

1. Report No. TX-96/1987-1		2. Government Accession No.		3. Recipient's Catalog No.	
4. Title and Subtitle MODULUS 5.0: USER'S MANUAL				5. Report Date November 1995	
				6. Performing Organization Code	
7. Author(s) Chester H. Michalak and Tom Scullion				8. Performing Organization Report No. Research Report 1987-1	
9. Performing Organization Name and Address Texas Transportation Institute The Texas A&M University System College Station, Texas 77843-3135				10. Work Unit No. (TRAIS)	
				11. Contract or Grant No. Study No. 7-1987	
12. Sponsoring Agency Name and Address Texas Department of Transportation Research and Technology Transfer Office P. O. Box 5080 Austin, Texas 78763-5080				13. Type of Report and Period Covered Interim: August 1994 - August 1995	
				14. Sponsoring Agency Code	
15. Supplementary Notes Research performed in cooperation with the Texas Department of Transportation. Research Study Title: Pavement Design Support					
16. Abstract <p>MODULUS 5.0 is the latest version of the widely used flexible pavement backcalculation system developed by the Texas Transportation Institute for the Texas DOT. This report is a Users Manual for MODULUS 5.0. The major additions to this system are routines to:</p> <ol style="list-style-type: none"> 1. Estimate remaining structure life, and 2. Classify surface, base and subgrade layer strengths. <p>Appendix A provides a discussion of the background to both of these routines. Appendix B provides guidelines on how to perform the backcalculation and how to interpret the results.</p> <p>MODULUS 5.0 is now being implemented state wide as an integral part of TxDOT's pavement evaluation and design system.</p>					
17. Key Words Modulus, Backcalculation, Pavements, NDT, FWD, Remaining Life			18. Distribution Statement No restrictions. This document is available to the public through NTIS: National Technical Information Service 5285 Port Royal Road Springfield, Virginia 22161		
19. Security Classif.(of this report) Unclassified		20. Security Classif.(of this page) Unclassified		21. No. of Pages 104	22. Price

MODULUS 5.0: USER'S MANUAL

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Research Report 1987-1
Research Study Number 7-1987
Research Study Title: Pavement Design Support

Sponsored by
Texas Department of Transportation

November 1995

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IMPLEMENTATION STATEMENT

TxDOT is currently implementing a new Flexible Pavement Design System. A crucial input to that system is the subgrade resilient modulus value and its variance along the highway. Both of these can be readily calculated from Falling Weight Deflectometer data using the system described in this report.

MOD 5.0 also contains the structural strength assessment and remaining life routines, both of which should be used by district pavement engineers as the first step in the pavement rehabilitation design process. Structurally weak or strong pavements can be identified prior to modulus backcalculation. For those sections which are classified as structurally strong, it may not be necessary to undertake layer modulus backcalculation.

Any technical question regarding a data analysis should be directed to Tom Scullion at the address below. Any questions regarding the programming or computer code should be directed to C. H. Michalak at the same address.

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There is no invention or discovery conceived or reduced to practice in the course of or under this contract; including any art, method, process, machine, manufacture, design, or composition of matter; or any new and useful improvement thereof; or any variety of plant which is or may be patentable under the patent law of the United States of America or any foreign country.

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SUMMARY

MODULUS 5.0 is the latest version of the widely used flexible pavement backcalculation system developed by the Texas Transportation Institute for the Texas DOT. This report is a Users Manual for MODULUS 5.0. The major additions to this system are routines to:

1. Estimate remaining structure life, and
2. Classify surface, base and subgrade layer strengths.

Appendix A provides a discussion of the background to both of these routines. Appendix B provides guidelines on how to perform the backcalculation and how to interpret the results.

MODULUS 5.0 is now being implemented state wide as an integral part of TxDOT's pavement evaluation and design system.

CHAPTER I

INTRODUCTION

1.1 DIFFERENCES BETWEEN MODULUS 5.0 AND EARLIER VERSIONS OF MODULUS

The MODULUS 5.0 computer program consists of two separate computer codes that use FWD deflection data to analyze an existing pavement structure.

One of the computer codes is the Remaining Life Analysis Program. This computer code uses the FWD deflection data measured on an existing pavement structure to make predictions of the remaining life of the pavement and to make an estimate of the strength of the surface, base, and subgrade layers of the pavement. (See Appendix A for a detailed explanation of the Remaining Life Analysis Program). The pavement remaining life predictions and the pavement layer strength estimates are displayed on the screen and are available in a format for hard copy output to a printer. The pavement layer strength estimates are also available in a graphical display format to provide for section delineation analysis along the length of the pavement to determine where one part of the pavement structure differs from the remainder of the pavement structure.

The second computer code that makes up MODULUS 5.0 is a modified version of the layer backcalculation computer program MODULUS 4.2. This computer code uses the FWD deflection data measured on an existing pavement structure to backcalculate the moduli values of the individual layers of the pavement structure. This computer code also displays the backcalculated layer moduli values on the screen and provides for hard copy output of the layer moduli values on a printer and can display the layer moduli values in a graphical format for section delineation analysis.

For those users who are familiar with an earlier version of MODULUS, the following are the changes and features that have been made to create version 5.0.

- 1) The user can make predictions of the remaining life of the pavement structure and can make estimates of the layer strengths of the surface, base and subgrade layers

of the pavement structure. To use this option, the FWD deflections must be collected at 305 mm (12 inch) sensor spacings.

- 2) The user can now access data files and store output files from directories other than where the program is stored.
- 3) The program saves all the .OUT and .DAT files.
- 4) For a non-decreasing deflection bowl, the user can accept, delete, or correct the non-decreasing bowl.
- 5) The <HOME> key can be used from any input field to get back to the main menu.
- 6) For most of the input fields, the <ESC> key can be used to go back to correct the last data entry field that was entered from the keyboard (unless the FK2, FK3, or FK4 key is to be used).
- 7) For FWD conversion, the user can ignore non-decreasing deflection bowls if the data is rigid deflection data.
- 8) After the remaining life or backcalculation, the user can go directly to the output options menu.
- 9) The user has the option to re-run the same backcalculation problem or analysis after entering new data values. This option retains the same weighting factors from the first run unless changed by the user.
- 10) The backcalculation program automatically drops a maximum of one sensor if a non-linear subgrade stiffening with depth is detected (transparent to the user). The sensor to be dropped is assigned a zero weighting factor. However, the user may overwrite the automatic weighting factor process by inputting the desired factors on the "Full Analysis" Menu.
- 11) On the backcalculation section report, the user can identify the layer that caused the "Failed the Convexity Test" message.
- 12) The remaining life and backcalculation programs provide a summary report for on-screen viewing.
- 13) The backcalculation program prints the Poisson's ratio of the layer materials on the summary and section reports.

- 14) The backcalculation program incorporates a subroutine for viewing the plot of the observed and computed deflection bowls. The graph also displays the composite section modulus for each sensor.
- 15) For the delineation and printing menu options, the user can use the <FK1> key to get a listing of all the files in the directory that are available for the delineation analysis or for printing.
- 16) The backcalculation program provides a menu option to save the summary report as an ASCII file for later analysis.
- 17) The backcalculation program provides an option for the user to save all the files from the run for future analysis, delineation, or for printing at a later time.
- 18) The fixed designs option has been eliminated from the backcalculation menu.
- 19) The user can now input stations or mileposts in decreasing order.
- 20) The remaining life and backcalculation programs can handle stations or mileposts greater than 3100 meters (9999.999 feet).
- 21) The delineation program was made easier to use by displaying the last filename run, eliminating the user from having to re-enter this every time.
- 22) The program unloads the TSR module DISPLAY.COM from memory at the end of the program run to eliminate having to re-boot after running MODULUS 5.0.

1.2 SYSTEM REQUIREMENTS

The minimum system requirements to run the program are:

- IBM AT or compatible microcomputer,
- 640 Kb of RAM,
- DOS (version 3.00 or later) operating system,
- Math coprocessor chip (80287, 80387, or similar),
- A hard disk with 1MB of available storage space,
- An EGA or VGA graphics card with 256 Kb of screen memory and a compatible RGB or monochrome monitor, and
- A dedicated Printer.

It is recommended that an advanced microcomputer, a 486-based machine, be used in order to minimize program execution time. Printers that are on a network may have problems producing the output reports. For this setup the user may have to save the output in ASCII format for later display and printing.

Note: The MODULUS 5.0 program requires a minimum of 500k of memory when all of the program modules are executing. If the system displays the message "Unable to load" an .EXE module, the user must terminate the program and unload any unnecessary device drivers or memory resident software that are not needed to run MODULUS 5.0 until there is 500k of memory available. Use the DOS "MEM" command to determine the amount of memory available.

1.3 GETTING STARTED

Version 5.0 of the TTI MODULUS Backcalculation and Remaining Life Analysis Program is furnished on a 3½" high density diskette containing twenty-five files. The twenty-five files are listed below in alphabetical order.

021F2818.FWD	LISTCAXP.EXE
BEG.COM	LISTDIRT.EXE
BRUN40.EXE	LISTOUTT.EXE
BRUN45.EXE	MENUP.EXE
CAXP.EXE	MODDRV.T.EXE
CLIM1.DAT	MODULUS.BAT
DEFAULT.DAT	PRMODREP.EXE
DELINATP.EXE	PRTRLIFE.EXE
DELINATT.EXE	RELAPS.DAT
DISPLAY.COM	RERUN.CHK
END.COM	SAVEOUT.OUT
FWDREADT.EXE	SCREENST.LBR
GMODT.RXE	

To copy the MODULUS 5.0 program to your computer, just follow the steps outlined below. For this example it is assumed that the "A" drive is the 1.44MB 3½" diskette drive and that the program will be copied to the directory named <MODULUS> on the "C" hard disk drive.

- 1) Assuming you are in the root directory of "C" drive, make a directory to hold the MODULUS 5.0 program files.

Ex: C:\> MKDIR MODULUS, cr

- 2) Make the MODULUS directory the active directory.

Ex: c:\> CD C:\MODULUS, cr

- 3) Copy the files from the distribution diskette to the MODULUS directory.

Ex: c:\MODULUS> Copy A:*.*,cr

- 4) Verify that the twenty-five files from the distribution diskette were copied to the MODULUS directory.

Ex: c:\MODULUS> DIR/W,cr

You are now ready to run the MODULUS 5.0 Backcalculation and Remaining Life Analysis program. It is advisable to make a back-up copy of the distribution diskette and keep both copies in a safe place in case you have to re-load the program files.

1.4 PROGRAM FILE DESCRIPTION

A brief description of the twenty-five files on the distribution diskette follows:

- MODULUS.BAT Batchfile to start MODULUS 5.0 program.
- RERUN.CHK A file created during the backcalculation procedure to alert the user that the automatic re-run feature of the backcalculation was triggered by the data (i.e., 10% of the time, a max or min limit was

encountered, or the calculated subgrade was larger than 50% above or below the user supplied subgrade value).

- **BEG.COM** Marks the RAM memory where the screen input command file DISPLAY.COM is loaded in memory.
- **DISPLAY.COM** The screen input command file that manages the input from the screen fields to the program modules.
- **END.COM** Unloads the screen input command file DISPLAY.COM from RAM memory.
- **CLIM1.DAT** Contains the average monthly temperatures for five temperature zones in Texas, which are used to correct the FWD deflections for temperature in the remaining life program.
- **DEFAULT.DAT** Contains the data inputs from the last backcalculation run, which are displayed as a starting point for the current backcalculation run.
- **RELAPS.DAT** Contains the data inputs from the last remaining life analysis run, which are displayed as a starting point for the current remaining life run.
- **BRUN40.EXE** Microsoft Quickbasic run time MODULES that contain
- **BRUN45.EXE** routines linked with the MODULUS 5.0 program modules that were written in the MICROSOFT Quickbasic 4.5 program language.
- **CAXP.EXE** Program module to do the remaining life calculation.
- **DELINATP.EXE** Program module that displays the selected data item in a graphical form on the screen and does the subsectioning for the remaining life program.
- **DELINATT.EXE** Program module that displays the selected data item in a graphical form on the screen and does the subsectioning for the backcalculation program.
- **FWREADT.EXE** Program module to convert the FWD field data diskette to the .OUT deflection file, or the user can manually input the deflection bowl data in the format for the backcalculation procedure.

- GMODT.EXE Program module to display the observed and calculated deflection bowls and the computed surface modulus values on the screen in graphical form.
- LISTCAXP.EXE Program module to list all the .OUT files that are available for remaining life calculation on the directory.
- LISTDIRT.EXE Program module to list all the .OUT files that are available for backcalculation on the directory.
- LISTOUTT.EXE Program module to list all the .DA1 files on the directory that are available for printing.
- MENUP.EXE Program module that displays the Main Program Menu.
- MODDRV.T.EXE Program module that does the backcalculation.
- PRMODREP.EXE Program module that does the printed output and the delineation analysis for the modulus backcalculation program.
- PRTRLIFE.EXE program module that does the printed output and the delineation analysis for the remaining life program.
- 021F2818.FWD An example FWD field data file.
- SAVEOUT.OUT This file contains the directory and file names of the last FWD backcalculation analysis.
- SCREENST.LBR A library file containing all the menu and data input screens.

1.5 FILE NAMING CONVENTION

In addition to the program modules and files described above, the program produces several types of files to be used for various parts of the backcalculation procedure. Each of these files is identified by a file name extension, as described below:

- .ASC The modulus backcalculation summary report saved as an ASCII file.
- .DA1 Contains the final results of a backcalculation analysis for the SUMMARY REPORT.
- .DA2 Contains the final results of a backcalculation analysis for the SECTION REPORT.

- .DAT Contains the deflection readings and the backcalculated layer moduli at each station or milepost. This file is used by the DELINATT.EXE and the DELINATP.EXE program modules to display the selected data item on the screen and to do subsectioning.
- .DPT Contains the depth to bedrock calculated for each deflection bowl during the backcalculation procedure.
- .OUT Contains the FWD deflection bowls as produced by the automatic data conversion of an FWD field data diskette, or from the manual entry data input option.
- .POR Contains the POISSON'S RATIO values for each pavement layer.
- .STS Contains the mean and standard deviation for the depth to bedrock values.
- .ZAB Contains the absolute error values of the fit between the observed and calculated deflection readings.
- TMP.DEF Created during each backcalculation analysis to pass the backcalculation input data to the search program.
- TMP.WES Created from the backcalculation input data that is used by the WESLEA program to calculate the deflection database.
- WES.RES The calculated deflection database from the WESLEA program that is used by the search program in the backcalculation procedure.

CHAPTER II

RUNNING THE PROGRAM

2.1 STARTING THE PROGRAM

Unless the directory where the MODULUS 5.0 program is stored is in your computer's path statement, you must make the directory where the MODULUS 5.0 program is stored the active directory. Do this as shown below:

Ex: C:\> CD C:\MODULUS, cr

Once you are in the MODULUS directory, type MODULUS and <ENTER> to run the MODULUS.BAT batch file that starts the modulus backcalculation and the remaining life analysis programs. The MAIN PROGRAM MENU Screen will now be displayed (Figure 1).

2.2 MAIN PROGRAM MENU OPTIONS

The Main Program Menu screen permits the selection of any one of the four main program modules that make up the modulus backcalculation and remaining life analysis system. To execute any of the program modules, use the up/down arrow keys to highlight the menu selection and press <ENTER>. All menus in this software package work in the same way.

The following program modules are available:

1. Convert FWD data to INPUT data: This program module creates the .OUT file which contains the FWD deflection bowls used during the modulus backcalculation or the remaining life calculation procedures. Two options are available:
 1. Automatic conversion of the Dynatest FWD field diskette, and
 2. Manual input of the station, ID, Load and deflection data.

V5.0

« MODULUS »

Main Program Menu

- 1) Input Data Conversion Options
- 2) Run Remaining Life Analysis program
- 3) Run Modulus Backcalculation program
- 4) Print results of latest analysis
- 5) Exit to DOS

Use the ↑ or ↓ keys or enter the option NUMBER and press <ENTER>

TxDOT version. Developed by the Texas Transportation Institute.

Figure 1. MODULUS 5.0 Main Program Menu.

2. Run Remaining Life Analysis program: This option uses the .OUT files created from menu option 1) above and performs the remaining life calculation.
3. Run Modulus Backcalculation program: This option does the modulus backcalculation. This program module uses the .OUT files that were created from menu option 1) above.
4. Print results of latest analysis: This option allows the user to skip directly to the OUTPUT OPTIONS MENU to obtain summary and section report printouts for those backcalculation analysis program runs for which the program files were saved. If this option is chosen, the user can use the FK1 key to display a listing of the program files on the directory that are available for printing.
5. Exit to DOS: Select this menu option to end the current modulus backcalculation analysis program run and return to DOS.

CHAPTER III

OPTION 1 - INPUT DATA CONVERSION OPTION

The first screen for the input data conversion option is shown in Figure 2. To get the FWD deflection data in a form usable by the backcalculation or the remaining life procedures, the user has two options. The first option is the automatic conversion of the DYNATEST FWD field data diskette. The second option provides for the manual input of the ID, Station, load, and deflection data. Both options are described below.

3.1 CONVERT .FWD DATA FILES TO .OUT FILES

The format used to record the DYNATEST FWD data files is highly elaborate and most of the information contained on the .FWD field diskette is not relevant to the program modules that make up the MODULUS 5.0 Backcalculation and Remaining Life Analysis program. Consequently, a program was written to extract the specific data needed from the .FWD field diskette. This program extracts the district number, county number, highway name, station or mile-post location, lane, load level, and the deflection readings (up to seven) for a specified FWD drop location along the length of a project. The program stores this information in a file with the .OUT extension that is in the format required by the program modules that do the modulus backcalculation or the remaining life calculation. These files form the actual input to the MODULUS Backcalculation and Remaining Life program and are referred to as INPUT or .OUT files. In general, during FWD testing one or more drops are made at each location. This program can convert .FWD field diskette files with up to eight drops recorded at each location. The user is required to select which one of the recorded FWD drops to use for the analysis.

To select the FWD conversion, select option one from the menu and press <ENTER>. The Falling Weight Deflectometer Data Conversion Program Input Screen (Figure 3) will be displayed. There are five fields of required information that the user must provide before the FWD conversion program will run. These are:

V5.0

« M O D U L U S »

INPUT DATA OPTIONS MENU

1) Connect IAD to OUT data

2) Enter OUT data manually

3) Return to MAIN MENU

Use the F and J keys to enter the option NUMBER and press **ENTER**

TxDOT version. Developed by the Texas Transportation Institute.

Figure 2. Input Data Options Menu.

« M O D U L U S »

FALLING WEIGHT DEFLECTOMETER DATA CONVERSION
 PROGRAM INPUT SCREEN

DRIVE WHERE FWD FILE RESIDES (CENTER DRIVE & DIR-
 ECTORY(S) UP TO 30 CHAR EX: A:\DIR1\DIR2\DIR3\
 (ENTER FINAL "\")

FWD DATA FILENAME ----->

OUTPUT FILE NAME (UP TO 8 CHAR)---->

NUMBER OF DROPS RECORDED AT EACH POINT ----->

NUMBER OF FWD DROP TO USE FOR CONVERSION ----->

PROCESS ANOTHER FILE?

TxDOT version. Developed by the Texas Transportation Institute.
 Enter the drive & directory(s) where the FWD data file is located

Figure 3. Falling Weight Deflectometer Data Conversion Program Input Screen.

- DRIVE and DIRECTORY(s) where FWD file resides: This feature of the Modulus 5.0 program allows the user to process FWD data files that are stored on a diskette drive or hard drive directory other than the directory where the Modulus 5.0 programs are installed. Enter the diskette drive and directory name or the hard disk drive and directory(s) name, up to thirty characters including the trailing backslash (\), and press <ENTER>. Note: the name that is entered in this field will also be the location where all the files for this run of the program will be stored. The user can change this name for each successive problem run, depending on where the .FWD or .OUT files are located. If the .FWD or .OUT files are located in the same directory that the MODULUS 5.0 program is installed in, then the user can leave the directory field blank, and the current directory is used by default.
- FWD Data Filename: Enter the name of a DYNATEST FWD field diskette file to be converted. Type in up to eight alphanumeric characters (The .FWD extension is automatically appended to the name). To see a listing of all the .FWD filenames stored on the drive and directory name entered above, press the <FK1> key. To select a file from this list for data conversion, use the up/down arrow keys until the desired filename is highlighted and press <ENTER>.
- OUTPUT file name: Type in the name for the output file, and press <ENTER>. The .OUT file extension will automatically be appended to this name. This name will also be the root filename for the .ASC through .ZAB files that are created for this run.
- Number of drops recorded at each point: The number of FWD drops recorded at each station (up to eight) is displayed in this field.
- Number of FWD drop to use for conversion: The user must enter the number of the FWD drop to use for this program run.

At this point, a window will overlay the previous field displaying the message "CHECK FOR NON-DECREASING DEFLECTION?--->N" (Figure 4). This option allows the user to check for non-decreasing deflection bowls. The default for this field is "no" or "N", do not check for non-decreasing deflection bowls. However, if the user wants to check the deflection data for non-decreasing deflection data, type in "Y" and press <ENTER>. If the FWD conversion program detects a non-decreasing deflection bowl, a warning message will be displayed on the screen. The user will have the option to accept the bowl, delete the bowl, or modify the bowl (Figure 5). If the user elects to correct the non-decreasing deflection bowl data, the user should move the cursor to the field to be corrected and type in the desired data value. At the VALIDATE field, type "Y" and press <ENTER>. If no more non-decreasing deflection bowls are encountered, or if this option was not selected, the user will see the output file name displayed and the number of deflection bowls that were converted (Figure 6).

The last field of this screen is a prompt to convert another .FWD file by typing in "Y", or to quit the .FWD conversion program by typing "N" and pressing <ENTER>.

Note that for each input field there are two <ESCAPE> keys provided to correct mistyped data input values. Press the <ESC> key to return to the beginning of a data field to correct erroneous data. The <ENTER> key validates the data entered at each input field. Check the data that is entered at each field carefully before pressing <ENTER> to go to the next field. Press the <Home> key to get back to the main program menu from any input field to abort the data input process and start over.

3.2 MANUAL INPUT OF DEFLECTION BOWL DATA

Select option two from the Input Data Options Menu (Figure 2) and press <ENTER>.

The Manual Input Deflection Bowl Data Input Screen (Figure 7) will be displayed. The user must supply the following data values to create the .OUT file:

« M O D U L U S »

```
XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
```

DRIVE WHERE FWD FILE RESIDES (ENTER DRIVE & DIR-
ECTORY(S) UP TO 30 CHAR EX: A:\DIR1\DIR2\DIR3\
(ENTER FINAL "\")

FWD DATA FILENAME ----->

OUTPUT FILE NAME (UP TO 8 CHAR)---->

NUMBER OF DROPS RECORDED AT EACH POINT ----->

CHECK FOR NON-DECREASING DEFLECTIONS?---->

PROCESS ANOTHER FILE? |

TxDOT version. Developed by the Texas Transportation Institute.
Enter Y to check for non-decreasing deflections, N to not check

Figure 4. Check for Non-Decreasing Deflections.

« M O D U L U S »

FALLING WEIGHT DEFLECTOMETER DATA CONVERSION
PROGRAM INPUT SCREEN

NOTE! NOTE! NOTE! NOTE! NOTE!

THE DEFLECTION BOWL DISPLAYED BELOW HAS NON-DECREASING
DEFLECTIONS. INDICATE YOUR OPTION TO (1) ACCEPT THE
BOWL, (2) DELETE THE BOWL, OR (3) MODIFY THE BOWL.

ENTER A 1 OR 2 OR 3

DISTRICT-> 7 COUNTY-> 021 HIGHWAY-> 2410 STATION\MILEPOST> 1160

W1> 11.92 W2> 12.52 W3> 13.21 W4> 13.78 W5> 14.33 W6> 14.85 W7> 15.49

VALIDATE ? -->

TxDOT version. Developed by the Texas Transportation Institute.
ENTER 1 OR 2 OR 3 TO ACCEPT, DISCARD, OR MODIFY THE DEFLECTION BOWL

Figure 5. Accept, Delete, or Modify a Non-Decreasing Deflection Bowl.

« M O D U L U S »

TRANSLATING INPUT DEFLECTION BOWL DATA (COMPRESSION)
PROGRAM INPUT SCREEN

DRIVE WHERE FWD FILE RESIDES (ENTER DRIVE & DIR-
ECTORY(S) UP TO 30 CHAR EX: , A:\DIR1\DIR2\DIR3\
(ENTER FINAL "\")

FWD DATA FILENAME -----> F2818.FWD

OUTPUT FILE NAME (UP TO 8 CHAR)----> F2818.OUT

NUMBER OF DROPS RECORDED AT EACH POINT -----> 2

FILE F2818.OUT CONTAINS 25 POINTS

PROCESS ANOTHER FILE? █

TxDOT version. Developed by the Texas Transportation Institute.
Enter <Y> to perform another conversion or <N> to go to MAIN MENU

Figure 6. Number of Deflection Bowls.

- **OUTPUT FILE NAME:** Enter the full file name, including the disk drive and directory(s) (up to thirty-eight alphanumeric characters) where the .OUT file will be stored. The .OUT file will be automatically appended to the name entered above. If the .OUT file will be stored in the current directory, then it is only necessary to type in a file name of up to eight alphanumeric characters and press <ENTER>.
- **Number of Bowls to Be Entered:** Enter the total number of deflection bowls to be entered manually.
- **District:** Enter the TxDOT district number in this field (2 digits max).
- **County:** Enter the TxDOT county number in this field (3 digits max).
- **Highway:** Enter the TxDOT highway prefix number (6 alphanumeric characters max).
- **Enter information for bowl number:** This field will display the number of the deflection bowl for which data is being entered.
- **Station or milepost:** Enter the station or milepost where the deflection bowl was measured (3 decimal places max).
- **Lane:** Enter the lane in which the deflection bowl was measured (L or R, usually).
- **Load:** Enter the load in pounds for the deflection test drop (6 digits).
- **W1 to W7:** Enter the deflection in mils at each of the FWD Sensors one through seven for this deflection test.

- **VALIDATE:** Carefully check the data in the fields. If everything is correct, type "Y" to validate the entries, and the data will be read by the program and written to the .OUT file. To change any of the entries type "N," and the cursor will be re-positioned at the STATION or MILEPOST field. Press enter to move the cursor to the field to be changed, type in the new data entry, and press <ENTER> to get to the validate field again. Type "Y" to validate the data. Note that as each deflection bowl is entered and validated, the ENTER INFORMATION FOR BOWL No. field is automatically updated and the cursor is positioned at the STATION OR MILEPOST field for each subsequent deflection bowl. Note also that for this Modulus 5.0 version the user can press the <ESC> key to immediately correct any of the W1 through W7 deflection entries before getting to the VALIDATE field. The <HOME> key is also available as an escape back to the main program menu if the user elects to exit the manual input before entering all the data bowls.

For the experienced or knowledgeable microcomputer user, a text editor can be used for creating .OUT deflection bowl data files using the data input format of the .OUT file listed below.

Data Item	Input Format	Column
(a) District	I3	1-3
(b) County	I4	4-7
Blank Field	1X	8
(c) Highway	A8	9-16
(d) Milepost	F9.3	17-25
(e) Lane	A1	26
(f) Load (lbs)	I6	27-32
(g) Sensor 1 (mils)	F6.2	33-38
(h) Sensor 2 (mils)	F6.2	39-44
(i) Sensor 3 (mils)	F6.2	45-50
(j) Sensor 4 (mils)	F6.2	51-56
(k) Sensor 5 (mils)	F6.2	57-62
(l) Sensor 6 (mils)	F6.2	63-68
(m) Sensor 7 (mils)	F6.2	69-74

CHAPTER IV

OPTION 2 - REMAINING LIFE CALCULATION PROCEDURE

Option two of the main program menu allows the user to run the Remaining Life Calculation program. Note: This routine will only process FWD data collected with the sensors setup used by TxDOT (305 mm or 12-inch spacings).

After selecting Option (2) from the Main Program Menu, the RELAPS INPUT/OUTPUT FILE INFORMATION screen will be displayed (Figure 8).

The first field allows the user to enter a path to a directory where the data files are located if the data files are not in the MODULUS root directory. The output files will also be stored in this directory. This field can be left blank if the data files are in the MODULUS root directory. To correct or change a data entry in any of the data fields, just press the "ESC" key to re-display the data field. To abort option two entirely, press the <HOME> key to return to the MODULUS 5.0 Main Program Menu.

The input file field is self-explanatory. Enter the name of the FWD .OUT file (without the .OUT extension) that is to be used for the remaining life analysis. Press the F1 key to get a list of all the .OUT files that are on the directory named in the first field (Figure 9). The user can select the .OUT file to use by moving the select bar to highlight the file name and pressing <ENTER>. This file name will be transferred to the input file field to be used for the analysis. The beginning and ending mile point fields allow the user to select a part of the .OUT file to use for the remaining life analysis, or by entering 0.0 in both these fields the entire .OUT file will be used.

The number of bowls field is not an input field. This value is displayed from the number of FWD bowls read from the .OUT file and is an indication to the user of the number of FWD tests that are being used for the remaining life analysis.

Press <ENTER> to continue the program. The Remaining Life Analysis Program DATA INPUT screen will be displayed (Figure 10). The section identification values for TxDOT DISTRICT, COUNTY, and HIGHWAY are read from the .OUT file that is being used for the analysis and are displayed for the user to verify as being correct. The district

« R E L A P S »

ENTER DRIVE & DIRECTORY NAME (ENTER <ENTER> TO CONTINUE)

DRIVE WHERE OUT FILE RESIDES (ENTER DRIVE & DIRECTORY(S) UP TO 30 CHAR EX: C:\DIR1\DIR2\DIR3\
(NOTE: BE SURE TO ENTER ALL "\" OF THE DIR NAME)

C:\M005\

NAME OF THE INPUT FILE ----> US87.OUT

BEGINNING MILE POINT -----> 0.000

ENDING MILE POINT -----> 0.000

NUMBER OF BOWLS FOR THIS ANALYSIS --> 24

PRESS <ENTER> TO CONTINUE

TxDOT version. Developed by the Texas Transportation Institute.

Figure 8. Remaining Life Input/Output File Information.

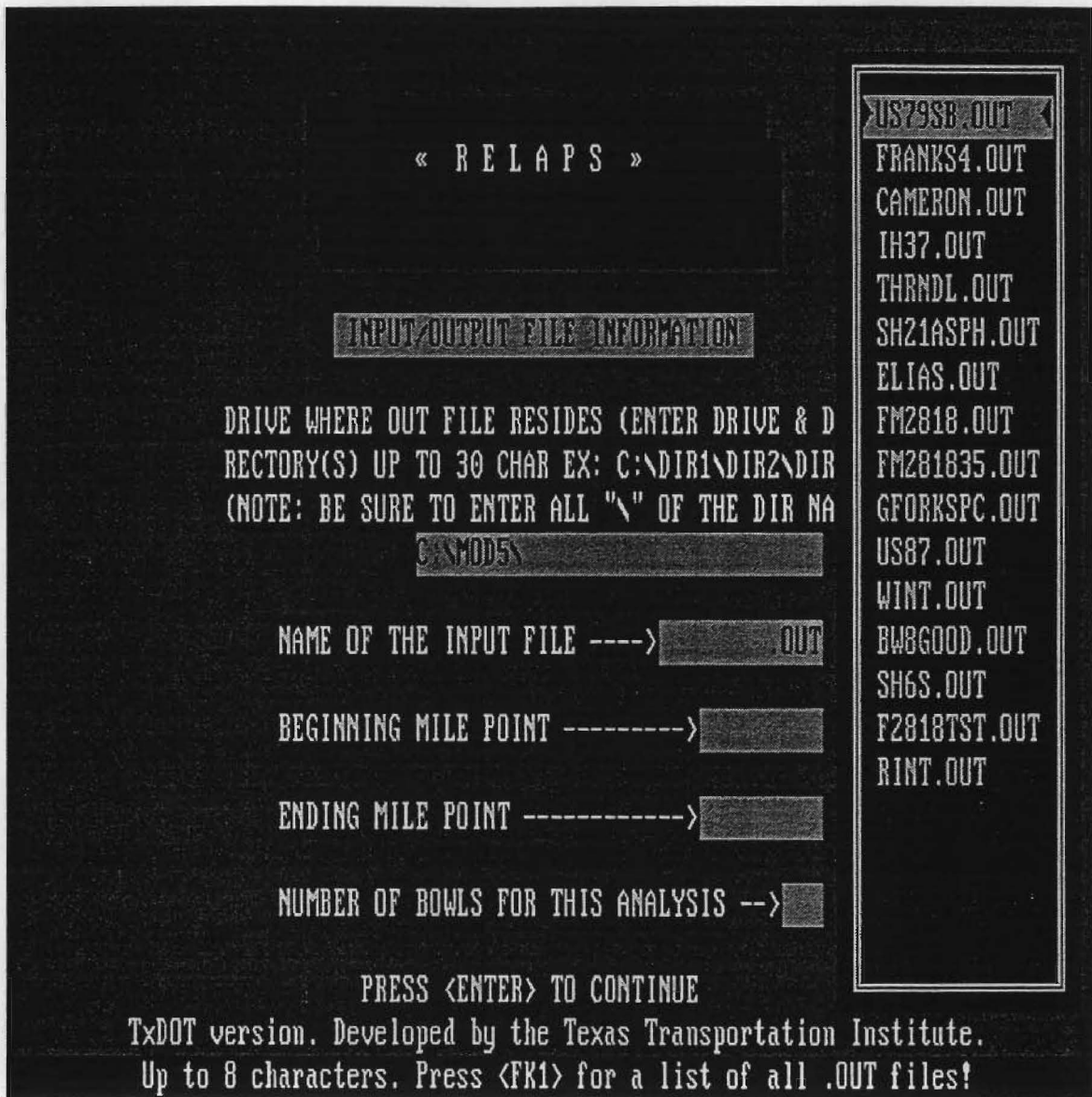


Figure 9. List of .OUT Files in the Directory.

REMAINING LIFE ANALYSIS PROGRAM			U5.0
DATA INPUT SCREEN			
SECTION IDENTIFICATION			
DISTRICT	COUNTY	HIGHWAY	
11	187	FM0062	
AVERAGE RUT DEPTH		ALLIGATOR CRACKING	
0.80 (in.)		47.5 (%)	
ACP THICKNESS	HIGHWAY FUNCTIONAL CLASS		
2.0	5		
20 YEAR 18 KIPS (singletons) =>			1.5000
NUMBER OF LANES >	2	LENGTH OF PAD TEST >	1
PAD TEST DUMP START >	55.0	PAD >	65.0
PAD TEST NUMBER			US79SB
USE ARROW KEYS TO MOVE TO FIELD TO EDIT			
PRESS 'ESC' TO CORRECT AN ENTRY, 'ENTER' TO CONTINUE			

Figure 10. Remaining Life Analysis Data Input Screen.

number is critical; it is a number from 1 to 25, and it is used to identify the environmental zone of the highway. If the district, county, or highway values are not correct, the user should type in the correct values(s) and correct the .OUT file at a later time.

The remainder of the input data values are default values that are displayed from the last remaining life analysis run. Any value can be edited by moving the cursor with the arrow keys to that field and typing a new value.

The average rut depth and percentage alligator cracking are preferably collected by the FWD operator or may be obtained from the Pavement Management Information System (PMIS). The ACP thickness is the total thickness of asphalt surfacing, including asphalt stabilized base. The highway functional class is a number from 1 to 6, with 1 being Interstate facilities, 5 and 6 representing two-lane, low-volume facilities. The “20 year 80 kN (18 kip) is the estimated one-directional 80 kN (18 kip) Equivalent Single Axles for 20 years.

The number of lanes of the highway, the month the FWD test was recorded, and the pavement surface temperature at the beginning and end of the FWD test complete the data inputs. This temperature should be the temperature at 25 mm below the surface, or for very thin surfacings, the temperature at middepth. Press "ESC" to correct any of the data input fields, press <HOME> to return to the MODULUS 5.0 Main Program Menu, or press <ENTER> to continue the program.

The output from the Remaining Life Analysis program is displayed on the screen. For large data files press <ENTER> until all the data has been displayed. This output consists of the section identification information and for each FWD station, the normalized deflections, the asphalt surface temperature, the SCI (defl. 1 - defl. 2), the estimate of the surface, base, and subgrade layer strengths, and the estimate of the life (Figure 11). The mean, standard deviation, and coefficient of variation of the deflections, the SCI, and the surface, base, and subgrade layer strengths are listed at the bottom of the output. A discussion of each of these is given in Appendix A. Press <ENTER> to continue the program.

The RELAPS Output Options Menu will be displayed (Figure 12). The options are:

 * R E L A P S *

TTI FLEXIBLE PAVEMENT DEFLECTION BASIN ANALYSIS PROGRAM

DISTRICT: 17 ASPH. THICKNESS : 6.0 LANES : 2
 COUNTY : 166 DESIGN LOAD (lbs): 9000 MONTH TESTED: FEB
 HIGHWAY : US7900 20 year 18 KIP(m): 6.5000 SENSORS: 0 12 24 36 48 60 72

STATION	** NORMALIZED DEFLECTION (mils) **					TEMP DEF F	ASPH DESIGN LAYER			REMAINING LIFE (yrs)		
	R1	R2	R3	R4	R7		MILS	UPR	LWR	SGR	RUT	CRK
.000	20.91	15.07	8.82	4.93	1.13	65.0	6.38	MD	VP	GD	10+	2-5
200.000	14.96	10.81	7.49	5.04	1.35	65.8	4.48	GD	MD	GD	10+	10+
400.000	8.00	6.74	5.37	4.05	1.47	66.7	1.38	VG	VG	MD	10+	10+
603.000	12.10	9.55	7.07	5.24	1.86	67.5	2.69	VG	GD	PR	10+	10+
800.000	22.52	15.76	8.51	4.45	1.11	68.3	6.96	MD	VP	GD	10+	2-5
1001.000	21.93	15.77	8.96	5.10	1.26	69.2	6.26	MD	VP	GD	10+	2-5
1200.000	7.85	6.27	4.19	2.70	.85	70.0	1.58	VG	GD	VG	10+	10+
1402.000	6.27	5.29	4.24	3.20	1.25	70.8	.96	VG	VG	GD	10+	10+
1602.000	7.70	6.30	5.08	3.92	1.57	71.7	1.34	VG	VG	MD	10+	10+
1806.000	16.50	12.87	8.81	5.73	1.43	72.5	3.43	VG	MD	MD	10+	10+
2000.000	12.49	9.44	6.13	3.85	1.08	73.3	2.84	VG	MD	GD	10+	10+
2180.000	15.07	10.31	6.64	4.57	1.44	75.0	4.35	GD	MD	MD	10+	10+
MEAN:	13.86	10.35	6.78	4.40	1.32		3.55	GD	MD	GD		
STD DEV:	5.80	3.82	1.78	.89	.27		2.13					
COF VAR:	41.87	36.92	26.34	20.20	20.18		59.96					

Figure 11. Screen Display of Remaining Life Results.

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« RELAPS »

Output Options Menu

▶ 1) Print the Results ◀

2) Plot SCI and/or Layer Strength Values

3) Return to Main Menu

Use the ↑ or ↓ keys or enter the option NUMBER and press <ENTER>

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Figure 12. Remaining Life Output Options Menu.

- (1) Print the Results,
- (2) Plot SCI and/or Layer Strength Values, or
- (3) Return to Main Menu.

For output option (1), the PRINTING REMAINING LIFE OUTPUT screen (Figure 13) will be displayed and the output that was displayed on the screen will be directed to the appropriate print device for a hard copy of the program output (Figure 14).

For output option (2), the RELAPS pavement Response Variable screen (Figure 15) will be displayed. This screen allows the user to select the SCI, surface, base, or subgrade layer strengths to be plotted along the length of the highway. The minimum section length allows the user to select the number of stations or points to be considered as a single section for the delineation analysis.

The minimum section length value should be input in the same units that the FWD test stations were recorded. For example, if the FWD tests were recorded at mile points 1-10 (for a total of 10 deflection bowls), then the minimum section length should be entered as the number of mile points to consider together as a single section for the delineation analysis. To continue this example, if the user entered a minimum section length of 4 (meaning every four mile points to a section), then mile points 1-4 would be considered section one, mile points 5-8 would be section two, and mile points 9-10 would be section three for the delineation analysis. In this example, if the user entered 10 as the minimum section length, then the entire pavement would be considered as a single section and no delineation would be performed.

If the FWD test stations were recorded in feet or odometer readings rather than mile points, then the appropriate section length units should be entered as described above.

Figure 16 shows the plot of SCI vs mile point with three sections being delineated (0.0-2.592, 2.592-4.031, and 4.031-4.816).

Figure 17 shows the plot of subgrade strength estimate vs mile point, showing the five levels of the strength rating from very good to very bad.

When the user exits the plot option, the Output Options Menu is displayed and the user can select option (3) to return to the MODULUS 5.0 Main Program Menu.

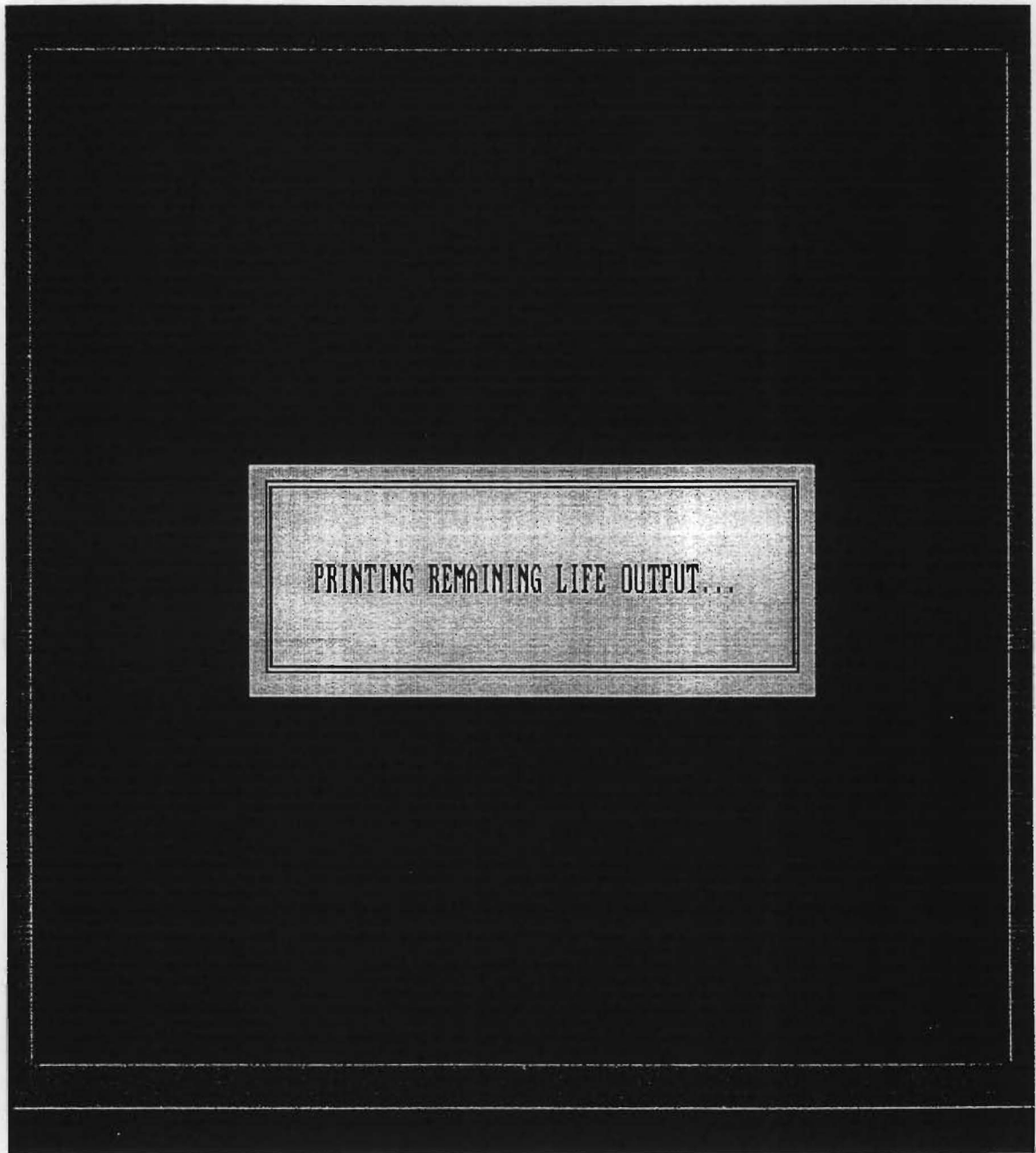


Figure 13. Printing Remaining Life Output Screen.

 * R E L A P S *

TTI FLEXIBLE PAVEMENT DEFLECTION BASIN ANALYSIS PROGRAM

DISTRICT: 8 ASPH. THICKNESS : 1.0 LANES : 2
 COUNTY : 115 DESIGN LOAD (lbs): 9000 MONTH TESTED: JAN
 HIGHWAY : us0087 20 year 18 KIP(m): 2.8600 SENSORS: 0 12 24 36 48 60 72

STATION	** NORMALIZED DEFLECTION (mils) **					TEMP DEF F	ASPH DESIGN LAYER			REMAINING LIFE (yrs)	
	R1	R2	R3	R4	R7		SCI MILS	UPR	LWR	SGR	RUT
.000	15.16	7.11	2.83	1.55	.59	69.0	8.05	VG	VG	VG	10+
.202	8.31	4.58	2.21	1.31	.55	69.1	3.73	VG	VG	VG	10+
.413	10.14	5.65	2.33	1.24	.59	69.3	4.49	VG	VG	VG	10+
.629	22.57	8.59	1.89	.87	.35	69.4	13.98	VG	VG	VG	10+
.804	17.93	7.09	1.90	1.26	.54	69.5	10.84	VG	VG	VG	10+
1.020	14.75	6.43	1.69	1.28	.72	69.6	8.32	VG	VG	VG	10+
1.212	14.79	6.74	2.62	1.68	.67	69.8	8.05	VG	VG	VG	10+
1.535	18.27	8.70	2.91	1.49	.59	69.9	9.57	VG	VG	VG	10+
1.707	21.18	9.97	2.89	.96	.20	70.0	11.21	VG	VG	VG	10+
2.018	14.39	7.36	2.88	1.82	.92	70.1	7.03	VG	VG	VG	10+
2.269	14.05	4.49	.80	.51	.27	70.3	9.56	VG	VG	VG	10+
2.467	21.57	9.50	3.00	1.51	.64	70.4	12.07	VG	VG	VG	10+
2.592	13.97	8.21	2.74	1.65	.87	70.5	5.76	VG	VG	VG	10+
2.791	15.20	8.84	3.80	1.95	1.03	70.6	6.37	VG	VG	GD	10+
3.022	14.50	7.28	3.22	1.87	.88	70.8	7.22	VG	VG	VG	10+
3.206	12.42	6.33	3.44	2.23	.86	70.9	6.09	VG	VG	VG	10+
3.461	16.90	6.18	2.29	1.59	.78	71.0	10.72	VG	VG	VG	10+
3.625	17.72	8.50	3.39	1.98	1.18	71.1	9.21	VG	VG	GD	10+
3.815	17.61	7.61	3.09	2.11	1.20	71.3	10.00	VG	VG	GD	10+
4.031	12.93	7.21	3.79	2.55	1.16	71.4	5.72	VG	VG	GD	10+
4.197	8.13	4.74	2.88	2.12	1.12	71.5	3.39	VG	VG	GD	10+
4.422	8.98	4.41	2.25	1.58	.78	71.6	4.57	VG	VG	VG	10+
4.695	4.69	2.57	1.61	1.13	.73	71.8	2.12	VG	VG	VG	10+
4.816	8.30	3.58	1.05	.60	.34	72.0	4.72	VG	VG	VG	10+
MEAN:	14.35	6.74	2.56	1.54	.73		7.62	VG	VG	VG	
STD DEV:	4.58	1.92	.79	.51	.29		3.04				
COF VAR:	31.91	28.57	30.69	33.03	39.03		39.86				

Figure 14. Remaining Life Printed Output.

« RELAPS »

PAVEMENT RESPONSE VARIABLE
GRAPHIC REPRESENTATION AND DELINEATION ANALYSIS

THE FOLLOWING INFORMATION IS REQUIRED:

ENTER ***** TO PLOT *****

- 1 SCI
- 2 UPPER LAYER STRENGTH
- 3 LOWER LAYER STRENGTH
- 4 SUBGRADE STRENGTH

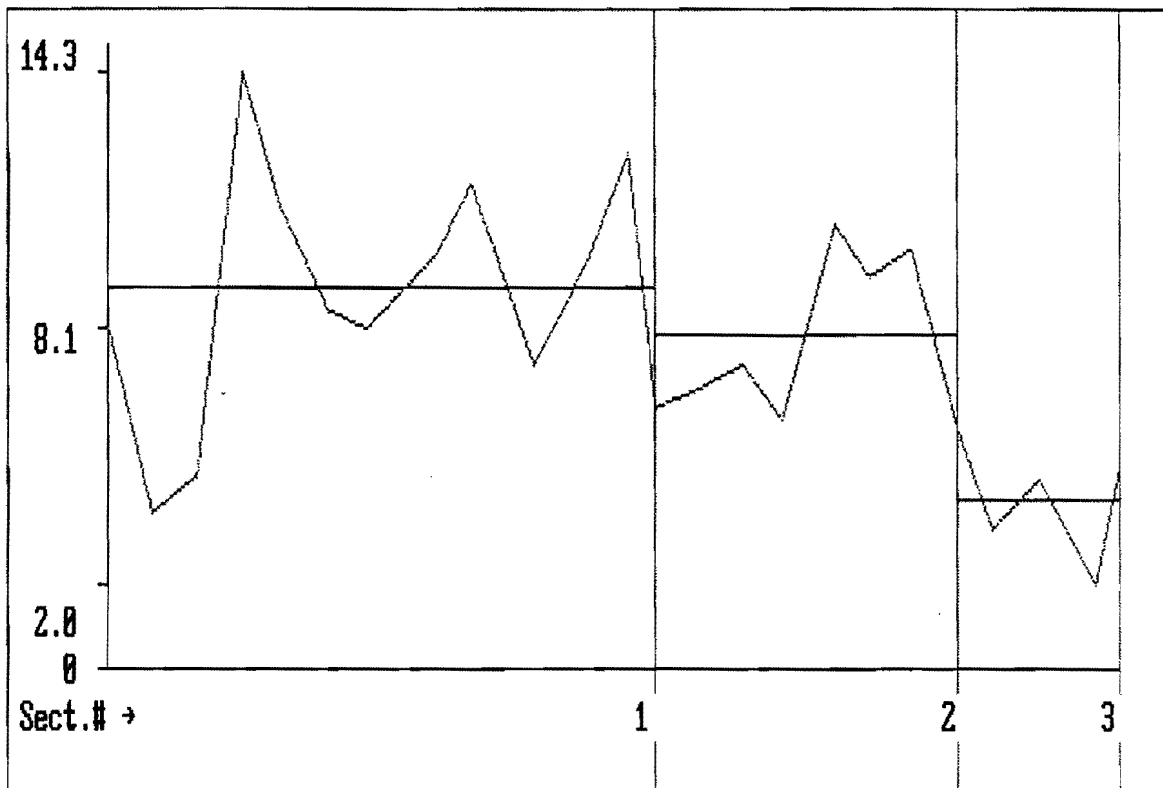
RESPONSE VARIABLE ----->1

MINIMUM SECTION LENGTH ----->5

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Desired section length over the entire project

Figure 15. Remaining Life Delineation Analysis Input Screen.

Road: us0087 Pavement Response Variable: SCI (Surface Curvature Index, mils)

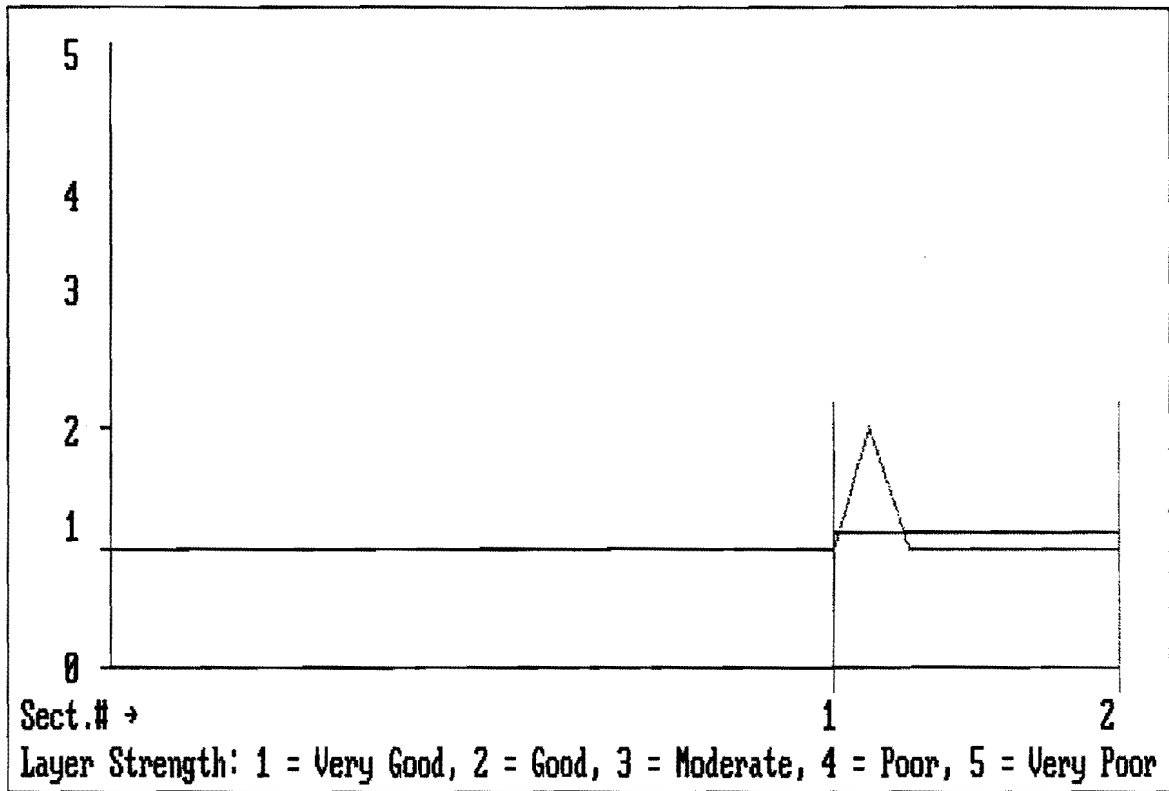


Section #	From	To	Mean	S.Dev.
1	0.000	2.592	9.10	3.04
2	2.592	4.031	8.01	1.94
3	4.031	4.816	4.08	1.43

Press any key to continue

Figure 16. Plot of SCI for a Section of US 87.

Road: us0087 Pavement Response Variable: SGS (Subgrade Strength)



Section #	From	To	Mean	S.Dev.
1	0.000	3.461	1.00	0.00
2	3.461	4.816	1.13	0.35

Press any key to continue

Figure 17. Plot of Subgrade Strength Estimate for a Section of US 87.

CHAPTER V

OPTION 3 - MODULUS BACKCALCULATION PROCEDURE

Option three of the main program menu allows the user to run the Modulus Backcalculation program. Inputs to the program consist of a series of default and temporary files, which are transparent to the user, that are created and used by the program automatically. The only file that is user supplied is the .OUT file, which was created using option one of the Main Program Menu, as explained earlier in this report.

After selecting option three from the Main Program Menu the INPUT/OUTPUT FILE INFORMATION Screen (Figure 18) is displayed.

The following information is requested from the user:

- **DRIVE WHERE .OUT File Resides:** The same drive and directory(s) that was entered during option one will be displayed, or if the user is skipping the data conversion option to go directly to the backcalculation option three, the user should enter the drive and directory(s) where the .OUT file for this program run is located (up to thirty alpha-numeric characters). If the .OUT file is in the active directory, enter blank characters and press <ENTER> to validate the entry.
- **Name of the Input File:** Enter the name of the INPUT deflection data file (up to eight alphanumeric characters). The .OUT extension will be appended automatically. An output .DAT file will be created automatically with the same filename prefix as the .OUT file entered above. To see a listing of all the .OUT files available for modulus backcalculation in the directory entered above, press <FK1>. Use the up/down arrow keys to select the .OUT file to use and press <ENTER>.

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« M O D U L U S »

INPUT/OUTPUT FILE INFORMATION

DRIVE WHERE OUT FILE RESIDES (ENTER DRIVE & DIR-
RECTORY(S) UP TO 30 CHAR EX: C:\DIR1\DIR2\DIR3\
(NOTE: BE SURE TO ENTER ALL "\" OF THE DIR NAME)

NAME OF THE INPUT FILE ---->

BEGINNING MILE POINT ----->

ENDING MILE POINT ----->

NUMBER OF BOWLS FOR THIS ANALYSIS -->

PRESS <ENTER> TO CONTINUE

TxDOT version. Developed by the Texas Transportation Institute.
ENTER THE DRIVE & DIRECTORY(S), UP TO 30 CHAR (USE THE TRAILING \)

Figure 18. Backcalculation Input/Output File Information.

- **Beginning Mile Point:** Enter the mile point or station to begin modulus backcalculation from the .OUT file selected above, or press <ENTER> and the first station or mile point in the .OUT file will be selected as the starting point.
- **Ending Mile Point:** Enter the station or mile point from the .OUT file as the ending value for the analysis. Press <ENTER> and the entire .OUT file will be used for the analysis. Entering 0 for both beginning and ending mile points will cause all bowls in the .OUT file to be used.
- **Number of Bowls for This Analysis:** The number of bowls between the beginning and ending mile points will be displayed in this field. Press <ENTER> to continue the modulus backcalculation and display the MODULUS BACKCALCULATION Menu (Figure 19).

As with the other input fields, the <ESC> key can be used to return to the start of any input field to correct a data entry before the field is validated by pressing the <ENTER> key. The <HOME> key is also available as an escape back to the Main Program Menu to abort this part of the modulus backcalculation.

The Modulus 5.0 backcalculation program has been shortened by deleting the existing fixed designs option from the backcalculation menu. The two options for backcalculation are: a) Run a Full Analysis and b) Input Material Types.

- **Run a Full Analysis:** In this option, the user supplies all of the input data needed for the backcalculation analysis. The user has full control over all the inputs for the analysis.
- **Input Material Types:** For this option the user selects the material types, layer thicknesses, and test temperature, and the program assigns acceptable moduli and Poisson ratio values to be used for the analysis. This option is intended for the user who is unfamiliar with realistic ranges of moduli values to use for an analysis.

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« M O D U L U S »

MODULUS BACKCALCULATION MENU

> 1) Run a Modulus Analysis

2) Input Material Types

3) Return to Main Menu

Use the 0 and 9 keys to enter the option 00000 and press (ENTER)

TxDOT version. Developed by the Texas Transportation Institute.

Figure 19. Modulus Backcalculation Menu.

5.1 USING THE MODULUS BACKCALCULATION MENU OPTIONS

The principal difference in the two options of the Modulus Backcalculation menu is that in option one, Run a Full Analysis, the user must supply all the data inputs. For option two, Input Material Types, the user specifies the material for each layer and the layer thickness; the program selects acceptable ranges of moduli values and Poisson ratio values. Each option is discussed below.

5.2 OPTION 1 - RUN A FULL ANALYSIS

This option of the Modulus Backcalculation Menu lets the user specify the thickness, moduli ranges, and Poisson ratios for up to four layers within a pavement section. When you request this option, the input screen (Figure 20) is displayed. The values that are displayed on the screen are the values used in the most recent run of the program. To run the program with these values, press <ENTER>. The existing values can be edited at three levels which are accessible through function keys two to four. The editing levels correspond to the degree of likelihood that the user will change the values, from less to more likely.

For all practical purposes, information such as plate radius, number of sensors, and sensor distance to the plate are likely to remain the same throughout the length of a project, since these values reflect the characteristics of the FWD. At this point, press the <HOME> key if you want to abort the program. Editing is done in the same way as for the previous programs; that is, you enter the desired value and validate it by pressing <ENTER>. To correct a data entry before validating it, press the <ESC> key to return the cursor to the start of the field and re-enter the data value. Use the <HOME> key from any input field to return to the Main Program Menu.

If the user wants to change all the values on the screen, press the <FK2> key. The cursor will be positioned in the plate radius field. Enter the plate radius in inches and the number of deflection sensors. Then enter the spacing of the sensors in inches and the weighting factor to be used for each sensor. For the FWD, a typical plate radius is 150 mm (5.91 in) with spacings at 0, 305, 610, 914, 1219, 1524 and 1829 mm (0, 12, 24, 36, 48, 60 and 72 in). Note: Sensors must be placed at 0, 305, 610 and 914 mm (0, 12, 24 and 36 in) in MODULUS 5.0. The user may wish to assign weighting factors to each geophone or let the program assign them automatically. Leave all the weighting factors at zero for

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<FK2>
 PLATE RADIUS(In) ----> 5.000 NUMBER OF SENSORS -> 7

SENSOR No.	1	2	3	4	5	6	7
DISTANCE FROM PLATE ->	0.00	0.00	0.00	0.00	0.00	0.00	0.00
WEIGHT FACTOR ----->	0.00	0.00	0.00	0.00	0.00	0.00	0.00

<FK3>

LAYER THICKNESSES(In) ----->	H1	H2	H3	H4
	0.0	0.0	0.0	0.0

MODULUS RANGES FOR:

	MINIMUM (KSI)	MAXIMUM (KSI)	POISSON'S RATIO
<FK4> SURFACE LAYER ----->	100.00	100.00	0.10
BASE LAYER ----->	50.00	150.00	0.10
SUBBASE LAYER ----->	10.00	50.00	0.30

(KSI) POISSON'S RATIO

SUBGRADE MODULUS (MOST PROBABLE VALUE) ----> 50.00 0.10

Press F10 to run the program, <FK1>=HELP, <FK2-4>=edit, <ESC>=ABORT

Figure 20. Full Analysis Data Input Screen.

automatic assignment. However, if the user wishes to override this, simply input the desired weighting factors. Weighting factors typically range from 0 to 1.0; a weighting factor of 0 will remove that sensor from the calculation process.

To change layer thicknesses and moduli ranges, press the <FK3> key. In these four fields labeled H1 to H3, enter the pavement thicknesses in inches. H1 represents the surface layer, H2 the base layer and H3 the subbase layer. The H4 value is automatically calculated and represents the depth in the pavement at which a stiff layer is calculated to occur. (See Report 1123-3 for details.)* This may be bedrock or a stiff clay layer, for example. The user can overwrite this number, if needed. Use 7620 mm (300 in) as the maximum possible value of depth to bedrock. For a four-layer pavement, enter the thicknesses in the respective fields. For a three-layer system with no subbase, enter the surface thickness, the base thickness, then zero <0> to indicate the absence of subbase. For a two-layer pavement, the procedure is the same except that a thickness of <0> is entered for the base layer.

To change the modulus ranges only, press the <FK4> key. Enter (in ksi) the modulus lower boundary value, the modulus upper boundary value, and the Poisson value for the surface layer. Then, depending on whether the pavement is a two, three, or four-layer system, the cursor will move to the corresponding field allowing you to edit or enter the modulus lower, upper, and Poisson values for the particular layer. Next, enter the most probable modulus value (in ksi) and the corresponding Poisson ratio value for the subgrade. After entering the value for the subgrade layer Poisson ratio, check all the input values and, if necessary, change any values using the appropriate function key and repeat the above process. If satisfied with the input, press <ENTER> to execute the program. The "WES5 Program is Running ..." message should appear on the screen.

The next message to be displayed on the screen will be from the search program, showing the number of deflection bowls for which moduli values are being backcalculated. Modulus has an automatic rerun feature built into it if the user's initial subgrade guess is more than 50% higher or lower than the calculated value. No user input is required and only one rerun will be performed.

When the backcalculation program is complete, the user is requested to press any key. The output options menu will be displayed; this part of the program will be discussed later.

*G. T. Rhode and T. Scullion, (Nov. 1990), "Modulus 4.0: Expansion & Validation of the Modulus Backcalculation System", Research Report 1123-3, Texas Transportation Institute, College Station, Texas.

5.3 OPTION 2 - INPUT MATERIAL TYPES

When this option is selected, the program prompts for the required information using two separate input screens. The first screen (Figure 21) displays default settings for the FWD test. The cursor is automatically positioned at the HMAC surface layer thickness input. However, if the FWD default setting needs to be changed then press <FK2>. Press <ENTER> to move through the fields and make the necessary changes, until the cursor returns to the HMAC surface layer thickness input field. Otherwise, enter the surface layer thickness in inches and press <ENTER>. The cursor moves to the second field where the program requests the surface layer material. Enter <L> for crushed limestone aggregate or <G> for crushed river gravel aggregate, and press <ENTER> to continue to the next input field. The options to be selected in this field deserve a brief explanation.

The program has equations built into it for Elastic Modulus versus temperature for typical mixes found in Texas (crushed limestone or river gravel mixes). In the backcalculation procedures, if the user wishes to use a fixed default asphalt modulus, which is often the case on these pavements, then a single value is calculated based on the coarse aggregate type and FWD test temperature. However, if an asphalt modulus is to be backcalculated, then an acceptable range of moduli values is generated, based upon the test temperature.

This option was intended for field personnel who are familiar with materials information but who have limited experience with modulus backcalculation techniques. In this field, select whether you want the program to backcalculate a fixed value or a range of values for the asphalt moduli. Enter <F> for a fixed value or <R> for a range and press <ENTER> or press <FK1> to see the formulas used for each of these two options. The last field in this screen prompts for the pavement temperature in degrees Fahrenheit. Enter the temperature value and press <ENTER>. Use the <ESC> key to return to the first field and make changes, as explained previously.

After validating the pavement temperature with an <ENTER>, the program displays a second screen (Figure 22). In this screen, the user selects the material to be used for the base, subbase if any, and subgrade of the pavement sections to be analyzed. The input sequence is organized in five fields. In the first field, enter any of the nine available base material options.

The second field takes the base thickness in inches. If a subbase is present, input its type and thickness as for the base. Leave the subbase type blank by pressing <ENTER> if there is no subbase.

Enter the predominant type of subgrade for the section as per the option list. Changes to the screen can be made using the <ESC> key as described above. The <HOME> key from any input field will go back to the Main Program Menu. Press <ENTER> to validate the input and to run the program. The message "The WES5 Program is running ..." will be displayed, followed by the message from the search program listing the total number of deflection bowls for which moduli values are being backcalculated will be displayed. When the backcalculation program is finished, the user is requested to press any key, and the Output Options Menu will be displayed.

CHAPTER VI

OPTION 4 - PRINT RESULTS PROGRAM

The Print Results of Latest Analysis option of the Main Program Menu allows the user to print the results of any analysis for which the program files were saved (see Save Files menu choice below). When the user selects this menu option, a screen (Figure 23) that displays the drive and directory name of the last analysis that was run will be displayed. The user can enter the drive and directory that has the program files to be used for the output. The user is requested to enter the specific filename for output. Press <FK1> to get a listing of all the .DA1 files that are stored on the drive and directory that are available for output. Use the up/down arrow keys to highlight the filename and press <ENTER> to select the filename for output.

The Output Options Menu (Figure 24) that is displayed at the conclusion of the backcalculation program is now displayed. The output options for MODULUS 5.0 are discussed below.

- **Display Summary Results on the Screen:** This option gives the user the opportunity to view an abbreviated version of the Summary Report on the screen. Deflection reading one, two and seven are displayed on the screen (Figure 25). The remaining information displayed is the same as on the Summary Report. Press <ENTER> until all the data for the analysis are displayed, and the Output Options Menu will be re-displayed.
- **Print the Results.** The four options for this menu choice are as follows:
- **PRINT DEFLECTION & MODULI SUMMARY TABLE:** This option lets the user print a table listing the deflection readings, the calculated moduli values, and the estimated absolute percent error per sensor for each station in the project and the estimated depth to a stiff layer for each deflection bowl. At the bottom of

U5.0

« M O D U L U S »

DRIVE WHERE DA1 FILE RESIDES (ENTER DRIVE & DIR-
RECTORY(S) UP TO 30 CHAR EX: C:\DIR1\DIR2\DIR3\
(NOTE: BE SURE TO ENTER ALL "\" OF THE DIR NAME)

NAME OF THE .DA1 FILE----->

PRESS <ENTER> TO CONTINUE

TxDOT version. Developed by the Texas Transportation Institute.
ENTER THE DRIVE & DIRECTORY(S), UP TO 30 CHAR (USE THE TRAILING \)

Figure 23. Backcalculation Select Drive, Directory, and Filename to Print.

« M O D U L U S »

Output Options Menu

1) Display Summary Results on the Screen

2) Print the Results

3) Save the Results in ASCII Files

4) Display Measured vs Computed Bowls

5) Plot Deflections and/or Moduli Values

6) Re-run this Problem

7) Return to Main Menu

Use the ↑ or ↓ keys or enter the option NUMBER and press <ENTER>

TxDOT version. Developed by the Texas Transportation Institute.
Up to 8 characters. Press <FK1> for a list of all .OUT files!

Figure 24. Backcalculation Output Options Menu.

TTI MODULUS ANALYSIS SYSTEM (SUMMARY REPORT) (Version 5.0)														
District	: 17		Thick.		MODULI RANGE (psi)				POISSON					
County	: 21		(in)		Minimum		Maximum		Ratio Values					
Highway/Road:	FM2818	Pvmt:	3.50		200,000		800,000		H1: $\mu = 0.35$					
		Base:	12.00		5,000		50,000		H2: $\mu = 0.35$					
		Sbse:	0.00		0		0		H3: $\mu = 0.34$					
		Sbgr:	139.60				10,000		H4: $\mu = 0.35$					
Station	(lbs)	Load	Mesrd Defl (mils)		Calcltd Moduli values (ksi)					Absolute Dpth to				
		R1	R2	R7	SRF	E1	BSE	E2	SBS	E3	SGR	E4	ERR/Sens	Bedrock
0.041	11,471	30.60	21.19	2.89	800.	24.6	0.0	8.2	2.04	249.88*				
0.104	11,903	42.29	17.34	2.97	200.	24.1	0.0	10.0	10.88	300.00*				
0.214	11,367	38.07	19.93	1.81	357.	14.7	0.0	11.8	2.32	101.89				
0.295	12,479	39.96	20.70	2.01	355.	14.4	0.0	13.5	4.47	104.63				
0.418	11,495	44.33	28.32	3.45	542.	13.5	0.0	7.0	2.26	144.19				
Mean	:	39.05	21.50	2.63	451.	18.3	0.0	10.1	4.4	153.0				
Std. Dev	:	5.28	4.09	0.69	230.	5.6	0.0	2.7	3.8	69.3				
Var Coeff(%)	:	13.52	19.04	26.31	51.	30.5	0.0	26.2	85.5	45.3				

Figure 25. Screen Display of Summary Report.

the figure, statistics are printed for all of the above variables (Figure 26). The asterisk printed at the end of the line denotes moduli values which hit upper or lower limits of either the range of allowable input moduli values or modular ratios used within the program to generate the deflection data base. If more than 10% of deflection bowls hit a limit, the user should rerun the program with wider limits to eliminate this problem.

- PRINT ESTIMATED DEFLECTION TABLE: Option <2> of the Print Results Menu produces a detailed station-by-station result report which includes the back calculated deflection values, absolute error and squared error values, force and pressure at the loading plate, and a list of checks indicating if the moduli values are close to the given limits, if the convexity test fails, or if the solution to the particular station was infeasible (Figure 27).
- PRINT BOTH OF THE ABOVE TABLES: This option prints the summary table first, advances the paper to the beginning of a new page, and then prints the detailed section by section report.
- Return to Output Options Menu: This option returns the user to the Output Options Menu.
- Save the Results in ASCII Files: This option saves the Summary Report as an ASCII file with the filename extension .ASC automatically appended to the root filename. This file will be saved in the same drive and directory that was entered previously.
- Display Measured vs. Computed Bowls: This option allows the user to view a plot of the observed vs. the computed deflection bowls and the composite modulus values computed for each sensor deflection. This composite modulus uses the single-layer Boussinesq solution, a composite modulus is computed

TTI MODULUS ANALYSIS SYSTEM (SUMMARY REPORT)													(Version 5.0)	
District:	17									MODULI RANGE(psi)				
County:	21		Thickness(in)							Minimum	Maximum	Poisson Ratio Values		
Highway/Road:	FM2818		Pavement:	4.00		300,000		600,000		H1: % = 0.35				
			Base:	10.00		5,000		100,000		H2: % = 0.35				
			Subbase:	0.00		0		0		H3: % = 0.34				
			Subgrade:	145.20		10,000				H4: % = 0.35				
Station	Load (lbs)	Measured Deflection (mils):							Calculated Moduli values (ksi):				Absolute Dpth to	
		R1	R2	R3	R4	R5	R6	R7	SURF(E1)	BASE(E2)	SUBB(E3)	SUBG(E4)	ERR/Sens	Bedrock
0.041	11,471	30.60	21.19	12.25	7.48	5.06	3.61	2.89	600.	26.2	0.0	8.4	2.08	249.88 *
0.104	11,903	42.29	17.34	10.28	6.75	4.86	3.65	2.97	300.	19.3	0.0	10.3	14.52	300.00 *
0.214	11,367	38.07	19.93	9.45	4.97	3.16	2.28	1.81	300.	13.0	0.0	12.1	2.19	101.89 *
0.295	12,479	39.96	20.70	8.59	4.61	3.24	2.40	2.01	300.	12.8	0.0	13.8	5.22	104.63 *
0.418	11,495	44.33	28.32	15.50	8.81	5.77	4.19	3.45	350.	15.1	0.0	7.0	2.07	144.19
0.501	11,047	61.20	38.45	19.73	11.69	7.43	5.39	4.54	300.	8.2	0.0	5.3	3.23	157.08 *
0.604	11,071	34.21	21.19	11.63	7.80	5.34	3.77	3.17	300.	29.0	0.0	8.0	3.27	232.12 *
0.708	12,111	29.76	19.45	11.10	6.83	4.66	3.28	2.65	481.	32.3	0.0	9.7	2.01	230.27
0.803	11,271	12.77	11.14	8.51	6.15	4.35	3.03	2.33	600.	100.0	0.0	12.1	15.05	222.33 *
0.948	11,159	34.13	16.49	6.66	3.40	2.37	1.87	1.65	300.	12.6	0.0	16.3	6.09	91.50 *
Mean:		36.73	21.42	11.37	6.85	4.62	3.35	2.75	383.	26.8	0.0	10.3	5.57	158.42
Std. Dev:		12.35	7.39	3.81	2.35	1.46	1.03	0.87	127.	26.9	0.0	3.3	5.05	69.45
Var Coeff(%):		33.63	34.48	33.53	34.25	31.56	30.77	31.56	33.	100.0	0.0	32.2	90.61	43.84

Figure 26. Summary Listing.

TTI MODULUS ANALYSIS SYSTEM (SECTION REPORT)								(Version 5.0)
District: 17	County: 21	Distance (in) from center of loading plate to sensor:						R1 = 0.000
Highway/Road: FM2818							R2 = 12.000	
Radius of loading plate(in):	5.910	POISSON RATIO VALUES						R3 = 24.000
Surface thickness(in):	3.500						R4 = 36.000	
Base thickness(in):	12.000						R5 = 48.000	
Subbase thickness(in):	0.000						R6 = 60.000	
Subgrade thickness(in):	139.600						R7 = 72.000	
Station: 0.041	R1	R2	R3	R4	R5	R6	R7	Plate Load = 11,472 lbs
Measured Deflection:	30.60	21.19	12.25	7.48	5.06	3.61	2.89	Plate Pressure = 104,550 psi
Calculated Deflection:	31.09	20.74	12.23	7.73	5.11	3.46	2.44	
Weight Factor:	1.00	0.69	0.40	0.24	0.17	0.12	0.00	
% ERROR	-1.60	2.14	0.13	-3.34	-0.90	4.12	0.00	Absolute Sum of % ERROR = 12.200
Layer:	SURFACE(E1)	BASE(E2)	SUBBASE(E3)	SUBGRADE(E4)				Square Error = 0.004
Moduli Values (ksi):	800.0	24.6	0.0	8.2				
Close to limits?	YES	NO	N/A	-				Failed Convexity Test? NO
Station: 0.104	R1	R2	R3	R4	R5	R6	R7	Plate Load = 11,903 lbs
Measured Deflection:	42.29	17.34	10.28	6.75	4.86	3.65	2.97	Plate Pressure = 108,480 psi
Calculated Deflection:	39.22	20.23	10.69	6.54	4.23	2.87	2.00	
Weight Factor:	1.00	0.41	0.24	0.16	0.11	0.09	0.00	
% ERROR	7.27	-16.65	-4.00	3.14	12.88	21.31	0.00	Absolute Sum of % ERROR = 65.300
Layer:	SURFACE(E1)	BASE(E2)	SUBBASE(E3)	SUBGRADE(E4)				Square Error = 0.098
Moduli Values (ksi):	200.0	24.1	0.0	10.0				
Close to limits?	YES	NO	N/A	-				Failed Convexity Test? NO
Station: 0.214	R1	R2	R3	R4	R5	R6	R7	Plate Load = 11,368 lbs
Measured Deflection:	38.07	19.93	9.45	4.97	3.16	2.28	1.81	Plate Pressure = 103,600 psi
Calculated Deflection:	37.99	20.11	9.16	5.12	3.25	2.19	1.52	
Weight Factor:	1.00	0.52	0.25	0.13	0.08	0.06	0.00	
% ERROR	0.20	-0.92	3.08	-2.97	-2.87	3.89	0.00	Absolute Sum of % ERROR = 13.900
Layer:	SURFACE(E1)	BASE(E2)	SUBBASE(E3)	SUBGRADE(E4)				Square Error = 0.004
Moduli Values (ksi):	357.4	14.7	0.0	11.8				
Close to limits?	NO	NO	N/A	-				Failed Convexity Test? NO
Station: 0.295	R1	R2	R3	R4	R5	R6	R7	Plate Load = 12,480 lbs
Measured Deflection:	39.96	20.70	8.59	4.61	3.24	2.40	2.01	Plate Pressure = 113,730 psi
Calculated Deflection:	40.08	20.51	8.83	4.83	3.08	2.09	1.44	
Weight Factor:	1.00	0.52	0.21	0.12	0.08	0.06	0.00	
% ERROR	-0.31	0.93	-2.84	-4.83	4.93	12.99	0.00	Absolute Sum of % ERROR = 26.800
Layer:	SURFACE(E1)	BASE(E2)	SUBBASE(E3)	SUBGRADE(E4)				Square Error = 0.023
Moduli Values (ksi):	354.9	14.4	0.0	13.5				
Close to limits?	NO	NO	N/A	-				Failed Convexity Test? NO
Station: 0.418	R1	R2	R3	R4	R5	R6	R7	Plate Load = 11,496 lbs
Measured Deflection:	44.33	28.32	15.50	8.81	5.77	4.19	3.45	Plate Pressure = 104,770 psi
Calculated Deflection:	44.39	28.22	15.38	9.16	5.85	3.89	2.75	
Weight Factor:	1.00	0.64	0.35	0.20	0.13	0.09	0.00	
% ERROR	-0.13	0.34	0.78	-3.93	-1.32	7.05	0.00	Absolute Sum of % ERROR = 13.600
Layer:	SURFACE(E1)	BASE(E2)	SUBBASE(E3)	SUBGRADE(E4)				Square Error = 0.007
Moduli Values (ksi):	542.4	13.5	0.0	7.0				
Close to limits?	NO	NO	N/A	-				Failed Convexity Test? NO

Figure 27. Detailed Bowl by Bowl Listing.

using the deflection at each sensor location. To view the results of the latest analysis, press <ENTER> (Figure 28) or type in the complete filename (drive, directory(s), and filename without the .DA1 extension) of the file you want to see and press <ENTER>. Press <ESC> to return to the Output Options Menu if the filename you entered is incorrect or if the file does not exist. Press <ENTER> to view the plot of each deflection bowl (Figure 29) in the analysis or press <ESC> to return to the Output Options Menu.

- **Plot Deflections and/or Moduli Values:** This option allows the user to analyze pavement response variables, mainly deflection readings, calculated moduli values, depth to bedrock, and average errors, from a graphical point of view, along the entire project length. It will also perform a unit delineation analysis using the cumulative difference approach in order to identify units of sections having similar characteristics. (See Report 1123-1.) This option is discussed in more detail in 6.1 below.
- **Rerun this Problem:** This option gives the user the opportunity to return to the modulus backcalculation program to rerun the same problem after making changes to the input data without having to return to the Main Program Menu. For this option, the weighting factors from the previous run will be used unless changed by the user.
- **Return to Main Menu:** A window (Figure 30) will overlay this menu choice to give the user the opportunity to save all the program files from an analysis for processing at a later time. This should be helpful when a printer is not available when the analysis was run or if the user would want to do the delineation analysis at a later time. The default for this is "N" to not save the program files. Type "Y" and press <ENTER> to save the .DA1 through .ZAB program files from the analysis. Note that this option will not save the Summary Results as an ASCII file. The user must save the results in an ASCII file in a previous menu choice.

PROGRAM GMODULUS

Press ENTER to run the last .DA1 file that was created,
or, enter the drive, directory(s), and filename of the
file you want to use (up to 38 total characters).

Example: C:\DIR1\DIR2\DIR3\FILENAME

(NOTE: Do not enter the .DA1 extension.)

ENTER Filename >

F1/HELP

Esc/END

Figure 28. Select Filename For the Observed vs. Computed Deflection Plot.

MEAS.	40.0	20.7	8.6	4.6	3.2	2.4	2.0	MILS
CALC.	40.1	20.5	8.8	4.8	3.1	2.1	1.4	MILS
SMOD.		10.4	12.5	15.6	16.6	17.9	17.8	KSI

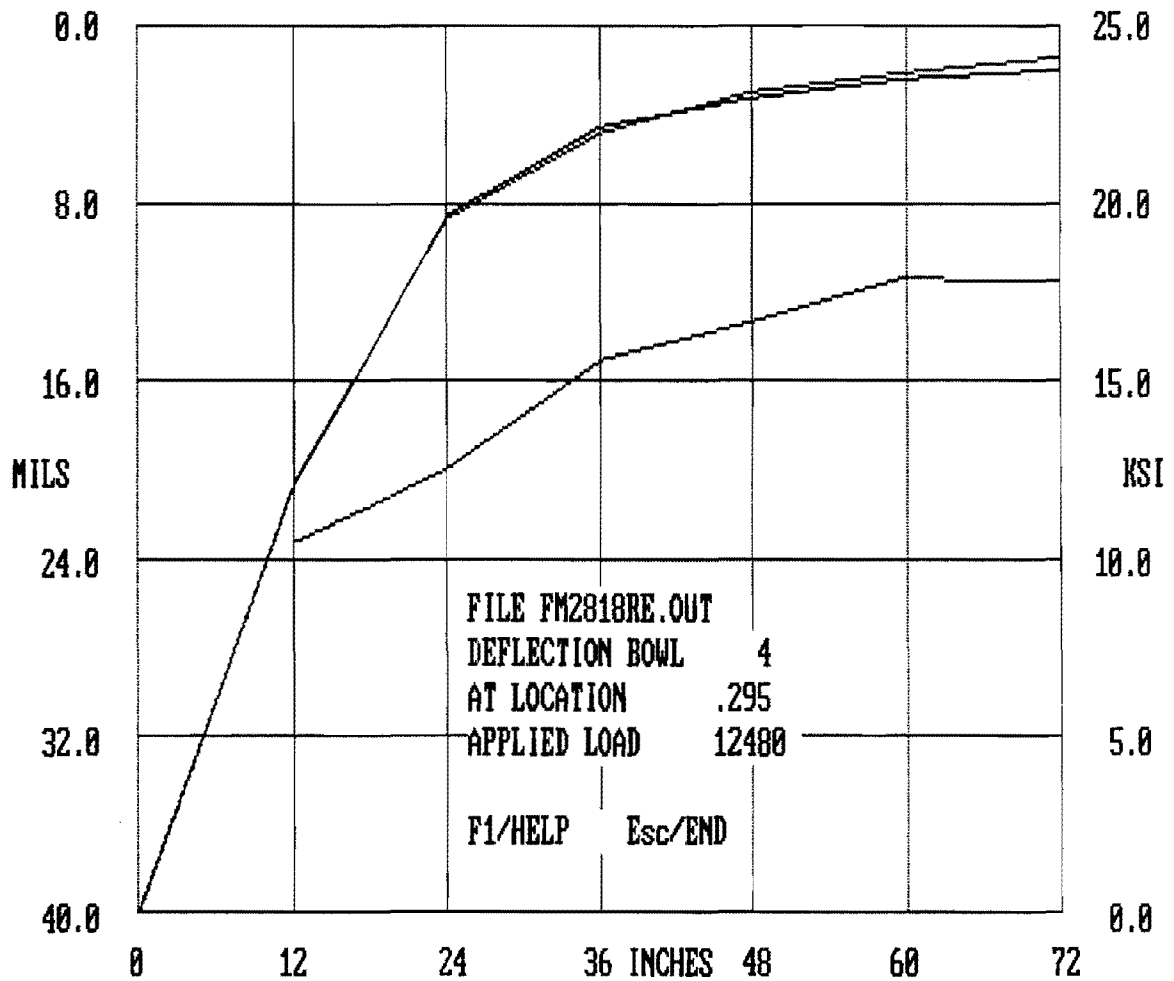


Figure 29. Plot of the Observed vs. Computed Deflection Bowl.

« MODULUS »

Display Options Menu

- 1) Display Summary Results on the Screen
- 2) Print the Results
- 3) Save the Results in ASCII Files
- 4) Display Measured vs Computed Bowls
- 5) Plot Deflections and/or Moduli Values
- 6) Re-run this Problem

Save Files for Future Analysis--->

Use the F10 key to affect the option choice and press <ENTER>

TxDOT version. Developed by the Texas Transportation Institute.
Enter Y to save the files for this run, N to delete these files

Figure 30. Example of the Save Files Option.

6.1 PLOT DEFLECTION AND/OR MODULI VALUES OPTION

To run this program, select option three from the Main Program Menu and press <ENTER>. After validating the choice, the Pavement Response Variable Graphic Representation and Delineation Analysis screen is displayed (Figure 31). The "DRIVE WHERE .DAT FILE RESIDES" field will have displayed the drive directory(s) that was entered during the FWD conversion, or this field will display the drive and directory from the last analysis. Enter the correct drive and directory(s) and press <ENTER>.

Next, enter the name of the .DAT file containing the deflection readings, backcalculated moduli values, absolute error value, and the depth to bedrock values for graphical output and delineation analysis. Press the <FK1> key to get a listing of the .DAT files that are stored on the drive and directory entered previously. Use the up/down arrow keys to highlight a filename and press <ENTER> to select the file for delineation analysis.

Next, select the response variables to be plotted. There are a maximum of seven deflection readings and four moduli values for each station. Deflections are identified by a number from 1 to 7, with 1 corresponding to the sensor closest to the loading plate, 2 to the second closest, and so on. Moduli values are variables 8 to 11, where 8 identifies the modulus of the surface layer, 9 the base, 10 the subbase, and 11 the subgrade. Variable 12 displays the absolute error, and 13 shows the depth to bedrock. Enter the number corresponding to the response variable required (1 through 7 for deflections or 8 through 11 for moduli values, 12 for absolute error or 13 for depth to bedrock) and press <ENTER>.

The last item of information requested is the minimum section length that will be used by the delineation subroutine to perform the unit delineation of the chosen response variable. If consecutive inflection points in the cumulative difference curve occur at intervals that are less than the minimum section length entered, the program will ignore them. This feature is provided to avoid the clutter of unit delineations that might occur in projects with unusually high response variable variability.

Enter this value in miles including fractions of a mile (that is, as a decimal value) and press <ENTER>. To make any changes, use the <ESC> sequence as in the other programs.

As soon as the <ENTER> key is pressed, the program starts executing; in a few seconds the screen is cleared, and a plot of the selected response variable as a function of distance along the project is produced (Figure 32). At the bottom of the screen a table of

« M O D U L U S »

TRANSPORTATION RESPONSE VARIABLE
GRAPHIC REPRESENTATION AND DIRECTION ANALYSIS

THE FOLLOWING INFORMATION IS REQUIRED:

DRIVE WHERE THE .DA1, .DAT, .DPT, & .ZAB FILES ARE
STORED. ENTER DRIVE & DIRECTORY(S), UP TO 30 CHARS
EX:, C:\DIR1\DIR2\DIR3\ (INCLUDE FINAL "\" OF THE
DRIVE & DIR. NAME)->

NAME OF THE .DA1 DATAFILE ----->

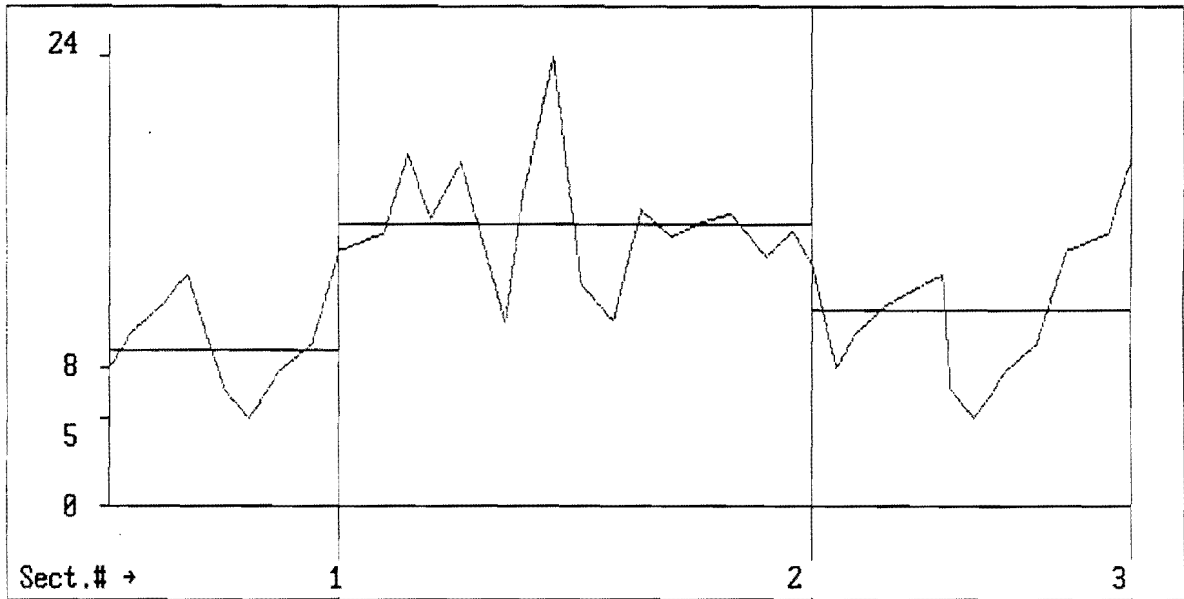
RESPONSE VARIABLE ----->

MINIMUM SECTION LENGTH ----->

TxDOT version. Developed by the Texas Transportation Institute.
ENTER THE DRIVE & DIRECTORY(S) UP TO 30 CHAR (INCLUDE THE FINAL "\")

Figure 31. Backcalculation Delineation Analysis Input Screen.

Road: FM2818 Pavement Response Variable: E4 (Moduli values in KSI)



Section #	From	To	Mean	S.Dev.
1	0.041	0.803	8.54	2.52
2	0.803	2.359	15.47	3.48
3	2.359	3.427	10.79	4.12

Press any key to continue

Figure 32. Plot of Subgrade Moduli Values for a Section of FM 2818.

statistics for each of the unit delineations is displayed. If there are more than three delineated sections in the plot, press any key to see the statistics for the remaining sections. Press any key until the message "Would you like to combine sections manually or Quit? (C/Q)" appears. To quit the program at this point enter <Q>; otherwise, enter <C>. The manual combination routine then prompts for the number of sections the user would like the combination to have. Enter the number and press <ENTER>. To combine all sections, enter the total number of sections that were delineated in the plot. If the user did not elect to combine all sections, a prompt is displayed asking for the number of the last section to be included as the new section one. The subroutine repeats the last prompt until all of the sections have been accounted for. Then it recalculates and replots the curve showing the new delineations and their respective statistics.

Repeat the above sequence for manual combination if there are sections left to combine or quit the program. When answering <Q> to the prompt, the user is given the choice of printing the statistics for the latest delineation. Then, the following prompt is displayed: "Enter <R> to analyze other Responses or <Q> to quit to the Main Program Menu." Selecting <Q> returns to the Main Program Menu, while entering <R> redisplay the Pavement Response Variable Graphic Representation and Delineation Analysis Screen, allowing the user to select another response variable for graphical analysis.

The user is advised that each run of the modulus backcalculation program creates a minimum of eight program files (nine if the results are saved as an ASCII file) and that the user should make sure that there is ample space on the hard drive or diskette to contain the program files if he or she chooses to save the files for later printing or delineation analysis.

CHAPTER VII

USER ASSISTANCE SUGGESTIONS

This Modulus 5.0 program represents a major revision of the Modulus 4.2 backcalculation program with the intent of giving the pavement design engineer information about the remaining life of the pavement structure and strength estimates of the surface, base, and subgrade layers of the pavement structure. MODULUS 5.0 is intended to assist the design engineer in formulating decisions concerning the level of rehabilitation or maintenance for the pavement structure. Listed below are a few of the features of MODULUS 5.0 that should make the program easier for the user.

1. Accesses data files and stores program files from directories other than where the MODULUS program is installed.
2. Uses the <ESC> key to return to the beginning of an input field to correct a data entry.
3. Uses the <HOME> key from any input field to return to the Main Program Menu.
4. Saves the program files from an analysis for printing or delineation analysis at a later time.
5. Allows the user to correct non-decreasing deflection readings during FWD conversion.
6. Goes directly to the output menu after the remaining life or modulus backcalculation is finished.
7. Inspects visually the Summary Report on the screen.
8. Saves the Summary Report as an ASCII file.
9. Identifies the layer that failed the convexity test on the Section Report.
10. Re-runs the same problem without going back to the Main Program Menu.

In addition, the example FWD field data file 021F2818.FWD has a non-decreasing deflection bowl at station 1.801 of FWD drop one that can be used to try out the various options of the FWD conversion.

As a way to provide initial display items for the drive, directory and filename fields, these items are saved from the last analysis run and stored in a file called "SAVEOUT.OUT." The drive and directory from SAVEOUT.OUT are displayed in the drive and directory field for each of the four options of the Main Program Menu. This drive and directory can be changed from one analysis run to the next, or it can be held constant if all the data files to be analyzed are stored on the same drive and directory.

One other feature that should help the user is that the <FK1> can be pressed at the filename input field of all four options of the Main Program Menu to give the user a listing of all the files stored on the current drive and directory that are available for FWD conversion, remaining life calculation, modulus backcalculation, or printing and delineation analysis.

The user is directed to make a trial run with the 021F2818.FWD data file if he or she experiences problems with running this MODULUS 5.0 program. Carefully review the steps outlined in this user's manual and follow the procedure using the 021F2818.FWD data file to see if the difficulty can be resolved.

APPENDIX A

BACKGROUND TO REMAINING LIFE ANALYSIS ROUTINE

1. INTRODUCTION

There is a vast amount of information about the subsurface condition of a pavement that can be obtained by interpreting the shape of the deflection bowl. In fact, an understanding of the significance of the measured deflections is essential in order to perform a sound structural evaluation. Backcalculation of layer properties is sometimes a frustrating experience for young engineers, who often view programs such as MODULUS as black boxes. Often, little checking is done of how reasonable the computed Moduli values are. A lot of this frustration can be minimized by using the simple interpretation scheme proposed in this Appendix. This scheme is intended to provide the engineer with the following information:

- a. the structural adequacy of each layer in the pavement system on five level scale from Very Poor to Very Good, and
- b. the remaining life category of the pavement section, on a four level scale (0-2, 2-5, 5-10, or 10+ years).

These computations do not rely on backcalculation of layer moduli; they are based on interpretation of bowl parameters. They are intended as simple procedures whereby the engineer can rapidly assess the pavement's structural condition. In every deflection survey performed by TxDOT it is strongly recommended that this remaining life routine be run prior to any backcalculation of layer moduli for the following reasons:

1. This procedure can rapidly assess the level of rehabilitation that a given pavement section may require. Having a classification of surface, base and subgrade condition will help to identify potential rehabilitation strategies. For example, knowing the subgrade is poor and the base is good helps in identifying candidate rehabilitation strategies.
2. The procedure may preclude the need for backcalculation. If an overlay is being planned and the section is rated as very strong with a 10-year remaining life, then only the minimum resurfacing thickness is needed to repair non-structural problems. Backcalculation of moduli is not required to make this determination.

3. This rapid procedure provides the engineer with a quick assessment of the variation in strength along the highway. This provides insight on whether the highway should be subdivided into 2 or more sections for backcalculation.
4. The layer strength assessment from very poor to very good should correlate with the backcalculated moduli values. For example, if the subgrade is classified as very poor for a typical flexible pavement, the backcalculated moduli should be less than 5 ksi.
5. A major requirement of District Pavement Engineers is to classify the pavement in terms of the required rehabilitation strategy. For example, does the pavement require:
 - a) an overlay,
 - b) surface repair,
 - c) base repair, or
 - d) full reconstruction.

The outputs of this procedure are intended to help in this area.

The background to the two procedures (layer strength characterization and remaining life estimation) has been documented in Texas Transportation Institute Report 409-3F, entitled "Incorporating a Structural Strength Index into the Texas Pavement Evaluation", (Scullion, April 1988).

This system was established for the traditional flexible pavement structure, consisting of asphalt surfacing over granular base over the subgrade. Heavily stabilized bases were not considered in this development and the results obtained by using this procedure with these pavements is questionable.

2. LAYER STRENGTH CHARACTERISTICS

Falling Weight Deflectometer testing on flexible pavements in Texas is conducted with the sensors at 305 mm (12 inch) spacings. A typical deflection bowl is shown in Figure A1. Several parameters are defined on this figure, namely the Surface Curvature

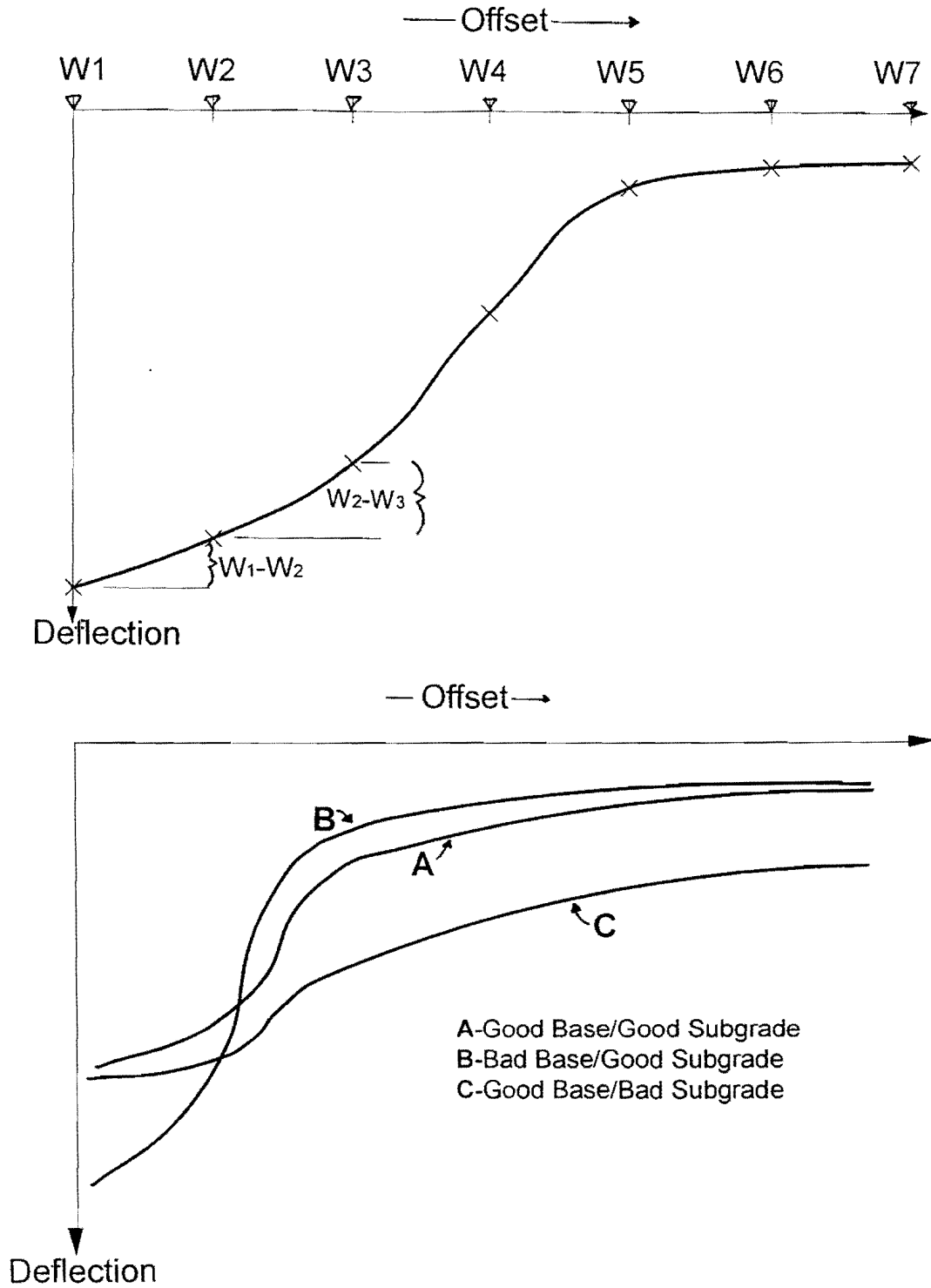


Figure A1. Deflection Bowl Parameters and Their Significance.

Index ($W_1 - W_2$) and the Base Curvature Index ($W_2 - W_3$) in mils. The lower graph in Figure A1 illustrates how changes in these parameters could be interpreted with regard to layer strength. The significance of these indices is as follows:

Surface Curvature Index ($W_1 - W_2$)

Is related to the strength of the top 200 mm (8 inches) of the structure. On thin Farm to Market highways, this may be the base layer; on thick Interstate Pavements, this may be the asphalt surfacing. The higher the value of SCI the lower is the strength of the layer.

Base Curvature Index ($W_2 - W_3$)

Is related to the strength from 200 to 400 mm (12 to 15 in) below the surface. Depending on the structure this may be the top of the subgrade or the base layer. The higher the value of BCI, the lower the strength of the layer.

W7

The deflection at sensor number seven, 1.83 m (72 inches) from the center of the load plate, is related to the subgrade strength. Again, the higher the value the weaker the subgrade.

In order to perform the layer strength assessment, each FWD deflection bowl is first normalized to 40 kN (9,000 lbs) and then temperature corrected to 21°C (70°F). A straight linear correction is applied for the load level normalization. For the temperature correction, use is made of the Corps of Engineers procedure described in (Bush, 1987) in which the relationship between measured deflection and asphalt layer temperature was graphed for a range of surfacing thicknesses. The equations of these curves were provided by Mr. Don Alexander of the US Army Corps of Engineers and these have been incorporated into this routine to generate temperature correction factors.

The Corps procedure is intended to apply correction factors to the maximum deflection W_1 ; however, as the temperature increases, the deflections measured at sensors W_2 and W_3 may also increase. Based on seasonal FWD data collected in Texas DOT Study 1123, significant changes were noted in W_2 and W_3 as the temperature changed. These

changes were not as large as the changes observed in W_1 . It was therefore decided to use the Corps of Engineers factors to generate the corrections for W_1 and to apply a percentage of this correction factor to the other deflections. These percentages are shown in the following table.

Table A1. Percentage of Temperature Correction Factor Applied to Each FWD Sensor.

Asphalt Thickness		< 75 mm	75 - 125 mm	> 125 mm
Percent Correction Factor Applied	W_1	0	100	100
	W_2	0	45	62
	W_3	0	12	34
	W_4	0	5	10

No corrections are made if the asphalt thickness is less than 75 mm (3 inches). Once normalized and temperature corrected to 21°C (70°F) the SCI, BCI and W_7 are calculated. The SCI, BCI and W_7 are used to compute the UPR, LWR and SGR strength classifications as shown Figure 11. UPR is the strength of the UPPER pavement layers (to 200 mm), LWR is the LOWER pavement layers (200-400 mm), and SGR is SUBGRADE strength. The transformation of SCI, BCI and W_7 into the strength classification VG (Very Good), GD (Good), MD (Moderate), PR (Poor) and VP (Very Poor) is shown in Table A2.

The basis of this table is correlation of FWD deflection readings to the Dynamic Cone Penetrometer strength characteristics described in Report 930-5F.

Table A2. Layer Strength Classification (in mils).

Asphalt Thickness		> 125 mm	62-125 mm	13-62 m	< 13 mm
SCI	VG	< 4	<6	<12	<16
	GD	4-6	6-10	12-18	16-24
	MD	6-8	10-15	18-24	24-32
	PR	8-10	15-20	24-30	32-40
	VP	>10	>20	>30	>40
BCI	VG	<2	<3	<4	<8
	GD	2-3	3-5	4-8	8-12
	MD	3-4	5-9	8-12	12-16
	PR	4-5	8-10	12-16	16-20
	VP	>5	>10	>16	>20
W7	VG	<1.0	<1.0	<1.0	<1.0
	GD	1.0-1.4	1.0-1.4	1.0-1.4	1.0-1.4
	MD	1.4-1.8	1.4-1.8	1.4-1.8	1.4-1.8
	PR	1.8-2.2	1.8-2.2	1.8-2.2	1.8-2.2
	VP	>2.2	>2.2	>2.2	>2.2

3. REMAINING LIFE ESTIMATES

Details of this procedure are summarized in Chapter 5 of TTI Report 930-5F. A summary of the steps involved is given below. The intent of the procedure is to combine the structural strength of the pavement with its current levels of cracking and rutting, with the anticipated truck loading to provide the engineer with the following remaining life classification:

Class	Remaining Life	Comments
1	0 -2 years	Failed Pavement
2	2 - 5 years	Failure in Near Future
3	5 - 10 years	Adequate for Now, Potential Problem in Future
4	10+ years	Structurally Strong Pavement

The procedures are simple and do not involve layer backcalculation. The fundamental assumptions are:

1. The tensile strain at the bottom of the asphalt layer (ϵ_t) is related to the surface curvature index of the pavement.
2. The vertical compressive strain at the top of the subgrade (ϵ_v) is correlated to both the maximum deflection W_1 and the deflection at the outermost sensor W_7 .

In the computational process, the measured deflection bowls are first, normalized to 40 kN (9,000 lbs) and then temperature-corrected to the mean monthly temperature at the time of test. Then the monthly deflection bowls based on mean monthly surfacing temperature (Table A3) are projected for each month of the year. For each monthly deflection bowl both ϵ_t and ϵ_v are computed and used in standard life prediction equations to predict the number of 18 kip ESAL's in each month to both rutting and cracking failure. Estimating the anticipated 18 kip ESAL's, it is possible to determine what percentage of the life is used each month. Different failure levels for rutting and cracking are set based on the importance of the pavement. The number of months to failure is also adjusted by the existing levels of cracking and rutting on the section at the time the FWD testing.

The environmental zones in Texas and the average monthly asphalt temperature are shown in Table A3. Temperature correction of the deflection bowls and projecting the monthly deflection bowls is performed using the Corps of Engineers procedure described earlier. The computation of strains within the pavement layer is achieved by using the following regression equations,

$$\begin{aligned}\epsilon_v &= A + B * W_1 + C * W_7 \\ \epsilon_t &= D + E * (W_1 - W_2)\end{aligned}$$

where:

A, B, C, D, E are regression coefficient shown in Table A4,

W_1 , W_2 , W_7 are normalized deflections in mils,

ϵ_v is vertical compressive strain at the top of the subgrade in microstrain, and

ϵ_t is tensile strain at the bottom of the asphalt in microstrain.

The rutting and cracking life equations are:

$$N_R = \frac{1.94 \times 10^5}{(\epsilon_v/1000)^4}$$

$$N_c = 10^{**}[A_0 - 3.291 \log(\epsilon_t) - 0.854 \log(SM/1000)]$$

$$A_0 = 16.086 + ACP/15$$

where:

N_R is number of 18 kip ESAL's to induce a 12 mm rut,

N_c is number of 18 kip ESAL's to induce cracking in 30% of the wheel paths,

SM is stiffness of asphalt in month of analysis, computed from monthly asphalt temperatures in Table A3, and

ACP is thickness of asphalt layer in inches.

Table A3. Mean Temperature Data for 12-Month Test Period (Poehl and Scrivner, 1971).

Zone	Dec	Jan	Feb	Mar	Apr	June	July	Aug	Sept	Oct	Nov
1	48	40	39	66	87	103	116	104	82	49	60
3	65	72	53	76	100	86	118	112	93	61	61
3	56	46	66	78	89	100	114	89	90	70	70
4	55	76	82	96	103	114	112	108	106	98	67
5	66	74	71	77	95	93	110	118	99	93	63

Zone 1 = Districts 3, 4, 5, 25

Zone 2 = Districts 2, 8, 9, 14, 23

Zone 3 = Districts 1, 10, 11, 17, 18, 19

Zone 4 = Districts 15, 22

Zone 5 = Districts 12, 13, 20, 16, 21

Table A4. Regression Parameters Used to Compute Strains in Pavement.

Asphalt Thickness Range mm	A	B	C	D	E
0-13	-210	41	303.8	0	0
13-37	-91.2	32.6	235.2	-231.1	14.7
37-62	-11.0	26.92	123.7	-147.85	27.06
62-87	1.19	23.4	69.4	-98.7	35.15
87-113	-1.15	20.7	43.68	-66.6	40.28
113-128	-4.59	18.5	30.04	-43.5	42.75
128-175	-7.19	16.6	22.74	-25.1	42.72
175+	-10.36	13.38	16.63	1.28	37.3

The failure criteria in this procedure are set as follows:

Asphalt Thickness	Rutting Failure	Cracking Failure
≤ 12 m	37 mm	Not Used
13 mm - 63 mm	25 mm	40%
> 63 mm	19 mm	30%

4. REFERENCES

- Bush, A. J. (1987), "Development of a Pavement Evaluation Method for Low Volume Airfield Pavements," Ph.D. Dissertation, University of Illinois, Urbana, ILL.
- Scullion, T. (1988), "Incorporating a Structural Strength Index into the Texas Pavement Evaluation System," TTI Report 409-3F.
- Poehl, R. and Scrivner, F. H., "Seasonal Variations of Pavement Deflections in Texas," TTI Report 136-1, January 1971.

APPENDIX B
GUIDELINES ON FWD DATA COLLECTION, MODULUS
BACKCALCULATION AND INTERPRETATION

1. INTRODUCTION

This appendix is intended to provide guidance to TxDOT personnel who are interested in structurally evaluating flexible pavements and obtaining inputs for pavement design.

2. FWD PROJECT LEVEL TESTING

- Sensor Locations, 305 mm (1 foot) spacing.
- Load Level - for design purpose the load level closest to 40 kN (9,000 lbs) is recommended. This usually corresponds to FWD drop height 2. Taking multiple drops at the same location at different load levels is not recommended. Rather, collect only one or two drops at each location and use the time saved to collect data more frequently.
- Frequency of Data Collection - on any project a minimum of 20 drops should be taken. A maximum spacing of 152 m (500 ft) should be used.
- The FWD operator must monitor the temperature of the asphalt surface at the beginning and end of FWD data collection. The preferred method is by drilling a hole to a depth of 25 mm (1 inch) and measuring the temperature at that depth. As a minimum, surface temperature must be recorded.
These temperatures are used to correct the asphalt layer moduli and for inputs to the remaining life routine. However, temperature measurements are not required if the surfacing layer is less than 75 mm thick.
- The FWD operator should enter frequent comments into the FWD file, noting areas of structural damage (alligator cracking, rutting) or extensive maintenance (patching). Also note crests of hills, cut/fill sections, presence of standing water in ditches, etc. Avoid badly cracked areas when collecting data. While collecting data on any section, it is often beneficial to take the maintenance supervisor along so that any unusual features can be recorded as the FWD data is collected.
- The FWD operator should measure the average rut depth in the wheel paths and the percentage of alligator cracking in the wheel paths for each complete section. As a fall-back position, these values can be obtained from PMIS. However, the Pavement Management values may underestimate the amount of distress.

3. REMAINING LIFE ESTIMATION

As the first step in using MODULUS 5.0 to evaluate any flexible pavement option 2, the remaining life analysis program should be run. From outputs such as Figure 11, the user should be able to determine:

- a. the overall structural adequacy,
- b. which layer within the pavement is weak,
- c. the remaining life classification, and
- d. the uniformity of the section.

The layer strength classification will also be useful in validating the backcalculated moduli values.

4. BACKCALCULATION OF LAYER MODULI

4.1 Assigning Layer Moduli

The following general guidelines should be used in the majority of cases when running the "FULL ANALYSIS" procedure:

- a. Always start with a 3-layer analysis problem. For this first run, ignore possible stabilized subgrades. Guidelines will be given later on, when a 4-layer problem should be run.
- b. Combine all asphalt layers into a single layer.
- c. Assign a nominal surfacing thickness of 12 mm (0.5 inches) to surface treated pavements (surface treatment over a granular base).
- d. Use the following default moduli values in the "FULL ANALYSIS" option:

Layer	Modular Range (ksi)	Poisson's Ratio
Asphalt	See Figure B1	0.35
Flexible Base	10-150	0.35
Lightly Stabilized Base < 3% Stabilizer	50-1000	0.25
Heavily Stabilized Base > 3%	250-5000	0.25
Concrete	1000-7000	0.20

When using Figure B1, the user inputs the average surface layer temperature at the time of FWD testing and uses the two outer curves to generate an acceptable moduli range. For a typical asphaltic layer, the backcalculated moduli value should fall in this range. If the value is outside of this range, then either the pavement is incorrectly modeled (probably wrong layer thicknesses) or there is a problem with the asphalt. A high number may indicate an aged stiff layer; a low number indicates a soft or cracked layer.

- e. The weighting factors should be left at 0.0, which means that MODULUS 5.0 automatically assigns weights to each sensor.

4.2 When To Stop

Under normal conditions the user should attempt to reduce the average error per sensor to less than 4% per sensor. When rerunning the problem it may be necessary to:

- a. Adjust the acceptable moduli range for a layer if a limit is being hit;
- b. Remove non-representative deflection bowls from the .OUT file. Often, data may be collected on sections where maintenance forces may have done extensive base repair work. These significantly lower deflection bowls should be excluded;
- c. Break the highway into 2 or more sections if significant variations in strength are found; or
- d. Adjust the weighting factors to eliminate a sensor which cannot be matched by the theoretical model. Setting the weighting factors to 1 for the sensors to be used and 0 to those to be dropped will eliminate these sensors from consideration.

However, as will be described in the following section, the 4% per sensor rule cannot be rigidly enforced in Texas.

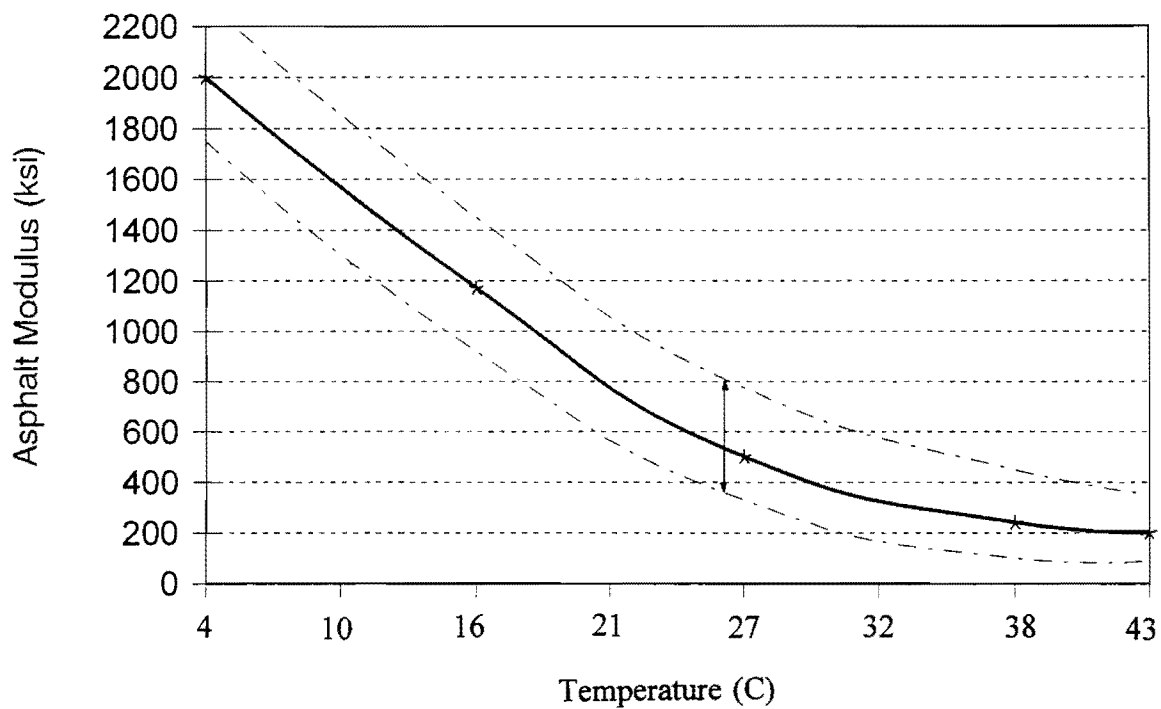


Figure B1. Influence of Temperature on Layer Moduli. The Outer Lines Represent Acceptable Modular Range. (For example, at 26°C (78°F) the Low Value is 360 ksi and High Value is 810 ksi)

4.3 Interpreting The Moduli Values

The goal of any backcalculation analysis must be to provide realistic inputs for pavement design. Achieving a low error per sensor does not guarantee realistic answers. Backcalculated solutions are not unique; there may be several combinations of layer moduli that result in low error per sensor. Under Texas conditions, additional factors often occur which make it extremely difficult to reach the 4% per sensor goal; these include shallow bedrock situations where the outer sensor measure deflections are of less than 1 mil. The presence of additional layers (often stabilized), the general poor information on layer thickness and testing on repaired sections are also contributing factors.

With all of these uncertainties, how is the user to determine if the backcalculated moduli values are reasonable and of sufficient accuracy to be used for design?. The answer, however, is not simple. The user has to gain experience with the backcalculated numbers and decide, based on his knowledge of the materials used and subsequent pavement performance, if the values are reasonable. To assist in this task, guidelines are given below on how to interpret these moduli values.

Subgrade Classification

Backcalculated Moduli Range	Interpretation
1-4	Very Poor
4-8	Poor
8-12	Fair
12-16	Good
16+	Very Good

Flexible Base Classification

Modular Ratio $E_{\text{base}}/E_{\text{subgrade}}$	Interpretation
>3	Good
2-3	Marginal
<2	Poor

Stabilized Base

Base Modulus (ksi)	Interpretation
> 100	Light (<3%)
> 500	Intermediate (3-5%)
> 1000	Heavy (>5%)

Asphalt

Refer to Figure B1 to determine if the backcalculated moduli are within acceptable limits based on the surface temperature at the time of testing.

To supplement these interpretation guidelines, the user should also review the UPR, LWR and SGR strength classifications computed in the Remaining Life Routine.

4.4 When to Use 4-Layer Analysis

Four-layer analysis should only be performed if the three layer results are unsatisfactory. Often in Texas, four-layers are required primarily to handle stabilized subbases and subgrades. To check if a stabilized lower layer is present within MODULUS 5.0, review the plot of measured versus computed solutions for the 3-layer case. If a stabilized layer is present, a plot such as shown in Figure B2 is expected:

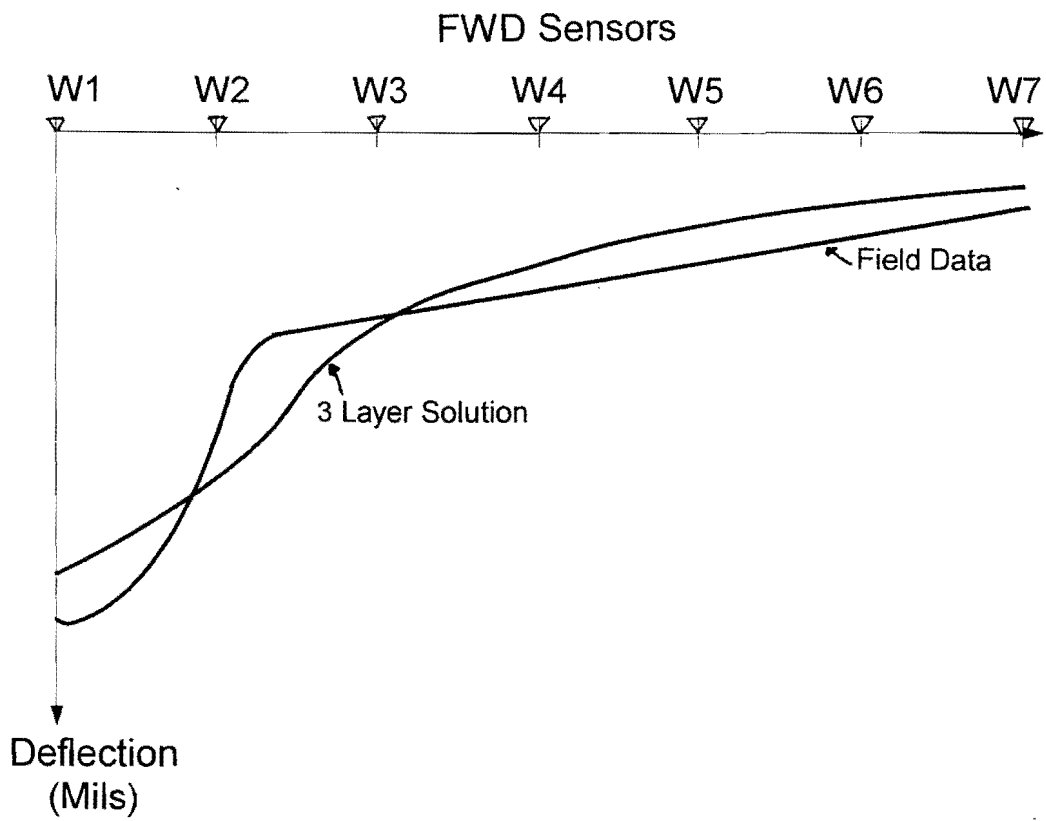


Figure B2. Evaluating the Need for a 4-Layer Analysis. The Field Data Shows a Discontinuity Between Sensors 2 and 3 Indicating a Possible Stabilized Subbase or Subgrade.

The field data will not plot on a smooth curve if there is a discontinuity between sensors 2 and 3. The 3-layer solution will have problems matching sensors 2 and 3, producing large errors (frequently > 10% per sensor).

The discontinuity is generated by having a stiff layer beneath the flexible base. Another indicator of a stabilized subbase is the LWR layer classification, as shown in Figure 11. If this is consistently Good or Very Good, then a stabilized layer may be present.

If a stabilized subgrade layer is to be included as Layer 3, assign it a modular range from 25 to 250 ksi. If the results are still unsatisfactory, both coring and Dynamic Cone Penetrometer testing should be performed.

