5.00   1.50 12.00    .00     192                  .49E+07
   5.50   1.50 12.00    .00     255                  .68E+07
   H1     H2     H3      H4    RUT LIFE   ESALS TO RUT   MAX. RUT
 ------------------------------------------------------------
   2.00   1.50 12.00    .00      20         .61E+07        .43
   2.50   1.50 12.00    .00      20         .61E+07        .43
   3.00   1.50 12.00    .00      20         .61E+07        .44
   3.50   1.50 12.00    .00      20         .61E+07        .45
   4.00   1.50 12.00    .00      20         .61E+07        .46
   4.50   1.50 12.00    .00      20         .61E+07        .48
   5.00   1.50 12.00    .00      20         .61E+07        .50
```

NCFLEX- FLEXOUT.DAT

The output file (FLEXOUT.DAT) is automatically brought up, using the NOTEPAD feature of windows. The output can be saved to another file, or printed based on the users preference using the menu feature of the NOTEPAD.

References:

1. Khosla, N.P., Y.R. Kim, S. Satish, and N. Kim, " A Comparative Study of Performance of Different Designs for Flexible Pavements," Final Report, Research Project No.23241-87-1, Department of Civil Engineering, North Carolina State University, June 1996. (document in preparation).

2. Shook, J.F., F.N. Finn, M.W. Witczak, and C.L. Monismith. Proceedings, Fifth International Conference on the Structural Design of Asphalt Pavements held at The Delft University of Technology, The Netherlands, August 23-26, 1982, Vol. I, pp. 17-44.

Table 1(a) Sample input file for NCFLEX program (flexinp.dat)

```
FILENAME
**********
 SEC1
DATE&TIME
**********
Wednesday, July 24, 1996, @, 07:47 SLIP
*****************************************
1    1   .35    2.00       1.
2    2   .35    1.500      1.
3    4   .35    12.000     1.
4    8   .40    20.000     1.
5    8   .40    SEMI-INFIN
LAYER MODULI IN PSI
SEASON TEMP   1           2           4          8          8
*****************************************************************
1  60.00  600000.00   800000.00   30400.00  14200.00  14200.00
2  42.00  1050000.00  1300000.00  30400.00  14200.00  14200.00
3  58.00  670000.00   850000.00   30400.00  14200.00  14200.00
4  74.00  350000.00   500000.00   30400.00  14200.00  14200.00
TOTAL NUMBER OF ESALS/YEAR
*****************************************
      150000
TRAFFIC ANNUAL GROWTH FACTOR
*****************************************
      1.0
STRAIN AT THE BOTTOM OF LAYER #
*****************************************
      2
FATIGUE EQUATION PARAMETERS
*****************************************
ID  TEMP   PHI(DEG)  ZHI  VOIDS(%)
2   60.00  28.00     .40  6.00
2   42.00  15.00     .40  6.00
2   58.00  25.00     .40  6.00
2   74.00  30.00     .40  6.00
RUTTING COEFFICIENTS
*********************************
0.0011 0.00049 0.00059 0.00038 0.00053 0.00036
0.2897 0.2999 0.2708 0.2636 0.2471 0.2492
INCREMENT LAYERS
*********************************
1     0.5
CALIBRATION FACTOR FOR FATIGUE MODEL
*****************************************
 0.0
MIN DESIGN LIFE     MIN DESIGN ESALS     MAXIMUM ALLOWABLE RUTTING (inches)
*****************   *****************    ********************************
 5                   0.0                  .5
```

Fatigue calculated over 4 seasons

Increment any one layer at a time for arriving at thickness design

For internal calibration of fatigue use 0.0 in input.

3 Design criteria - Minimum Design Life
- Minimum Design ESALs
- Maximum Allowable rutting

Need to choose a minimum of 1 out of the three. To skip any one criteria enter 0.0

Table 1(b) Sample output file for NCFLEX program (flexout.dat)

```
PROJECT TITLE
*************
US421
DATE&TIME
*************
Wednesday, July 24, 1996, @, 07:47
LAYER#      ID     NU     THICK.,IN     SLIP
*********************************************
 1          1      .35    2.000         1.
 2          2      .35    1.500         1.
 3          4      .35    12.000        1.
 4          8      .40    20.000        1.
 5          8      .40
--------------
LAYER MATERIAL -> ID
HDS-> 1 HDB -> 2 HB -> 3 ABC -> 4 CTB -> 5
LIME_SUBGRADE -> 6 CEMENT_SUBGRADE -> 7 SUBGRADE -> 8
-----------------------------------------
      MODULI    MODULI     MODULI    MODULI
      SEASON 1  SEASON 2   SEASON 3  SEASON 4
LAYER:1 600000.00 1050000.00 670000.00 350000.00
LAYER:2 800000.00 1300000.00 850000.00 500000.00
LAYER:3  30400.00   30400.00  30400.00  30400.00
LAYER:4  14200.00   14200.00  14200.00  14200.00
LAYER:5  14200.00   14200.00  14200.00  14200.00
-----------------------------------------
LAYER ID--> 1 2 4 8
 H1   H2   H3    H4   FAT.LIFE(MONTHS)  ESALS TO FAT.
--------------------------------------------------
 2.00 1.50 12.00 20.00   36        .89E+06
 2.50 1.50 12.00 20.00   51        .13E+07
 3.00 1.50 12.00 20.00   72        .18E+07

NCSU - ASPHALT RUT CRITERIA
 H1   H2   H3    H4   DESIGN YEARS  ESALS TO RUT  MAX. RUT
--------------------------------------------------
 2.00 1.50 12.00 20.00   5            .15E+07       .29
 2.50 1.50 12.00 20.00   5            .15E+07       .29
 3.00 1.50 12.00 20.00   5            .15E+07       .29

SHELL SUBGRADE RUT CRITERIA
 H1   H2   H3    H4   DESIGN YEARS  ESALS TO RUT 0.5"
--------------------------------------------------
 2.00 1.50 12.00 20.00   36   .98E+08
 2.50 1.50 12.00 20.00   36   .98E+08
 3.00 1.50 12.00 20.00   36   .98E+08
```

Input data

Rutting of AC layers - based on a maximum design life of 5 years or a maximum rut depth of 0.5 inches

Years & Esals the pavement will last before a rutting of 0.5 inches will occurr. - Based on SHELL Subgrade Rutting Criteria

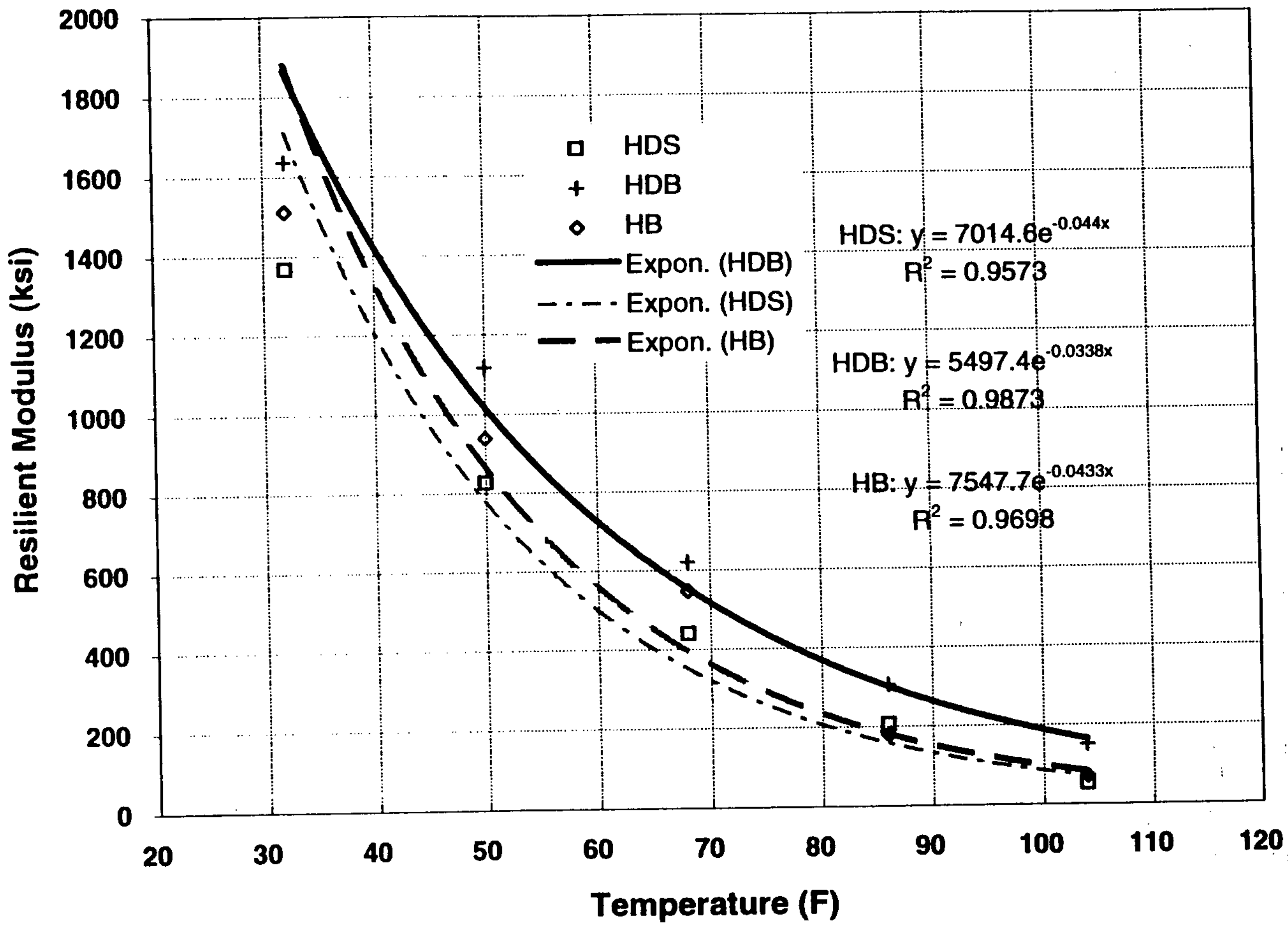


Figure 1. Resilient modulus versus temperature for AC mixes.

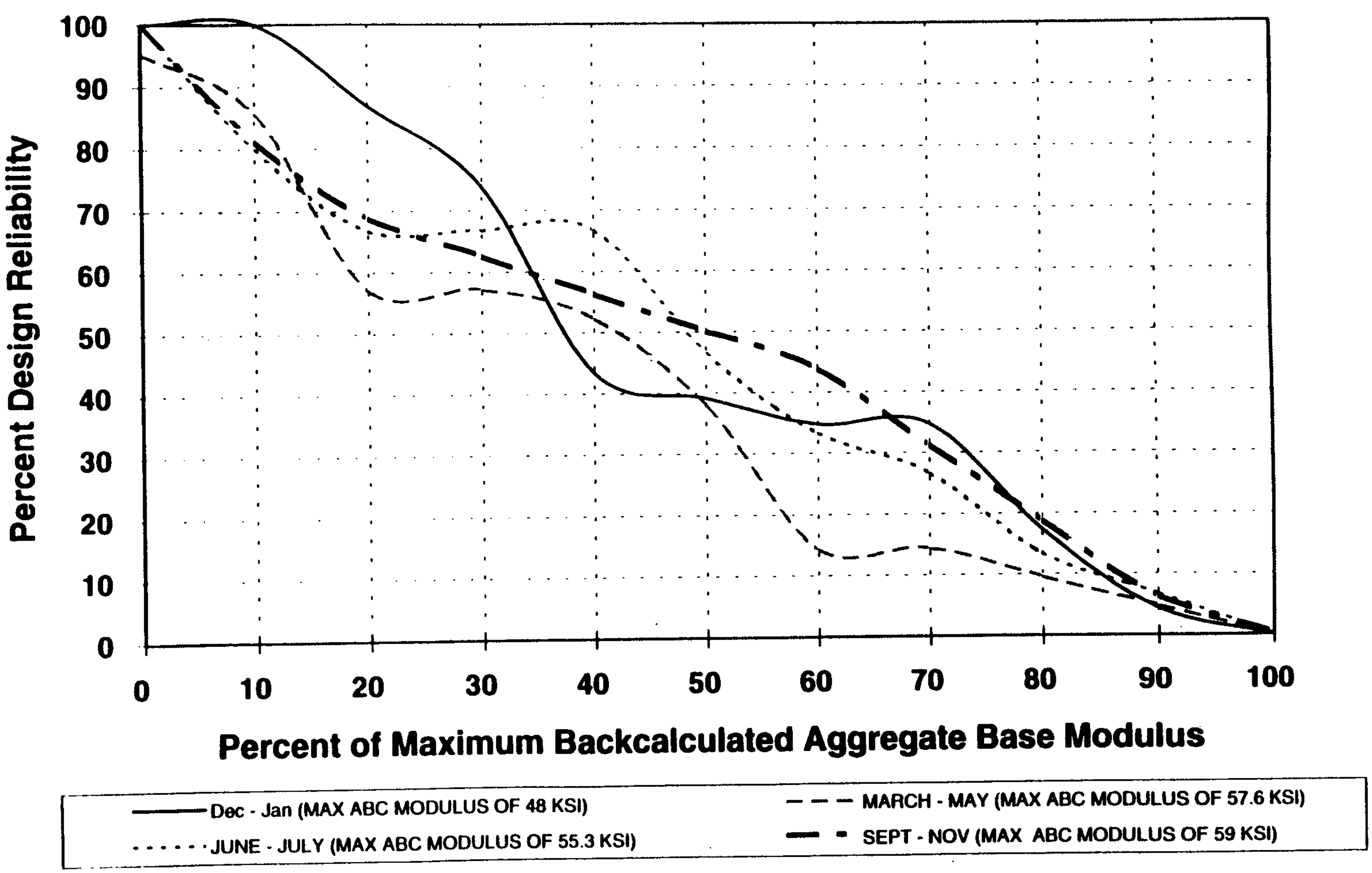


Figure 2a. Design reliability curve for aggregate base course modulus for different seasons.

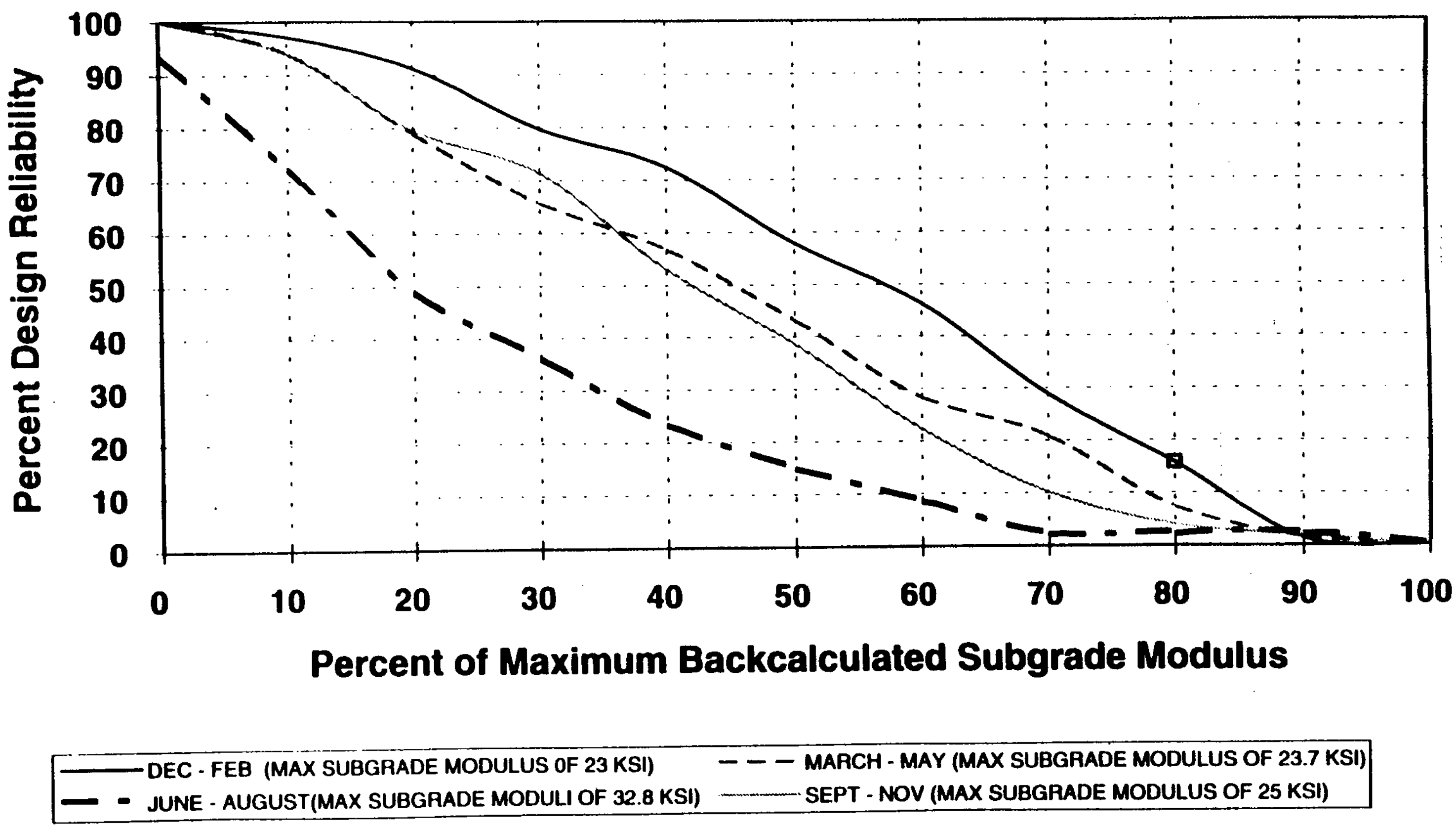


Figure 2b. Design reliability curve for subgrade modulus for different seasons.