DEVELOPMENT OF IMPROVED OVERLAY DESIGN PROCEDURE FOR THE STATE OF ALASKA

VOLUME IV

COMPUTER PROGRAMS

by

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16. Abstract

This volume describes six computer programs that are needed to implement the improved overlay design procedure developed for the state of Alaska. These programs are: ELSDEF, ELSCRN, BOUSDEF, AMOD, MECHOD, and ELSYM5. Each program is used for different purposes. Specifically, ESLDEF is used to determine pavement layer moduli from deflection basin data. ELSCRN is an auxiliary tool for use with the ELSDEF program and it makes ELSDEF much more easy and friendly. BOUSDEF is a backcalculation program. Like ELSDEF, the BOUSDEF determines pavement layer moduli using deflection basin data. BOUSDEF runs much faster than ELSDEF; therefore, it can be used for screening deflection data. AMOD is used to determine the modulus of asphalt concrete mixtures based on laboratory test data. MECHOD is a computerized procedure for mechanistic overlay design. Finally, ELSYM5 is a program used to calculate stresses, strains, deformation in a pavement using layered elastic theory.

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DISCLAIMER

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1.0 INTRODUCTION

This is Volume IV of "Development of an Improved Overlay Design Procedure for the State of Alaska." This volume consists of the following:

1. User's guide to ELSDEF program
2. User's guide to ELSCRN program
3. User's guide to BOUSDEF program
4. User's guide to AMOD program
5. User's guide to MECHOD program
6. User's guide to ELSYM5 program

These programs are the fundamental tools for implementing the improved overlay design procedure developed for Alaska. Each program is used for different purposes. Specifically, ELSDEF is used to determine pavement layer moduli from deflection basin data. ELSCRN is an auxiliary tool for use with the ELSDEF program and it makes ELSDEF much more easy and friendly. BOUSDEF is a backcalculation program. Like ELSDEF, the BOUSDEF determines pavement layer moduli using deflection basin data. BOUSDEF runs much faster than ELSDEF; therefore, it can be used for screening data. AMOD is used to determine the modulus of asphalt concrete mixtures based on laboratory test data. MECHOD is a computerized procedure for mechanistic overlay design. Finally, ELSYM5 is a program used to calculate stresses, strains, deformation in a pavement using layered elastic theory.

It should be noted that this volume does not include all programs that can be used for pavement analysis and overlay design. The intention of this volume is to describe only those programs that are needed for implementing the design procedure developed for Alaska DOT&PF.

2.0 USER'S GUIDE TO ELSDEF PROGRAM

2.1 Introduction

ELSDEF was modified from the program BISDEF which was developed by the Corps of Engineers at the Pavement Systems Division, Geotechnical Laboratory, Waterways Experiment Station. The modification was done by Peter Jordahl of 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 CHEV5L, the original elastic layer program, which was developed by Chevron Research Corporation. ELSYM5, and therefore ELSDEF, incorporate several improvements, including the capability of 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 an IBM-compatible microcomputer. ELSDEF87.EXE was compiled requiring the computer in use to be configured with a 8087 math coprocessor chip.

2.2 Create Data File

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. The user must build this file as for any file on the computer in use. The data must be input according to the format shown in Table 1. An example data file is shown in Figure 2.1. The user can save the data file under any name.

Table 2.1 Input Guide for ELSDEF

<u>Line 1</u>

LINENU NPROB

NPROB = Number of data sets

<u>Line 2</u>

TITLE 72 characters

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

<u>Line 3</u>

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

ND = Number of deflection readings (max. 10)

RRD(i) = Measured deflection in mils

i = 1 to ND

<u>Line 4</u>

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)

<u>Line 5-1 through 5-NL</u> (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

Table 2.1 Input Guide for ELSDEF (Cont.)

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.

Line 12

COL 1-8 COL 9-10 (I2)

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

Line 13

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

Line 14

COL 1-8 COL 9-10 (I2)

"ZOUT" 1.0

Line 15

Blank or zero

Line 16

"END"

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
```

Figure 2.1. Example Data File for a Three Layer Pavement Structure.

2.3 Execute Program

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 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

2.4 Output

ELSDEF writes the output to an ASCII text file under a name specified by the user. The output includes input data description, calculated deflection, and moduli. An example output is shown in Table 2.1.

To view the output, the user may use the following method:

a) To view on the screen, type

TYPE <output filename>

b) To obtain a printer output, type

TYPE <output filename> >PRN

where:

TYPE is a DOS command

>PRN stands for sending output to a printer.

Table 2.2 Example Output for ELSDEF

```
          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    SYSTEM        VALUE OF           VALUE OF
    LAYER NO    LAYER NO   MAXMUM MODULUS     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

             ELASTIC   POISSONS
   LAYER     MODULUS    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
```

Table 2.2 Example Output for ELSDEF (Cont.)

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	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

Table 2.2. Example Output for ELSDEF (cont.)

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	DEFLECTIONS CHANGED	DEFLECTIONS 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.

Table 2.2 Example Output for ELSDEF (Cont.)

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	DEFLECTIONS CHANGED	DEFLECTIONS 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 *****

3.0 USER'S GUIDE TO ELSCRN PROGRAM

3.1 Introduction

ELSCRN was developed exclusively for use with ELSDEF87.EXE which is a program for backcalculating pavement layer moduli. The ELSDEF87 program does not have a data file creating and editing routine so the user has to use some type of word processor software to create and/or edit a data file for the ELSDEF87 program to run. This process (used to create and edit a data file) can easily lead to errors. A misplaced decimal point may cause a computation error or crash the execution. The ELSCRN program eliminates this problem so the user needs not be concerned with the format of the data file. ELSCRN program provides a screen input and edit routine. All the data input and subsequent editing can be implemented in a user-friendly environment. ELSCRN also allows the user to execute the ELSDEF87 program directly under the ELSCRN environment. The output result may also be viewed on screen or printed out by following the program manual instructions. Figure 3.1 shows the menu screen of the program. Four selections can be made: create, edit, run, and print. A more detailed description of each of these follows.

3.2 Create Data File

This option allows the user to create a data file for ELSDEF87. By pressing key C (Create) in the menu screen (Figure 3.1), the program will display a data input screen, as shown in Figure 3.2. A file name is required to store data.

The data input screen is a very user-friendly environment. The user may use cursor keys on the right of the keyboard to move the cursor to any field and input data required. After entering all necessary information, the user may press Esc (Escape Key) to save the data.

```
SCREEN DATA INPUT/EDIT FOR ELSDEF PROGRAM

                    Developed by
   Haiping Zhou                          R.G. Hicks
   Research Ass't                        Professor
          Civil Engineering Department
             Oregon State University
               Corvallis, OR 97331

   Create          EDIT            Run          Print
```

```
Use or  to Select  ┘ to Activate  Esc to Exit
```

Figure 3.1. ELSCRN Menu Screen.

```
Title: Highway                                  File in Use: EXAMPLE

Number of Load(s):  1    Load Force (lbs):  9000   Load Radius:  5.90
Load Coordinates: X1   0.0  X2   0.0  X3   0.0  X4   0.0
                  Y1   0.0  Y2   0.0  Y3   0.0  Y4   0.0

Number of Layer(s):  0
Layer   Thickness    Minimum     Maximum     Seed      Poisson
 No.     (inch.)     Modulus     Modulus    Modulus     Ratio
 1.        0.0          0           0          0        0.00
 2.        0.0          0           0          0        0.00
 3.        0.0          0           0          0        0.00     Friction
 4.        0.0          0           0          0        0.00     Condition
 5.        0.0          0           0          0        0.00     [NF/FF] FF

Deflection Basin Data:
Number of Sensor Readings:  0
Deflection Readings (mil):  0.00  0.00  0.00  0.00  0.00  0.00  0.00
Sensor Locations (in.) X=   0.0   0.0   0.0   0.0   0.0   0.0   0.0
                       Y=   0.0   0.0   0.0   0.0   0.0   0.0   0.0

Tolerance (%): 10  Max. Iterations: 3    Press [Esc] to Save Data and Exit
```

Figure 3.2. Screen Data Input/Edit.

The following data are needed:

1. Title (optional) - can be any combination of characters and numerical numbers.
2. Number of load (required) - for FWD, the number of load is 1.
3. Load force (required) - in lbs.
4. Load radius (required) - in inches.
5. Load coordinates (required) - for FWD load, the coordinates are set at $X1 = Y1 = 0$.
6. Number of layers (required) - total pavement layers, including subgrade.
7. Thickness of each layer (required, except subgrade) - in inches.
8. Minimum and maximum modulus (required) - in psi. These values are used to set up the range of possible modulus. If one layer's modulus is fixed, then the minimum, maximum, and seed moduli should have the same value.
9. Seed modulus (required) - an initial modulus for program to determine final modulus.
10. Poisson's ratio (required) - for asphalt concrete, Poisson's ratio = 0.35. Dimensionless.
11. Friction condition (required) - full friction or nonfriction between layers.
12. Number of sensor readings (required) - maximum 7.
13. Deflection readings (required) - in mils (10^{-3} in). Readings start from load center line.

14. Sensor locations (required) - in inches. Starts from load centerline. For FWD, Y values are equal to 0.

15. Tolerance (required) - deflection error tolerance to stop program execution. Usually set at 5–10%.

16. Iterations (required) - usually set at 3 iterations.

3.3 Edit Data File

This option allows the user to edit a data file that has been created previously. By pressing key E (Edit) in the menu screen (Figure 3.1) and providing a file name to be edited, the same screen used to create the data file will be displayed. The information saved in the existing data file will be shown in corresponding fields. The user may use cursor keys to move to each field and edit. Again, press Esc key to save edited data.

3.4 Run ELSDEF87 Program

This option allows the user to run the ELSDEF87 program directly in the ELSCRN program environment using the data file previously created. By pressing key R (Run) in the menu screen and providing a file name, the ELSDEF87 program will be linked and executed. A message "Analyzing ..." will be shown on the screen, telling the user the program is running. The program will beep after the computation is completed. It should be noted that the program will not ask for output file name. The output will be saved in a file with an extension OUT. For example, if a file has name TEST.DAT, the output will be saved in TEST.OUT.

3.5 Print Output

This option allows the user to print the output results to either screen or printer. By pressing key P (Print) in the menu screen and providing a file name, the program will print the results to the specified destination. A printer must be connected and on-line if the output is going to be sent to the printer.

3.6 Summary

The ELSCRN program is only an auxiliary tool for use with the ELSDEF87 backcalculation program. The intention of developing this program was to make using ELSDEF87 easier. There are no calculations carried out by ELSCRN and no theoretical basis for this program.

4.0 USER'S GUIDE TO BOUSDEF PROGRAM

4.1 Introduction

BOUSDEF was developed at Oregon State University and used to determine in-situ pavement layer moduli using deflection data through backçalculation technique. The program is based on the method of equivalent thickness and Boussinesq theory. The backcalculated moduli may be used for evaluating the existing pavement and/or mechanistic overlay design.

BOUSDEF is an integrated program which includes creating, editing, and analyzing a data file. A menu screen of the program is shown in Figure 4.1. Five selections can be made and each of them is discussed in the following.

4.2 Create a Data File

This option allows the user to create a data file for later analysis. By pressing key C (Create) in the main menu, the program will ask for a file name and display a data input screen as shown in Figure 4.2.

The data input screen provides a friendly environment for data entry. The user may use cursor keys on the right of the keyboard to move the cursor to any field and enter required data. After entering all necessary information, the user may press Esc (Escape key) to save the data.

The following information are needed:

1. Number of layer (required) - total pavement layers, including subgrade.
2. Number of layer for modulus (required).
3. Tolerance (required) - deflection error tolerance to stop program execution. Usually set at 5-10%.
4. Number of iterations (required) - usually set at 3 iterations.

```
PROGRAM     MAIN     MENU

1.   Create a Data File
2.   EDIT A DATA FILE
3.   Analyze a Data File
4.   Print Result
5.   Operating System
```

Figure 4.1. BOUSDEF Program Main Menu.

```
                      BOUSDEF DATA INPUT/EDIT SCREEN
Number of Layer:          0     Number of Layer for Modulus:      0
Tolerance (%)   :        10     Number of Iterations        :     3
NDT Load (lb)   :         0     Load Plate Radius (inches)  :  0.00

Layer   Layer   Thickness  Poisson   Minimum   Maximum   Initial
 no.    for M   (inches)    Ratio    Modulus   Modulus   Modulus
  1.      1        0.0      0.00          0         0         0
  2.      1        0.0      0.00          0         0         0
  3.      1        0.0      0.00          0         0         0
  4.      0        0.0      0.00          0         0         0
  5.      0        0.0      0.00          0         0         0
  6.      0        0.0      0.00          0         0         0

Number of Sensors: 0
Sensor Spacing:    0.00   0.00   0.00   0.00   0.00   0.00   0.00
Number of Testing Locations:  0
  Location 1       0.00   0.00   0.00   0.00   0.00   0.00   0.00
  Location 2       0.00   0.00   0.00   0.00   0.00   0.00   0.00
  Location 3       0.00   0.00   0.00   0.00   0.00   0.00   0.00
  Location 4       0.00   0.00   0.00   0.00   0.00   0.00   0.00
  Location 5       0.00   0.00   0.00   0.00   0.00   0.00   0.00
File Name: EXAMPLE
                     Press Esc to Save Data & Exit
```

Figure 4.2. BOUSDEF Data Input/Edit Screen.

5. Layer for modulus (required) - 1 for calculating modulus for the layer. In this case, minimum, maximum, and initial modulus must be provided. 0 for not calculating modulus for the layer. In this case, minimum and maximum moduli are not required. Initial modulus must be given and is treated as fixed value for the layer.
6. Layer thickness (required, except subgrade) - in inches.
7. Poisson's ratio (required) - for asphalt concrete, Poisson's ratio = 0.35. Dimensionless.
8. Minimum and maximum modulus (required if modulus for the layer needs to be backcalculated) - in psi. These values are used to set up the range of possible modulus.
9. Initial modulus (required) - if layer for modulus is set at 0, this value will be used as a fixed modulus for the layer.
10. Number of sensors (required) - maximum 7.
11. Sensor spacings (required) - in inches. Starts from load center line.
12. Number of testing location (required) - maximum 5 locations can be entered.
13. Locations (required) - deflection readings at test locations. Maximum 7 deflections can be entered for each test location.

The input data are stored in a text file in an ASCII form and can be accessed and edited by the program or by other word processor software. An example of input data is shown in Figure 4.3.

FILE FORMAT:

```
Line 1:  FILE NAME:   EXAMPLE
Line 2:  3,3,5,5
Line 3:  14696,9
Line 4:  1,200000,1000000
Line 5:  2,20000,100000
Line 6:  3,10000,100000
Line 7:  11,.3,300000
Line 8:  15,.35,50000
Line 9:  240,.45,25000
Line 10:  4 , 0 , 18 ,36 , 60
Line 11: 1
Line 12:  6.47 , 4.27 ,2.34 , 1.47
```

INTERPRETATION:

```
Line 1  - File name
Line 2  - # layers, # layers for modulus, % tolerance, # iterations
Line 3  - NDT load in lbs, contact presure in psi
Line 4  - First layer, minimum modulus (psi), maximum modulus (psi)
Line 5  - Second layer, minimum modulus, maximum modulus
Line 6  - Third layer, minimum modulus, maximum modulus
Line 7  - First layer thickness (inch), Poisson ratio, Initial modulus
Line 8  - Second layer thickness (inch), Poisson ratio, Init. modulus
Line 9  - Third layer thickness (inch), Poisson ratio, Init. modulus
Line 10 - # of sensors, radial distances from load plate center
Line 11 - # of test location for modulus
Line 12 - Deflection readings at different sensor locations
```

Figure 4.3. Example of Data File.

4.3 Edit Data File

This option allows the user to edit a data file that has been created previously. By pressing key E (Edit) in the menu screen (Figure 4.1) and providing a file name to be edited, the same screen used to create the data file will be displayed. The information saved in the existing data file will be shown in corresponding fields. The user may user cursor keys to move to each field and edit. Again, pres Esc key to save edited data.

4.4 Analyze a Data File

This option allows the user to analyze a data file that has been created previously. By pressing key A (Analyze) and giving the file name to be analyzed, the analysis will begin. The program will return to the main menu after the computation is completed. The analysis results are stored in an ASCII text file which includes the following:

1. Reprint of the input data.
2. Calculated deflection for the specified layers and sensor locations.
3. Calculated modulus for the specified layers.
4. Final moduli for each layer of the pavement structure.

An example of output is shown in Figure 4.4.

4.5 Print Result

The result may be viewed on screen or printed to a printer. By pressing key P (Print) and giving the file name to be printed, the program will ask if the output is to be sent to screen or printer. Press key S for screen or P for printer; the output will be sent to the specified designation. A printer must be connected and on-line if the output is going to be printed out.

PROBLEM NUMBER: 1

DEFLECTION READINGS IN MILS:

POSIT NO	DEFLEC	WT. FACTOR
1	6.470	0.155
2	4.270	0.234
3	2.340	0.427
4	1.470	0.680

VARIABLE LAYER NO:	VALUE OF MIN MODULUS:	VALUE OF MAX MODULUS:
1	200000	1000000
2	20000	100000
3	10000	100000

ALL MODULUS IN PSI

------------------ESTIMATED PROPERTIES OF PAVEMENT # 1 ------------

NUMBER OF LAYER	CONTACT PRESSURE	RADIUS OF AREA
3	57.75	9

RADIUS POSITION FOR DEFLECTION CALCULATION

0.00 18.00 36.00 60.00

INITIAL MODULUS	POISSON'S RATIO	LAYER DEPTH
300000	0.30	11.0
50000	0.35	15.0
25000	0.45	SEMI-INFINITE

SPECIFIED TOLERANCE = 5
MAX NUMBER OF ITERATIONS = 5

----- TABLE OF DEFLECTIONS BASED ON INITIAL ESTIMATED MODULUS ------

RADIAL POSTIONS	CALCU DEFLE	MEASURED DEFLE	DIFFERENCE	% DIFFERENCE
1	12.155	6.470	-5.685	-87.861
2	7.345	4.270	-3.075	-72.003
3	4.383	2.340	-2.043	-87.293
4	2.630	1.470	-1.160	-78.935
		ABS SUM OF DIFF:	11.96	
		ABS SUM OF %DIFF:		326.09
		MTH SUM OF %DIFF:		-326.09

DATA FOR DEVELOPING EQUATIONS FOR ITERATION 4

LAYER #	INITIAL MODULUS	CHANGED MODULUS	OFFSET DIST.	DEFLECTIONS INITIAL	CHANGED	READING
1	775873	552841	0	6.490	7.280	6.47
			18	4.209	4.368	4.27
			36	2.439	2.437	2.34
			60	1.413	1.403	1.47

Figure 4.4. Example Output from BOUSDEF.

2	55983	43281	0	6.490	6.841	6.47
			18	4.209	4.453	4.27
			36	2.439	2.519	2.34
			60	1.413	1.422	1.47
3	46915	46079	0	6.490	6.544	6.47
			18	4.209	4.260	4.27
			36	2.439	2.479	2.34
			60	1.413	1.439	1.47

PREDICTED E DISREGARDING BOUNDARY CONDITIONS:
768455 57248 46803

----------------------- TABLE OF DEFLECTIONS -----------------------

RADIAL POSITION	CALCU DEFLE	MEASURED DEFLE	DIFFERENCE	% DIFFERENCE
1	6.488	6.470	-0.018	-0.285
2	4.201	4.270	0.069	1.624
3	2.439	2.340	-0.099	-4.214
4	1.416	1.470	0.054	3.682
		ABS SUM OF DIFF :	0.24	
		ABS SUM OF %DIFF:		9.81
		MTH SUM OF %DIFF:		0.81
		AVE SUM OF DIFF :	0.06	
		AVE SUM OF %DIFF:		2.45
		% OF MODU CHANGE:		2.26

THE FINAL MODULUS VALUES ARE:

768,455 57,248 46,803

MODULUS VALUES ARE IN TOLERANCE.

END OF PROBLEM 1

Figure 4.4. Example Output from BOUSDEF (Continued).

4.6 Operating System (DOS)

This option allows the user to leave the BOUSDEF program temporarily and work in the DOS environment. To return to the BOUSDEF program, type EXIT in DOS and press ENTER key.

5.0 USER'S GUIDE TO AMOD PROGRAM

5.1 Introduction

AMOD is a computer program developed by Alaska DOT&PF. AMOD computes the modulus of asphalt concrete mix for the given properties of the asphalt and aggregate using a relationship developed by the Asphalt Institute. The computed modulus can be used for the following purposes:

1. provide reference information for estimating asphalt concrete layer modulus
2. provide input to mechanistic overlay design.

5.2 Program Input

The program inputs include the following:

1. void ratio (%)
2. penetration
3. percent asphalt content by weight
4. percent aggregate passing the 200 sieve
5. temperature at time of test (°F)
6. frequency of loading (Hz).

A set of default data is also included in the program. These are: void ratio = 3%; penetration = 200; asphalt content = 6%; aggregate passing the 200 sieve = 5%; temperature at time of test = 50%; and frequency of loading = 40 Hz.

5.3 Program Output

The output of this program is modulus of an asphalt concrete mix. For the above default data, the modulus is calculated to be 1,371,823 (psi). By changing any of the parameters, a corresponding modulus will be calculated and displayed on the computer screen.

5.4 Program Execution

To execute the program, type AMOD and press ENTER key; the following screen will then be displayed.

```
PRESS APPROPRIATE NUMBER TO CHANGE DEFAULT VARIABLES

    1. VOID RATIO                          = 3
    2. PENETRATION                         = 200
    3. ABSOLUTE VISCOSITY @ 70 DEG F.      = .2640662
    4. % ASPHALT BY WT. OF TOTAL MIX       = 6
    5. PERCENT PASSING THE 200 SIEVE       = 5
    6. TEMPERATURE AT TIME OF TEST (F)     = 50
    7. FREQUENCY OF LOADING IN HZ.         = 40
    8. END


THE MODULUS FOR THE ASPHALTIC CONCRETE MIX IS: 1,371,823 (PSI)
```

By pressing an appropriate number to change default variables (for example, press 1 to change void ratio), the corresponding modulus for the asphalt concrete mix will be calculated and displayed.

6.0 USER'S GUIDE TO MECHOD PROGRAM

6.1 Introduction

The MECHOD program is a computerized procedure for MECHanistic Overlay Design. A detailed description of the design procedure may be found in the Appendix. The MECHOD program consists of two parts; one is for determining pavement damage and the other is a modified ELSYM5 (ELSYMZ.EXE) which is used to calculate pavement strains. The main program MECHOD uses the strains determined using ELSYM5 program to calculate failure repetitions and total pavement damage. For pavements with total damage greater than 100 percent, an overlay thickness may be assigned and the program will automatically reload the ELSYM5 program, calculate pavement strains and determine total pavement damage after overlay. This procedure is repeated until pavement damage is less than one.

Seasonal variations in traffic and pavement materials properties is also considered in this program. This is done by breaking traffic applications and pavement layer properties into four seasons and considering the pavement damage separately. The total pavement damage is then the sum of damage within each season.

The MECHOD program was developed considering the use of an FWD loading condition; therefore, only one load is required. Figure 6.1 shows the program main menu. Four selections can be made and each of them is discussed in the following.

6.2 Create a Data File

This selection allows the user to create a data file for later analysis. By pressing key C (Create) in the main menu, the program will ask for a file name and display a data input screen as shown in Figure 6.2.

```
PROGRAM   MAIN   MENU

1.  EDIT A DATA FILE
2.  Create a data file
3.  Analyze a data file
4.  Operating system (DOS)
```

Figure 6.1 MECHOD Program Main Menu.

```
Load Data:                                                        File in Use
Load Force (lbs):      0   Load Radius (in.):  0.00               EXAMPLE

Layer Properties:
Number of Layers: 0
                                   Season(s) for Analysis
Layer Thickness   Spring (Y)      Summer (N)      Fall    (N)     Winter (N)
 No.    (inch.)   Modulus  Pois   Modulus  Pois   Modulus  Pois   Modulus  Pois
 1.       0.0     1000000  0.35         0  0.00         0  0.00         0  0.00
 2.       0.0       12500  0.45         0  0.00         0  0.00         0  0.00
 3.       0.0      500000  0.40         0  0.00         0  0.00         0  0.00
 4.       0.0           0  0.00         0  0.00         0  0.00         0  0.00
 5.       0.0           0  0.00         0  0.00         0  0.00         0  0.00

Traffic Data:
Hist. Repetitions:          0            0               0               0
Future Repetitions:         0            0               0               0
Reliability Level (%):     50      (Optional, default @ 50 %)
Standard Deviation:      0.45      (Optional, default @ 0.45)

[F10] = Save & Exit             [F8] = Run                 [Esc] = Exit (No save)
```

Figure 6.2. MECHOD Screen Data Input/Edit.

The data input screen provides an easy data entry environment. The user may use cursor keys on the right of the keyboard to move the cursor to any field and enter required data. After entering all necessary information, the user may press [F10] key to save the data, or [F8] key to run the data, or [Esc] key to exit without saving the data. The following information is needed:

1. Load force (required) - in lbs.
2. Load radius (required) - in inches.
3. Number of layer (required) - total pavement layers, including subgrade.
4. Seasons for analysis (required) - can be one season or all seasons. Y stands for yes and N for no.
5. Layer thickness (required, except subgrade) - in inches.
6. Modulus and Poisson's ratio (required) - for seasons that will be analyzed, the modulus and Poisson's ratio are required.
7. Traffic data (required) - both historical and future traffic repetitions.
8. Reliability level (optional) - percent, (default is set at 50%).
9. Standard deviation (optional) - 0.4 to 0.5 for flexible pavements, (default is set at 0.45).

6.3 Edit a Data File

This option allows the user to edit a data file that has been created previously. By pressing key E (Edit) or 2 in the main menu and giving a file name to be edited, the same screen (Figure 6.2) used for creating a data file will be displayed. The information saved in the existing data file will be shown in corresponding fields. The user may use cursor keys to move to any field and edit the existing information. Again, follow the bottom menu for next step.

6.4 Analyze a Data File

This option allows the user to analyze a data file that has been created previously. By pressing key A (Analyze) or 3 and giving the file name to be analyzed, a message "Computing ..." will be shown on screen (Figure 6.3). Analysis results will then be displayed. An example is shown in Figure 6.4. If an overlay is needed, the program will assume an overlay thickness of 1 inch and ask the user for modulus of overlay material for the season(s) being analyzed (Figure 6.5). This allows different paving materials to be considered for overlay designs.

The overlay design procedure is a repeated process with an increment of 0.5 inch. This procedure is carried out by the program automatically until the total pavement damage is less than unity and the recommended overlay thickness will then be displayed. The output will be saved in a file with an extension OUT. For example, if a file has name TEST.DAT, the output will be saved to TEST.OUT. An example output is shown in Figure 6.6.

6.5 Operating System (DOS)

This option allows the user to leave the MECHOD program temporarily and work in the DOS environment. To return to the MECHOD program, type EXIT in DOS and press ENTER key.

```
PROGRAM   MAIN   MENU

1.  Edit a data file
2.  Create a data file
3.  ANALYZE A DATA FILE
4.  Operating system (DOS)
```

```
File name: example
```

```
Computing .....
```

Figure 6.3. Screen for Data Analysis.

Reliability = 50   Standard Dev. = 0.45
Layer Thickness (inches): 5.0   12.0

Seasons	Surface Modulus (ksi)	Calculated Starins AC.	Subg.	Traffic Repetitions Past	Future	Failure Repetitions Surface	Subgrade	Damage Ratio% AC	Subg
Spring	400	324	-603	500000	1000000	4.00E+05	3.61E+05	375	415

Total damage = 375.4 % for surface, 415.3 % for subgrade

OVERLAY OR RECONSTRUCTION. THE REMAINING LIFE OF SURFACE IS LESS THAN 20 %
OVERLAY OR RECONSTRUCTION. THE REMAINING LIFE OF SUBGRADE IS LESS THAN 20 %

Figure 6.4. Example Output Showing Overlay is Needed.

```
Modulus of Overlay Material for season(s)
being analyzed is required and should be
input in the following (in psi).
-----------------------------------------
For Spring < 400000 > ? 600000
```

Figure 6.5. Modulus of Overlay Material Can Be Considered.

Reliability = 50 Standard Dev. = 0.45
Layer Thickness (inches): 5.0 12.0

Seasons	Surface Modulus (ksi)	Calculated Starins AC.	Calculated Starins Subg.	Traffic Repetitions Past	Traffic Repetitions Future	Failure Repetitions Surface	Failure Repetitions Subgrade	Damage Ratio% AC	Damage Ratio% Subg
Spring	400	324	-603	500000	1000000	4.00E+05	3.61E+05	375	415

Total damage = 375.4 % for surface, 415.3 % for subgrade

OVERLAY OR RECONSTRUCTION. THE REMAINING LIFE OF SURFACE IS LESS THAN 20 %
OVERLAY OR RECONSTRUCTION. THE REMAINING LIFE OF SUBGRADE IS LESS THAN 20 %

Overlay thickness = 1.0 in.

Spring	400	261	-468	500000	1000000	8.14E+05	1.12E+06	184	133

Total damage = 184.3 % for surface, 133.4 % for subgrade

Overlay thickness = 1.5 in.

Spring	400	237	-421	500000	1000000	1.12E+06	1.81E+06	134	83

Total damage = 134.1 % for surface, 83.0 % for subgrade

Overlay thickness = 2.0 in.

Spring	400	216	-381	500000	1000000	1.52E+06	2.82E+06	99	53

Total damage = 98.8 % for surface, 53.1 % for subgrade

Recommendation: use 2.0 in. overlay.

Figure 6.6. Example Output.

7.0 USER'S GUIDE TO ELSYM5 PROGRAM

ELSYM 5
INTERACTIVE MICROCOMPUTER VERSION

Research, Development, and Technology
Turner-Fairbank Highway Research Center
6300 Georgetown Pike
McLean, Virginia 22101

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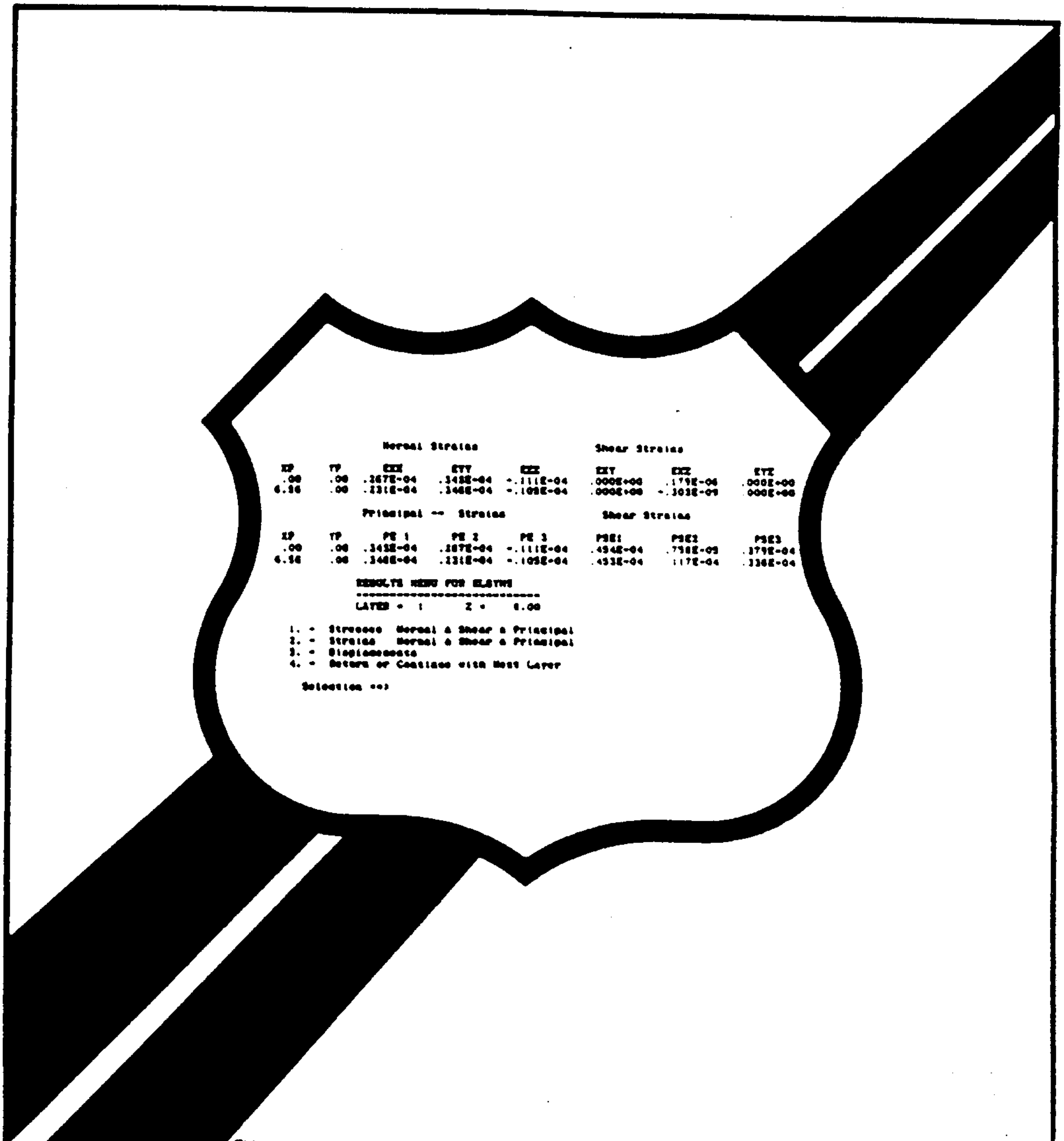
DECEMBER, 1986

U.S. Department of Transportation
Federal Highway Administration

USER'S MANUAL FOR IBM-PC AND COMPATIBLE MICROCOMPUTER



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16. Abstract

This documentation serves as a user's guide for the interactive microcomputer version of ELSYM5. This version contains interactive input and ouput processors designed to assist the user in the development of data files.

ELSYM5 will determine the various component stresses, strains, and displacements along with principal values in a three-dimensional ideal elastic layered system. The layered system (pavement) may be loaded with one or more identical circular loads normal to the surface of the system.

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Computer software, microcomputer software, pavement design, pavement analysis, ELSYM5, elastic layer theory	No restrictions. This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161

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FORWARD

This program documentation was written for the microcomputer version of ELSYM5. The program was developed as part of a project to convert existing mainframe pavement design and analysis programs to run on a microcomputer. It serves as a user's guide for the preparation of data and execution of the program. Included is a summary of the background theory upon which ELSYM5 is based.

ELSYM5 is a computerized procedure that models a three-dimensional idealized elastic layered pavement system. The microcomputer version operates on IBM-PC and compatible computers and includes an input processor for creating and modifying data sets.

This report was prepared by SRA Technologies, Inc. Stuart Kopperman was the Principal Investigator and Stephen Burnham was the COTR.

Additional copies of this report may be obtained from the National Technical Information Service, Springfield, Virginia 22161.

NOTICE

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LIST OF FIGURES

I. INTRODUCTION

ELSYM5 is a computerized procedure that models a three-dimensional idealized elastic layered pavement system. The pavement may be loaded with one or more identical uniform circular loads normal to the surface of the pavement. The program computes the various component stresses, strains, and displacements along with principal values at locations specified by the user, within the layered pavement.

The ELSYM5 computer program was developed at the University of California at Berkeley. It is a modification of the LAYER5 program allowing consideration of multiple loads as well as the presence of a rigid base below the subgrade.

Several microcomputer versions of the program have been developed. This version, for IBM-PC and compatible computers, was developed for the Federal Highway Administration. It combines the original program with an input processor and enhanced output options.

This manual summarizes the background of the ELSYM5 procedure. A full user's guide to input data preparation and program execution is provided. A sample session is included to familarize the user with the exectution of ELSYM5 on the microcomputer.

II. BACKGROUND

ELSYM5 is a computer program that will determine the various component stresses, strains, and displacements along with principal values in a three-dimensional ideal elastic layered pavement system. The layered pavement is loaded with one or more identical uniform circular loads normal to the surface of the pavement. This section of the manual summarizes the development of the procedure and the interactive microcomputer system based on the procedure. Much of the background information on ELSYM5 was extracted in part from Reference 1.

A. Development of the ELSYM5 Procedure

ELSYM5 was developed by Gale Ahlborn of the Institute of Transportation and Traffic Engineering (ITTE) at the University of California at Berkeley. It is based on the LAYER5 elastic layered computer model, with the ability to consider multiple loads as well as the presence of a rigid base below the subgrade. The coordinate system in ELSYM5 was also changed from a cylindrical system in LAYER5 to a three-dimensional cartesian system.

ELSYM5 has been used as a stand-alone mainframe analysis program and has been modified by many users to suit their requirements. One typical modification was the increase from 5 to 50 layers in the analysis by the University of Texas. The procedure has also been incorporated into many other pavement design and analysis program.

The program assumes that each layer is composed of a weightless, homogeneous, isotropic material. The material behaves in an ideally elastic manner, according to Hooke's Law. Each layer is of uniform thickness and infinite width in all horizontal directions. The bottom elastic layer may be semi-infinite in thickness or may be given a finite thickness, in which case the program assumes the bottom elastic layer is supported by a rigid base. The boundaries between the layers are assumed to be full friction, with the exception of the interface between the bottom layer and the rigid base where zero friction can be specified. The surface is free of shear and the loads applied there are assumed to be identical, vertical, and uniform over a circuluar area.

The principal of superpostion is used to determine the response at any given point when the multiple loads are specified. The input data consists of layer property data, load data, and evaluation coordinate data, as described in Section III.

The output of ELSYM5 contains a summary table of all the responses calculated at each point. These include principal stress and strains as well as the normal stresses, strains, and displacements calculated by the earlier layer programs (LAYER5, LAYR15, AND LAYIT).

B. Development of the Microcomputer System

The ELSYM5 microcomputer system is a single computer program for the IBM-PC and compatible microcomputers which combines three elements: interactive input processor, analysis program, and interactive output processor. The interactive input processor was developed under contract to FHWA as part of this study. The analysis routine is based on the microcomputer version converted FHWA, and the output processor is based on the University of New Hampshire's microcomputer version of ELSYM5.

1. Interactive Input Processor

The ELSYM5 input file must be in a specific, rigid format. To make ELSYM5 easier to use and more attractive to potential users, a user-friendly input processor was developed to assist in creating or modifying data sets. The input processor was developed to allow easy modification of data sets so that the user would not have to re-enter unchanged data between runs.

The most user-friendly type of interface is a full screen editor. ELSYM5 makes use of a new library of screen interaction routines to present the user with a series of screen images with blanks (or data fields) to be filled in with data (or numbers in the fields to be replaced or kept when modifying data). The library, GOXY.LIB, was also developed as part of this study. The input processor permits full screen movement between data fields and performs preliminary error checking of the input data. The user moves between data screens by selecting the data to be input from a series of menus. The input processor is fully described in Section IV.B. A description of the screen library may be found in a report by SRA Technologies to the Federal Highway Administration, titled: "Recommended General Procedures for Converting Mainframe Programs to Run on Microcomputers" (Ref. 2).

2. Analysis Program

The analysis portion of this version of ELSYM5 is identical to the original mainframe version. It was downloaded and converted to run on the IBM-PC. The input and output routines in the original version were removed and replaced with the new interactive input and output processors. The main program was converted into a subroutine which is called by the new main program when the user selects the analysis option from the main menu.

3. Interactive Output Processor

The output processor allows the user to view the output on the terminal screen as well as save it in an output file. The routines are taken from the University of New Hampshire version of ELSYM5 which uses their MENUZD subroutine library. Reference 3 describes the library of fourteen FORTRAN subroutines that allow a program to handle input in a free format manner without concern about spaces, commas, etc. UNH has a standard format for using these routines in interactive input and output processors. In ELSYM5, the UNH output processor routines were used with some modification to conform to the format of the new input processor menus.

III. DATA REQUIRED BY ELSYM5

The input file for the microcomputer version of ESLYM5 is identical to that required by the mainframe version. The format requirements of the file are transparent to the user through the input processor. Therefore, the user only needs to be concerned with the input data required for the analysis and not its format or sequence.

This section of the manual describes the input data required for ELSYM5 and is divided into the following three categories:

1. Layer Property Data,

2. Load Data, and

3. Evaluation Coordinate Data.

A. Layer Property Data

Each pavement analyzed by ELSYM5 may be composed of one to five elastic layers. The three properties required for each layer are the thickness (in inches), Poisson's ratio, and modulus of elasticity. The thickness is set equal to zero for the bottom elastic layer when the layer is assumed to be semi-infinite in thickness. If a thickness is given, it is assumed that the layer is resting on a rigid base and the user is prompted to determine if the base is a full friction rigid base or a no-friction base. The Poisson's ratio can never be equal to one, nor can it be in the range of 0.748 to 0.752 for the bottom layer on a rigid base. The input processor will verify that these conditions are satisfied.

B. Load Data

Loading is applied to the pavement by a series of up to ten uniform circular loads applied normal to the surface of the pavement. The loads are defined by any two of the following three properties: load force in pounds, load pressure in psi, or load radius in inches. ELSYM5 calculates the third property based on the two entered. The location is defined by X and Y coordinates along the surface of the top layer of the pavement. All load values must be positive, but the coordinates may be positive or negative distances.

C. Evaluation Coordinate Data

ELSYM5 evaluates stress, strains, and displacements at locations determined by the user. These locations are entered as a series of XY coordinate pairs and Z coordinate depths. All combinations of XY and Z coordinates are evaluated. Therefore, since a maximum of ten XY coordinate pairs and ten Z coordinate depths are permitted, a total of 100 (10 x 10) evaluation locations are possible. The values of X and Y may be positive or negative and the value of Z may only be positive. Z is limited to the depth to the bottom of the lowest layer in a rigid base pavement.

IV. The ELSYM5 Microcomputer Program

The ELSYM5 analysis program is essentially identical to the mainframe version--the same input data file will produce the same output. To aid the user in developing and modifying input data files, an interactive input processor was added to ELSYM5. An output processor was added to provide a faster method for a user to review the results. The processors make use of full screen interaction to present a user-friendly interface between users and ELSYM5.

This section of the manual details the program design, operation, and limitations of ELSYM5.

A. Program Design

ELSYM5 is a FORTRAN program that enables a user to develop a data set, perform an analysis, view the results, modify the data set, and repeat the analysis as desired. The interactive input processor portion makes use of the GOXY library of screen interaction routines which uses a standard format for data entry and program control. The library is documented in Reference 2.

The program reads a standard ELSYM5 data file as input and assign its data to internal variables for user modification. When a user is creating a new data file, the input step is skipped and the data is set equal to default values--most of which are zero. It appears to the user that new values are being entered, but the program treats the input as modifications to the default values. Because of this design, the same section of the program may used for data entry or modification.

The user enters or modifies data in groups of similar items arranged on a series of screens. The screens are selected from the main file-creation or file-modification menu. For ease of development and future enhancement, the program is modularized such that each screen is handled by a separate subroutine.

A data set is written to the output file in the standard ELSYM5 format whenever the user desires. The internal variables are not changed when the data is output. In this way, the user may make small modifications and create another data set on the same output file, without reentering the entire data set.

The analysis routine is essentially the same as the mainframe ELSYM5 program. Minor modifications were made to suit the input and output processors. The analysis is performed by choosing an option from the main menu. The most recent set of data (one pavement system) created or modified is analysed. If no data set is being created or modified, the user is prompted for the name of a data file. The results are stored in memory and the user automatically branches to the output processor.

The output processor allows the user to view portions of the results as well as send the output the printer, a disk file, or any valid DOS port (such as the console). The output processor is a modification of the one designed by the Department of Civil Engineering at the University of New Hampshire. The UNH version of ELSYM5 uses a set of FORTRAN routines contained in the MENUPC.FOR file. While the UNH version also contains a input processor, only the output section was incorporated into the FHWA version. The format of the menu was modified to correspond to that used in the input processor and the output disposition was modified.

B. Program Operation

To operate ELSYM5, the user responds to questions or enters data into fields on the screen. Execution is begun as described in Section V.A, Program Setup and Execution. The user initially is presented with a menu. Menu options are selected by entering the number corresponding to the choice on the menu. No carriage return is required. The program will branch to the desired section of the program.

Data entry screens contain descriptions of the data to be entered and data fields. The data field will usually contain the current value--either that being modified or a default value. The program automatically moves between the data fields on the screen. The user enters only a carriage return to accept the value shown, or enters a new value over the old one followed by a carriage return. At any time, the user may skip the remaining fields on the screen by depressing function key F2. The cursor jumps to the end of the screen and the user is given the opportunity to modify the data (F1) or return to the create or modify menu (F2). To modify the data, the cursor returns to the top of the screen and the user continues as before. When the user is finished with the current screen and choose function key F2 to return to the menu, all of the data is saved and the program continues. At all times, the options available to the user are displayed at the bottom of the screen.

A full description of the program is found in Section V.B, Sample Session.

The analysis portion operates in a batch-like mode without direct user interface. The user is told that ELSYM5 is performing calculations and branches to the results menu when they are completed. This is illustrated in Section V.B, Sample Session.

C. Program Limitations

There are several limitations imposed on the ELSYM5 procedure. The first two are based on the analysis procedure itself and the remaining are based on array size limits in the coding. The limitations follow:

1) The Poisson's ratio for any layer must not have a value of one. In addition, the poisson's ratio for a bottom layer on a rigid base must not equal 0.75 and therefore, should not in the range of 0.748 to 0.752. These values lead to impossible results or run-time errors because of the equations used in the analysis.

2) The program uses a truncated series for the integration process that leads to some approximation for the results at and near the surface and at points out at some distance from the load.

3) The number of different pavement systems for solution is limited only by the size of the data file on the diskette. Each pavement is analyzed individually and so, there is no program limitation.

4) The number of elastic layers in the pavement can not exceed five.

5) The number of identical uniform circular loads applied to the pavement can not exceed ten.

6) The number of evaluation coordinates where results are desired is limited to a maximum of ten XY coordinate pairs and ten Z coordinates, for a combined maximum of 100 points. The minimum number would be one XY pair and one Z for a total of one point.

7) For pavements with a rigid base specified, the maximum value for coordinate Z cannot exceed the depth to the rigid base.

8) All values except for the XY coordinates must be positive.

V. Microcomputer Program Usage on an IBM-PC

The standard distribution diskette contains the program ELSYM5 in executable form. The diskette is not bootable. This section describes how to set up a working diskette and execute the program. A sample session is shown to act as a tutorial. The session simulates the modification of the sample data set also contained on the distribution diskette. All user reponses are underlined for clarity. This section should be read by a user before attempting to execute ELSYM5.

A. Program Setup and Execution

The standard distribution diskette contains the execution file and sample data. It should not be used as a working diskette. The files should be copied to a new bootable diskette and the original diskette should be placed in a safe location for use as a back-up. To create a working diskette, the following basic steps should be followed. Comments are in parentheses and user responses are underlined.

```
(assuming a DOS system diskette is in drive A)
A> format b:/s
Insert new diskette for drive B:
and strike any key when ready
(insert a new diskette in B: and follow instructions)

Formatting...Format complete
System transferred

   362496 bytes total disk space
    40960 bytes used by system
   321536 bytes available on disk

Format another (Y/N)?n
(transfer ANSI driver to new diskette:)
A>copy ansi.sys b:
        1 File(s) copied
```

(continued on next page...)

```
(remove the DOS diskette from drive A and
replace it with the distribution diskette,
to copy the programs:)
A>copy *.* b:
ELSYM5.EXE
ELDATA
CONFIG.SYS
ELINS.DAT
(files may not be listed in the above order)
```

After completing the above operation, the distribution diskette may be placed in storage and the diskette in drive B: is the working diskette. To run the programs, the working diskette is placed in drive A: and the system rebooted (CTL-ALT-DEL) to ensure that the ANSI driver is installed. To run ELSYM5, the following is entered:

```
A>ELSYM5
```

The program takes control at this point. See the Sample Session below for details. ELSYM5 requires slightly less than 225K free memory (excluding the operating system) and since it is interactive, the execution time depends totally on user response. After creating or modifying a data set, the analysis may be selected from the main menu. Execution time for the sample data set is less than 1 minute with the math co-processor, and about 5 1/2 minutes without it. Use of a hard disk for output would decrease execution time while sending output directly to the printer increases execution time by several minutes.

B. Sample Session (Tutorial)

A sample session is presented to familiarize users with the operation of ELSYM5. Study of the screens also allows a user to assemble the necessary data before running the program. The session shows the modification and execution of the sample data set, ELDATA. which is supplied along with the program. No changes were actually made to the data set, but the sample session shows the steps required to make changes.

The first step shown is the booting of the working diskette which was created using the method described in the last section. This is followed by execution of ELSYM5. The presentation on the following pages uses a consistent format. Each page shows a copy of the terminal screen exactly as it appeared at some point during the execution of ELSYM5. Color, boldface, and underlining is not shown. All user input is shown underlined for clarity. Below the screen is a description of what was occuring during the program execution, e.g. what the user was doing and why. Since each screen is numbered in the upper right corner, the reader may flip pages backward and forward to see what would appear next if an option other than the one shown was chosen.

```
Current date is Tue  1-01-1980
Enter new date: 7-29-85
Current time is  0:00:49.43
Enter new time: 12:01


The IBM Personal Computer DOS
Version 2.00 (C)Copyright IBM Corp 1981, 1982, 1983

A>ELSYM5
```

Figure 1. Terminal Screen: Executing ELSYM5

The terminal screen reproduced above shows the results of booting the system with a standard DOS diskette. Date and time are entered. On many systems, it is not necessary to enter the time and date because of an internal clock. The last step shown on the screen is the execution of ELSYM5. After the program loads, the main menu appears, as shown on the next page.

```
                    -ELSYM5-
          Interactive Input Processor

                  Developed by
             SRA Technologies, Inc.

               Under contract to
        Federal Highway Administration

                   MAIN MENU

          1. Instructions
          2. Create a New Data File
          3. Modify an Existing Data File
          4. Perform Analysis
          5. Exit - Return to DOS

                   Selection:
```

Figure 2. Terminal Screen: Main Menu

The Main Menu is the first screen seen by the user when executing ELSYM5. A first time user should select "1" to read a description of the program and directions on how to use it. There instructions are reproduced on the next page.

In this example, option 3 was chosen to modify a data file. The user response is not shown because as soon as the user enters a valid selection, the program branches to that section. That means that for this and other menu screens a carriage return is not required for selection an option.

The other options available to the user at this time are: "2" to create a new data file (illustrated on page 16), "4" to perform the analysis (illustrated later), and "5" to end to execution of ELSYM5 and return to the DOS operating system.

The sample session continues on page 17, with the file modification menu.

ELSYM5

Elastic Layered System with Normal Loads
IBM-PC version

The Elastic Layered System computer program (ELSYM5) was modified by SRA Technologies, Inc., for FHWA under a study titled, "Pavement Design and Analysis Procedures on Microcomputers." The original analysis routine was developed at ITTE, University of California at Berkeley. This version contains interactive input and output processors to assist the user in the development of data files.

ELSYM5 will determine the various component stresses, strains, and displacements along with principal values in a three-dimensional ideal elastic layered system. The layered system being loaded with one or more identical uniform circular loads normal to the surface of the system.

All coordinates within the system are described by using the rectangular coordinate system (X,Y,Z), with the XY plane at Z=0 being the top surface of the elastic system where the loads are applied.

The positive Z axis extends vertically down from the surface into the system.

The applied loads are described by any two of the three following items: load in pounds, stress in psi, and radius of the loaded area in inches. The program determines the missing value. Each layer of the system is described by modulus of elasticity, Poisson's ratio and thickness. Each layer is number with the top layer as one and numbering each layer consecutively downward.

For more information, see:

"ELSYM5: Interactive Version, User's Guide," FHWA report, 1985.

Operation

The user is presented with a series of menus from which data entry/modification is chosen. Each selection displays a form on the screen which contains the current values for the selected data items. This could be the value from the file being modified, the last value entered when creating a file, or the program default values. The program navigates the user from data field to data field in a logical sequence.

At each field, the user has three choices: accept the value shown by pressing just the carriage return, enter a new value, or press function key F2 to signal that no more data is to be entered or modified on the current screen. When the end of a screen is reached, the user has another opportunity to modify the data before proceeding. At all times, the prompt lines at the bottom of the screen tell the user what options are available.

Output from the input processor is a ELSYM5 data file in the same format as used by the original mainframe version. The structure of ELSYM5 allows multiple cases per data file. When modifying, one case is read by the program at a time and available for modification.

Figure 3. Instructions

```
                                                   Screen 1.2

              Create a New Data File Menu
           1. Enter/Modify Run Title
           2. Enter/Modify Elastic Layer Data
           3. Enter/Modify Load Data
           4. Enter/Modify Evaluation Location Data
           5. Write Data to an Output File
           6. Return to Main Menu
                         Selection:
```

Figure 4. Terminal Screen: File Creation Menu

There are two version of Screen 1.2. The first is used when creating a new data file. It is shown above for illustration purposes only since this sample session shows the modification of an existing data file.

```
                                                          Screen 1.2

                    Modify an Existing Data File Menu

                  1. Modify Run Title

                  2. Modify Elastic Layer Data

                  3. Modify Load Data

                  4. Modify Evaluation Location Data

                  5. Read one Data Set from an Input File

                  6. Write Data to an Output File

                  7. Return to Main Menu

                              Selection: 5
 ENTER THE NAME OF DATA FILE TO BE MODIFIED: ELDATA

DATA SUCCESSFULLY READ.....
```

Figure 5. Terminal Screen: File Modification Menu

The terminal screen reproduced above shows a user beginning to modify a data set. When Screen 1.2 (for modifying data) appears, the user must first selection option 5 to read data from a data file. The program prompts the user for the filename and when a valid, existing filename is entered (here, ELDATA), one data set is read. A data file may contain multiple data sets. This version of ELSYM5 puts no practical limits on the number of data sets within a data file. However, only one data set may be modified or analyzed at a time. The sample data file, ELDATA, contains only one data set.

After the data was read, option 1 was chosen as illustrated on the next page.

Enter/Modify the following RUN TITLE:

ELSYM5 GR LAB 5

Modify the above RUN TITLE again (Y/N)? N

Figure 6. Terminal Screen: Run Title

The Run Title screen allows a user to enter or modify the heading used for the output. To keep the title as shown, only a carriage return is entered. To enter a new title, or modify the one shown, the new title is entered followed by a carriage return. Before returning to the modify (or create) menu, the user is given the opportunity to modify the title again. In this example, the title was not modified and the program returned to Screen 1.2 (modifying). At that screen, option 2, "Modify Elastic Layer Data," was chosen, as shown on the next page.

Screen 1.2.2

ELASTIC LAYER DATA

Number of layers: 3

Layer Number (top to bottom)	Thickness (inches)	Poisson's Ratio	Modulus of Elasticity
1	8.00	.15	4000000.00
2	6.00	.40	30000.00
3	.00	.45	5000.00

Note: Enter Zero thickness when bottom layer is semi-infinite.

Which one Layer will be deleted (If NONE, enter 0)? 0

Figure 7. Terminal Screen: Elastic Layer Data

When modifying elastic layer data, the user is first given the opportunity to delete any of the existing layers. Since no layers were to be deleted, "0" was entered in response to the prompt at the bottom of the screen.

As shown, the existing data are displayed on the screen. There are three (out of a possible 5) layers in the system. The thickness, Poisson's ratio, and modulus of elasticity are all contained on this screen. The next page illustrates the modification of one of the data items.

Screen 1.2.2

ELASTIC LAYER DATA

Number of layers: 3

Layer Number (top to bottom)	Thickness (inches)	Poisson's Ratio	Modulus of Elasticity
1	<u>8.00</u>	.15	4000000.00
2	6.00	.40	30000.00
3	.00	.45	5000.00

Note: Enter Zero thickness when bottom layer is semi-infinite.

CR: To Next Data Field; F2: Skip To End of Screen

Figure 8. Terminal Screen: Modifying Elastic Layer Data

This screen illustrates the modification of a data element. The prompt line at the bottom of the screen tells the user that a carriage return (CR) will skip to the next data field and the function key F2 will skip to the end of the screen. Data is modified by entering a new value over the existing value. In this case, "8.00" was entered for the thickness of layer 1. Although this is the same value as was existing, it illustrates the appearance of the screen when a data item is modified.

After modifying the first item, the function key F2 was depressed to skip to the end of the screen, as illustrated on the next page.

Screen 1.2.2

ELASTIC LAYER DATA

Number of layers: 3

Layer (top to Number bottom)	Thickness (inches)	Poisson's Ratio	Modulus of Elasticity
1	8.00	.15	4000000.00
2	6.00	.40	30000.00
3	.00	.45	5000.00

Note: Enter Zero thickness when bottom layer is semi-infinite.

F1: Modify This Screen; F2: Return To Screen 1.2

Figure 9. Terminal Screen: Results of Modification

The prompt line at the bottom of the screen has now changed to reflect the options now available to the user. Function key F2 will return the user to the modification menu (Screen 1.2) and function key F1 will allow the user to modify the screen again. If F1 were chosen, then the cursor would return to the first field (Number of layers) and the user would have the opportunity to modify the screen.

In this case, function key F2 was selected and the modification menu (Screen 1.2) was displayed again. At that point, option 3, "Modify Load Data," was selected as shown on the next page.

```
                                                     Screen 1.2.3
                         LOAD DATA

   Enter two of the following, the third is calculated.

   Load:     4500.00lbs  Pressure:      75.00 psi  Load Radius:       .00inches

   Number of load locations:  2

   Location                                 Coordinates
   number =                          X =                 Y =
            1                                  .00                   .00
            2                                13.11                   .00




CR: To Next Data Field; F2: Skip to End of Screen
```

Figure 10. Terminal Screen: Load Data

Screen 1.2.3 is illustrated above. Note that the load and pressure have been specified. Therefore, the program will calculate the load radius.

No changes were made to this data, so function key F2 was selected to skip to the end of the screen, as shown on the next page.

```
                                                              Screen 1.2.3
                                LOAD DATA

    Enter two of the following, the third is calculated.

    Load:      4500.00lbs  Pressure:       75.00 ps:  Load Radius:         .00inches

    Number of load locations:  2

    Location                                Coordinates
    number =                            X =                  Y =
                1                                   .00                    .00
                2                                 13.11                    .00




  F1: Modify This       1: F2: Skip to End of Screen
```

Figure 11. Terminal Screen: Load Data, Completed

Function key F2 was selected to return to the modification menu (Screen 1.2) where option 4, "Modify Evaluation Location Data," was selected, as shown on the next page.

```
                                                         Screen 1.2.4
                       EVALUATION LOCATION DATA
      Results are evaluated for all combinations of X-Y coordinates and
      Depths of Z.
   Number of X-Y positions:  2
   Number of  Z  position :  1

 Position     X          Y       |  Position          Z
    1        .00        .00      |     1             8.00
    2       6.56        .00      |

 CR: To Next Data Field; F2: Skip to End of Screen
```

Figure 12. Terminal Screen: Evaluation Location Data

Screen 1.2.4 is illustrated above. A total of two locations were chosen for evaluation (two 'XY' coordinate pairs times one 'Z' coordinate depth equals two locations). As before, no changes were made to this data and function key F2 was selected to skip to the end of the screen. Function key F2 was chosen again and the program returned to the modification menu (Screen 1.2) as shown on the next page.

```
                                                                Screen 1.2

                    Modify an Existing Data File Menu

                  1. Modify Run Title

                  2. Modify Elastic Layer Data

                  3. Modify Load Data

                  4. Modify Evaluation Location Data

                  5. Read one Data Set from an Input File

                  6. Write Data to an Output File

                  7. Return to Main Menu

                              Selection: 6
 ENTER THE NAME OF THE DATA FILE TO BE CREATED:ELDATA.OUT

DATA SUCCESSFULLY WRITTEN.....
```

Figure 13. Terminal Screen: Output File Creation

Now that all of the data have been modified, the user is ready to create an output file. The filename must be different than the input file, so when option 6 was chosen and the user was prompted for a filename, ELDATA.OUT was entered. Since this was a valid, new file, ELSYM5 output one data set. Had an output file already been opened, the user would have been given the opportunity to add the data set to the end of the file or close the file and open a new one.

After the data set was written, option 7 was selected to return to the Main Menu. At the Main Menu, option 4 was chosen to perform the analysis on the current data set. The analysis is always performed on the last data set read from the modification menu, or created (when creating new data sets). The analysis begins on the next page. The data set is listed on the next page.

```
ELSYM5 GR LAB 5
  3  2  2  1
        8.000          .150 4000000.000
        6.000          .400   30000.000
         .000          .450    5000.000
     4500.000        75.000        .000
         .000          .000
       13.110          .000
         .000          .000
        6.560          .000
        8.000
```

Figure 14: Data File Created by ELSYM5

```
ANALYSIS MODE OF ELSYM5
-----------------------
Do you wish the Results Saved on a File (Y/N) ==> Y

Enter Filename  (DEV:FILE.EXT or PRN or CON)  ==> B:TMP


*** PERFORMING CALCULATIONS ***
```

Figure 15. Terminal Screen: Analysis Mode of ELSYM5

The analysis begins by asking the user if the results should be saved on a file. If not, the results are only available through the output processor and could be copied using the "Prt-Scn" key. If the user wants the results saved, as shown above, the program prompts for a filename. Any valid DOS name or device is permitted. For example, the results could be directed to the printer by typing "PRN". In this case, the output is saved on a diskette in drive B (drive A is the default drive), named TMP.

After the output file information has been entered, the calculations are performed. The sample data file takes less than one minute with the 8087 math co-processor or about 5 1/2 minutes without it. When the calculations are completed, the program automatically branches to the output processor. The screen is cleared and the results menu is displayed as shown on the next page.

```
                RESULTS MENU FOR ELSYM5
                ----------------------------
                LAYER =  1        Z =    8.00

        1. -  Stresses  Normal & Shear & Principal
        2. -  Strains   Normal & Shear & Principal
        3. -  Displacements
        4. -  Return or Continue with Next Layer

          Selection ==>
```

Figure 16. Terminal Screen: Results Menu

The output processor presents the results menu for each layer (or 'Z' coordinate depth) for which the user requested evaluation. The user may look at any of the three categories of output by choosing options 1 through 3. Options may be selected in any order and repeated if desired. After the user has seen all that is desried for one layer, option 4 is chosen and the next layer is shown. When there are no more layers, ELSYM5 returns to the Main Menu. If further study of the results is desired, the user must exit the program and look at the output file, if one was created.

The next few pages show the results for options 1 through 3. Since there was only one Z coordinate depth, selection 4 returned to the Main Menu. The final page of the sample session illustrates the output file, TMP, created during the analysis.

```
                 Normal Stresses                         Shear Stresses

 XP       YP       SXX         SYY        SZZ         SXY         SXZ          SYZ
  .00     .00  .130E+03    .156E+03  -.158E+01    .000E+00    .311E+00     .000E+00
 6.56     .00  .116E+03    .156E+03  -.142E+01    .000E+00  -.527E-03     .000E+00

             Principal  -- Stresses                    Shear Stresses

 XP       YP       PS1         PS2        PS3         PSS1        PSS2         PSS3
  .00     .00  .156E+03    .130E+03  -.159E+01    .790E+02    .132E+02     .658E+02
 6.56     .00  .156E+03    .116E+03  -.142E+01    .788E+02    .204E+02     .585E+02

            RESULTS MENU FOR ELSYM5
            ---------------------------
            LAYER =  1        Z =     8.00

   1. -  Stresses   Normal & Shear & Principal
   2. -  Strains    Normal & Shear & Principal
   3. -  Displacements
   4. -  Return or Continue with Next Layer

     Selection ==>
```

Figure 17a. Terminal Screen: Output Option 1
Stresses Normal and Shear and Principal

```
                 Normal Strains                          Shear Strains

 XP       YP       EXX         EYY        EZZ         EXY         EXZ          EYZ
  .00     .00  .267E-04    .343E-04  -.111E-04    .000E+00    .179E-06     .000E+00
 6.56     .00  .231E-04    .348E-04  -.105E-04    .000E+00  -.303E-09     .000E+00

             Principal --  Strains                      Shear Strains

 XP       YP      PE 1        PE 2       PE 3        PSE1        PSE2         PSE3
  .00     .00  .343E-04    .267E-04  -.111E-04    .454E-04    .758E-05     .379E-04
 6.56     .00  .348E-04    .231E-04  -.105E-04    .453E-04    .117E-04     .336E-04

            RESULTS MENU FOR ELSYM5
            ---------------------------
            LAYER =  1        Z =     8.00

   1. -  Stresses   Normal & Shear & Principal
   2. -  Strains    Normal & Shear & Principal
   3. -  Displacements
   4. -  Return or Continue with Next Layer

     Selection ==>
```

Figure 17b. Terminal Screen: Output Option 2
Strains Normal and Shear and Principal

```
                    Displacements

   XP       YP        UX          UY          UZ
   .00      .00 -.172E-03   .000E+00    .145E-01
  6.56      .00  .174E-06   .000E+00    .142E-01

               RESULTS MENU FOR ELSYM5
               ---------------------------
               LAYER =  1       Z =    8.00

   1. -  Stresses  Normal & Shear & Principal
   2. -  Strains   Normal & Shear & Principal
   3. -  Displacements
   4. -  Return or Continue with Next Layer

     Selection ==>
```

Figure 17c. Terminal Screen: Output Option 3 Displacements

```
ELASTIC SYSTEM - ELSYM 5 GR LAB 5

            ELASTIC    POISSONS
LAYER       MODULUS    RATIO        THICKNESS
  1        4000000.      .150         8.000 IN
  2          30000.      .400         6.000 IN
  3           5000.      .450       SEMI-INFINITE

  TWO LOAD(S), EACH LOAD AS FOLLOWS

TOTAL LOAD.....      4500.00 LBS
LOAD STRESS....        75.00 PSI
LOAD RADIUS....         4.37 IN

       LOCATED AT
LOAD      X          Y
  1      .000       .000
  2    13.110       .000

RESULTS REQUESTED FOR SYSTEM LOCATION(S)

DEPTH(S)
Z=    8.00   14.01
X-Y POINT(S)
  X          Y
    .00         .00
   6.56         .00


  Z=    8.00 LAYER NO,   1

  X          Y
    .00        .00
   6.56        .00


NORMAL STRESSES
SXX     .1301E+03   .1155E+03
SYY     .1565E+03   .1562E+03
SZZ    -.1585E+01  -.1424E+01
```

Figure 18. Printed Output from Sample Data File

SHEAR STRESSES

SXY	.0000E+00	.0000E+00
SXZ	.3108E+00	-.5270E-03
SYZ	.0000E+00	.0000E+00

PRINCIPAL STRESSES

PS 1	.1565E+03	.1562E+03
PS 2	.1301E+03	.1155E+03
PS 3	-.1586E+01	-.1424E+01

PRINCIPAL SHEAR STRESSES

PSS 1	.7903E+02	.7882E+02
PSS 2	.1319E+02	.2035E+02
PSS 3	.6584E+02	.5846E+02

DISPLACEMENTS

UX	-.1717E-03	.1736E-06
UY	.0000E+00	.0000E+00
UZ	.1451E-01	.1416E-01

NORMAL STRAINS

EXX	.2672E-04	.2307E-04
EYY	.3430E-04	.3477E-04
EZZ	-.1114E-04	-.1055E-04

SHEAR STRAINS

EXY	.0000E+00	.0000E+00
EXZ	.1787E-06	-.3030E-09
EYZ	.0000E+00	.0000E+00

PRINCIPAL STRAINS

PE 1	.3430E-04	.3477E-04
PE 2	.2672E-04	.2307E-04
PE 3	-.1114E-04	-.1055E-04

PRINCIPAL SHEAR STRAINS

PSE 1	.4544E-04	.4532E-04
PSE 2	.7581E-05	.1170E-04
PSE 3	.3786E-04	.3362E-04

Z= 14.01 LAYER NO, 3

X	Y
.00	.00
6.56	.00

Figure 18 continued. Printed Output from Sample Data File

APPENDIX

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APPENDIX

MECHOD: A Mechanistic Overlay Design Program for Flexible Pavements

MECHOD: A Mechanistic Overlay Design Program for Flexible Pavements

Haiping Zhou,[1] R.G. Hicks,[2] and Billy Connor[3]

ABSTRACT

One of the most cost effective pavement rehabilitation techniques is to provide an asphalt overlay. Asphalt overlays can strengthen existing pavements, reduce maintenance costs, increase pavement life, provide a smooth ride, and reduce safety hazards by improving pavement surface skid resistance.

This paper presents a fully mechanistic asphalt overlay design procedure for use on microcomputers. The procedure is based on fundamental characteristics of pavement layer properties and uses a linear elastic layer program ELSYM5 to determine strains at critical locations within a pavement structure. Tensile strain at the bottom of the surface layer is used to control fatigue and compressive strain on top of the subgrade is used to control rutting. Failure criteria developed by the Asphalt Institute (1982) have been adopted to estimate the pavement life. The design procedure also considers the seasonal effects on pavement life by considering traffic application and pavement strength variations for each season and determining the pavement damage within each season.

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Miner's rule, a cumulative damage theory, is used to determine the total pavement damage. Overlay thickness is determined using an iterative procedure by assuming an overlay thickness and calculating damage so that the total damage is less than or equal to one.

The program runs on IBM compatible microcomputers, is menu driven, allows screen data input and edit, and is user friendly. The development of the program makes a complicated mechanistic overlay design procedure very easy to implement for routine design work.

INTRODUCTION

One of the most cost-effective methods of improving existing pavements is by using an asphalt overlay. Asphalt overlays can be used to strengthen existing pavements, to reduce maintenance costs and increase pavement life, to provide a smooth ride, and to reduce safety hazards by improving pavement surface skid resistance. The design approach used to determine the thickness of the overlay can range from engineering judgement to a fully mechanistic analysis. Generally, the design procedures may be categorized into four types: 1) engineering judgement, 2) component analysis, 3) nondestructive testing with limiting deflection criteria, and 4) mechanistic analysis based on interpretation of nondestructive testing or laboratory data with appropriate failure criteria (Hicks and Zhou, 1988). The mechanistic type of analysis represents the current trend for overlay design. It considers the fundamental properties of materials to be used, is capable of considering changed traffic loading and tire pressures, and characterizes the response of the pavement to traffic loads in terms of strains and/or stresses. This type of analysis allows practicing engineers to address, more realistically, factors such as type of pavement structure, materials, and environmental impacts so that the behavior of the pavement may be better understood.

This paper presents a computerized mechanistic overlay design procedure for flexible pavements. A linear multilayered elastic model, as shown in Figure 1, is used for analyzing the pavement structure. In the model, the pavement material properties are represented by modulus of elasticity and Poisson's ratio. The linear elastic program ELSYM5 (Hicks, 1982) was modified and used to determine the traffic induced strains. Two pavement strains, tensile

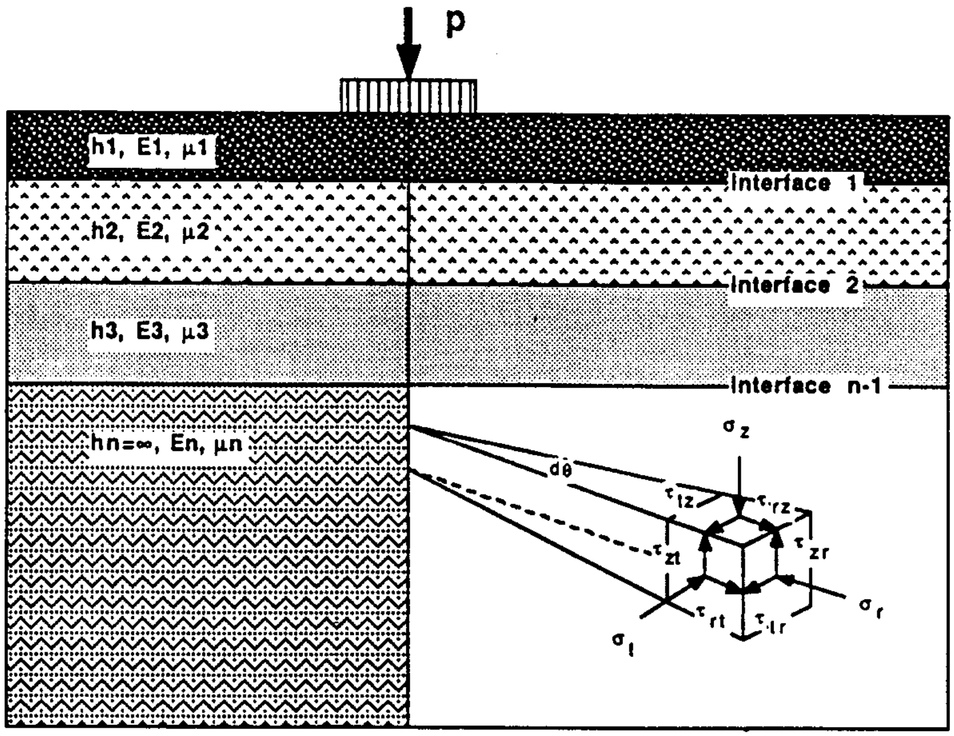


Figure 1. Generalized Multilayered Elastic System

strain on the underside of the existing asphalt bound layer and compressive strain on the top of the subgrade, are considered to be the critical ones. The Asphalt Institute's fatigue and rutting criteria (the Asphalt Institute, 1982) are used to predict the pavement life. Miner's rule is used to assess the pavement damage.

COMPONENTS OF THE DESIGN PROCEDURE

Program Flowchart

MECHOD, MECHanistic Overlay Design, is a computerized overlay design program for flexible pavements. This program incorporates recent theoretical developments in mechanistic analysis of pavement structures. With this program, a rational and yet speedy mechanistic analysis for designing an overlay can be routinely performed very easily. Figure 2 shows a flowchart of this program. Some of the major features of this program are explained below.

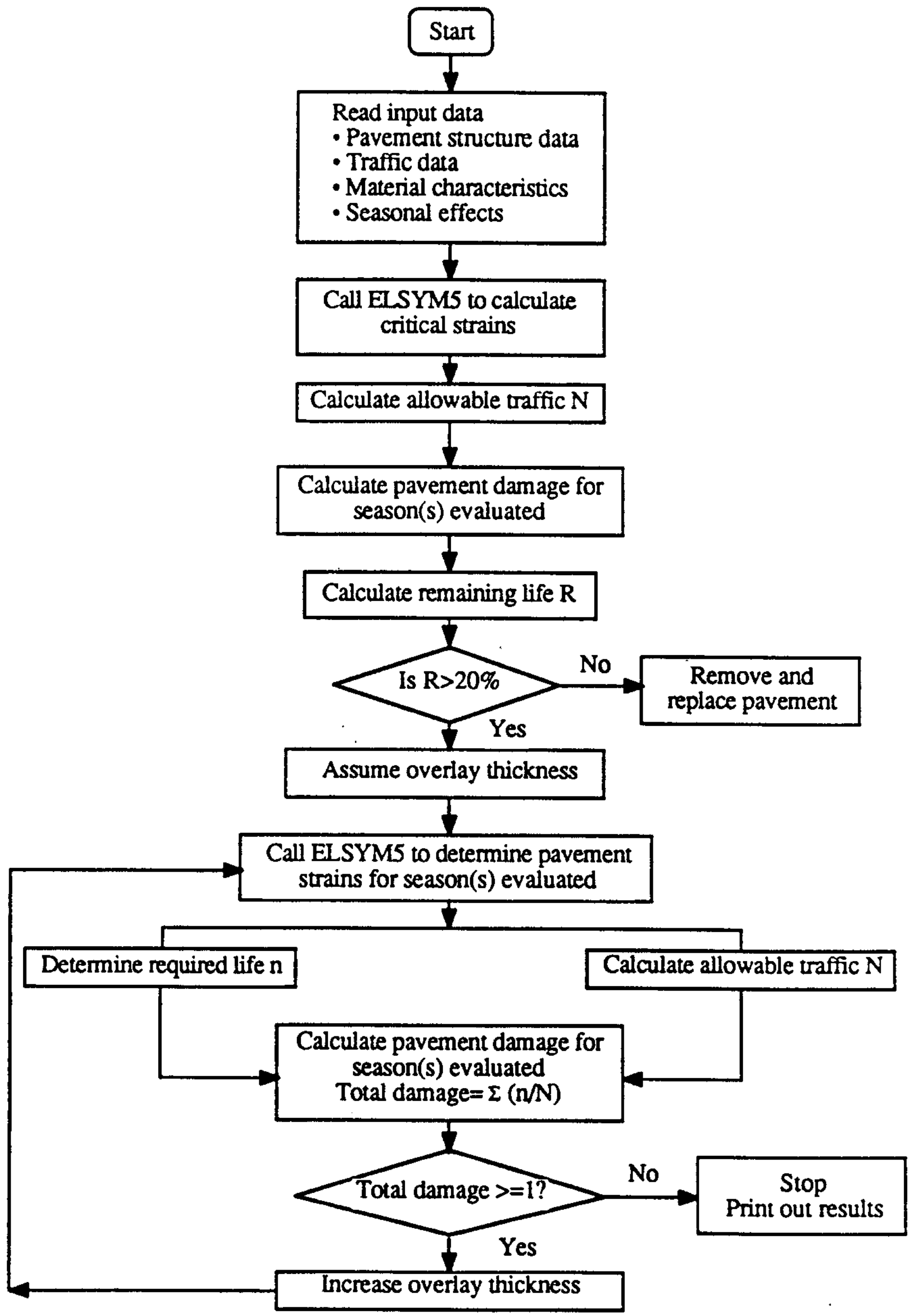


Figure 2. Program Flowchart

Seasonal Effects

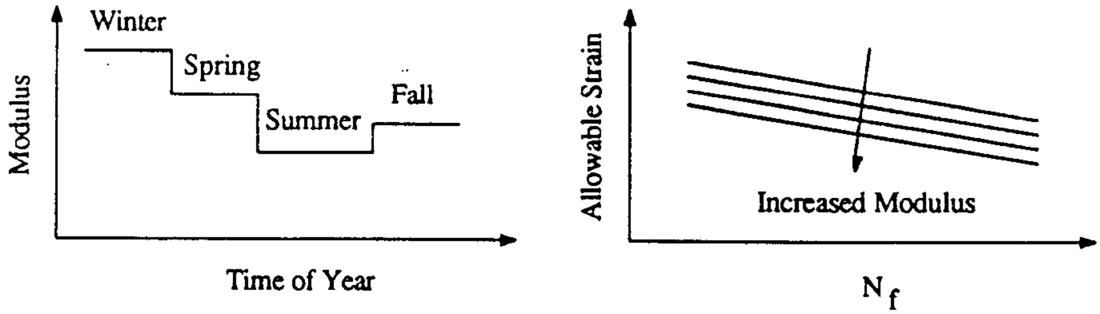
Pavement damage generally results from three factors: environmental effects, materials problems, and/or loads (Hudson and Flanagan, 1986). The most important environmental effects are moisture and temperature effects. Moisture in the pavement produces several problems including ice lens formation (swell or frost heave), base failure, slope instability, and volume changes (Hudson, 1984). Temperature differentials cause shrinkage and expansion and these induce stresses in pavement.

Seasonal effects cause temperature variations and moisture changes in the pavement structure; therefore, the resilient modulus of pavement materials will also vary with the change in season, as shown schematically in Figure 3. Very likely, traffic volume may also be affected by different seasons of the year. Because of the variations of pavement material strength and traffic load applications, pavement damage induced by traffic can be different for each season. A better estimation of the pavement damage can be obtained through considering seasonal effects on material properties and traffic applications. In MECHOD, four seasons can be taken into account: spring, summer, fall, and winter. Resilient modulus and Poisson's ratio for each season can be input individually. Traffic can also be divided into seasonal volumes. Thus, a more reasonable assessment of the pavement damage can be achieved.

Determination of Critical Pavement Strains

Under traffic load, the pavement structure experiences stresses, strains, and deformations. For flexible pavements, it is generally accepted that two pavement strains are critical and used for design purposes: 1) the horizontal tensile strain on the underside of asphalt-bound layer, and 2) the vertical compressive strain on the top of the subgrade, as shown in Figure 4.

These two critical strains are considered to be associated with the major causes of pavement fatigue and rutting. If the horizontal tensile strain (ϵ_t) is excessive, fatigue cracking of the asphalt-bound layer will result. If the vertical compressive strain (ϵ_v) is excessive, rutting or permanent deformation will result at the surface of the pavement structure from overloading the



a) Asphalt Modulus b) Asphalt Fatigue Criteria

Figure 3. Seasonal Influence on Layer Modulus and Fatigue Criteria (Hicks, et al., 1988)

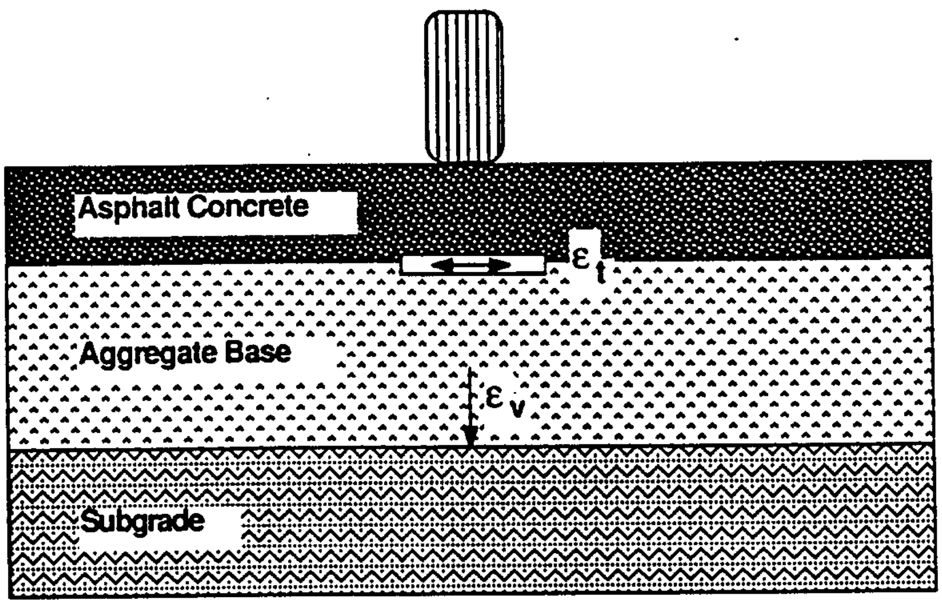


Figure 4. Location of Critical Strains

subgrade. In MECHOD, a linear elastic layer computer program (ELSYM5) is modified and used as a subroutine for the determination of the critical strains.

Fatigue Evaluation

Many researchers have found that pavement fatigue performance is generally a function of tensile strain and stresses of asphalt concrete (Finn and Monismith, 1984). A common expression is shown below,

$$N = A \left(\frac{1}{\epsilon_t}\right)^b \left(\frac{1}{S_{mix}}\right)^c \qquad (1)$$

where:

N = number of load applications to failure,

ϵ_t = tensile strain on the underside of asphalt- = bound layer

S_{mix} = stiffness modulus of asphalt-bound material, and

A,b,c = constants for specific asphalt mix.

In MECHOD, the Asphalt Institute's fatigue model (the Asphalt Institute, 1982) is used. This model is expressed by the following relationship:

$$\log N = 16.086 - 3.291 \log (\epsilon_t) - 0.854 \log (E_{ac}) \qquad (2)$$

where:

N = load applications to failure,

ϵ_t = tensile strain on the underside of asphalt-bound layer, in μ-strain, and

E_{ac} = stiffness modulus of asphalt-bound material, in ksi.

This particular relationship was obtained from laboratory fatigue data (Monismith et al., 1972) which had been adjusted to provide an indication of approximately 20 percent or greater fatigue cracking (based on total pavement area) in selected sections of the AASHTO Road Test.

For the evaluation of fatigue performance, the critical tensile strain considered in the MECHOD program is that occurring on the bottom either of the existing pavement surface layer or the overlay. Two cases are considered, as shown in Figure 5. For existing surface with resilient modulus greater than 100,000 psi, tensile strain in the existing surface is used to estimate the fatigue life. For existing surface with modulus less than 100,000 psi, tensile strain in the overlay is used.

Rutting Evaluation

Rutting or permanent deformation is controlled by limiting the vertical compressive strain at the top of the subgrade. A relationship developed by the Asphalt Institute (1982) is used in the program. The relationship is expressed as follows:

$$N = 1.36 * 10^{-9} (\epsilon_v)^{-4.48} \tag{3}$$

where:

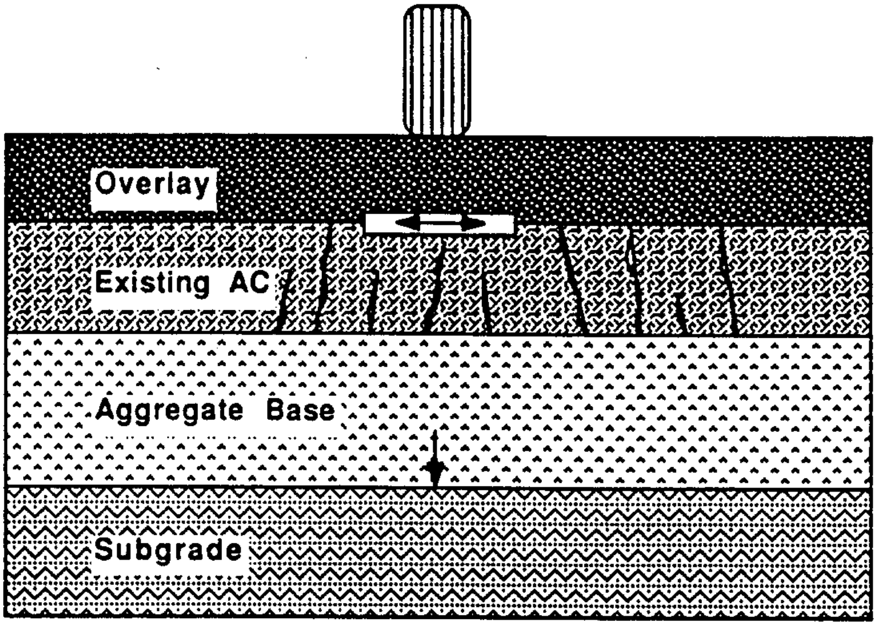
N = number of load applications, and

ϵ_v = vertical compressive strain on the subgrade top.

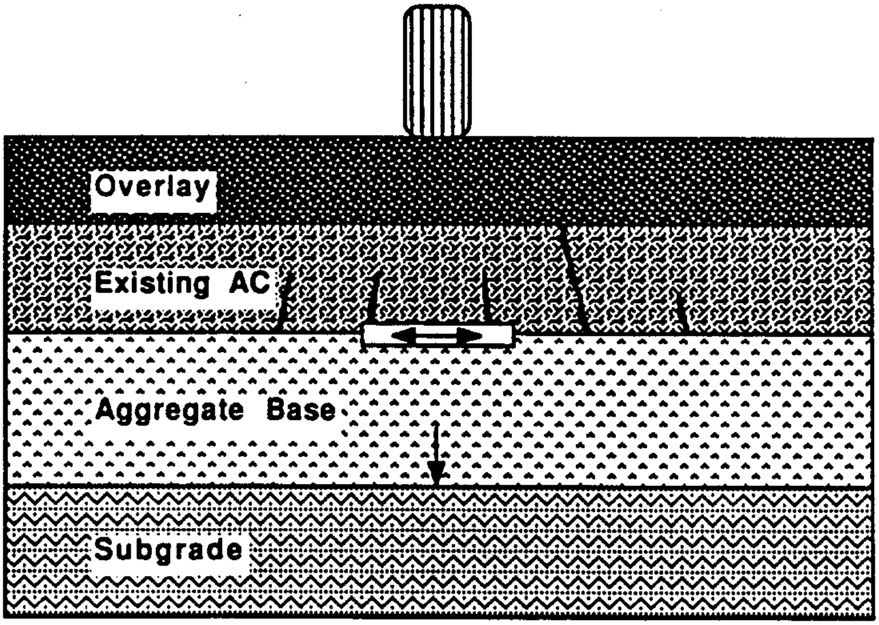
Figure 5 also shows the location of the critical strain for rutting analysis.

Determination of Pavement Damage

For every load application, there is some pavement damage. Pavements fail when the total damage accumulates to a point that the pavement serviceability is unsatisfactory. Miner's rule, a cumulative damage theory, is commonly used to assess the damage caused by mixed traffic



a) Existing Pavement Modulus Less Than or Equal to 100,000 psi



b) Existing Pavement Modulus Greater than 100,000 psi

Figure 5. Critical Strain Locations for Overlay Design

loads. In MECHOD, Miner's rule is used and it has the following form:

$$\sum_{i=1}^{\gamma} \frac{n_i}{N_i} \leq 1$$

where:

i = season i in analysis,

n_i = actual number of cycles of load applied to the pavement with season i

N_i = allowable number of cycles to failure, based on failure criteria for season i, and

γ = number of seasons considered for analysis.

For the existing pavement, if its damage is greater than 80% or its remaining life less than 20% (either fatigue or rutting), an overlay is required. If the existing pavement still has more than 20% of its life, the program will further consider projected future traffic to determine if the existing pavement is able to carry those future load applications. The total pavement damage is determined at this stage. If this total pavement damage is greater than unity, it indicates that the existing pavement is not capable of carrying the projected traffic. In such a case, the program will also perform an overlay design.

OVERLAY DESIGN PROCESS

Inputs Required

When using MECHOD, the following inputs are required:

1. Load Condition. This includes both load force and load radius.

2. Pavement Material Characteristics. This includes resilient modulus and Poisson's ratio for all pavement layers. If an overlay is needed, the program will ask the user for the resilient modulus of the overlay material. This option allows the designer to evaluate an overlay design using different paving materials.

3. Traffic Data. This includes both historical and future traffic applications in terms of 18-kip equivalent axle loads (EAL). For mixed traffic, conversions to repetitions of the 18-kip single axle load can be made using AASHTO equivalency factors.

Thickness Design

The program first asks for the resilient modulus of the overlay material for the seasons being considered and uses an initial overlay thickness of 1 inch. As shown in Figure 2, ELSYM5 is used to calculate critical pavement strains for the season(s) considered. Equations (2) and (3) are then used to determine the allowable traffic application for the season(s) considered. Total pavement damage is determined for overlaid pavement by using Miner's rule. Both fatigue and rutting are checked. If either has a total pavement damage greater than unity, it will be used as the controlling factor. Determination of overlay thickness is an iterative process. An increment of half-inch overlay thickness is used in the program for the next iteration. The above process is repeated automatically until the total pavement damage is less than unity. This overlay thickness is then recommended.

SUMMARY AND CONCLUSIONS

This paper describes a computerized mechanistic overlay design program (MECHOD) for flexible pavements. The program is operational on IBM compatible microcomputers, is menu driven, allows screen data input and edit, and is user friendly. The program is also versatile. By selecting the season(s) considered, pavement damage incurred in a particular period of the year may be determined. By considering overlay material properties, use of different paving materials becomes possible. By equating the materials properties for the overlay and existing pavement, the program may also be used for new pavement structural design. The development of this program makes a complicated mechanistic overlay design procedure very easy to implement for routine design work.

ACKNOWLEDGEMENTS

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