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16. Abstract

The program described in this report, developed by the Texas Transportation Institute for the Texas Department of Transportation, aids engineers in evaluating the structural characteristics of rigid pavements. The program, RMODS 2.0, (Rigid Modulus, version 2) analyzes deflection data collected with the Falling Weight Deflectometer (FWD). Technical details of the calculation procedures are given in companion report 1939-3F. The RMODS program has the following capabilities:

1. backcalculate slab and subgrade rigidities using Hertz or Westergaard models,
2. backcalculate slab and subgrade rigidities using layered elastic theory,
3. calculate Load Transfer Efficiency (LTE) at joints, and
4. detect the presence of subslab voids at joints.

This program requires careful attention during FWD testing to ensure that the deflection data can be used by the RMODS program. Four FWD drops at varying load levels must be recorded at each test location. There must be sensor readings at -305, 0, 305 and 1525 mm (-12, 0, 12 and 60 ins) from the test plate. When calculating LTE, the sensor at -305 mm is placed on one side of the joint, with the load plate and remaining sensors on the other side. Backcalculation of E, ℓ, and k can be performed either at center slab or at a free edge. RMODS 2.0 includes subsystems for data input/data conversion, LTE/VOID calculation, backcalculation, printing and delineation of LTE/VOID or backcalculation results.

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RMODS 2.0: USER'S MANUAL

by

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September 1995

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IMPLEMENTATION STATEMENT

The TxDOT is developing a Rigid Pavement Backcalculation System similar to the MODULUS Flexible Pavement Evaluation System.

The rigid pavement evaluation program described in this report, RMODS 2.0, uses Falling Weight Deflectometer deflection data to backcalculate slab and subgrade rigidities, to calculate load transfer efficiency at the joint, and to determine the presence or absence of voids at the joint. This program provides TxDOT with the capability of structurally evaluating rigid pavements. This capability should be used when rigid pavements are being considered for major maintenance or rehabilitation.

The backcalculation procedures incorporated into RMDOS were developed by Jacob Uzan of the Technion in Israel. They are documented in Research Report 1939-3F.

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

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DISCLAIMER

The contents of this report reflect the views of the authors who are responsible for the opinions, findings, and conclusions presented herein. The contents do not necessarily reflect the official views or policies of the Texas Department of Transportation (TxDOT). This report does not constitute a standard, specification, or regulation, nor is it intended for construction, bidding, or permit purposes. The engineer in charge of the project was Tom Scullion, P.E. #62683.

There is no invention or discovery conceived or reduced to practice in the course 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

The program described in this report, developed by the Texas Transportation Institute for the Texas Department of Transportation, aids engineers in evaluating the structural characteristics of rigid pavements. The program, RMODS 2.0, (Rigid Modulus, version 2) analyzes deflection data collected with the Falling Weight Deflectometer (FWD). Technical details of the calculation procedures are given in companion report 1939-3F. The RMODS program has the following capabilities:

1. backcalculate slab and subgrade rigidities using Hertz or Westergaard models,
2. backcalculate slab and subgrade rigidities using layered elastic theory,
3. calculate Load Transfer Efficiency (LTE) at joints, and
4. detect the presence of subslab voids at joints.

This program requires careful attention during FWD testing to ensure that the deflection data can be used by the RMODS program. Four FWD drops at varying load levels must be recorded at each test location. There must be sensor readings at -305, 0, 305 and 1525 mm (-12, 0, 12 and 60 ins) from the test plate. When calculating LTE, the sensor at -305 mm is placed on one side of the joint, with the load plate and remaining sensors on the other side. Backcalculation of E, ℓ, and k can be performed either at center slab or at a free edge. RMODS 2.0 includes subsystems for data input/data conversion, LTE/VOID calculation, backcalculation, printing and delineation of LTE/VOID or backcalculation results.

CHAPTER 1

INTRODUCTION

1.1 DESCRIPTION OF THE SOFTWARE

The software described in this user's manual was developed to aid pavement engineers in evaluating rigid pavements by determining the following characteristics of rigid pavements:

1. calculate the Load Transfer Efficiency of the pavement at the joint,

2. detect the presence or absence of voids at the joint,

3. backcalculate the modulus of the rigid layer, the radius of relative stiffness, and the modulus of subgrade reaction using the Hertz or Westergaard (center slab loading edge loading) theory, and

4. backcalculate the moduli of the pavement structure using layered elastic theory.

1.2 SYSTEM REQUIREMENTS

The minimum system requirements to run this Rigid Pavement Evaluation System software are as follows:

- IBM compatible microcomputer,

- 640 Kb of RAM,

- DOS operating system (version 3.0 or later),

- math coprocessor chip (80287, 80387, or similar),

- hard disk drive with at least 1 Mb of storage space available,

- an EGA or VGA graphic card with 256 Kb of screen memory and a compatible RGB or monochrome monitor, and

- a dedicated printer, preferably a laser printer.

Use of a 486 or faster microcomputer will minimize program execution time.

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Program designers recommend that users unload all memory resident or TSR device drivers before running this software. Use the DOS "MEM" command to determine the amount of RAM available.

1.3 INSTALLING THE PROGRAM

The TTI Rigid Pavement System Backcalculation (RMODS 2.0) is furnished on a 3 1/2" high density diskette containing 29 files. Follow the steps listed below to install the Rigid Pavement Evaluation System on a microcomputer hard drive. Instructions assume that the distribution diskette is in the "A" floppy disk drive. Program files will be copied to a directory named "RPES" on the "C" hard disk drive.

1. From the root directory of the "C" hard drive make a directory to hold the RPES program files using the following command.

   C:> MD RPES   <ENTER>

2. Make the RPES directory the active directory.

   C:> CD C:\RPES   <ENTER>

3. Copy the files from the distribution diskette to the RPES directory.

   C:RPES> COPY A: *.*   <ENTER>

4. Verify that all 29 files from the distribution diskette were copied to the RPES directory.

   C:RPES> DIR/W   <ENTER>.

You are now ready to run the RMODS program. Make a back-up copy of the distribution diskette in case you need to re-load the program files.

1.4 PROGRAM FILE DESCRIPTION

Following is a brief description of the 29 files that make up the RMODS program.

- RMODS.BAT   Batchfile that starts the RMODS program.

- BEG.COM

  Marks the RAM memory where the screen input command file DISPLAY.COM is loaded in memory.

- DISPLAY.COM

  Transfers input from the screen fields to the program modules.

- END.COM

  Unloads the screen input command file DISPLAY.COM from RAM memory.

- PRINTIT.CHK

  Used by the print program module to determine type of results to print (LT/VOID or backcalculation).

- DEFAULT.DAT

  Contains the data inputs from the last backcalculation run, which are displayed as a starting point for the next backcalculation run.

- HERTZOUT.DAT

  Contains a database of values used in the Hertz backcalculation procedure.

- WESTOUT.DAT

  Contains a database of values used in the Westergaard backcalculation procedure.

- BRUN40.EXE

  Basic run time modules that BRUN45.EXE contain routines linked with the program modules that were written in the Basic program language.

- DELINATR.EXE

  Displays the selected data item in graphical form on the screen and does delineation subsectioning.

- FWDR.EXE

  Converts the FWD field data files to the .OUT deflection file.

- IH10CD.FWD

  Contains sample Falling Weight Deflectometer data, for center slab deflections only. Use this file to create the IH10C.OUT and produce Figures 34 and 35.

- IH10ECD.FWD

  Contains Falling Weight Deflectometer data for edge and corner deflection, starting at corner. Use this file to create the IH10EC.OUT file discussed on pages 14-22 and to calculate k at edge using Westergaard theory as shown in Figure 36.

- INTROR.EXE

  Displays the introductory screen and starts the program by calling the main menu program module.

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- JUCAL.EXE   Performs the Hertz, Westergaard, and Modulus backcalculation.

- LISTOUTR.EXE   Lists all the .OUT files available on the directory.

- LTMOD.EXE   Performs Load Transfer Efficiency and void detection calculation.

- MENUR.EXE   Displays the Main Program menu.

- PRTJUR.EXE   Prints output.

- COURB.FON   Microsoft font files used in the LTMOD.EXE
  HELVB.FON   module to display the deflection bowl on the screen.
  MODERN.FON
  ROMAN.FON
  SCRIPT.FON
  TMCRB.FON

- SCREENSR.LBR   Contains all the menu and data input screens for the RMODS program.

- SCREENST.LBR   Contains menu and data input screens for the Modulus backcalculation program.

- SAVEOUT.OUT   Contains the directory and file names used in the last RMODS program run.

1.5 FILE NAMING CONVENTION

The RMODS program produces several files used by the different program modules. These files have a user defined name and are identified by a file name extension described below.

- .BAC   These files contain the final results of a backcalculation analysis in a form the print module can use for onscreen viewing or for output to a printer. This file is also used by the delineation module for the onscreen delineation analysis display of the backcalculation results.

- .LTV   These files contain the final results of a Load Transfer/Void detection analysis in a form the print module can use for the onscreen summary

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report or to print the Summary Report. It is also used by the delineation module for the onscreen delineation display of the Load Transfer Efficiency results.

- .OUT   These files contain the FWD deflection bowls produced by the automatic data conversion of an FWD field data diskette or manual entry.

1.6 FWD DATA COLLECTION REQUIREMENTS

For this release of the Rigid Modulus System (RMODS) the following data collection requirements are mandatory for all analyses:

Load Levels

Four drops at each test point correspond to four different load levels. This is a standard set up for TxDOT with the levels corresponding to approximately 6, 9, 11 and 14 kips. Four drops are required so that the National Cooperative Highway Research Program (NCHRP) void detection algorithm can be used.

Data Collection Sequence

Collect data from either the center of the lane or from the edge in a single pass along the highway. For center lane data the user can collect center slab only, down stream joint only, or both sets of data, maintaining a consistent format throughout. It is not necessary to test every slab; however, the same test sequence must be maintained throughout the job, (for example: center slab -joint - center slab - joint - center slab -...).

For data collected from the pavement edge, choose center of free edge only, down stream corner only, or both.

Do not mix center of the lane with edge data in the same .FWD file. Instead, create separate files.

Note the starting location of the first set of drops. RMODS requires it as an input. For example, was the first drop made in the center of the slab or at the joint?

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Sensor Location

For the load transfer and void detection procedures RMODS requires FWD sensors to be placed at the following locations -305, 0, 305 and 1525 mm (-12, 0, 12 and 60 ins). The other three sensors can be anywhere, although 610, 915 and 1829 mm (24, 36 and 72 ins) work well. RMODS reads the sensor locations from line 3 of the .FWD data file, ensure that these are entered correctly in the field - the program does permit editing the fields prior to processing.

Joint and Corner Testing

When performing FWD testing on joints or corners only the downstream deflection bowl is taken. The load plate and six sensors are placed downstream of the joint. The sensor at -305 mm (-12 ins) is placed upstream of the joint. The joint should be midway (to the nearest 25 mm) between the loading plate and upstream sensor.

1.7 TYPICAL .FWD FILES

Two typical .FWD data files containing raw FWD data are included on the distribution diskette. These files (IH10CD.FWD and IH10ECD.FWD) produce the output reports given in this User's Manual.

The sensor locations are 0, 12, 24, -12, 48, 60 and 72 inches in IH10CD.FWD, these are correctly entered in the header information. In the other file, IH10ECD.FWD, sensor locations are not correct and must be corrected to those given above.

CHAPTER 2

RUNNING THE PROGRAM

2.1 STARTING THE PROGRAM

If you did not add the Rigid Pavement Backcalculation System directory to your path statement, change to that directory by typing for example the following command.

C:> CD C:\RPES <ENTER>

Once you are in the required directory, type RMODS <ENTER> to run the program. The introductory screen will be displayed until the user presses a key to continue (Figure 1). The next screen lists the memory requirements for the RMODS program (Figure 2). Press any key and the MAIN PROGRAM MENU screen will be appear (Figure 3).

If the system displays a message that it cannot execute a particular module, this probably means that there is not enough RAM memory for the RMODS program. Exit the program and delete device drivers and memory resident software until there is enough RAM memory for the RMODS program to run, then restart the RMODS program again. To select options from the menu screens, use the arrow keys to highlight your selection and then press <ENTER>.

2.2 MAIN PROGRAM MENU OPTIONS

The Main Program Menu screen allows the user to select any of the three calculation options that make up the RMOD 2.0 program. Use the up/down arrow keys to highlight the menu selection and press <ENTER>.

The following calculation options are available from the Main Program menu.

- Input Data Conversion Options: This program module creates the .OUT file which contains the FWD deflection bowls used by the RMODS program. Two options are available for creating the .OUT file:

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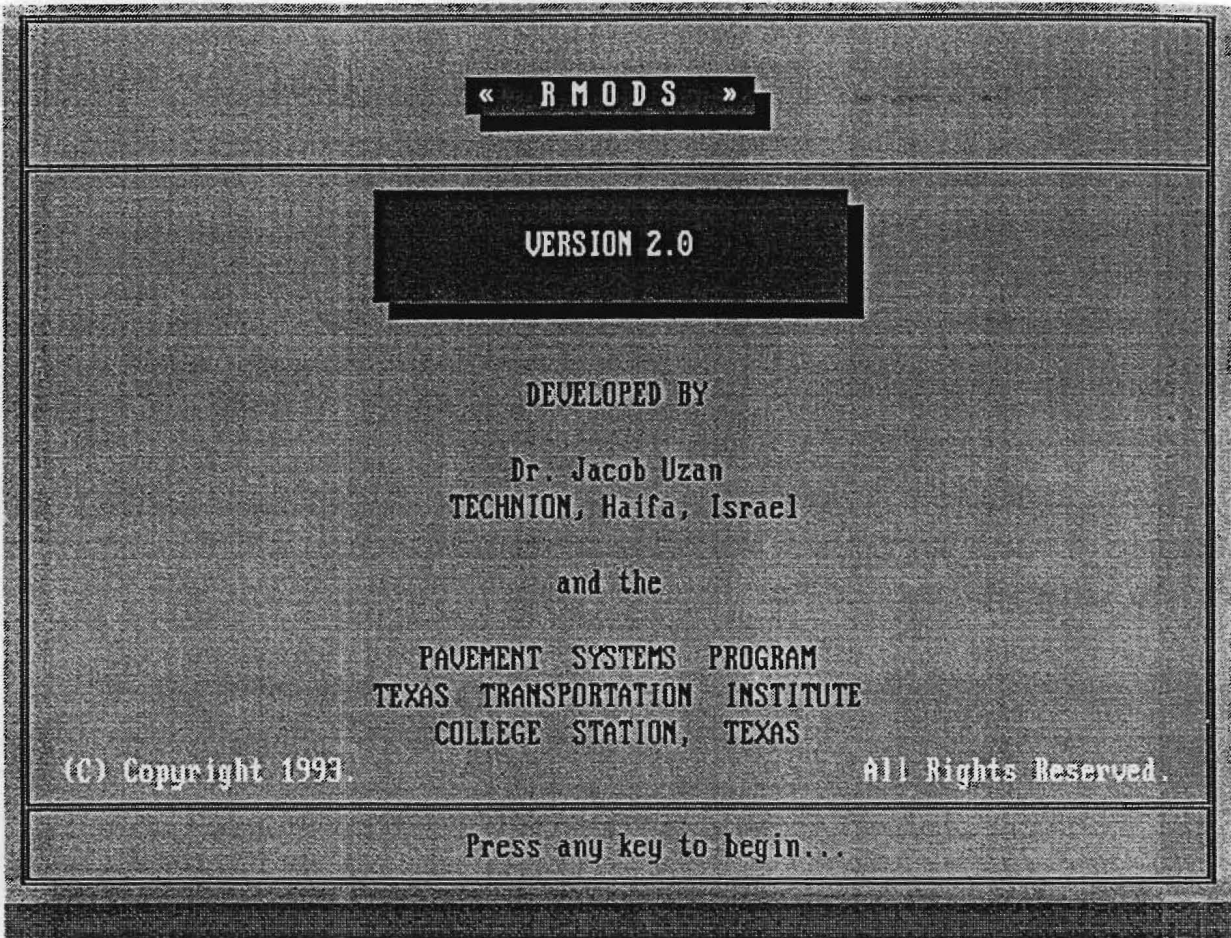
Figure 1. Introductory Screen.

```
              «  R M O D S  »

                  VERSION 2.0


              NOTE!  NOTE!  NOTE!
      This program requires a minimum of 500K memory
      to execute all the options listed on the menus.
      If you do not have sufficient memory, exit the
      program and delete any device drivers or memory
      resident software that's not needed to run the
      program.  Use the DOS "MEM" command to check on
      the amount of memory available.  See System Re-
      quirements, Section 1.2, page 2, User's Manual.


                  Press any key to begin.
```

Figure 2. Memory Requirement Screen.
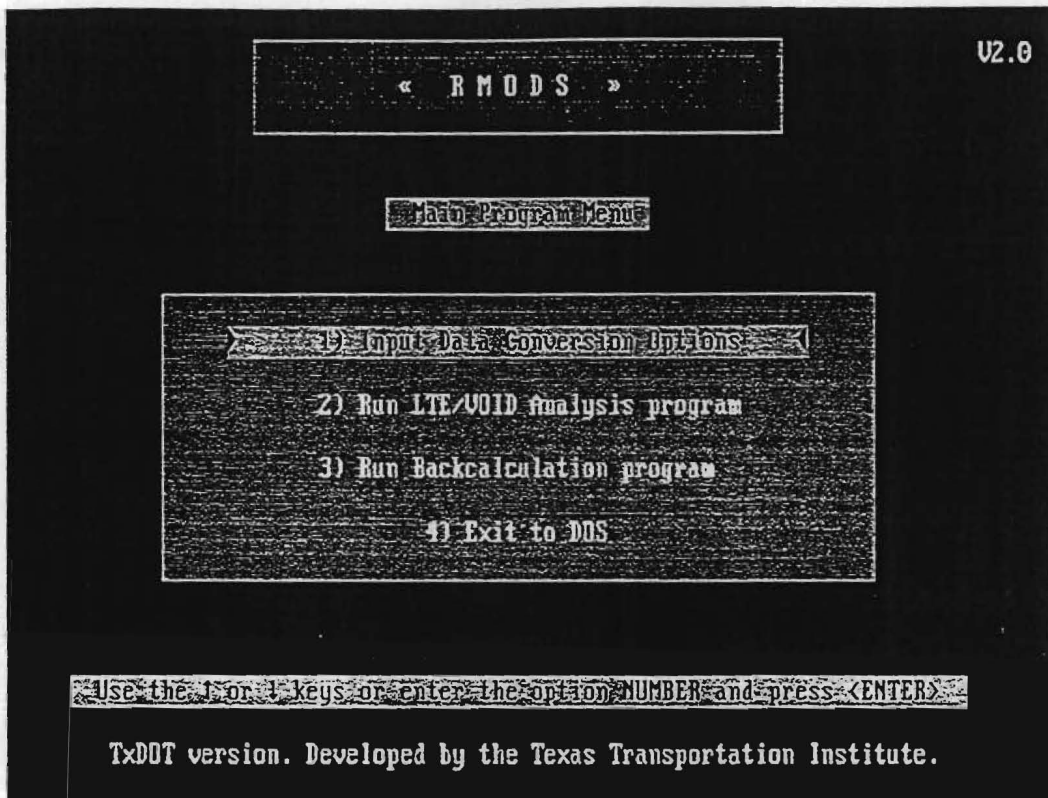
Figure 3. Main Program Menu.

1. Automatic conversion of the Dynatest FWD field diskette.
2. Manual input of the FWD deflection bowl data.

- Run LTE/VOID Analysis program: This option uses the .OUT file created from menu option one above to calculate the Load Transfer Efficiency at the joint and to detect voids at the joint.

- Run Backcalculation Program: This option uses the .OUT file created by menu option one to perform the Hertz or Westergaard backcalculation for the modulus of the rigid layer, the radius of relative stiffness, and the modulus of subgrade reaction, or to do backcalculation of the moduli of the pavement structure layers using layered elastic theory.

- Exit to DOS: Select this menu option to end the current RMODS program run.

CHAPTER 3

OPTION ONE - INPUT DATA CONVERSION OPTIONS

The first screen for the input data conversion option is shown in Figure 4. To get the FWD deflection data in a form useable by the RMODS program, the user has two options. The first option is the automatic conversion of the Dynatest FWD field data diskette. The second option permits the user to manually input the FWD deflection bowl 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 RMODS program. A program was written to extract the specific data needed by the RMODS program from the FWD field diskette. This program extracts the TxDOT district number, the TxDOT county number, highway name, station or mile-point location, lane, FWD load level, and the FWD deflection readings (up to seven) for each FWD test drop. The conversion program stores this information in a file with the .OUT extension in the format required by the program modules for Load Transfer/Void and backcalculations. These .OUT files are the actual input to the RMODS program and are referred to as the INPUT data files. Four FWD drops at each station, mile-point, or location are required for the RMODS program and each of the four FWD drops is converted and stored in the .OUT file.

To do the automatic FWD conversion, select option one from the Input Data Options menu and press <ENTER>. The Falling Weight Deflectometer Data Conversion Program Input screen will be displayed (Figure 5). There are three fields of required information that the user must provide before the FWD conversion program will run. These are:

- DRIVE AND DIRECTORY(S) WHERE .FWD FILE RESIDES: This allows the user to convert FWD data files that are stored on a diskette drive or hard disk directory other than the directory where the RMODS program is installed. Enter

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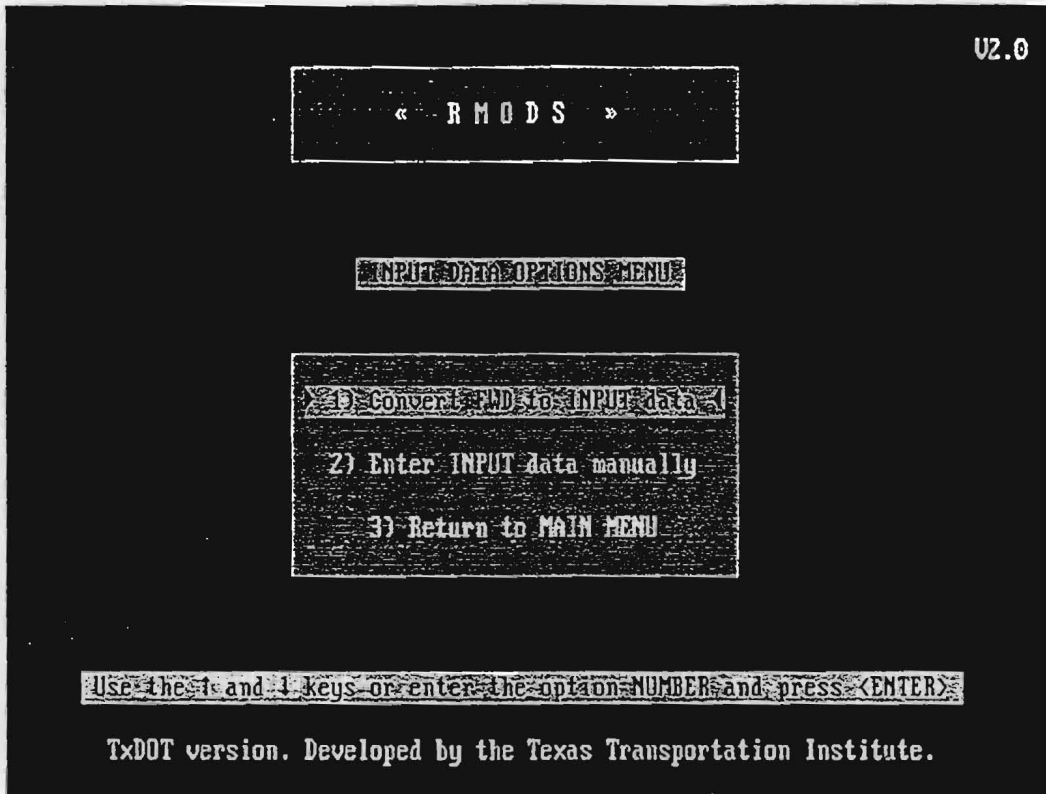
Figure 4. Input Data Options Menu.

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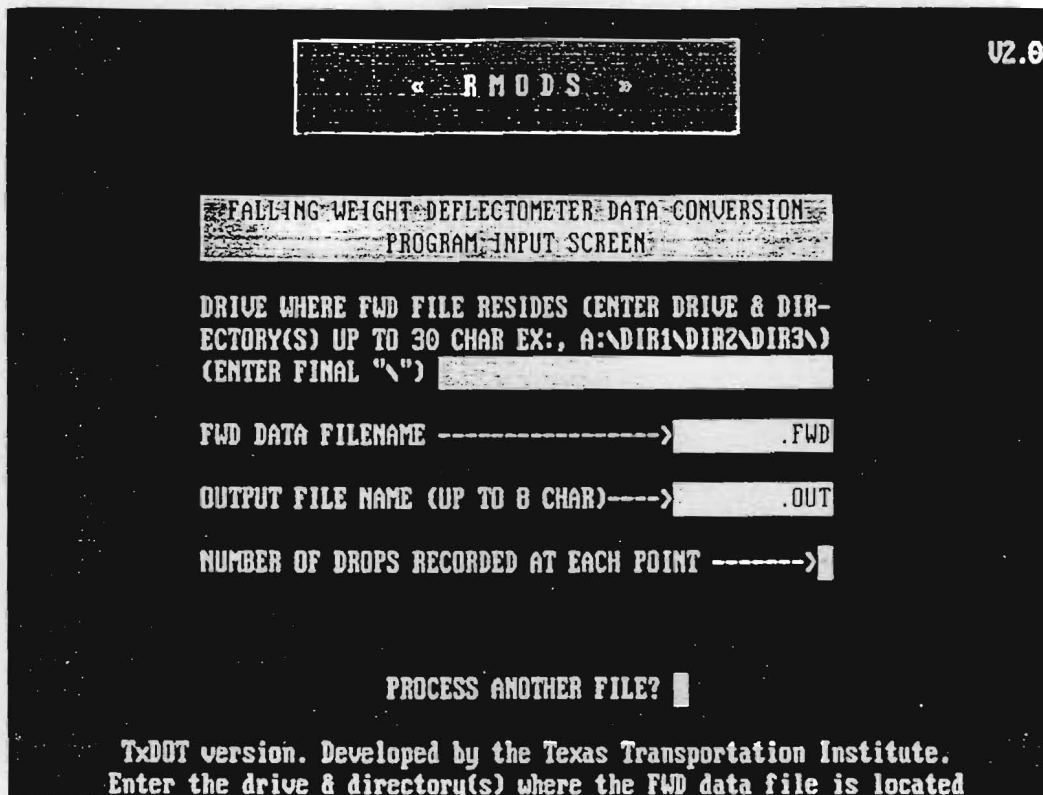
Figure 5. Falling Weight Deflectometer Data.

the diskette drive and directory name or the hard disk directory(s) name, up to thirty characters including the trailing backslash (\), and press <ENTER>. Note: the name that is entered in this field will 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 run, depending on where the .FWD or .OUT files are located. If the .FWD or .OUT files are located in the current directory, leave the directory field blank.

- 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 entered above, press the <F1> 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 be automatically appended to this name. This name will also be the root filename for the .LTV and .BAC files that are created for this run.

At this point a window will overlay the screen to prompt the user to select the FWD test starting location (Figure 6). A correct FWD test starting location is vital to ensure accurate conversion. The four possible starting locations for the FWD test are:

1. middle of the slab,
2. edge of the slab,
3. downstream joint, middle of slab, and
4. downstream corner, edge of slab.

Indicate the FWD test starting location by entering the correct number and pressing <ENTER>.

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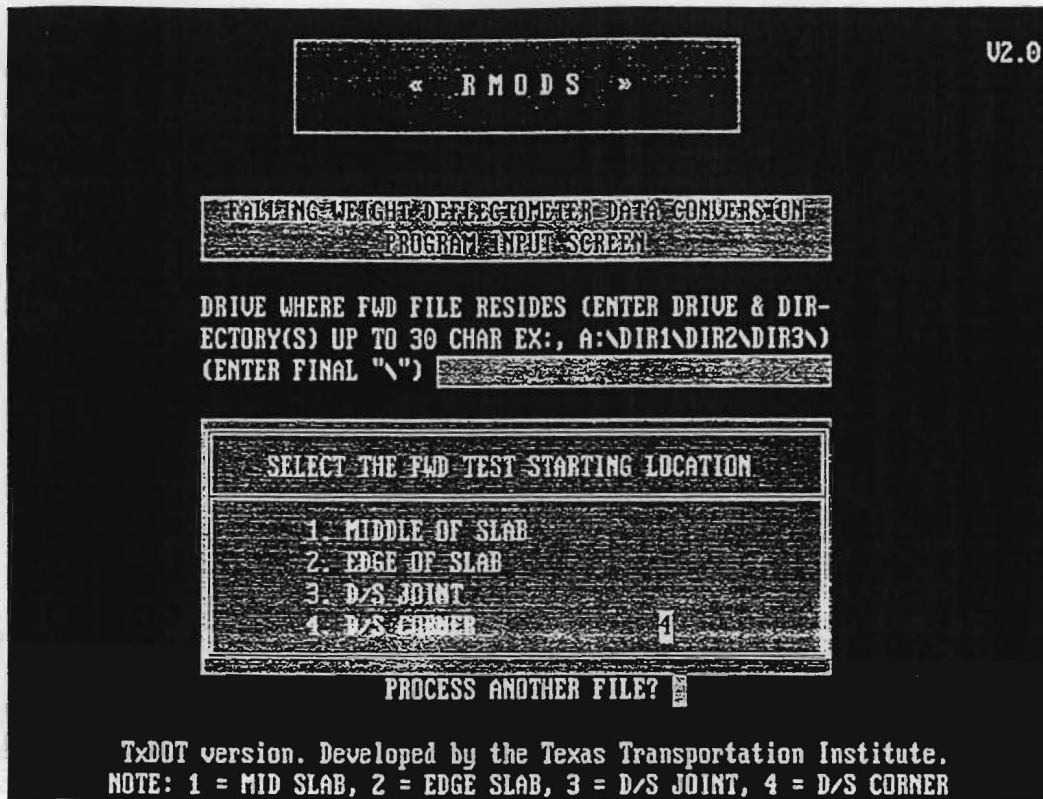
Figure 6. FWD Test Starting Location.

A second window will overlay the screen to prompt the user to indicate the sequence of the FWD test drops. If the user entered a 2 or 4 on the previous screen (to indicate the FWD starting location was at the edge or downstream corner of the slab), the edge slab test location window will be displayed (Figure 7). Specify the sequence of the FWD tests on the remaining slabs as:

1. edge only,
2. downstream corner only, or
3. edge and corner.

If the user entered a 1 or 3 on the previous screen (to indicate the FWD starting location was at the middle of the slab or the downstream joint of the slab), the center slab test location window will be displayed (Figure 8). Specify the sequence of the FWD test on the remaining slabs as:

1. center slab drop only,
2. downstream joint drop only, and
3. center slab and downstream joint drops.

The FWD sensor spacing window will now be displayed (Figure 9). This gives the user the opportunity to verify the FWD sensor spacings and to indicate which of the FWD sensors was placed in front of the FWD load plate. Indicate the FWD sensor that was placed in front of the FWD load plate by entering -12.0 as the location for this sensor. Note that for the load transfer and void detection calculations, there must be sensor readings at -305, 0, 305 and 1525 mm (-12.0, 0.0, 12.0, and 60.0 ins). The remaining sensor spacings are not critical. Use the left/right arrow keys to move to a sensor spacing field to enter or correct a sensor spacing and press <ENTER> when the sensor spacings are correctly entered.

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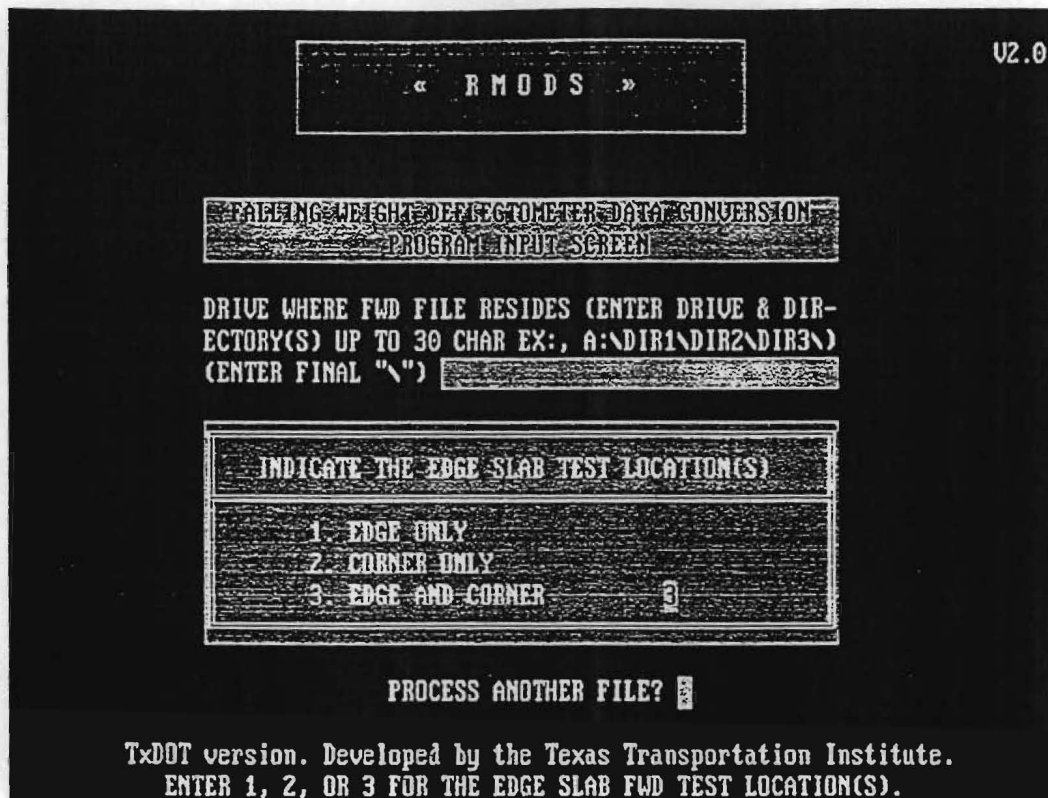
Figure 7. FWD Edge Slab Test Location.
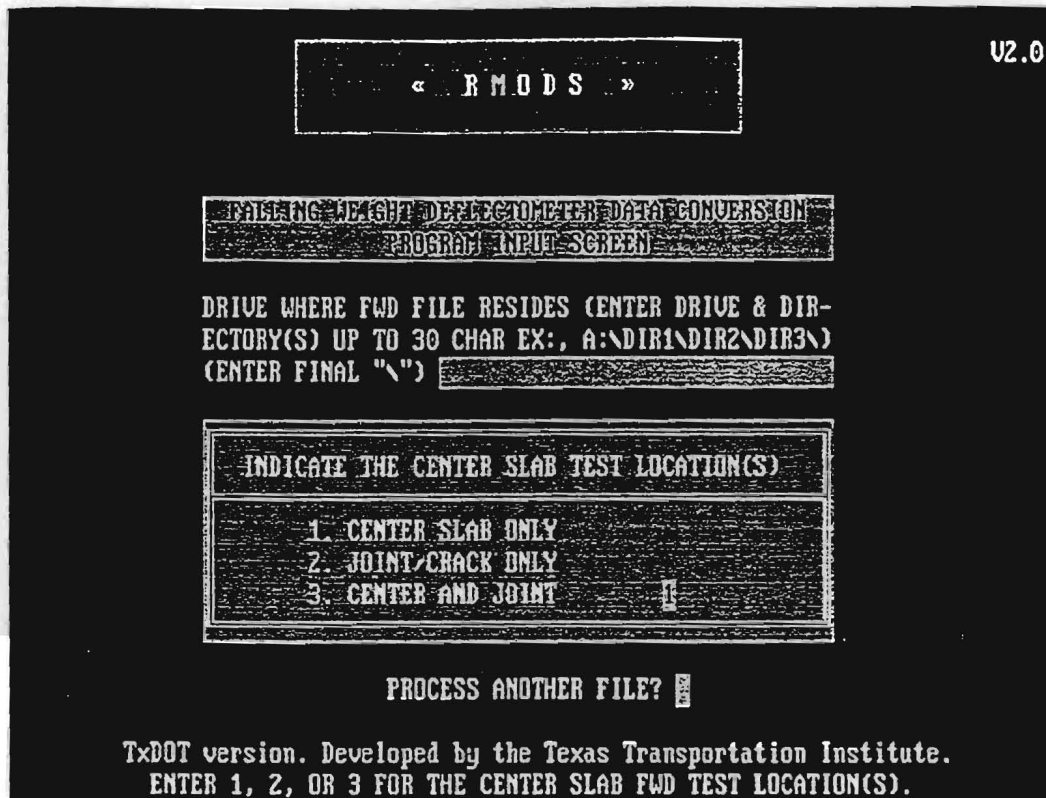
Figure 8. FWD Center Slab Test Location.
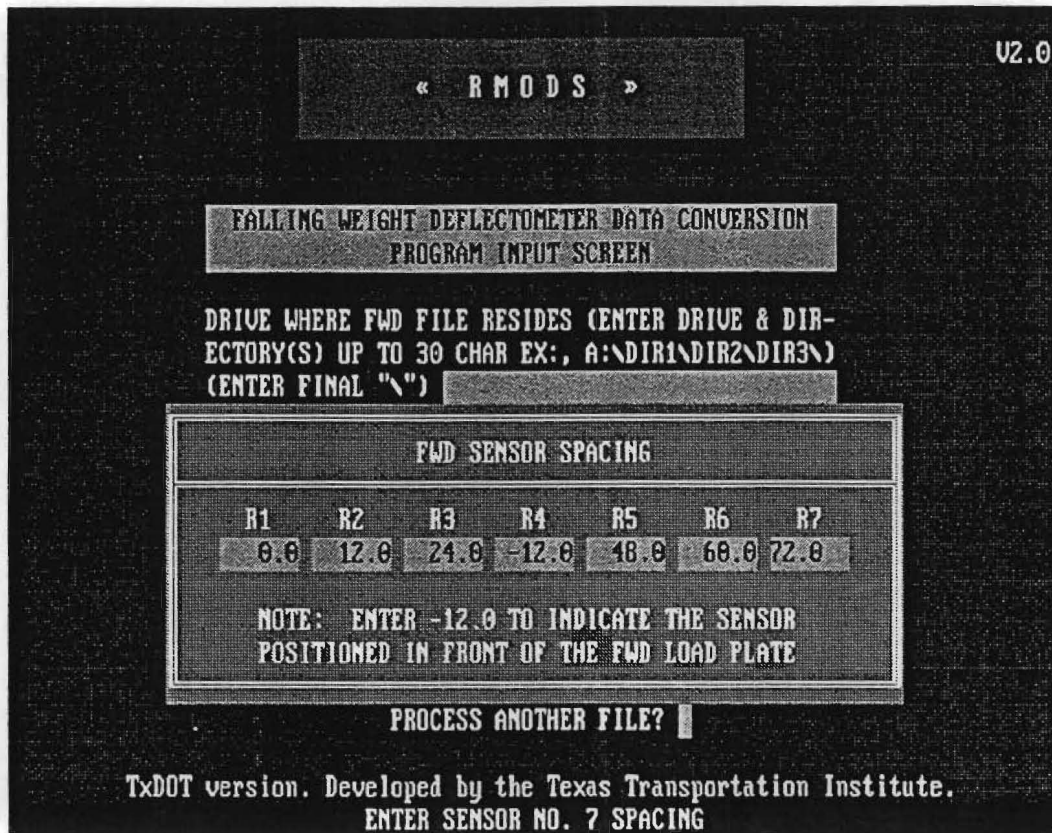
Figure 9. FWD Sensor Spacing.

After the FWD test location, test sequence, and sensor spacings are entered, the Program Input Screen will be restored and the number of drops recorded at each point will be displayed (Figure 10). For this version of RMODS four deflection drops must be recorded at each test point. The number 4 must be displayed otherwise the program will not execute correctly.

The .OUT filename will be displayed with the number of points (FWD tests) that were in the file. This is a way that the user can quickly tell that the .FWD field data diskette file was converted correctly.

The last field of the Program Input Screen is a prompt to convert another .FWD file by entering "Y", or to quit the FWD conversion program by entering "N" and pressing <ENTER>.

For each data input field there are two ways to correct mis-entered data input values. Press the "ESC" key to return to the beginning of a data field to correct erroneous data. Press the "HOME" key to get back to the Main Program menu from any input field to re-start the program if the user gets lost in the data input process. These escape keys are valid for the remaining data input screens as well. 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.

3.2 MANUAL INPUT OF THE DEFLECTION BOWL DATA

To enter the FWD deflection bowl data manually, select option two from the Input Data Options Menu (Figure 11).

The FWD Manual Input screen (Figure 12) will ask for the following data values to create the .OUT file.

- OUTPUT FILE NAME: Enter the full file name, including the disk drive and directory(s) (up to thirty-eight alphanumeric characters) where the .OUT will be stored. The .OUT file extension will be automatically appended to the name entered above. If the .OUT file will be stored in the current directory, it is only necessary to type in a file name (up to eight alphanumeric characters) and press <ENTER>.

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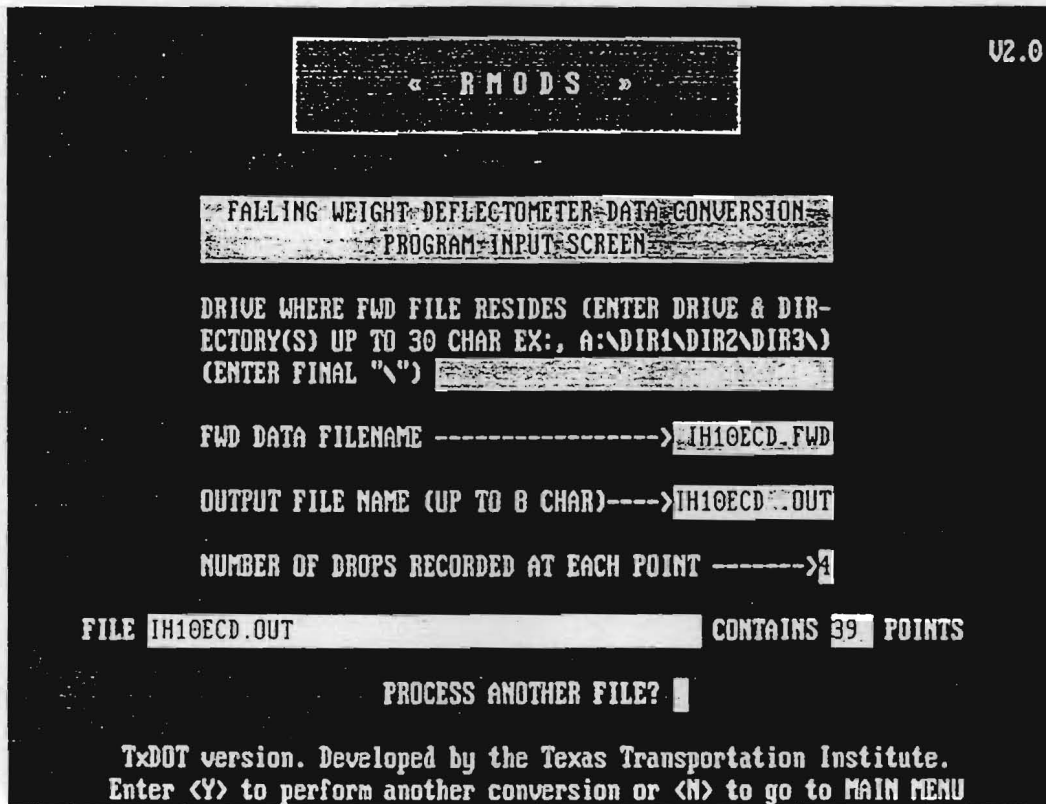
Figure 10. Number of Deflection Bowls.
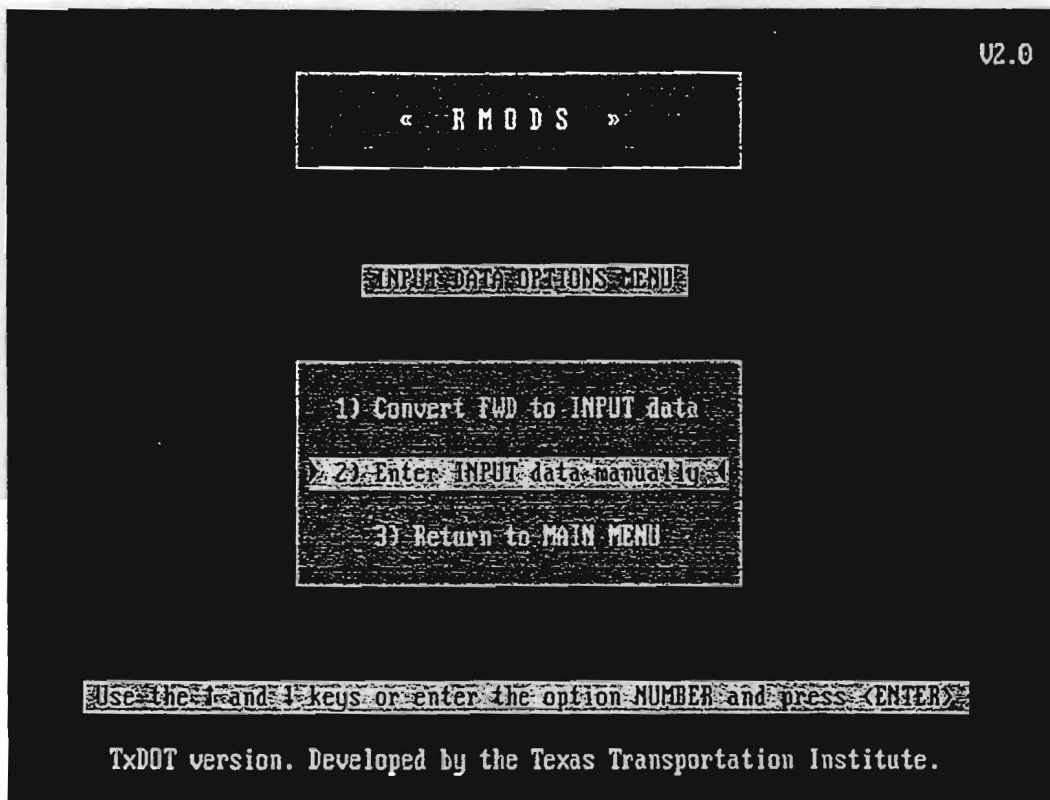
Figure 11. Select Manual Data Input.

Figure 12. Falling Weight Deflectometer Manual Input Screen.

- NUMBER OF BOWLS TO BE ENTERED: This is the total number of deflection bowls to be entered manually. Note that all four FWD drops recorded at each test location are used by the RMODS program. If only one FWD test is to be entered manually, then the number of bowls to be entered would be four.

- DISTRICT: Enter the TxDOT district number in this field (two digits max).

- COUNTY: Enter the TxDOT county number in this field (three digits max).

- HIGHWAY: Enter the TxDOT highway prefix number (six alpha-numeric characters max).

At this point a window will overlay the screen for the user to enter the following data (Figure 13):

1. number of FWD sensors (usually seven),
2. the radius of the FWD load plate, in millimeters, and
3. the FWD sensor spacing.

The sensor that was placed in front of the load plate should be designated by entering -12.0 as the location for that sensor. As noted earlier, the load transfer and void calculations require sensor readings at -305, 0, 305 and 1525 mm (-12.0, 0.0, 12.0, and 60.0 ins). The remaining sensor spacings are not critical. After entering the sensor spacings, the Manual Input screen will be restored, asking for further information.

- ENTER INFORMATION FOR BOWL NUMBER: Enter the number of the deflection bowl being entered.

- TEST LOCATION CODE: Use the following code numbers to indicate the location of the FWD test for which data is being entered:

  01 - Center of Slab
  3B - Downstream Joint
  04 - Edge of Slab
  5B - Downstream Corner

Figure 13. Number of Sensors, Load Plate Radius, Sensor Spacing.

- STATION OR MILEPOST: Enter the station or mile-post where the deflection bowl was measured (using zero to three decimal places).

- LANE: Enter the lane in which the deflection bowl was measured (L or R usually).

- LOAD: Enter the FWD load in pounds for the deflection test drop (up to six digits).

- W1 to W7: Enter the deflection in miles at each of the FWD sensors (one through seven) for the deflection test.

- VALIDATE: Carefully check the data in the fields. If everything is correct type "Y" to validate the entries. To change any of the entries, type "N" and the cursor will be repositioned at the STATION OR MILE-POST field. Press <ENTER> to move 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 entries.

Note that as each deflection bowl is entered and validated, the ENTER INFORMATION FOR BOWL NUMBER field is automatically up-dated and the cursor is positioned at the TEST LOCATION CODE field for each subsequent deflection bowl. Note also that 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 available as an escape back to the Main Program menu if the user elects to exit the manual input program before entering all the data fields.

CHAPTER 4

OPTION TWO - RUN LTE/VOID ANALYSIS PROGRAM

Option two of the Main Program Menu allows the user to run the Load Transfer Efficiency/Void Analysis program (Figure 14). The input to this program is the .OUT file previously created, which contains FWD deflection bowls measured at the downstream joint or downstream corner of the slab. If the .OUT file does not have deflection bowl data with "3B" or "5B" in columns one and two, then the .OUT file cannot be used for the LTE/VOID analysis. All four drops at each FWD test location must be recorded in the .OUT file, and there must be a sensor reading at -305, 0, 305, 1525 mm (-12.0, 0.0, 12.0, and 60.0 ins) in order to make the load transfer and void detection calculations.

Select option two from the Main Program Menu to run the LTE/VOID Analysis program. The INPUT DATA FILENAME screen (Figure 15) will ask for the following information.

- DRIVE WHERE .OUT FILE RESIDES: The same drive and directory(s) entered during the data conversion will be displayed. If no drive is shown, enter the drive and directory(s) where the .OUT file for this program run is located (up to thirty alphanumeric characters). If the .OUT file is in the current directory, leave this field blank and press <ENTER> to go to the next field.

- NAME OF THE .OUT FILE: Enter the name of the input deflection data file (up to eight alphanumeric characters). The .OUT extension will be appended automatically. To see a list of all the .OUT files available in the directory entered above, press the <F1> key. Use the up/down arrow keys to select the .OUT file to use and press <ENTER>.

A message screen will tell the user that the Load Transfer/Void program is running (Figure 16). If the message "CHECK SENSOR SPACING. YOU MUST HAVE A SENSOR AT -12, 0, 12 AND 60 INCHES" is displayed on the screen, exit the program and correct the .OUT file, then rerun the program.

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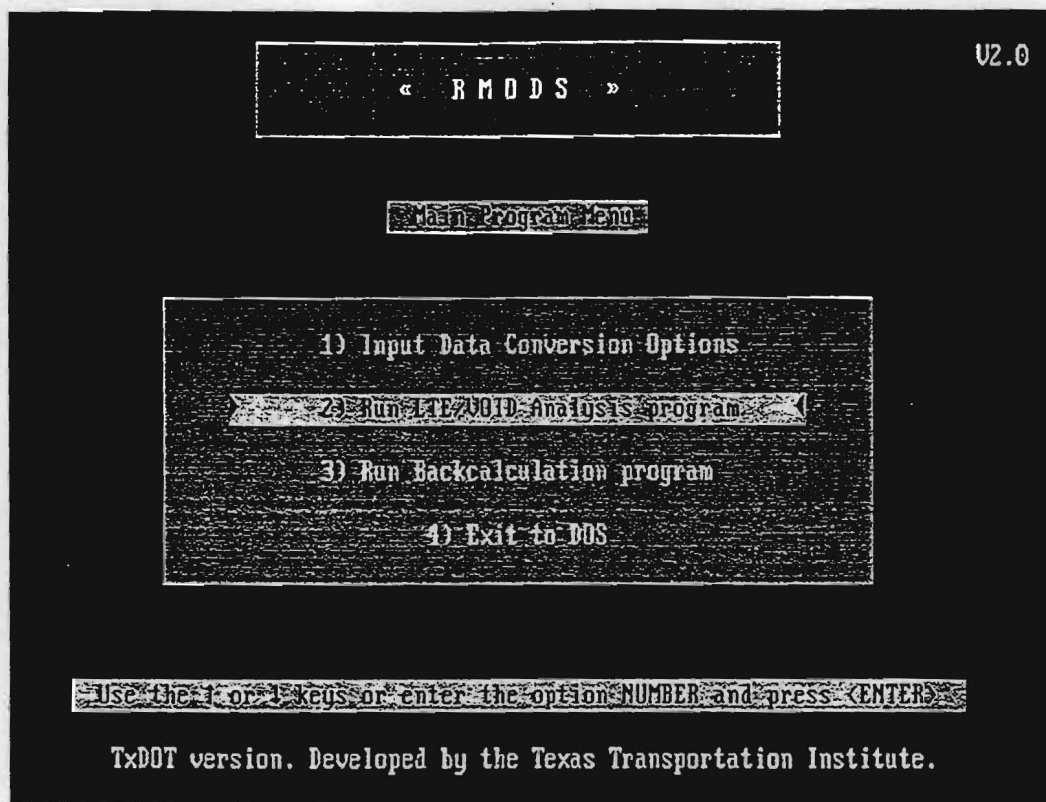
Figure 14. Select LTE/VOID Analysis.

Figure 15. Load Transfer Input/Output File Information.
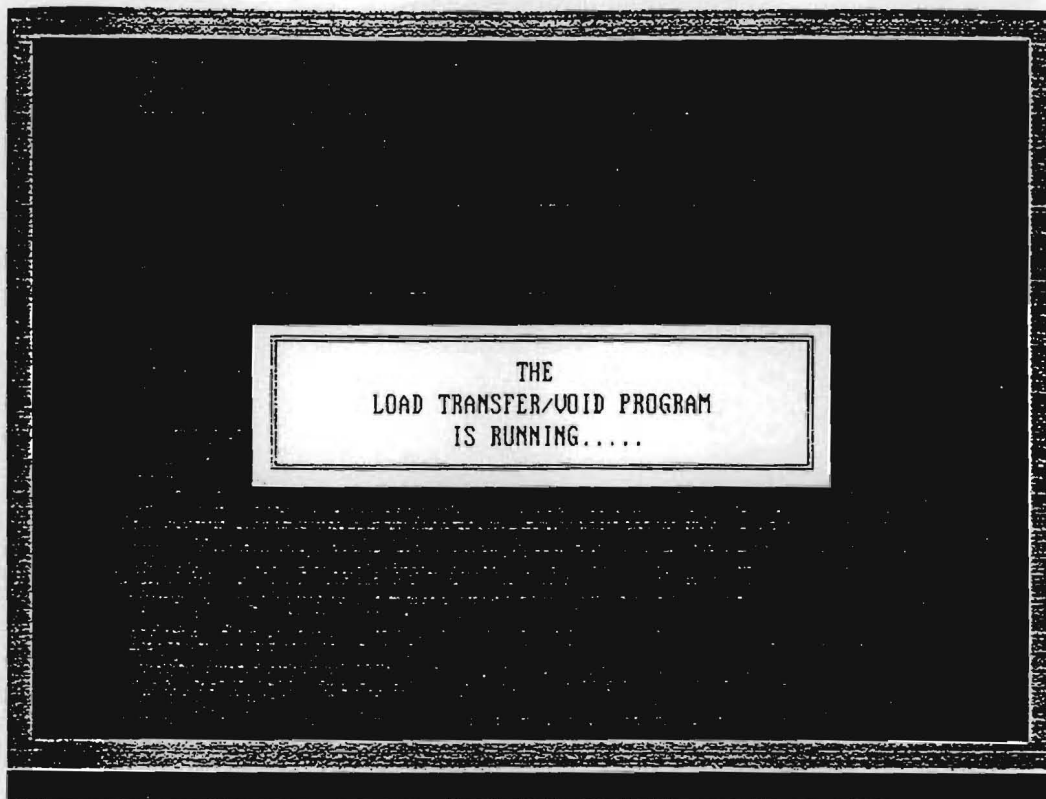
Figure 16. LTE/VOID Program Running.

When the LTE/VOID program has processed all the deflection bowl data in the .OUT file, the Load Transfer OUTPUT OPTIONS menu will appear (Figure 17). There are five options on the menu:

1. view summary results on the screen,

2. print load transfer/void results,

3. view bowl by bowl plot on the screen,

4. plot deflection and/or LT values, and

5. return to main menu.

OPTION ONE

To see a summary of the LTE/VOID results from the last program, choose option one. Figure 18 shows a sample summary, which includes the station, location, LTE value, the CTR void calculation results, and the NCHRP void calculation results for each deflection bowl. Press <ENTER> until all the results have been displayed on the screen.

OPTION TWO

Option two prints a copy of the LTE/VOID results from the last program run. The "Printing Summary Report" screen will be displayed while the results are being printed (Figure 19). The LTE/VOID Summary Report contains the station, location, FWD load, the deflection readings W1 to W7, the LTE value, the CTR void calculation results, and the NCHRP void calculation results for each deflection bowl (Figure 20). If the output is cropped on the right margin, select compressed mode from the laser printer font menu and print the results again.

OPTION THREE

The user can view a plot of each deflection bowl on the screen by choosing option three from the OUTPUT OPTIONS MENU (Figure 21). A summary of the LTE and void calculation results appears below the plot.

```
                                              V2.0
    ┌─────────────────────────────────┐
    │        « R M O D S »            │
    └─────────────────────────────────┘

           Load Transfer
         Output Options Menu

  ┌──────────────────────────────────────┐
  │  1) View Summary Results on the Screen │
  │                                        │
  │  2) Print LOAD TRANSFER/VOID Results   │
  │                                        │
  │  3) View Bowl by Bowl Plot on the Screen│
  │                                        │
  │  4) Plot Deflection and/or LT Values   │
  │                                        │
  │  5) Return to Main Menu                │
  └──────────────────────────────────────┘

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

    TxDOT version. Developed by the Texas Transportation Institute.
```
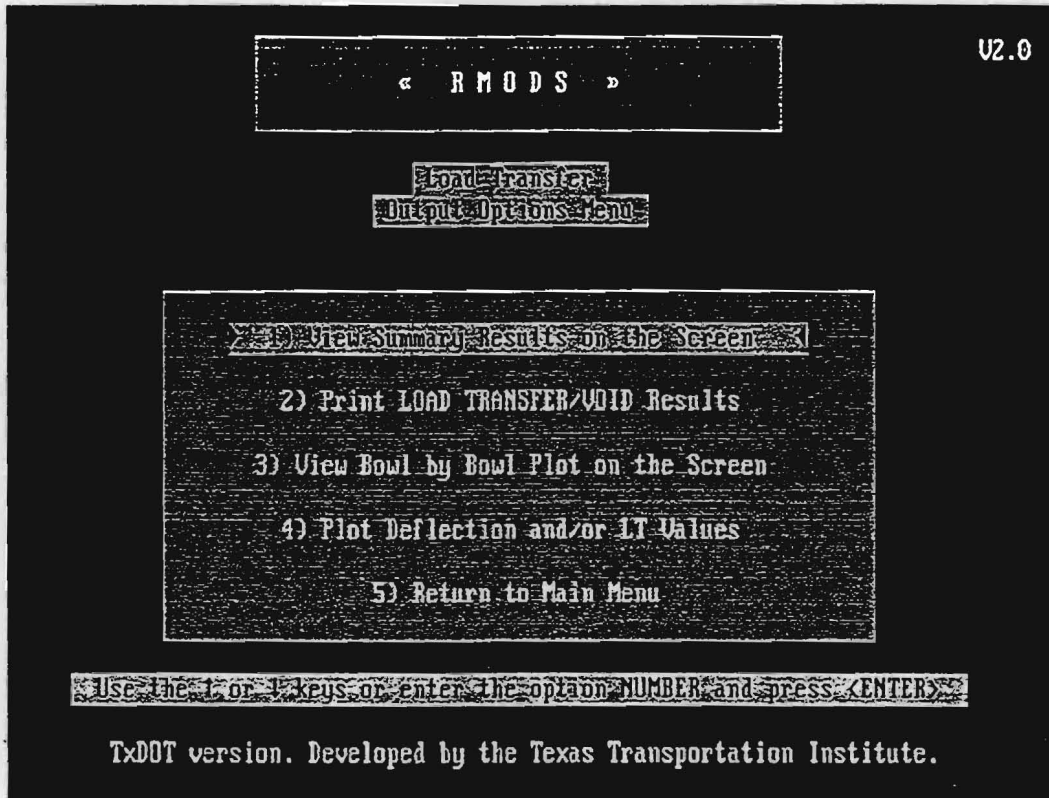
Figure 17. Load Transfer Output Options Menu.

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```
TTI RIGID MODULUS LOAD TRANSFER   ANALYSIS SYSTEM (SUMMARY REPORT)  (Ver 2.0)
---------------------------------------------------------------------------
  District: 20              County: 181         Highway/Road: IH0010
---------------------------------------------------------------------------

                        **** LOAD TRANSFER % ****   ** VOID DETECTION **
                        ****** C T R ******   CTR   **** NCHRP ****
   Station  * LOCATION *  LTE   DDR    QD      MD   VOID   INT SLOPE VOID
---------------------------------------------------------------------------
     3.000   D/S Corner  14.2  16.2   19.3   66.3  YES    0.9  0.7   NO
    17.000   D/S Corner  17.3  19.7   19.1   65.9  YES    1.6  0.7   NO
    32.000   D/S Corner  18.5  21.2   18.6   66.6  YES    3.5  0.8   YES
    48.000   D/S Corner  19.8  22.6   20.1   65.7  YES    2.5  0.7   YES
    63.000   D/S Corner  17.8  20.3   19.3   64.9  YES    1.5  0.6   NO
    78.000   D/S Corner  20.5  23.1   17.3   69.6  NO    -0.9  0.6   NO
    93.000   D/S Corner  15.7  17.8   19.4   65.9  YES    1.3  0.6   NO
   110.000   D/S Corner  21.0  23.9   16.0   70.0  NO     3.2  0.9   YES
   126.000   D/S Corner  21.9  24.8   14.3   70.8  NO     0.8  0.8   NO
   142.000   D/S Corner  15.6  17.9   17.3   68.0  NO     0.2  0.6   NO
---------------------------------------------------------------------------
  Mean:                  18.2  20.7   18.1   67.4         1.5  0.7
  Std. Dev:               2.6   2.9    1.8    2.1         1.3  0.1
  V Cof(%):              14.1  13.8   10.1    3.1        91.2 16.1
---------------------------------------------------------------------------
```

Figure 18. Screen Display of LTE/VOID Summary Report.
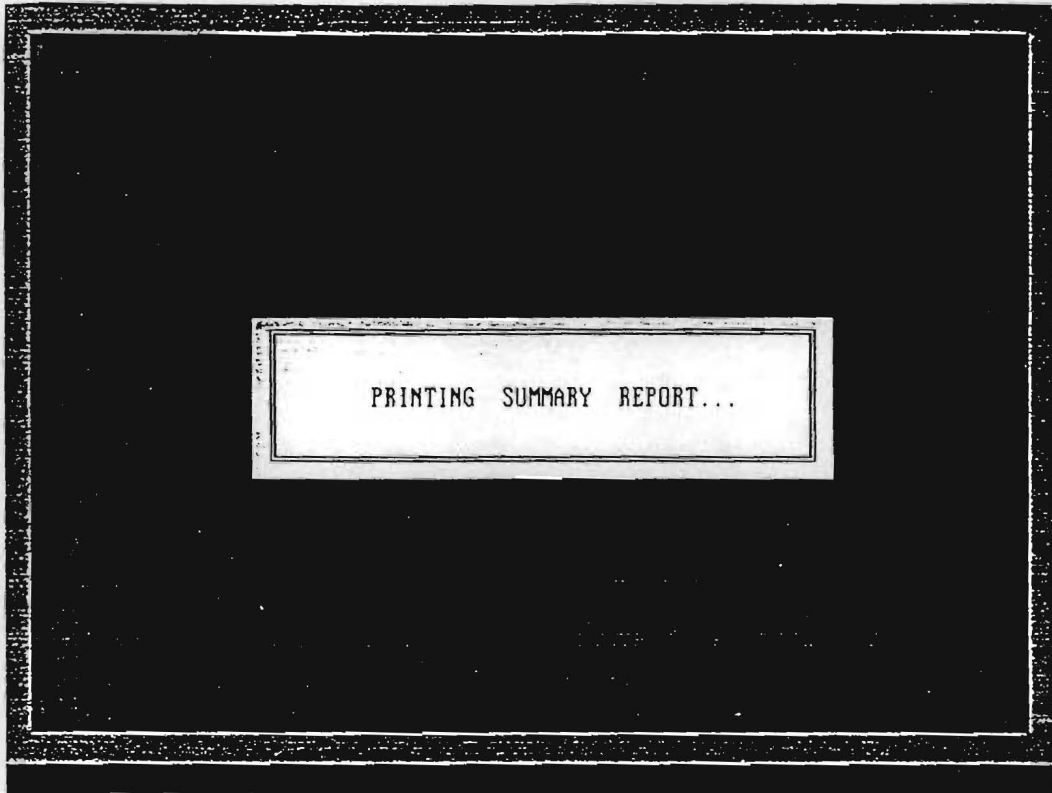
Figure 19. Printing Summary Report.

```
---------------------------------------------------------------------------------------------------------------
Page: 1                      TTI  RIGID MODULUS LOAD TRANSFER/VOID DETECTION ANALYSIS  SYSTEM  (SUMMARY REPORT)      (Version 2.0)
---------------------------------------------------------------------------------------------------------------

District: 20                          County: 181                        Highway/Road:  IH0010

---------------------------------------------------------------------------------------------------------------
```

			*** Measured Deflection, (mils)/Sensor Sp. (in) ***							**** LOAD TRANSFER % ****			** VOID DETECTION **			
	Load Plate	Load	W1	W2	W3	W4	W5	W6	W7		****** C T R ******		CTR	**** NCHRP ****		
Station	* Location *	(lbs)	0.00	12.00	24.00	-12.00	48.00	60.00	72.00	LTE	DDR	QD	NO	Void	Int	Slope	Void
3.000	D/S Corner	9,947	15.92	13.29	10.69	2.15	6.43	4.90	3.80	14.2	16.2	19.3	66.3	YES	0.9	0.7	NO
17.000	D/S Corner	9,701	15.61	12.93	10.27	2.55	6.07	4.63	3.42	17.3	19.7	19.1	65.9	YES	1.6	0.7	NO
32.000	D/S Corner	9,149	15.58	12.98	10.55	2.75	6.52	4.89	3.86	18.5	21.2	18.6	66.6	YES	3.5	0.8	YES
48.000	D/S Corner	9,002	16.57	13.86	11.12	3.13	6.62	5.10	3.98	19.8	22.6	20.1	65.7	YES	2.5	0.7	YES
63.000	D/S Corner	9,145	16.38	13.57	11.04	2.76	6.72	5.16	4.05	17.8	20.3	19.3	64.9	YES	1.5	0.6	NO
78.000	D/S Corner	8,986	14.30	12.07	9.74	2.79	5.91	4.60	3.59	20.5	23.1	17.3	69.6	NO	-0.9	0.6	NO
93.000	D/S Corner	8,966	16.13	13.44	10.76	2.39	6.54	4.98	3.93	15.7	17.8	19.4	65.9	YES	1.3	0.6	NO
110.000	D/S Corner	9,224	12.93	10.75	8.65	2.57	5.07	3.86	2.98	21.0	23.9	16.0	70.0	NO	3.2	0.9	YES
126.000	D/S Corner	9,109	12.07	9.98	8.08	2.48	4.91	3.85	2.99	21.9	24.8	14.3	70.8	NO	0.8	0.8	NO
142.000	D/S Corner	8,998	14.65	12.22	9.95	2.19	6.14	4.75	3.64	15.6	17.9	17.3	68.0	NO	0.2	0.6	NO
156.000	D/S Corner	9,335	12.50	10.59	8.67	2.50	5.41	4.17	3.30	21.2	23.6	15.0	72.3	NO	1.5	0.9	NO
172.000	D/S Corner	9,057	11.86	9.97	8.14	3.33	4.97	3.94	3.13	29.4	33.4	14.1	72.5	NO	2.4	1.0	YES
188.000	D/S Corner	9,022	11.66	9.85	7.93	3.87	5.02	3.88	3.00	34.5	39.3	14.0	73.2	NO	-1.4	0.7	NO
203.000	D/S Corner	8,958	9.47	8.05	6.71	6.66	4.29	3.40	2.84	72.7	82.7	11.0	76.7	NO	0.4	1.0	NO
218.000	D/S Corner	8,938	10.74	9.02	7.38	3.87	4.68	3.65	2.87	38.1	42.9	12.6	74.0	NO	0.6	0.9	NO
235.000	D/S Corner	8,835	10.93	9.00	7.19	3.09	4.35	3.32	2.61	30.1	34.3	13.3	72.2	NO	0.5	0.8	NO
249.000	D/S Corner	9,006	8.77	7.18	5.80	3.30	3.48	2.69	2.09	40.3	46.0	10.6	75.2	NO	1.1	1.2	NO
267.000	D/S Corner	8,847	7.50	6.08	4.93	4.76	2.95	2.27	1.79	66.6	78.3	9.0	76.7	NO	0.4	1.3	NO
281.000	D/S Corner	9,181	10.39	8.43	6.66	2.65	3.91	2.94	2.33	27.3	31.4	12.9	71.9	NO	1.1	1.0	NO
297.000	D/S Corner	8,740	9.41	7.63	6.04	2.59	3.56	2.72	2.13	29.5	33.9	11.6	73.5	NO	0.2	0.9	NO
Mean:			12.67	10.54	8.52	3.12	5.18	3.99	3.12	28.6	32.7	15.2	70.6		1.1	0.8	
Std. Dev:			2.83	2.40	1.93	1.05	1.17	0.89	0.68	16.0	18.5	3.4	3.8		1.2	0.2	
Var Coeff(%):			22.33	22.73	22.63	33.76	22.57	22.25	21.80	55.8	56.6	22.4	5.4		111.4	23.0	

Figure 20. LTE/VOID Summary Report Listing.
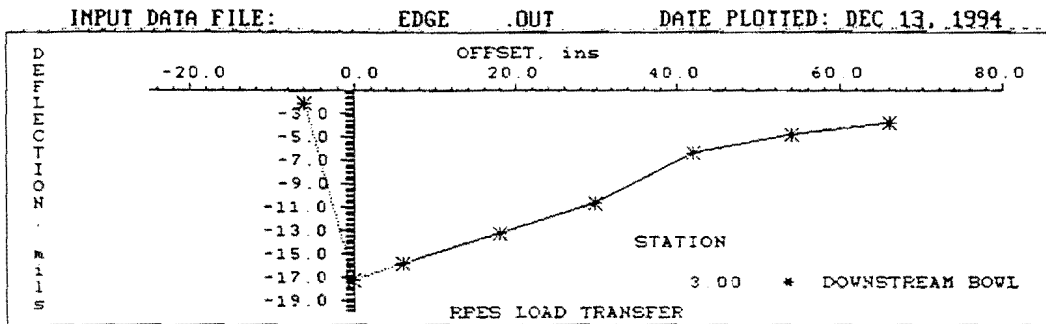
Figure 21. Deflection Bowl Screen Display.

OPTION FOUR

Option four allows the user to analyze the deflection readings and the LTE values along the entire project length. This option performs a unit delineation analysis using the cumulative difference approach to identify units or sections with similar characteristics. (See TTI Research Report 1123-1).

Option four brings up the PAVEMENT RESPONSE VARIABLE GRAPHIC REPRESENTATION AND DELINEATION ANALYSIS screen (Figure 22). This screen allows the user to select the response variable for plotting and sets the lower limit of the section length. The response variables are the deflection readings W1 to W7 and the LTE value. Enter one to seven to select deflection reading one through seven, or enter eight to select the LTE value as the response variable.

Enter the minimum section length in the same units that were recorded in the .OUT file. If the deflection bowls in the .OUT file were recorded in stations, mile-posts, miles, or feet, then enter the corresponding number of stations, mile-posts, miles, or feet to use for the minimum section length.

The delineation program displays a plot of the response variable as a function of distance along the project (Figure 23). The bottom of the screen shows a table of statistics for each of the unit delineations. If there are more than three delineated sections in the plot, press any key to see statistics for remaining sections. Continue to 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 combination routine then prompts you for the number of sections you would like to combine. To combine all sections, enter the total number of sections that were delineated in the plot. If you did not elect to combine all sections, a prompt asks for the number of the last section to be included as the new first section. This last prompt is repeated until all the sections have been accounted for. The program re-calculates and re-displays the plot showing the new delineations and their respective statistics.

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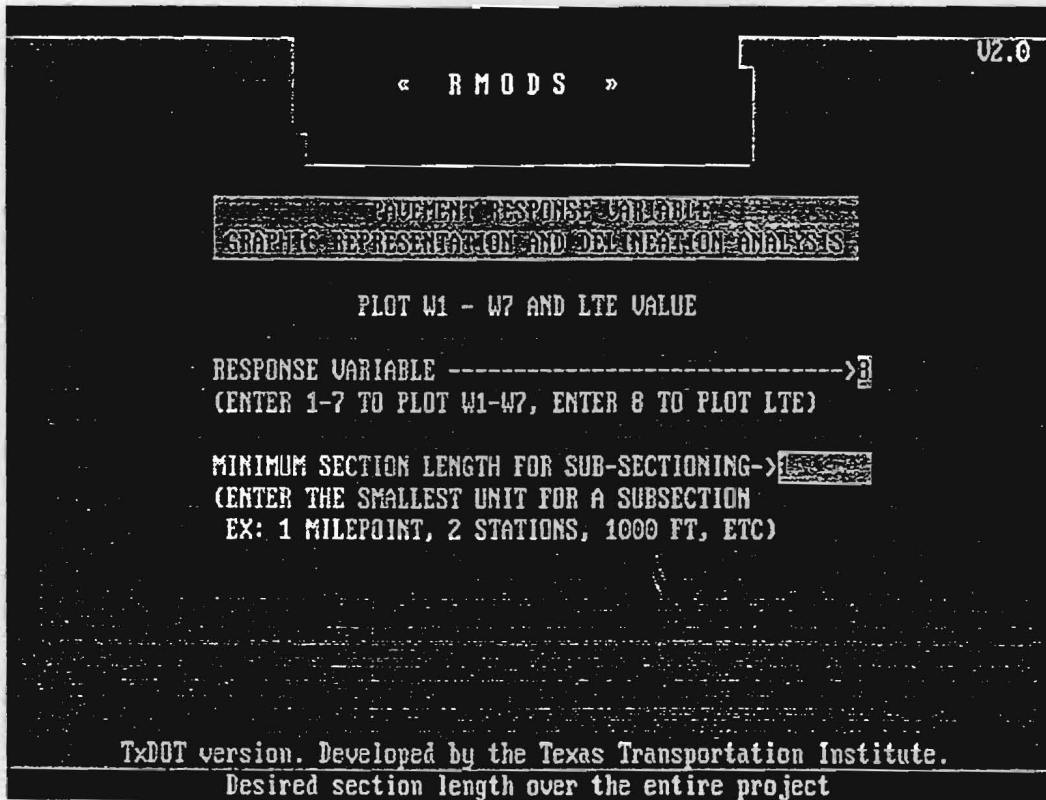
Figure 22. Response Variable and Section Length for LTE Delineation.

Road: IH0010   Pavement Response Variable: LT (Load Transfer, LTE)
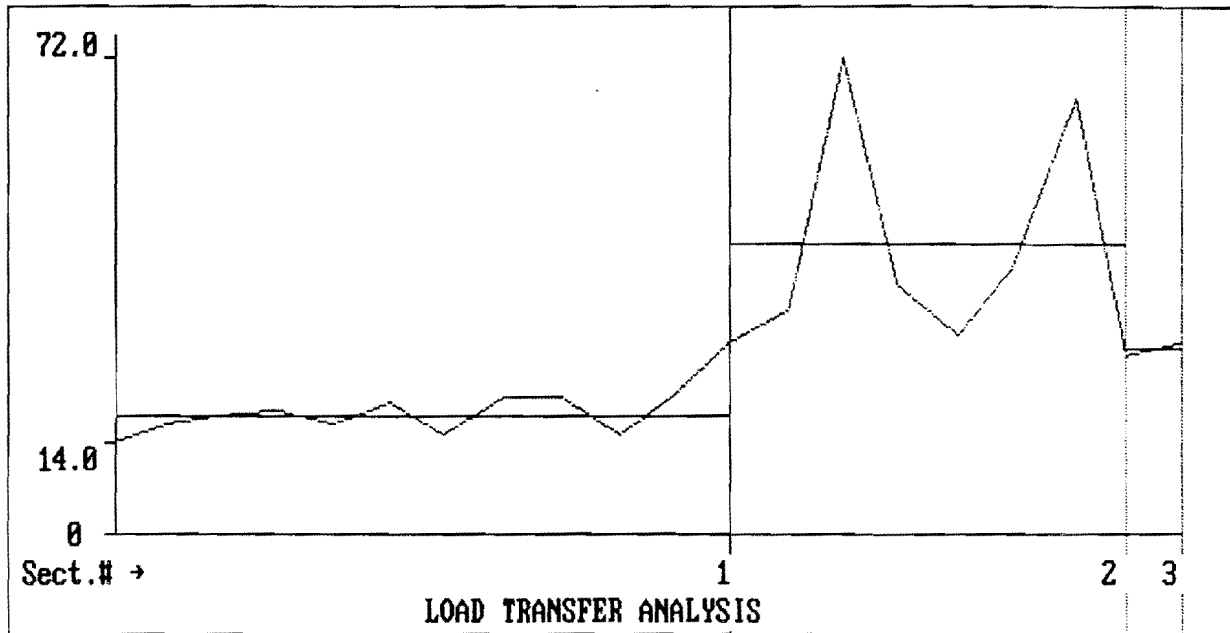
Section #	From	To	Mean	S.Dev.
1	3.000	172.000	18.00	2.61
2	172.000	281.000	44.14	17.52
3	281.000	297.000	28.00	1.41

Press any key to continue

Figure 23. Delineation Plot of Load Transfer Efficiency.

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Repeat the above sequence for manual combination if there are any sections left, or quit the program. On quitting, you will be given the option to print 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 Load Transfer OUTPUT OPTIONS MENU while entering <R> re-displays the Pavement Response Variable Graphic Representation and Delineation Analysis screen, allowing you to select another response variable for delineation analysis.

OPTION FIVE

Option five allows the user to quit the Load Transfer OUTPUT OPTIONS MENU and return to the Main Program Menu.

CHAPTER 5

OPTION THREE - RUN BACKCALCULATION PROGRAM

Option three of the Main Program Menu backcalculates values needed in rigid pavement design from FWD deflection data using Hertz, Westergaard, or layered elastic theory. The values calculated are the modulus of the concrete layer, the radius of relative stiffness, and the modulus of subgrade reaction using Hertz or Westergaard theory, or the elastic moduli of the pavement structure layers using layered elastic theory.

Select option three from the Main Program Menu as shown in Figure 24 and the INPUT DATA FILENAME screen will be displayed (Figure 25).

Supply the following information.

- DRIVE WHERE .OUT FILE RESIDES: The same drive and directory(s) entered during the data conversion will be displayed. If no drive is shown, enter the drive and directory(s) where the .OUT file for this program run is located (up to thirty alphanumeric characters). If the .OUT file is in the current directory, leave this field blank and press <ENTER> to go to the next field.

- NAME OF THE .OUT FILE: Enter the name of the input deflection data file (up to eight alphanumeric characters). The .OUT extension will be appended automatically. To see a list of all the .OUT files available in the directory entered above, press the <F1> key. Use the up/down arrow keys to select the .OUT file to use and press <ENTER>.

- THICKNESS OF THE SLAB: Enter the thickness of the slab, in inches.

- NUMBER OF BOWLS FOR THE ANALYSIS: The number of deflection bowls in the .OUT file will be displayed in this field.

When all information is complete, press <ENTER> to continue the backcalculation program and display the STRUCTURAL ANALYSIS screen (Figure 26). This screen lets the user select the desired backcalculation method: Hertz, Westergaard, Modulus (layered elastic theory). The backcalculation program uses only those deflection data bowls that were measured

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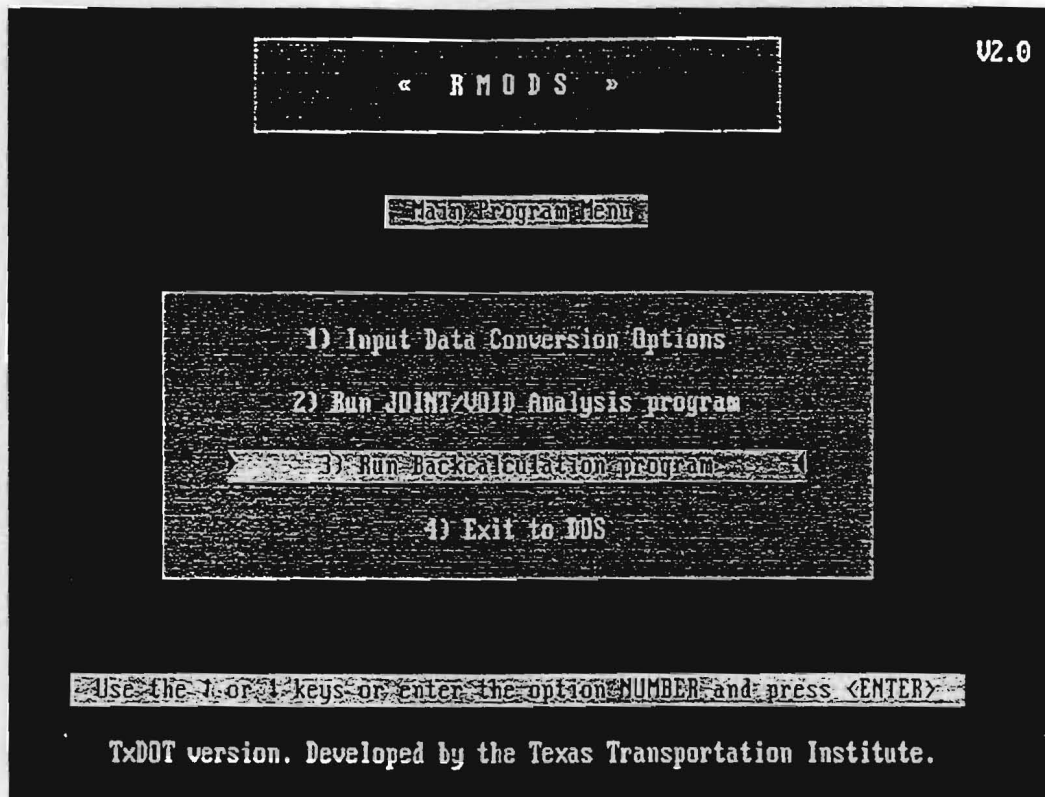
Figure 24. Select Backcalculation Analysis.

Figure 25. Backcalculation Input Data Filename.

Figure 26. Backcalculation Structural Analysis, Center Slab.

at the center of the slab for Hertz and layered elastic theory calculations or at the edge of the slab for Westergaard theory calculations. This means that the .OUT file must have deflection data bowls with the location code "01" in columns one and two in order to run the Hertz or layered elastic theory backcalculations, or with location code "04" in columns one and two to run the Westergaard theory backcalculation. If the .OUT file does not have the correct deflection data to do the backcalculation, return to the Main Program menu to start over.

SELECTING A METHOD

Select the backcalculation method as follows:

- CENTER: "YES" selects the Hertz backcalculation theory, "NO" skips the Hertz backcalculation.

- EDGE: "YES" selects the Westergaard backcalculation method, "NO" skips the Westergaard backcalculation.

- CENTER/MODULUS: "YES" selects layered elastic theory backcalculation "NO" to skips layered elastic theory backcalculation.

- SELECT THE FWD DROP TO USE: If "2" is showing, press <ENTER> to select FWD drop two, or type one, three, or four as appropriate.

- NUMBER OF SENSORS: Values displayed in the DISTANCE FROM PLATE fields are read from the LOAD PLATE RADIUS fields in the .OUT file. If the numbers displayed are not the same as in the .OUT file, exit the program and check the file.

- WEIGHTING FACTORS: These values are used in the Hertz and Westergaard backcalculation methods to adjust weights given to deflection readings. The program multiplies this inputted weighting factor by the calculated error. A "zero" will remove the deflection reading from the calculation process. Press <ENTER> to use the default weighing factor values or press <F3> and move the cursor to the field to change.

```
           «  R M O D S  »                        V2.0


                 STRUCTURAL ANALYSIS

<FK1>     CALCULATE SUBGRADE MODULUS OF REACTION K, USING:
                 1.  CENTER          NO
                 2.  EDGE            YES

          CALCULATE SUBGRADE MODULUS OF ELASTICITY E, USING:
                 1.  CENTER/MODULUS   NO

          SELECT THE FWD DROP TO USE:        2
          (ENTER 1, 2, 3, OR 4)
<FK2>
NUMBER OF SENSORS:------->7     LOAD PLATE RADIUS (in):-----> 5.900
<FK3>
SENSOR No.          1      2      3      4      5      6      7
DISTANCE FROM PLATE:-> 0.00  12.00  24.00 -12.00  48.00  60.00  72.00
WEIGHTING FACTOR:----> 1.00   1.00   1.00   1.00   1.00   1.00  1.00

              PRESS <ENTER> TO CONTINUE
   TxDOT version. Developed by the Texas Transportation Institute.
            Enter the weighting factor for this sensor
```

Figure 27. Backcalculation Structural Analysis, Edge Slab.

PREPARING FOR CALCULATIONS

Figure 26 shows how the STRUCTURAL ANALYSIS screen looks when the Hertz and MODULUS backcalculations have been selected and Figure 27 shows the STRUCTURAL ANALYSIS screen with the Westergaard backcalculation selected. Because of the way the FWD deflection data are collected, the user will not be able to run center slab (Hertz, MODULUS) backcalculations and edge slab (Westergaard) backcalculations at the same time. If the user creates a .OUT file using the manual data entry option that contains both center slab deflections and edge slab deflections, then center slab and edge slab backcalculations can be done during the same program run.

When all the fields on the STRUCTURAL ANALYSIS screen are correct, press <ENTER> to continue the backcalculation program. A message screen will be displayed while the Hertz program is running (Figure 28), or Westergaard backcalculation screen will be displayed if the Westergaard backcalculation method is running (Figure 29).

The MODULUS input screen will appear if the user selected the layered elastic theory backcalculation (Figure 30). In RMODS the first line of the *.OUT file contains the plate radius, number of sensors and sensors spacings as read from the .FWD file. These field are automatically filled on Figure 30. The remaining input values required to run the MODULUS backcalculation are as follows:

- WEIGHT FACTOR: The weighting factors are calculated automatically from the deflection bowl data by the program and any data in these fields are ignored by the program.

- LAYER THICKNESSES: Enter the thickness, in inches, of the layers in the pavement structure. Enter 0.0 for H2 and H3 if there are no base or sub-base layers. Note that H4 is automatically calculated from the H1, H2, and H3 input values and represents the depth in the pavement at which a stiff layer occurs. The H4 value can be manually entered by the user (600 inches is the maximum value to enter for H4).

- SURFACE LAYER: Enter a minimum and maximum value for the surface layer modulus (in ksi) the surface layer, and the Poisson's ratio of the surface layer.

THE HERTZ THEORY
IS CALCULATING E1, 1, AND k
USING MID-SLAB DEFLECTIONS ONLY
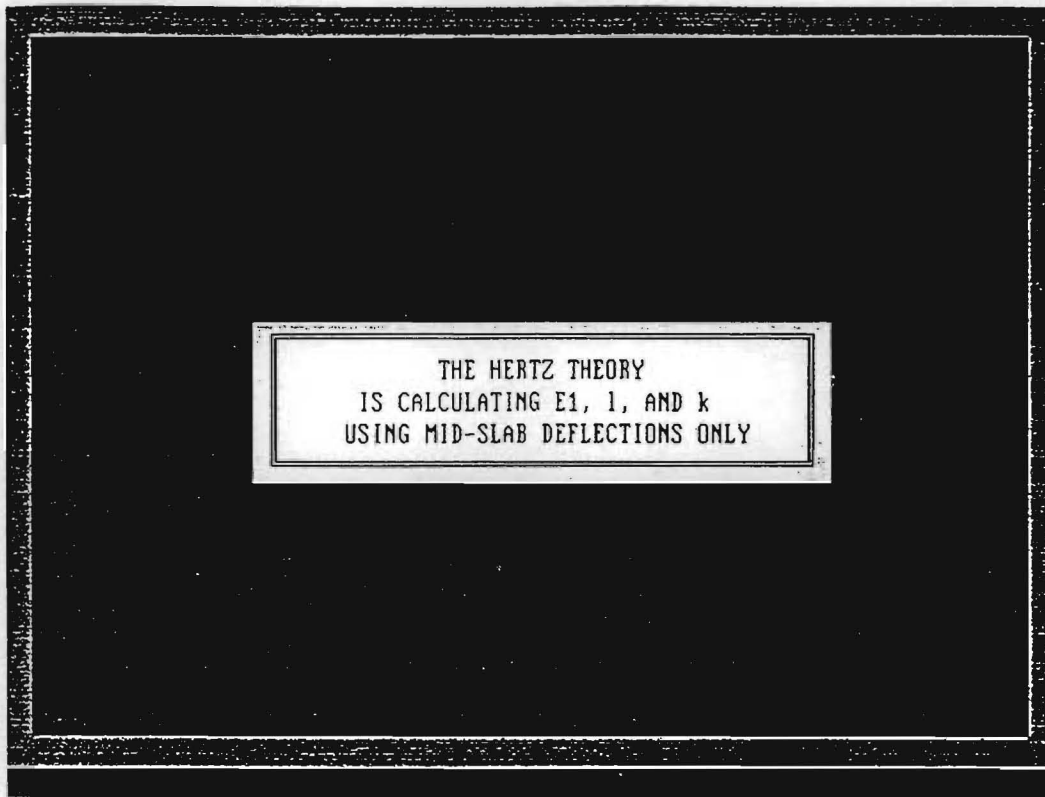
Figure 28. Hertz Backcalculation Program Running.
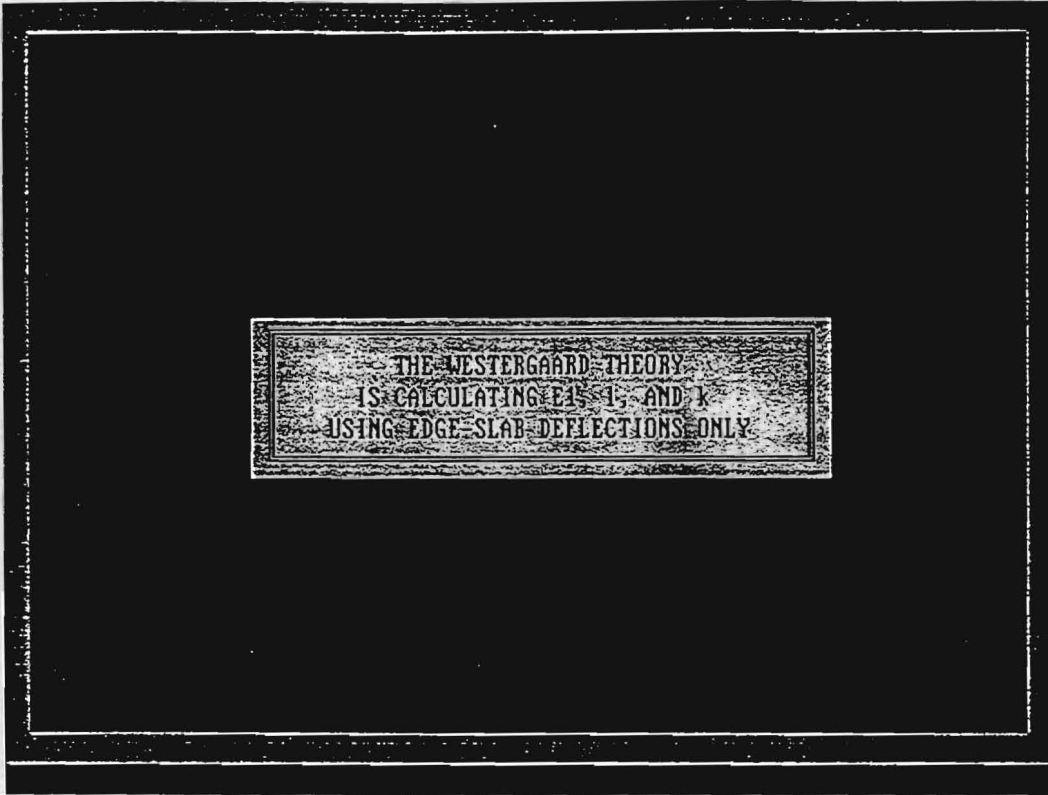
Figure 29. Westergaard Backcalculation Program Running.

```
                    ┌ «MODULUS» ┐                          V4.2
<FK2>
PLATE RADIUS(In) ----> 5.900              NUMBER OF SENSORS ->7

SENSOR No.           1      2      3      4      5      6      7
DISTANCE FROM PLATE -> 0.00  12.00  24.00  12.00  48.00  60.00  72.00
WEIGHT FACTOR -------> 0.00   0.00   0.00   0.00   0.00   0.00   0.00

<FK3>                                H1     H2     H3     H4
LAYER THICKNESSES(In) --------------> 10.5   0.0    0.0   589.5

MODULUS RANGES FOR:            MINIMUM   MAXIMUM   POISSON'S
                                (KSI)     (KSI)    RATIO
<FK4>    SURFACE LAYER --------> 2000.00   9000.00   0.40

         BASE LAYER ----------->

         SUBBASE LAYER -------->

                                         (KSI)       POISSON'S RATIO
SUBGRADE MODULUS (MOST PROBABLE VALUE) ---->  25.00        0.35

    Press <ENTER> to continue, <FK1>= HELP, <FK2-4>= edit, <ESC>= ABORT
```

Figure 30. MODULUS 4.2 Input Screen.

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- BASE LAYER: Enter a minimum and maximum value for the base modulus (in ksi), and the Poisson's ratio of the base layer. Note that these fields are skipped if there is no base layer.

- SUB-BASE LAYER: Enter a minimum and maximum value for the sub-base modulus (in ksi), and the Poisson's ratio of the sub-base layer. Note that these fields are skipped if there is no sub-base layer.

- SUBGRADE MODULUS: Enter the best estimate for the subgrade modulus (in ksi), and the Poisson's ratio of the subgrade.

To change or correct the layer thickness values press <F3>. Press <F4> to change or correct the minimum or maximum layer modulus values or the Poisson's ratio value. Press <ENTER> to continue the MODULUS backcalculation program when the MODULUS input data has been entered.

A message screen will tell the user that calculated deflections based on data entered on the previous screen are being calculated (Figure 31). The next screen that is displayed shows the progress of the backcalculation (Figure 32).

When the backcalculation program is finished - whether it be the Hertz, Westergaard, or MODULUS method - a message screen will notify the user, who can then press any key to continue to the output portion of the program.

VIEWING RESULTS

The Backcalculation Output Options Menu has the same output options for the Hertz, Westergaard, or MODULUS results (Figure 33).

1. view summary results on the screen,

2. print backcalculation results,

3. plot deflection and/or K values, and

4. return to main menu.
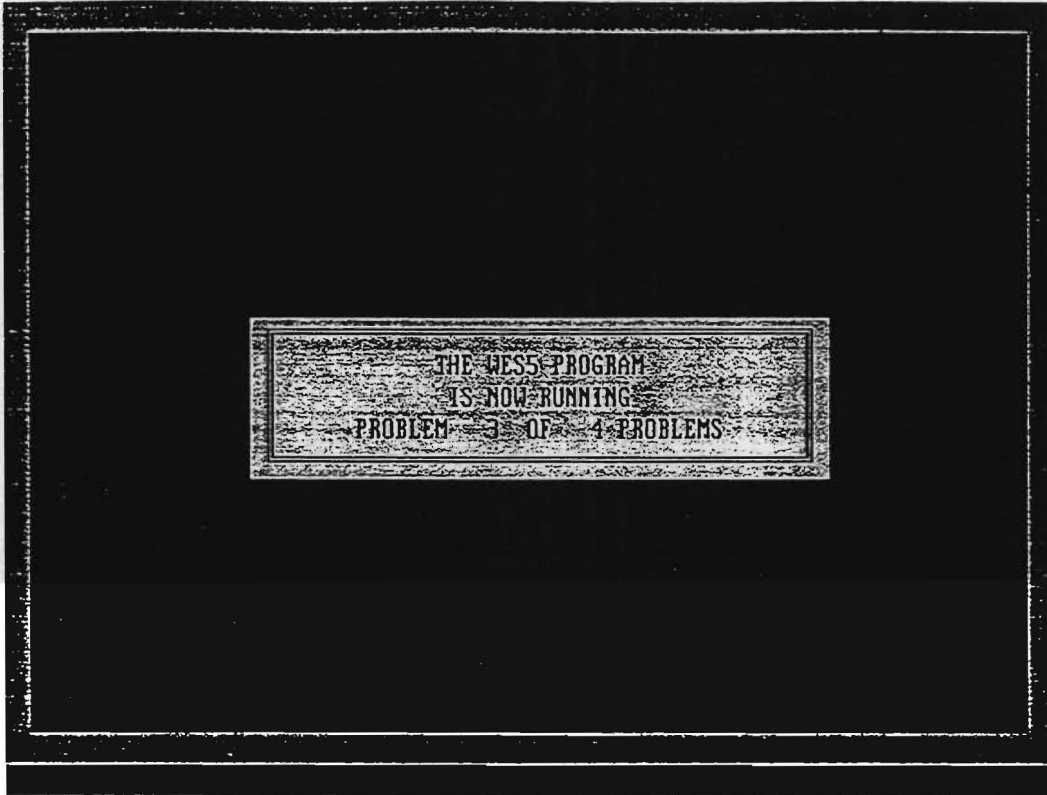
Figure 31. WESLEA Program Creating Deflection Database.
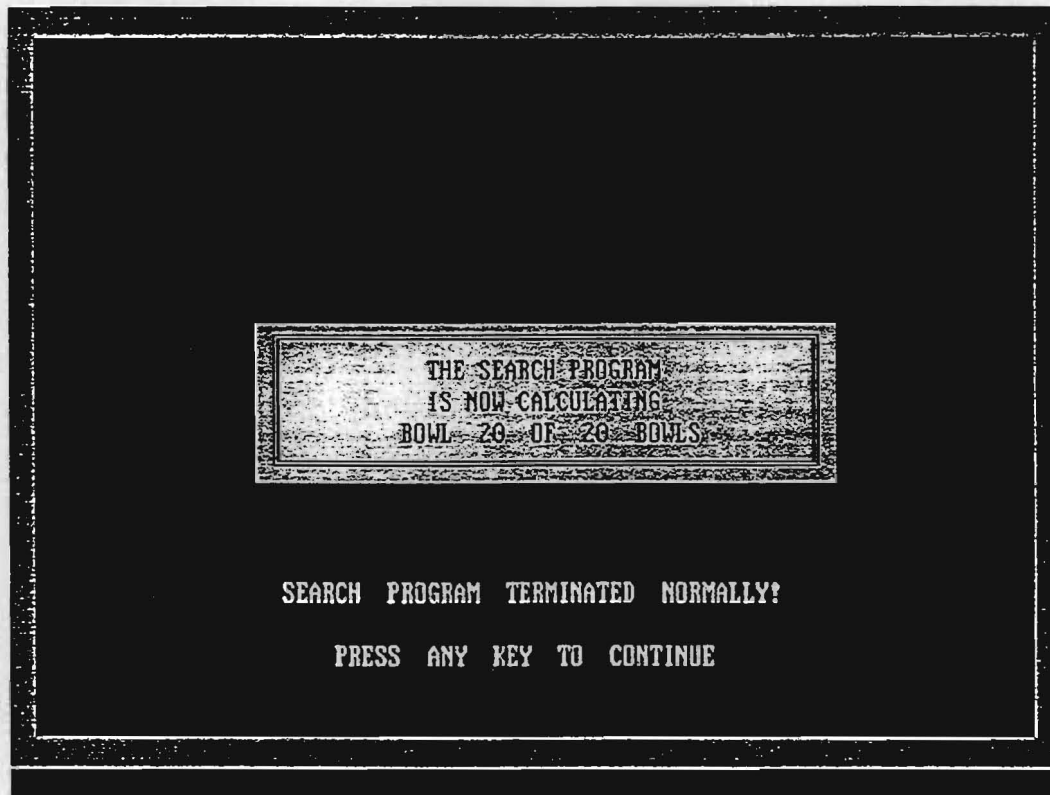
Figure 32. Backcalculation of Deflection Bowls.
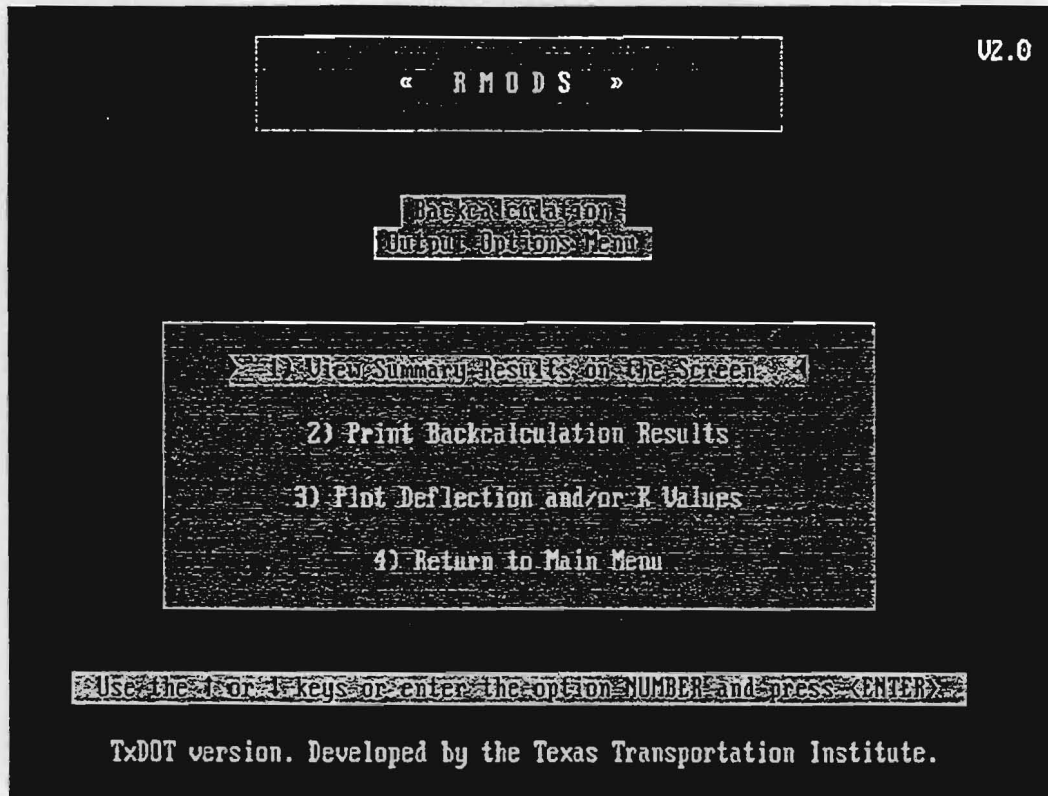
Figure 33. Backcalculation Output Options Menu.

Option one allows the user to view a short summary of the backcalculation results on the screen. For the Hertz and Westergaard results the station, load, W1-W5, W7, the modulus of the rigid layer, the modulus of subgrade reaction, and the absolute error per sensor are displayed for each deflection bowl (Figure 34). For the MODULUS, layered elastic, results the station, load, W1-W5, W7, the modulus of the surface layer, the modulus of the subgrade, and the absolute error per sensor are displayed for each deflection bowl (Figure 35). Press <ENTER> until all the results have been displayed on the screen.

If the FWD deflections from the free edge of the slab from IH10ECD.FWD file are processed using the Westergaard theory then the screen display shown in Figure 36 will be obtained.

Option two prints the backcalculation results. The "PRINTING SUMMARY REPORT" screen will be displayed while the backcalculation results print (Figure 37). For the Hertz and Westergaard results the station, location, FWD load, W1 to W7, modulus of the rigid layer, radius of relative stiffness, modulus of subgrade reaction, the sensor squared error, and the absolute error per sensor for each deflection bowl are printed (Figure 38). For the MODULUS results the station, location, FWD load, W1 to W7, surface layer modulus, base layer modulus, sub-base layer modulus, subgrade modulus, the sensor squared error, and the absolute error per sensor is printed for each deflection bowl (Figure 39). A typical Westergaard solution is shown in Figure 40.

ANALYZING READINGS

Option three allows the user to analyze the deflection readings, the modulus of the rigid layer, the radius of relative stiffness, the modulus of subgrade reaction, the surface layer modulus, the base layer modulus, the sub-base layer modulus, and the subgrade modulus values along the entire project length. This option performs a delineation analysis using the cumulative difference approach to identify units or sections having similar characteristics (See TTI Research Report 1123-1).

When option three is selected the PAVEMENT RESPONSE VARIABLE GRAPHIC REPRESENTATION AND DELINEATION ANALYSIS screen is displayed (Figure 41). This screen allows the user to specify the type of results to plot, to select the response variable to

```
------------------------------------------------------------------------
 TTI RIGID MODULUS SYSTEM  HERTZ THEORY, CENTER DEFLECTION      (Uer 2.0)
------------------------------------------------------------------------
 District: 20    County: 181   Highway/Road: IH0010   SLAB THICKNESS: 10.500
------------------------------------------------------------------------
            Load  * Deflections: Observed/Computed * Surface Subgrde Absolute
Station/Ln  (lb)  W1    W2    W3    W4    W5    W7     E1      K    Err/Sens
------------------------------------------------------------------------
     .000L  9105  3.43  3.13  2.84  3.15  2.09  1.42
                  3.34  3.18  2.84  3.18  2.09  1.40   7680.  148.8 .12E+001
   16.000L  8994  3.66  3.36  3.07  3.43  2.28  1.65
                  3.54  3.39  3.07  3.39  2.34  1.65   8521.  117.5 .16E+001
   32.000L  8970  3.72  3.46  3.14  3.45  2.31  1.61
                  3.62  3.46  3.11  3.46  2.33  1.60   7573.  125.1 .92E+000
   48.000L  8914  3.60  3.32  3.07  3.32  2.42  1.93
                  3.38  3.29  3.07  3.29  2.55  2.00  14493.   74.5 .32E+001
   63.000L  8891  3.52  3.25  2.98  3.24  2.32  1.76
                  3.27  3.18  2.98  3.18  2.49  1.97  15446.   74.1 .56E+001
------------------------------------------------------------------------
 Mean:            3.59  3.30  3.02  3.32  2.28  1.67  10742.  108.0 .25E+001
 Std. Dev:        0.11  0.12  0.12  0.13  0.12  0.19   3890.   32.9 .19E+001
 Var Coeff(%):    3.19  3.74  3.83  3.82  5.28 11.26     36.   30.4 .78E+002
------------------------------------------------------------------------
```

Figure 34. Screen Display of Hertz Backcalculation Summary Results.

```
------------------------------------------------------------------------------
  TTI RIGID MODULUS SYSTEM  LAYERED THEORY, CENTER DEFLECTION        (Ver 2.0)
------------------------------------------------------------------------------
 District: 20     County: 181   Highway/Road: IH0010   SLAB THICKNESS: 10.500
------------------------------------------------------------------------------
              Load  * Deflections: Observed/Computed * Surface Subgrde Absolute
 Station/Ln   (lb)  W1    W2    W3    W4    W5    W7     E1     ESG   Err/Sens
------------------------------------------------------------------------------
      .000L  9104  3.43  3.13  2.84  3.15  2.09  1.42
                   3.46  3.16  2.79  3.16  2.05  1.46   4915.    23.3 .14E+001
   16.000L  8993  3.66  3.36  3.07  3.43  2.28  1.65
                   3.69  3.40  3.03  3.40  2.28  1.65   5142.    20.1 .70E+000
   32.000L  8969  3.72  3.46  3.14  3.45  2.31  1.61
                   3.78  3.46  3.07  3.46  2.28  1.63   4678.    20.4 .10E+001
   48.000L  8913  3.60  3.32  3.07  3.32  2.42  1.93
                   3.53  3.34  3.07  3.34  2.46  1.90   8022.    16.2 .94E+000
   63.000L  8890  3.52  3.25  2.98  3.24  2.32  1.76
                   3.48  3.27  2.97  3.27  2.33  1.76   6975.    17.9 .51E+000
------------------------------------------------------------------------------
 Mean:            3.59  3.30  3.02  3.32  2.28  1.67   5946.    19.6 .91E+000
 Std. Dev:        0.11  0.12  0.12  0.13  0.12  0.19   1473.     2.7 .34E+000
 Var Coeff(%):    3.19  3.74  3.83  3.82  5.28 11.26     25.    13.8 .37E+002
------------------------------------------------------------------------------
```

Figure 35. Screen Display, Layered Theory Backcalculation Summary.

```
--------------------------------------------------------------------------------
  TTI RIGID MODULUS SYSTEM   WESTERGAARD THEORY, EDGE DEFLECTION       (Ver 2.0)
--------------------------------------------------------------------------------
  District: 20      County: 181   Highway/Road: IH0010   SLAB THICKNESS: 10.500
--------------------------------------------------------------------------------
            Load  * Deflections: Observed/Computed * Surface Subgrde Absolute
Station/Ln  (lb)  W1    W2    W3    W4    W5    W7     E1      K     Err/Sens
--------------------------------------------------------------------------------
   9.000L   9844  7.15  6.76  6.09  6.80  4.39  3.09
                  7.15  6.82  6.06  6.82  4.33  2.78   7848.   289.1 .24E+001
  23.000L   9848  6.77  6.46  5.91  6.31  4.39  3.29
                  6.77  6.50  5.85  6.50  4.34  2.94  10033.   263.8 .29E+001
  39.000L   9395  7.75  7.41  6.76  7.24  5.14  3.88
                  7.71  7.44  6.76  7.44  5.16  3.63   9631.   196.6 .16E+001
  55.000L   9252  6.45  6.09  5.56  6.04  4.08  2.93
                  6.45  6.17  5.51  6.17  4.00  2.63   8853.   283.5 .30E+001
  70.000L   9391  7.35  6.98  6.33  6.89  4.78  3.71
                  7.17  6.93  6.34  6.93  4.91  3.51  11115.   198.8 .17E+001
--------------------------------------------------------------------------------
  Mean:           7.09  6.74  6.13  6.66  4.56  3.38   9496.   246.4 .23E+001
  Std. Dev:       0.50  0.50  0.45  0.48  0.41  0.40   1231.    45.4 .65E+000
  Var Coeff(%):   7.11  7.45  7.35  7.19  9.00 11.96     13.    18.4 .28E+002
--------------------------------------------------------------------------------
```

Figure 36. Screen Display, Westergaard Backcalculation Summary.

60
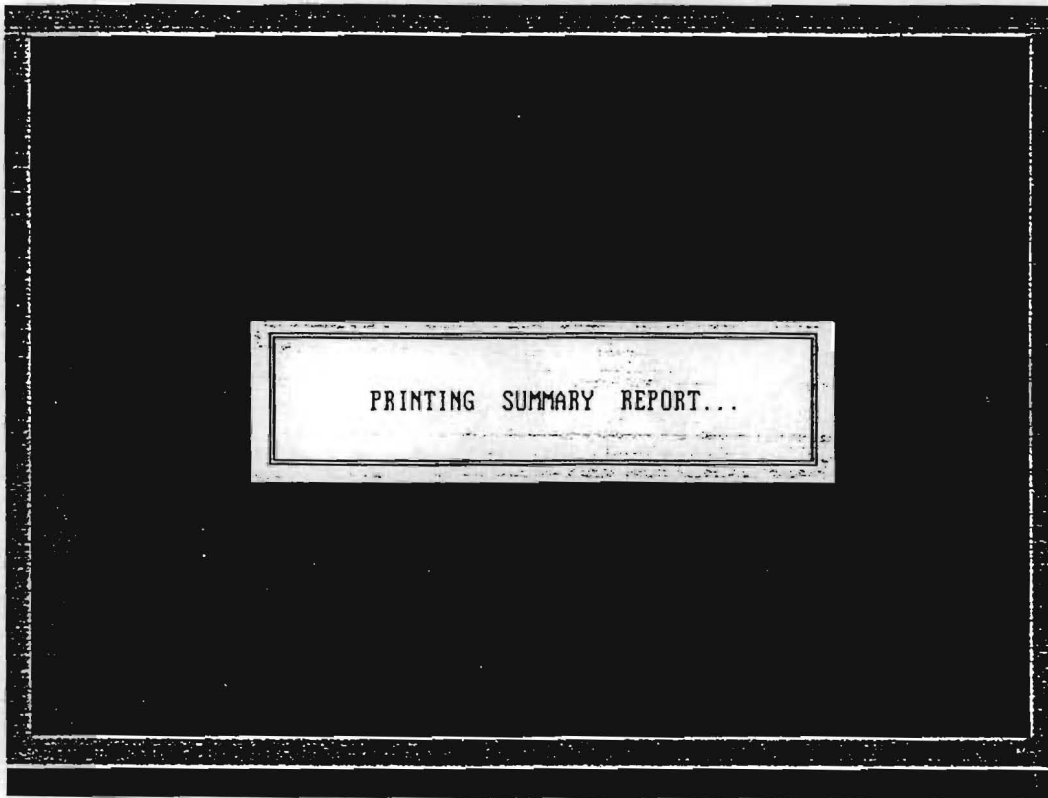
Figure 37. Printing Backcalculation Summary Report.

District: 20   County: 181   Highway/Road: IH0010   HERTZ THEORY, CENTER DEFLECTION

| | | | | | | | | | | Modulus E, Radius of Relative Stiff- | | | | |
| | *Load Plate* | Load | ** | Measured/Computed Deflection, (mils): | | | | | ** | ness l, & Mod. of | | Subg. Reaction k | Err/ | |
Station	* Location *	(lbs)	W1	W2	W3	W4	W5	W6	W7	E1	l	k	Err2	sens.
0.000	Cent/HERT	9,105	3.43	3.13	2.84	3.15	2.09	1.75	1.42					
			3.34	3.18	2.84	3.18	2.09	1.73	1.40	7680.0	47.7	148.8	.16E-02	.12E+01
16.000	Cent/HERT	8,994	3.66	3.36	3.07	3.43	2.28	1.93	1.65					
			3.54	3.39	3.07	3.39	2.34	1.98	1.65	8520.8	52.0	117.5	.28E-02	.16E+01
32.000	Cent/HERT	8,970	3.72	3.46	3.14	3.45	2.31	1.93	1.61					
			3.62	3.46	3.11	3.46	2.33	1.95	1.60	7573.1	49.7	125.1	.11E-02	.92E+00
48.000	Cent/HERT	8,914	3.60	3.32	3.07	3.32	2.42	2.17	1.93					
			3.38	3.29	3.07	3.29	2.55	2.27	2.00	14492.5	66.5	74.5	.11E-01	.32E+01
63.000	Cent/HERT	8,891	3.52	3.25	2.98	3.24	2.32	2.04	1.76					
			3.27	3.18	2.98	3.18	2.49	2.23	1.97	15445.5	67.6	74.1	.33E-01	.56E+01
77.000	Cent/HERT	8,930	3.50	3.23	2.97	3.22	2.29	1.99	1.74					
			3.33	3.22	2.96	3.22	2.36	2.05	1.76	11267.3	58.3	98.2	.44E-02	.18E+01
93.000	Cent/HERT	8,922	3.31	3.05	2.81	3.07	2.15	1.89	1.65					
			3.15	3.05	2.81	3.05	2.25	1.96	1.69	12234.3	59.1	100.7	.66E-02	.24E+01
109.000	Cent/HERT	8,875	3.47	3.21	2.94	3.15	2.20	1.87	1.56					
			3.35	3.21	2.90	3.21	2.21	1.88	1.56	8877.0	51.9	122.6	.18E-02	.11E+01
123.000	Cent/HERT	8,875	3.36	3.08	2.81	3.09	2.13	1.82	1.56					
			3.20	3.08	2.81	3.08	2.19	1.88	1.59	10414.6	55.0	114.6	.45E-02	.19E+01
139.000	Cent/HERT	8,958	3.09	2.85	2.61	2.86	1.96	1.65	1.38					
			3.04	2.91	2.61	2.91	1.94	1.62	1.33	8757.1	49.1	151.6	.29E-02	.17E+01
156.000	Cent/HERT	8,891	3.30	3.04	2.83	3.03	2.23	2.00	1.14					
			3.30	3.11	2.71	3.11	1.86	1.48	1.14	5897.9	42.1	188.9	.98E-01	.75E+01
169.000	Cent/HERT	8,887	3.44	3.22	3.03	3.13	2.44	2.19	1.96					
			3.25	3.17	2.97	3.17	2.48	2.22	1.96	15537.4	67.7	74.3	.41E-02	.19E+01
184.000	Cent/HERT	8,847	3.78	3.52	3.28	3.48	2.49	2.17	1.89					
			3.59	3.48	3.22	3.48	2.60	2.28	1.97	11266.8	60.7	83.3	.96E-02	.31E+01
200.000	Cent/HERT	8,831	3.63	3.35	3.08	3.40	2.31	1.99	1.73					
			3.37	3.29	3.08	3.29	2.58	2.31	2.05	15095.3	68.2	70.0	.79E-01	.83E+01
215.000	Cent/HERT	8,859	3.66	3.40	3.15	3.40	2.40	2.09	1.80					
			3.45	3.36	3.15	3.36	2.63	2.35	2.08	14598.1	67.8	69.5	.53E-01	.65E+01
230.000	Cent/HERT	8,839	3.48	3.23	2.95	3.18	2.19	1.84	1.04					
			3.48	3.27	2.81	3.27	1.87	1.45	1.09	4904.1	39.6	200.2	.73E-01	.71E+01
246.000	Cent/HERT	8,902	3.48	3.25	3.06	3.12	2.39	2.12	1.00					
			3.48	3.27	2.81	3.27	1.87	1.45	1.09	4944.2	39.6	201.5	.17E+00	.11E+02
261.000	Cent/HERT	8,835	3.57	3.32	3.06	3.28	2.27	1.93	1.63					
			3.46	3.32	3.01	3.32	2.30	1.95	1.63	8727.5	52.5	115.8	.18E-02	.13E+01
275.000	Cent/HERT	8,887	3.09	2.83	2.57	2.82	1.87	1.55	1.21					
			2.98	2.84	2.54	2.84	1.87	1.55	1.26	8536.8	48.1	160.8	.32E-02	.14E+01
289.000	Cent/HERT	8,871	3.22	2.96	2.72	2.97	2.04	1.74	1.44					
			3.22	3.06	2.71	3.06	1.96	1.61	1.29	7294.7	46.2	160.4	.21E-01	.41E+01
Mean:			3.47	3.20	2.95	3.19	2.24	1.93	1.55	10103.2	54.5	122.6		
Std. Dev:			0.19	0.19	0.18	0.19	0.16	0.18	0.28	3490.3	9.6	43.8		
Var Coeff(%):			5.57	5.90	6.23	5.94	7.29	9.08	18.29	34.5	17.6	35.7		

Figure 38. Hertz Backcalculation Summary Listing.

```
-----------------------------------------------------------------------------------------------------------------------
Page: 1                          TTI  RIGID MODULUS BACKCALCULATION ANALYSIS  SYSTEM  (SUMMARY REPORT)              (Version 2.0)
-----------------------------------------------------------------------------------------------------------------------
District: 20      County:  181        Highway/Road:  IH0010                      LAYERED THEORY, CENTER DEFLECTION
-----------------------------------------------------------------------------------------------------------------------
          *Load Plate*  Load  **** Measured/Computed Deflection, (mils): **** Modulus E, of the Pavement Layers      Err/
Station   * Location *  (lbs)  W1    W2    W3    W4    W5    W6    W7    E1      E2    E3    ESG   Err2     sens.
-----------------------------------------------------------------------------------------------------------------------
  0.000   Cent/MODU    9,104  3.43  3.13  2.84  3.15  2.09  1.75  1.42
                              3.46  3.16  2.79  3.16  2.05  1.73  1.46  4915.4               23.3  .17E-02 .14E+01
 16.000   Cent/MODU    8,993  3.66  3.36  3.07  3.43  2.28  1.93  1.65
                              3.69  3.40 ·3.03  3.40  2.28  1.94  1.65  5142.2               20.1  .47E-03 .70E+00
 32.000   Cent/MODU    8,969  3.72  3.46  3.14  3.45  2.31  1.93  1.61
                              3.78  3.46  3.07  3.46  2.28  1.93  1.63  4678.2               20.4  .11E-02 .10E+01
 48.000   Cent/MODU    8,913  3.60  3.32  3.07  3.32  2.42  2.17  1.93
                              3.53  3.34  3.07  3.34  2.46  2.17  1.90  8021.5               16.2  .98E-03 .94E+00
 63.000   Cent/MODU    8,890  3.52  3.25  2.98  3.24  2.32  2.04  1.76
                              3.48  3.27  2.97  3.27  2.33  2.03  1.76  6974.5               17.9  .25E-03 .51E+00
 77.000   Cent/MODU    8,929  3.50  3.23  2.97  3.22  2.29  1.99  1.74
                              3.47  3.25  2.95  3.25  2.30  2.00  1.73  6821.3               18.4  .32E-03 .66E+00
 93.000   Cent/MODU    8,921  3.31  3.05  2.81  3.07  2.15  1.89  1.65
                              3.28  3.07  2.79  3.07  2.18  1.89  1.64  7185.9               19.5  .42E-03 .67E+00
109.000   Cent/MODU    8,874  3.47  3.21  2.94  3.15  2.20  1.87  1.56
                              3.48  3.21  2.87  3.21  2.17  1.86  1.58  5588.1               20.6  .13E-02 .11E+01
123.000   Cent/MODU    8,874  3.36  3.08  2.81  3.09  2.13  1.82  1.56
                              3.35  3.10  2.79  3.10  2.12  1.83  1.56  6080.1               20.8  .17E-03 .43E+00
139.000   Cent/MODU    8,957  3.09  2.85  2.61  2.86  1.96  1.65  1.38
                              3.11  2.87  2.56  2.87  1.93  1.65  1.40  6133.4               23.5  .91E-03 .98E+00
156.000   Cent/MODU    8,890  3.30  3.04  2.83  3.03  2.23  2.00  1.14
                              3.44  3.11  2.71  3.11  1.94  1.62  1.35  4244.2               24.7  .91E-01 .91E+01
169.000   Cent/MODU    8,886  3.44  3.22  3.03  3.13  2.44  2.19  1.96
                              3.43  3.25  3.01  3.25  2.44  2.17  1.91  9000.0               15.8  .25E-02 .14E+01 *
184.000   Cent/MODU    8,846  3.78  3.52  3.28  3.48  2.49  2.17  1.89
                              3.77  3.53  3.21  3.53  2.51  2.18  1.88  6254.4               16.8  .77E-03 .80E+00
200.000   Cent/MODU    8,830  3.63  3.35  3.08  3.40  2.31  1.99  1.73
                              3.64  3.38  3.04  3.38  2.33  2.00  1.72  5701.8               18.7  .44E-03 .74E+00
215.000   Cent/MODU    8,858  3.66  3.40  3.15  3.40  2.40  2.09  1.80
                              3.66  3.42  3.10  3.42  2.41  2.09  1.80  6246.5               17.6  .33E-03 .47E+00
230.000   Cent/MODU    8,838  3.48  3.23  2.95  3.18  2.19  1.84  1.04
                              3.70  3.26  2.76  3.26  1.87  1.52  1.24  3016.8               26.5  .97E-01 .96E+01
246.000   Cent/MODU    8,901  3.48  3.25  3.06  3.12  2.39  2.12  1.00
                              3.73  3.28  2.78  3.28  1.88  1.53  1.25  3015.8               26.5  .20E+00 .14E+02
261.000   Cent/MODU    8,834  3.57  3.32  3.06  3.28  2.27  1.93  1.63
                              3.59  3.33  2.98  3.33  2.25  1.93  1.65  5425.8               19.7  .11E-02 .95E+00
275.000   Cent/MODU    8,886  3.09  2.83  2.57  2.82  1.87  1.55  1.21
                              3.14  2.85  2.50  2.85  1.81  1.51  1.27  4874.8               26.3  .51E-02 .24E+01
289.000   Cent/MODU    8,870  3.22  2.96  2.72  2.97  2.04  1.74  1.44
                              3.23  2.99  2.67  2.99  2.02  1.72  1.47  5938.9               22.2  .11E-02 .11E+01
-----------------------------------------------------------------------------------------------------------------------
Mean:                        3.47  3.20  2.95  3.19  2.24  1.93  1.55  5763.0               20.8
Std. Dev:                    0.19  0.19  0.18  0.19  0.16  0.18  0.28  1478.8                3.4
Var Coeff(%):                5.57  5.90  6.23  5.94  7.29  9.08 18.29   25.7               16.4
-----------------------------------------------------------------------------------------------------------------------
```

Figure 39. Layered Theory Backcalculation Summary Listing.

District: 20   County: 181   Highway/Road: IH0010   WESTERGAARD THEORY, EDGE DEFLECTION

Station	*Load Plate* * Location *	Load (lbs)	** W1	Measured/ W2	Computed W3	Deflection, W4	(mils): W5	W6	** W7	Modulus E, Radius of Relative Stiffness l, & Mod. of Subg. Reaction k E1	l	k	Err/ Err2	sens.
9.000	EDGE/WEST	9,844	7.15	6.76	6.09	6.80	4.39	3.65	3.09					
			7.15	6.82	6.06	6.82	4.33	3.51	2.78	7848.1	40.6	289.1	.12E-01	.24E+01
23.000	EDGE/WEST	9,848	6.77	6.46	5.91	6.31	4.39	3.76	3.29					
			6.77	6.50	5.85	6.50	4.34	3.61	2.94	10033.3	44.2	263.8	.14E-01	.29E+01
39.000	EDGE/WEST	9,395	7.75	7.41	6.76	7.24	5.14	4.39	3.88					
			7.71	7.44	6.76	7.44	5.16	4.37	3.63	9630.8	47.1	196.6	.50E-02	.16E+01
55.000	EDGE/WEST	9,252	6.45	6.09	5.56	6.04	4.08	3.43	2.93					
			6.45	6.17	5.51	6.17	4.00	3.28	2.63	8852.7	42.1	283.5	.14E-01	.30E+01
70.000	EDGE/WEST	9,391	7.35	6.98	6.33	6.89	4.78	4.19	3.71					
			7.17	6.93	6.34	6.93	4.91	4.19	3.51	11114.8	48.7	198.8	.42E-02	.17E+01
85.000	EDGE/WEST	9,097	6.49	6.12	5.54	6.13	4.20	3.62	3.15					
			6.32	6.12	5.60	6.12	4.36	3.74	3.14	12564.5	49.3	213.9	.33E-02	.16E+01
99.000	EDGE/WEST	9,125	6.21	5.89	5.31	5.96	3.87	3.24	2.76					
			6.24	5.96	5.31	5.96	3.82	3.12	2.48	8682.3	41.4	297.5	.12E-01	.24E+01
116.000	EDGE/WEST	9,276	5.69	5.34	4.82	5.37	3.54	2.89	2.38					
			5.60	5.37	4.82	5.37	3.55	2.93	2.38	10943.2	43.4	310.1	.53E-03	.58E+00
132.000	EDGE/WEST	9,177	5.50	5.28	4.80	5.17	3.58	3.00	2.60					
			5.33	5.17	4.75	5.17	3.74	3.22	2.73	15978.6	50.7	243.8	.11E-01	.33E+01
149.000	EDGE/WEST	8,918	6.28	5.93	5.34	5.89	4.24	3.67	3.22					
			6.07	5.89	5.42	5.89	4.27	3.68	3.12	13752.9	50.9	205.6	.22E-02	.13E+01
163.000	EDGE/WEST	9,133	6.08	5.81	5.29	5.79	3.97	3.39	2.90					
			6.08	5.81	5.18	5.81	3.74	3.05	2.44	9001.0	41.6	303.2	.39E-01	.49E+01
179.000	EDGE/WEST	9,463	6.00	5.77	5.31	5.75	4.05	3.47	3.01					
			6.00	5.79	5.27	5.79	4.04	3.43	2.86	12748.7	47.5	251.0	.28E-02	.12E+01
195.000	EDGE/WEST	9,038	6.63	6.41	6.05	6.24	5.04	4.70	4.46					
			6.32	6.24	6.03	6.24	5.47	5.14	4.79	45123.2	89.8	69.8	.24E-01	.47E+01
210.000	EDGE/WEST	9,463	6.34	6.00	5.42	6.04	3.96	3.26	2.67					
			6.34	6.06	5.40	6.06	3.88	3.17	2.52	8846.9	41.4	303.9	.43E-02	.17E+01
225.000	EDGE/WEST	8,811	6.07	5.70	5.22	5.76	3.83	3.22	2.65					
			6.07	5.81	5.18	5.81	3.75	3.07	2.45	8826.9	41.8	289.9	.87E-02	.25E+01
242.000	EDGE/WEST	8,823	5.36	5.00	4.56	5.04	3.31	2.77	2.35					
			5.24	5.04	4.55	5.04	3.40	2.84	2.33	12035.0	45.0	295.1	.22E-02	.14E+01
256.000	EDGE/WEST	8,855	5.16	4.92	4.57	4.72	3.45	3.00	2.62					
			4.84	4.72	4.39	4.72	3.59	3.16	2.75	21476.4	56.5	212.2	.14E-01	.40E+01
273.000	EDGE/WEST	8,982	5.17	4.83	4.39	4.77	3.00	2.59	2.13					
			5.04	4.83	4.33	4.83	3.17	2.62	2.11	11555.6	43.0	340.0	.44E-02	.18E+01
289.000	EDGE/WEST	8,843	4.82	4.50	4.04	4.48	2.91	2.41	1.98					
			4.70	4.50	4.03	4.50	2.96	2.44	1.97	12233.4	43.0	359.0	.11E-02	.94E+00
Mean:			6.17	5.85	5.33	5.81	3.99	3.40	2.94	13223.6	47.8	259.3		
Std. Dev:			0.78	0.76	0.70	0.75	0.61	0.59	0.61	8356.9	11.0	66.3		
Var Coeff(%):			12.59	13.02	13.15	12.90	15.42	17.39	20.79	63.2	23.1	25.6		

Figure 40. Westergaard Backcalculation Summary Listing.
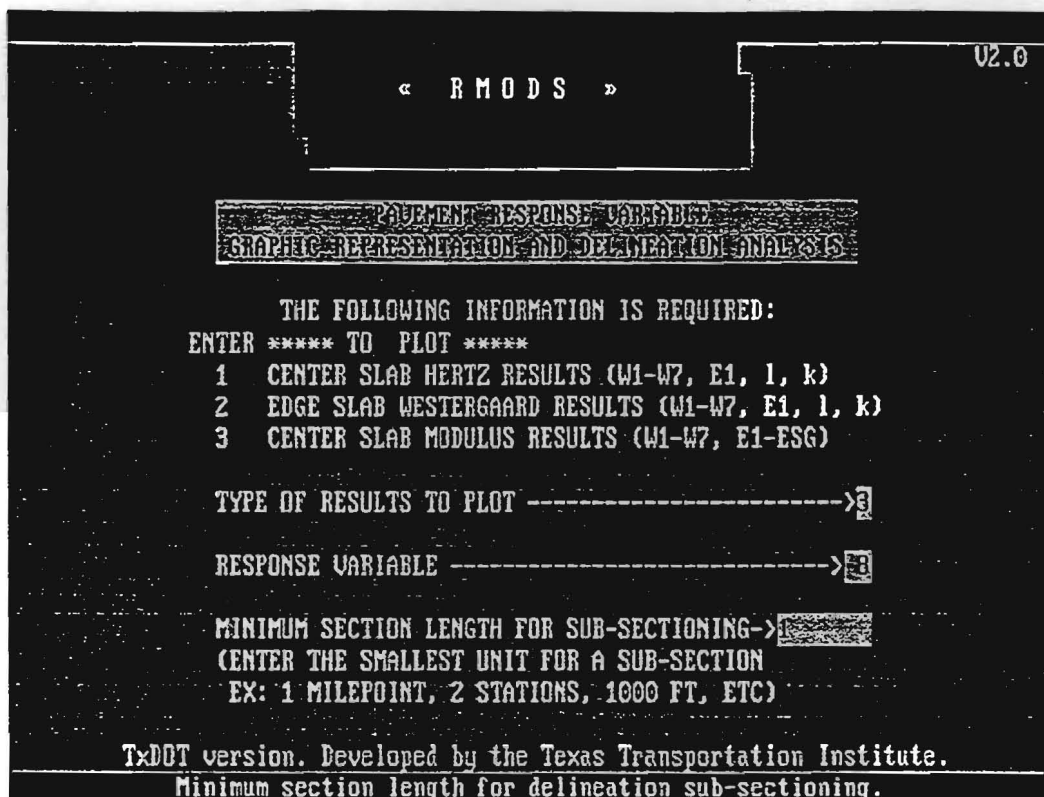
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Figure 41. Response Variable and Section Length for Backcalculation Delineation.

plot, and to set the lower limit of the section length to use by the delineation program. The type of the results to plot are the Hertz center slab results, the Westergaard edge slab results, or the MODULUS center slab results. For Hertz or Westergaard results, the response variables are the deflection readings W1 to W7, rigid layer modulus E1, stiffness radius 1, or subgrade reaction k. For layered theory results, response variables are the deflection readings W1 to W7, surface modulus E1, base modulus E2, sub-base modulus E3, and subgrade modulus ESG. Enter one through seven to select deflection reading one through seven, eight, nine, or ten to select rigid layer modulus E1, stiffness radius 1, or subgrade reaction k as the response variable for Hertz or Westergaard results. Enter one through seven to select deflection readings one through seven, eight through eleven to select surface modulus E1, base modulus E2, sub-base modulus E3, or subgrade modulus ESG as the response variable for the MODULUS results. Note that if there is no base or sub-base layer, the user must still enter eleven to select the subgrade modulus ESG as the response variable.

The minimum section length for sub-sectioning is the minimum section length used by the delineation program to perform the delineation of the chosen response variable. If cumulative inflection points in the cumulative difference curve occur at intervals that are less than the minimum section length, the program will ignore them.

Enter the minimum section length in the same units that the station or location was recorded in the .OUT file. If the deflection bowls in the .OUT file were recorded in stations, mile-posts, miles, or feet, then enter the corresponding number of stations, mile-posts, miles, or feet.

The delineation program displays a plot of the response variable as a function of distance along the project (Figure 42). The bottom of the screen shows a table of statistics for each of the unit delineations. If there are more than three delineated sections in the plot, press any key to see the statistics for the remaining sections. Continue to 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 combination routine then prompts you for the number of sections you would like combine. To combine

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Road: IH0010   Pavement Response Variable: E1 (Moduli values in KSI)
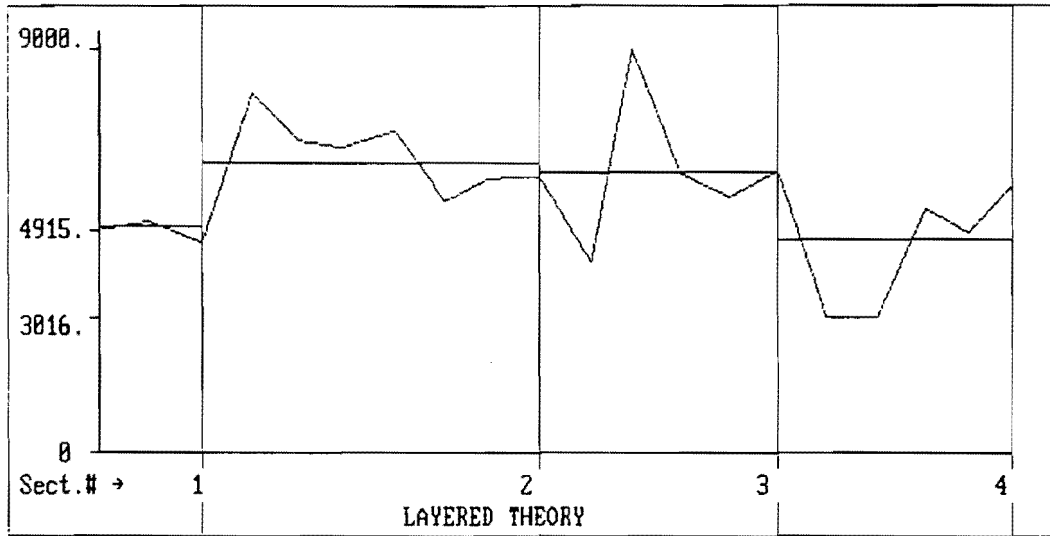
Section #	From	To	Mean	S.Dev.
1	0.000	32.000	5028.80	160.37
2	32.000	139.000	6478.51	1113.36
3	139.000	215.000	6266.76	1724.71

Press any key to continue

Figure 42. Delineation Plot of Layered Theory Backcalculated E1.

all sections, enter the total number of sections that were delineated in the plot. If you did not elect to combine all sections, a prompt asks for the number of the last section to be included as the new first section. This last prompt is repeated until all the sections have been accounted for. The program recalculates and redisplays the plot showing the new delineations and their respective statistics.

Repeat the above sequence for manual combination if there are any sections left, or quit the program. On quitting, the user is given the option to print 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 Backcalculation Output Options Menu while entering <R> re-displays the Pavement Response Variable Graphic Representation and Delineation Analysis screen, allowing the user to select the type of results to plot and to select another response variable for delineation analysis.

ENDING CALCULATIONS

Option four allows the user to exit the backcalculation program and return to the Main Program menu (Figure 43). The user is reminded that the RMODS program does not save the output files from each program run for viewing, printing, or plotting at a later time. The RMODS program will have to be repeated for the same .OUT file if the user wishes to view, print, or plot the results after leaving the OUTPUT OPTIONS menu.

The user can terminate the Rigid Pavement Evaluation System program by selecting option four from the Main Program Menu to exit to DOS (Figure 44).
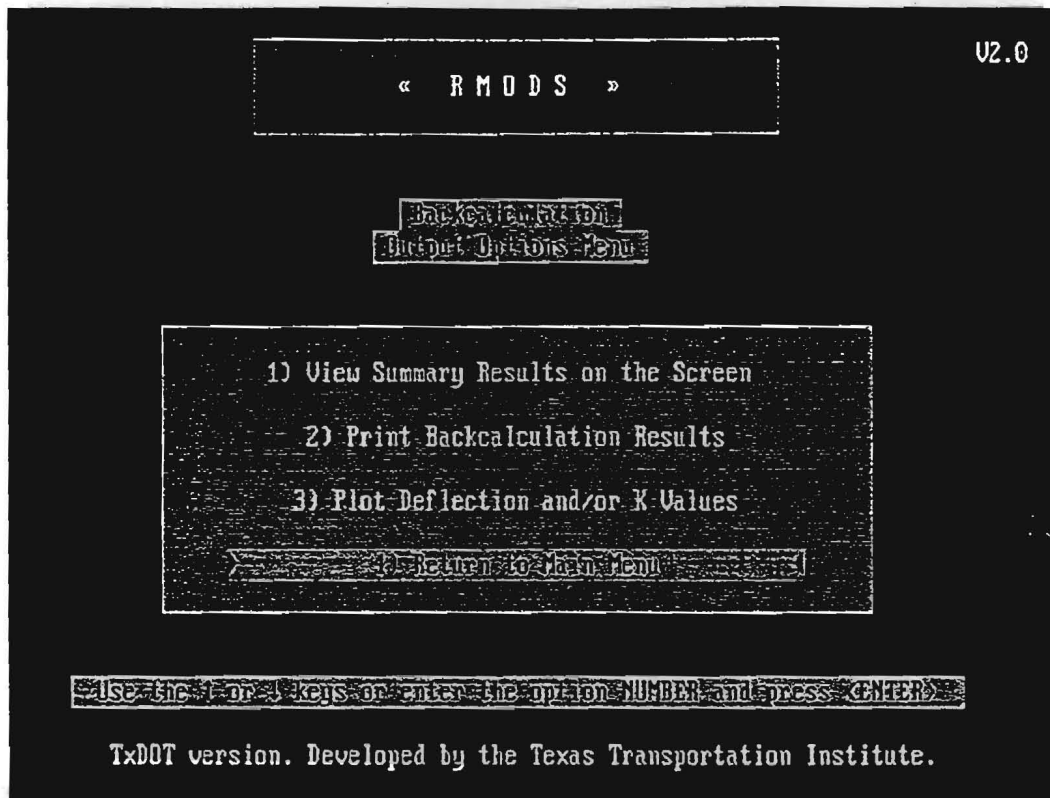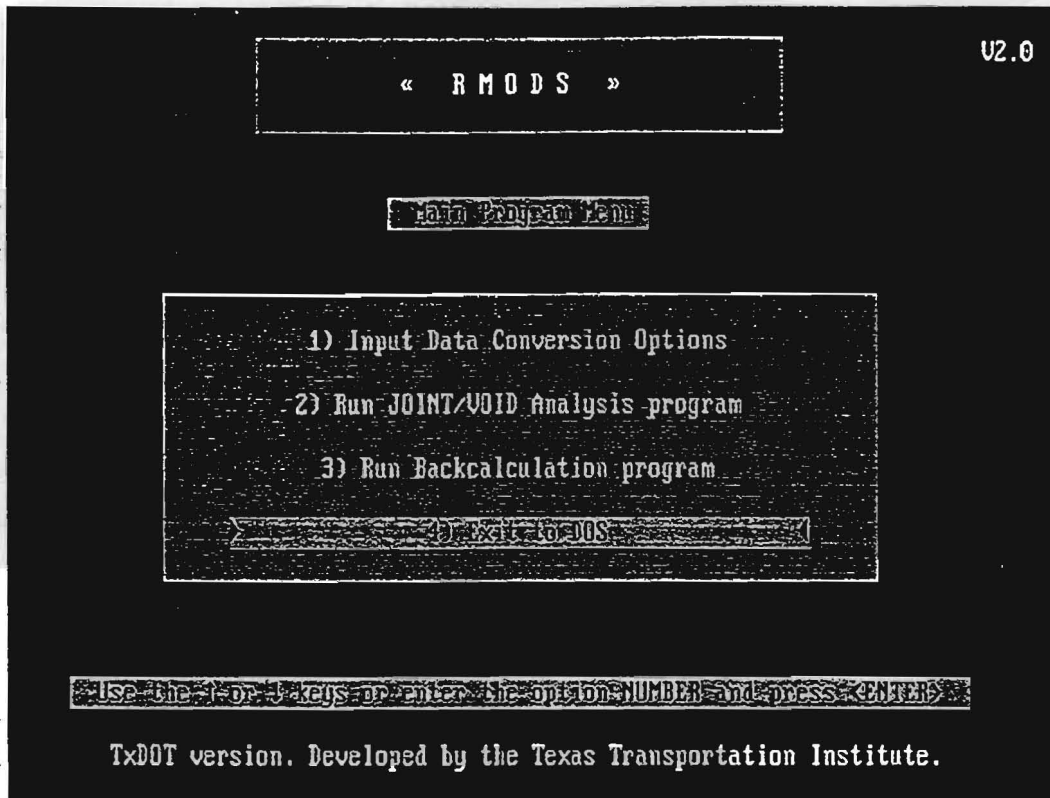
Figure 43. End Backcalculation Analysis.

Figure 44. End the RMODS Program.