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16. Abstract

Texas has approximately 17,500 miles of load-zoned pavements, comprising over 20 percent of the number of centerline miles on the state-maintained system. These pavements are primarily low-volume farm-to-market roads constructed in the 1950s at a time when legal load limits were lower than they are now. About 98 percent of the load-zoned pavements in Texas are posted with a gross vehicle weight (GVW) restriction of 58,420 lbs. While load limits based on gross vehicle weight are simple to implement, the procedure is fundamentally flawed since the gross load from a vehicle is transmitted through the axle tires. Recognizing the need for a better methodology of determining load limits, the Texas Department of Transportation (TxDOT) sponsored a project with the Texas Transportation Institute (TTI) to develop a procedure for evaluating load restrictions on the basis of axle load and axle configuration. The product of this project is the **P**rogram for **L**oad-**Z**oning **A**nalysis, **PLZA**, which is described in this report. PLZA may be used to evaluate the need for load restrictions and to determine, as appropriate, the single and tandem axle load limits based on a user-prescribed reliability level for the route under investigation. The program incorporates a layered elastic pavement model for predicting the induced response under surface wheel loads. Both linear and nonlinear pavement materials may be modeled. The predicted horizontal strain at the bottom of the asphalt layer and the vertical strain at the top of the subgrade are used to determine the service life for a given pavement and loading condition. To combine the effects of different axle loads and axle configurations, Miner's hypothesis of cumulative damage is used to predict pavement service life. Instructions in the operation of the PLZA software are provided in this guide. The program is now implemented in TxDOT for evaluating load zoning needs.

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PROGRAM FOR LOAD-ZONING ANALYSIS (PLZA): USER'S GUIDE

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DISCLAIMER

The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Texas Department of Transportation (TxDOT), or the Federal Highway Administration (FHWA). 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 Dr. Emmanuel G. Fernando, P.E. # 69614.

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The work reported herein was conducted as part of a research project sponsored by the Texas Department of Transportation (TxDOT) and the Federal Highway Administration (FHWA). The objective of the study was to develop a procedure for evaluating the need for load restrictions and to determine, as appropriate, the allowable axle load limits along a given route based on predicted pavement performance. The researchers gratefully acknowledge the support and guidance of Mr. Joe Leidy, project director, and Dr. Michael Murphy, assistant director of the Pavements Section of TxDOT.

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CHAPTER I
INTRODUCTION

BACKGROUND AND SCOPE OF REPORT

Freight movement by trucks on the highway infrastructure is vital to the economic well-being of any government. However, this movement of commodities also impacts the condition of the highway network. Indeed, governments are often confronted with the dilemma of balancing the need to promote commerce and economic activity, through increased trucking productivity, with the equally important need of preserving the highway infrastructure. Thus, there are laws empowering state authorities to post load restrictions on highways, particularly those not built to accommodate today's heavier truck traffic.

In Texas, there are approximately 17,500 miles of load-zoned pavements, comprising more than 20 percent of the number of centerline miles on the state-maintained system. These pavements are primarily low-volume farm-to-market roads constructed in the 1950s at a time when legal load limits were lower than they are now. Like most other governments, Texas does not have the revenue to upgrade all existing load-zoned pavements to accommodate present truck traffic, nor is this justifiable for many of these pavements because of the continuing low traffic volumes. To do so would divert funds from higher priority highway and bridge improvement projects.

About 98 percent of the load-zoned pavements in Texas are posted with a gross vehicle weight (GVW) restriction of 58,420 lbs. While load limits based on gross vehicle weight are simple to implement, the procedure is fundamentally flawed since the gross load from a vehicle is transmitted through the axle tires. Thus, the tire loads and the geometric arrangement of the tires comprising the axle are the factors that more directly influence the response of the pavement to the vehicle rather than its gross weight. Indeed, a vehicle may be in compliance with the GVW limit but still be damaging because of axle loads that exceed the pavement's structural capacity.

Recognizing the need for a methodology of determining load limits on the basis of axle load and axle configuration, the Texas Department of Transportation (TxDOT) sponsored a study with the Texas Transportation Institute (TTI) to develop a procedure for evaluating load restrictions on this basis. The product of this study is the **P**rogram for **L**oad-**Z**oning **A**nalysis, **PLZA**, that is described in this report. To predict pavement response due to surface wheel loads, PLZA uses the structural response model in the Program to Analyze Loads Superheavy (PALS) developed by Jooste and Fernando (1995). The predicted pavement response, specifically the horizontal strain at the bottom of the asphalt layer, and the vertical strain at the top of the subgrade, are used with the Asphalt Institute (1982) equations for fatigue cracking and rutting to determine the service life for a given pavement and loading condition. To combine the effects of different axle loads and axle configurations, Miner's (1945) hypothesis of cumulative damage is used in predicting pavement service life.

This report provides a user's guide to the PLZA program. Chapter I of this guide describes the procedure for evaluating load restrictions using the computer program, identifies system requirements for its use, and provides easy instructions for installing the program on a microcomputer. Chapter II explains the application of PLZA to evaluate the need for load restrictions on a specified route, while Chapter III provides instructions on evaluating load limits using the computer program. Finally, the appendix presents the formats of output files generated by PLZA during analysis, which may be of use to the pavement engineer in certain special applications. These output files present the predicted pavement strains based on the specified wheel loads and axle configurations, the corresponding predicted service lives based on fatigue cracking and rutting criteria, and the expected number of axle load applications during the specified design period.

PROCEDURE FOR LOAD-ZONING ANALYSIS

The PLZA program may be used to evaluate the need for load restrictions on a specified route and to establish, as appropriate, the single and tandem axle load limits that satisfy the user-prescribed reliability level in the load-zoning analysis. The program may be used to determine the applicability of removing load limits on an existing route that has undergone recent rehabilitation, or alternatively, to evaluate the need for posting load limits on a route. Many load-zoning evaluations are done in response to inquiries from the districts pertaining to removal of existing load limits on roads that have been upgraded in rehabilitation or reconstruction projects. Where it is possible, the districts make every effort to rehabilitate an existing load-zoned road to a higher standard to sustain truck traffic at the legal load limits. Thus, it is expected that most applications of PLZA will relate to the applicability of removing existing load limits, rather than to load zoning.

To use the program for load-zoning analysis, users must first characterize the route to be analyzed. This will require characterizing the truck traffic on the route, determining pavement layer thicknesses, and evaluating material properties. Table 1 summarizes the input requirements of the computer program. Truck traffic data may be requested from the Transportation Planning and Programming (TP&P) Division of TxDOT. The beginning and ending average daily traffic (ADT) values, directional factor, and percent trucks are normally reported by TP&P in *Traffic Analysis for Highway Design* sheets that it provides in response to requests from the Districts or the Pavements Section of TxDOT's Design Division. Pavement layer thicknesses may be determined nondestructively using ground penetrating radar (GPR) supplemented, as necessary, by coring or dynamic cone penetrometer (DCP) measurements. Researchers strongly suggest a GPR survey on the route to establish the variations in layer thicknesses from the profiles obtained. This survey should be conducted at the beginning of the evaluation for the following purposes:

1. to detect possible changes in pavement cross-section along the route and divide the route into analysis segments, as appropriate;
2. to establish the need for cores or DCP data to supplement the radar survey and identify locations where coring or DCP measurements should be made; and
3. to establish the locations of Falling Weight Deflectometer (FWD) measurements consistent with pavement section changes identified from the radar data of the route.

Additionally, a video log may be made during the radar survey to provide a record of the pavement surface condition at the time of the evaluation. GPR surveys may be scheduled with the Pavements Section, which is staffed with engineers trained to operate, maintain, and analyze radar data for pavement evaluation purposes.

Table 1. Input Data Requirements for Load-Zoning Analysis.

Data Requirements	Methods of Getting Data
Layer thicknesses	•Ground Penetrating Radar (GPR) •Coring •Dynamic Cone Penetrometer (DCP)
Nonlinear, stress-dependent material parameters, K_1, K_2, and K_3	•Falling Weight Deflectometer (FWD) •Resilient Modulus Test (AASHTO T-292-91) •Correlations with physical soil properties
Truck traffic characteristics ▸ Beginning and ending ADTs for design period ▸ directional factor ▸ percent trucks ▸ average axles per truck ▸ percent single axles ▸ percent tandem axle groups ▸ design single axle load ▸ design tandem axle load	•contact TP&P •truck counts and classifications •axle load measurements

Route segmentation based on GPR layer thickness profiles may be accomplished using the cumulative difference method as described by the American Association of State Highway and Transportation Officials (1993), and as illustrated by Fernando and Chua (1994). Because of the strong influence of layer thickness on predicted pavement response and layer moduli backcalculated from FWD deflections, it is important to establish the variability in layer thickness along the route to minimize the inaccuracies that are caused by layer thickness variations. In a study of the variability of layer thicknesses on Long-Term Pavement Performance (LTPP) sections in Texas, Briggs, Scullion, and Maser (1992) found that thickness variations can cause up to 100 percent error in the backcalculated surface modulus, and up to 80 percent error in the backcalculated base modulus if not considered in the analysis. GPR is a nondestructive tool available to pavement engineers for establishing layer thickness variations so that these may be considered in the load-zoning analysis.

The segments delineated from the GPR data are subsequently used in the load-zoning procedure to plan the FWD survey, the purpose of which is to characterize the materials that comprise the pavement in terms of the resilient modulus. These surveys are now routinely performed by the districts for pavement design, forensic investigations, and superheavy load analysis. The nonlinear material constants, K_1, K_2, and K_3, in Table 1 are the parameters of the model proposed by Uzan (1985) to characterize the stress dependency of the resilient modulus, E_r, of pavement materials. This model is given by the equation:

$$E_r = K_1\, Atm \left(\frac{I_1}{Atm} \right)^{K_2} \left(\frac{\tau_{oct}}{Atm} \right)^{K_3} \tag{1}$$

where I_1 = first stress invariant,

τ_{oct} = octahedral shear stress, and

Atm = the atmospheric pressure = 14.5 psi.

The coefficients in Eq. (1) may be obtained from laboratory testing of base and subgrade specimens. Glover and Fernando (1995) tested a number of base and subgrade materials used in Texas and provided ranges of the values of the coefficients K_1, K_2, and K_3 at different moisture levels. Their results may be used to assign values for these coefficients in the absence of any laboratory test data. Typical values of these coefficients for different materials are provided later in this report.

In the application of the PLZA program, the K_2 and K_3 values are specified by the user. The coefficient K_1 is then estimated using these values with the backcalculated layer modulus for the material. The effects of stress dependency are more pronounced for thin-surfaced pavements, making it particularly important to model this behavior for these pavements. For thicker pavements, the effects are less pronounced. The program permits one to model a given layer as linear elastic or nonlinear elastic. For linear elastic materials, the coefficients K_2 and K_3 in Eq. (1) are zero. For these materials, K_1 is directly determined from the FWD backcalculated moduli that are input to the computer program.

FWD data are collected on each homogeneous segment following the current protocol established by TxDOT (1996) for this test. It is important to collect pavement temperature data because of the influence of this variable on the measured deflections. For this purpose, TxDOT's FWDs are equipped with cordless drills and temperature probes so that asphalt layer temperatures may be measured at least once in the beginning and again at the end of the test on a given segment. Temperature data are necessary to correct the backcalculated moduli to a reference temperature of 75 °F in the load-zoning program. Because of the influence of the surface modulus on predicted service life, it is important that the pavement temperature be known with a reasonable degree of confidence so that the asphalt concrete modulus may be appropriately determined.

Researchers recommend that pavement temperature measurements be made on homogenous segments, particularly where the asphalt layer thickness is three inches or more. At the very least, the temperature at mid-depth should be taken. However, additional measurements near the surface and bottom of the layer may be made at the discretion of the pavement engineer to characterize the temperature profile for establishing the pavement temperature at the time of test. These guidelines show the importance of determining the layer thicknesses for planning the FWD survey.

It is noted that FWD data collection may take some time depending on the frequency of testing and the length of the segment to be surveyed. In certain applications, taking pavement temperature measurements at the beginning and end of the segment will not provide enough information to consider the spatial and temporal variation in pavement temperatures during the survey. For these cases, researchers recommend that infrared surface temperatures be measured at least on every other station, so that pavement temperatures may be estimated using the BELLS3 equation developed by Stubstad et al. (1998). This equation permits pavement temperatures to be predicted for a given depth within the asphalt layer for the date and time of testing. Use of this equation requires the previous day's maximum and minimum air temperatures, which are readily obtained from the local weather service. This will provide a better estimate of the spatial and temporal variation of pavement temperatures along the route surveyed. The pavement temperatures measured at the beginning and end of the segment are then used to verify the temperature predictions from the BELLS3 equation.

Researchers recommend that the FWD data be stored in a separate file for each segment of the route surveyed. Each file is then analyzed with the MODULUS program (Michalak and Scullion, 1995) to estimate the resilient moduli of the pavement layers. The output file of the backcalculated moduli for each segment is directly input to the PLZA program for the load-zoning analysis.

In view of the possible variations in layer thicknesses and materials along the route, different results may be obtained for the different segments established from analysis of the

GPR data. In practice, it will be difficult to implement numerous postings on a given route. Thus, the pavement engineer must still use his or her judgment in taking the results of the load-zoning analysis to establish how a given route should be posted. For example, the engineer may make the decision to post the route based on the weakest segment. This decision should also consider the current truck use of the particular route, alternative roadways that may be taken, the presence of load-zoned bridges, and the need to upgrade the route to carry truck traffic at the legal load limits.

SYSTEM REQUIREMENTS AND PROGRAM INSTALLATION

PLZA requires a microcomputer operating under Windows 95, 98, or NT. Researchers recommend a Pentium microprocessor or its equivalent and a minimum of 32 Mb of memory. Program installation requires a 3.5-inch floppy drive. The files are stored in compressed format. During installation, these files are expanded and will occupy about 2.6 Mb of hard disk space when installed. Program use requires a working knowledge of the Windows operating system.

To install the analysis program, insert disk 1 of the setup disks into the computer's 3.5-inch floppy drive. Click on the ***Start*** button in Windows, and select ***Run***. At the dialog box, type ***drive letter:\setup***, where ***drive letter*** specifies the floppy drive (e.g., ***A:***). Click on the ***OK*** button of the dialog box to run the PLZA installation program. Simply follow the instructions that appear on screen. You will be prompted for a subdirectory or folder in which to store the program files on your computer's hard drive. By default, the files will be copied to ***C:\Program Files\PLZA***. However, you have the option to specify a different subdirectory, such as ***C:\PLZA***.

After installation, you may execute PLZA through your ***Programs*** list. Simply click on the ***Start*** button, move the pointer to ***Programs***, then to ***PLZA***. The program icon will be displayed. Click on the icon to load the program. The remainder of this user's guide provides instructions in the use of PLZA.

CHAPTER II
EVALUATING THE NEED FOR LOAD RESTRICTIONS

INTRODUCTION

A load-zoning analysis will generally address the following questions:

1. Is there a need for posting load limits on a given route?
2. If load restrictions are necessary, what axle load limits should be used?

This chapter explains the application of PLZA to evaluate the need for load restrictions. Traditionally, this problem dealt with determining whether a given route should be load zoned. However, the focus has shifted in recent years toward ascertaining whether load restrictions may be lifted after a roadway is upgraded through rehabilitation or reconstruction.

Herein, it is assumed that the user has collected the data required to characterize the truck traffic, pavement materials, and layer thicknesses along the route to be evaluated. Further, the backcalculation of layer moduli from FWD deflections should have been completed using the MODULUS program. The output file from this backcalculation is used directly in the PLZA program to predict pavement service life, which is assessed against the prescribed design life to determine the need for load restrictions. Instructions for using PLZA to evaluate the adequacy of an existing roadway to carry the present and projected truck traffic follow.

SPECIFYING INPUT DATA IN PLZA TO EVALUATE LOAD-ZONING NEEDS

User-interface screens in PLZA facilitate the entry of input data to perform a given analysis. Specifying input parameters is the first activity after loading the computer program. This is done by manually entering the required parameters using the interface screens. Before going further, here are two simple guidelines to remember when navigating through the different menus of PLZA:

1. To select a particular option, move the pointer to it and then click on the option with the left mouse button.

2. To enter data for a particular variable, move the cursor to the field or cell. Then type in the required data. To position the cursor to an input field, move the pointer to the field and click on it.

To load the analysis program, click on the ***Start*** button, move the pointer to ***Programs***, and then to ***PLZA***. The program icon will be displayed. Click on the icon to load the program. The title screen shown in Figure 1 will be displayed. Press the carriage return key to clear this screen and proceed to the Main Menu shown in Figure 2. Click on the ***Data Preparation*** button to specify input data to the computer program and create input files needed in the subsequent load-zoning analysis. Note that only two options are available in the initial Main Menu: ***Data Preparation*** and ***Exit Program***. The other two options, ***Evaluate Reliability*** and ***Evaluate Load Limits***, are dimmed until the ***Data Preparation*** step is completed.

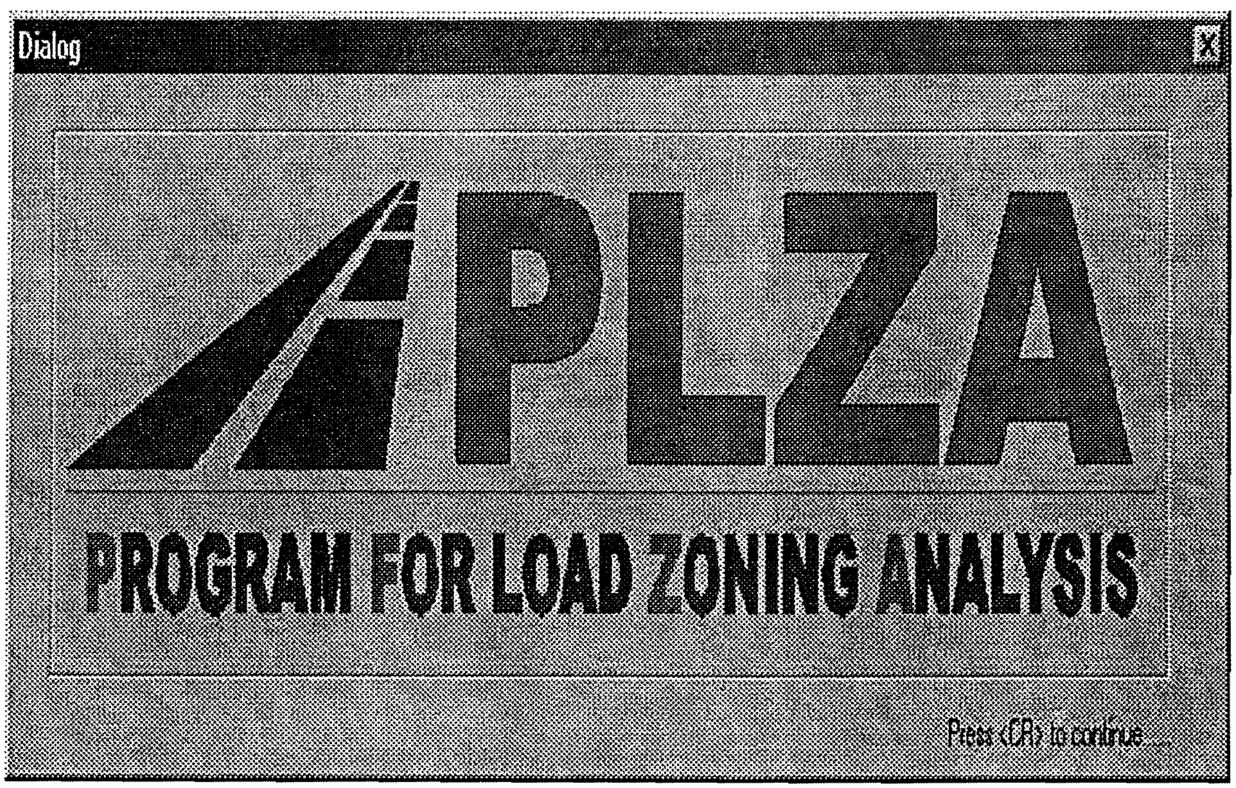


Figure 1. Header Screen of PLZA Program.

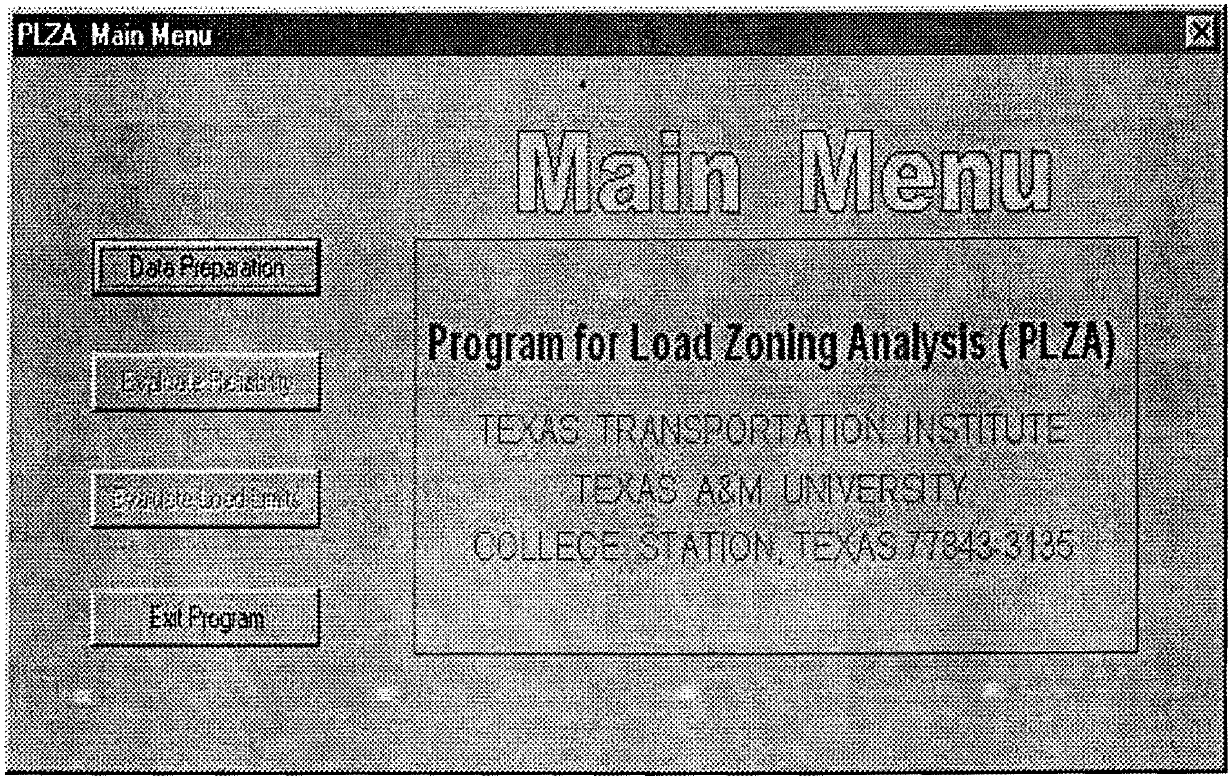


Figure 2. Initial Main Menu of PLZA Program.

After clicking on the ***Data Preparation*** button in Figure 2, the program prompts for the file of backcalculated layer moduli generated from the MODULUS program. The dialog box in Figure 3 is displayed on screen for the user to enter the name of the MODULUS output file. Click on the input field in the dialog box and type in the name of the output file corresponding to the analysis segment. If the program was used previously, the dialog box will display the MODULUS output file name used in the last analysis. You may overwrite this

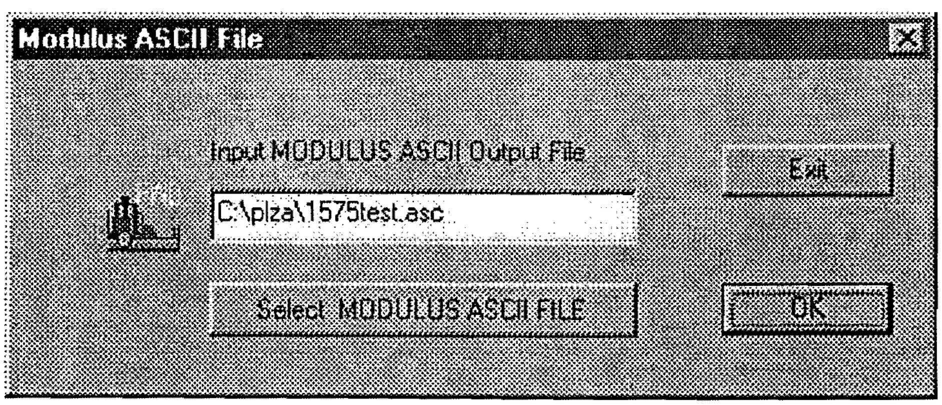


Figure 3. Dialog Box to Specify MODULUS Output File Name.

as appropriate or search your computer for the MODULUS file by clicking on the ***Select MODULUS ASCII FILE*** button of the dialog box in Figure 3. This will bring up another screen (Figure 4) from which you may browse the drives and subdirectories of your computer to search for the MODULUS output file of interest and select it for the load-zoning analysis. Note that if there are MODULUS ASCII (*.ASC) files in the subdirectory where the PLZA program is installed, the names of these files are displayed, as illustrated in Figure 4. You may select a file by first clicking on its name in the dialog box, and then on the ***Open*** button. The dialog box in Figure 3 is again displayed with the name of the selected file. To use this file in the load-zoning analysis, click on the ***OK*** button of the dialog box. PLZA then reads the file and displays the information illustrated in Figure 5. At the bottom of this dialog box are information on the name of the selected MODULUS ASCII file, the number of stations tested, and the district and county numbers read from the file. You are to use this menu to select the FWD test data that will be analyzed in the program. Two selection methods are available, as shown in Figure 5. You may specify the range of data to analyze by beginning and ending station numbers (the default choice in the PLZA program) or by milepost limits.

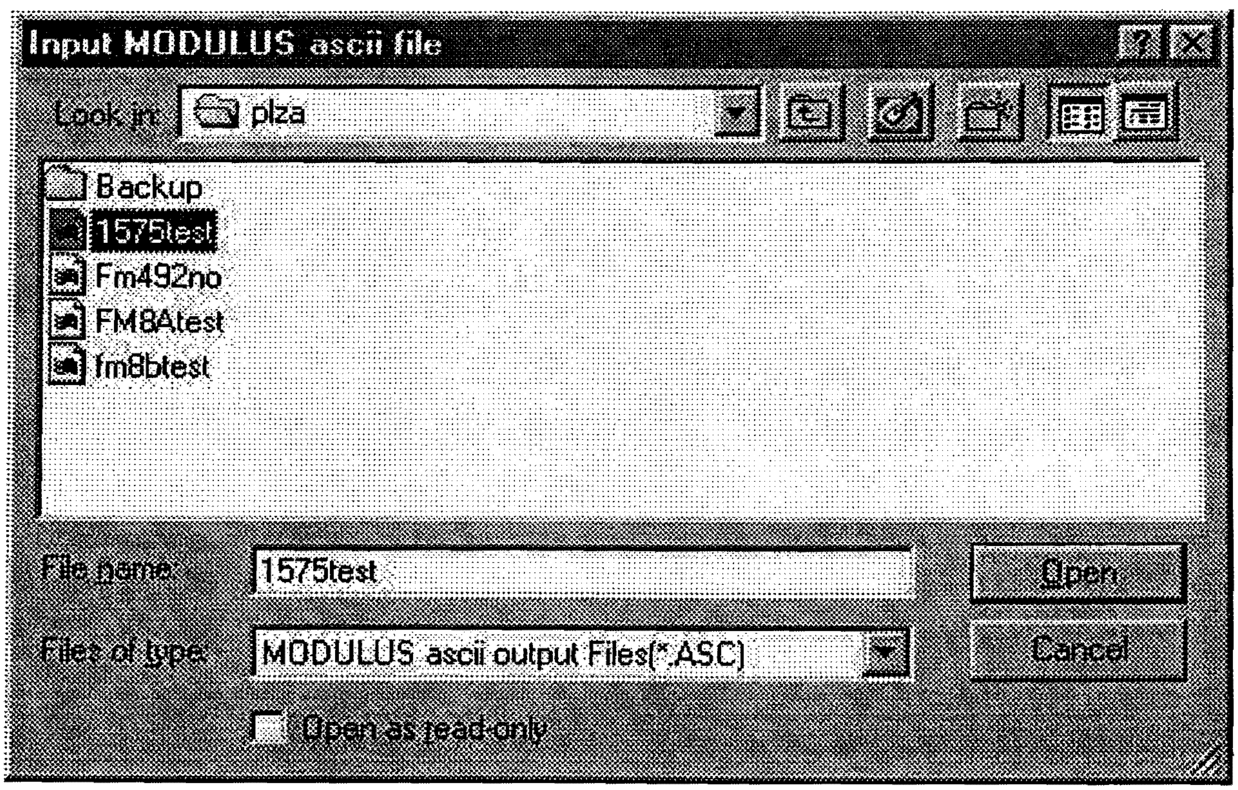


Figure 4. Dialog Box to Search for MODULUS ASCII Files for Load-Zoning Analysis.

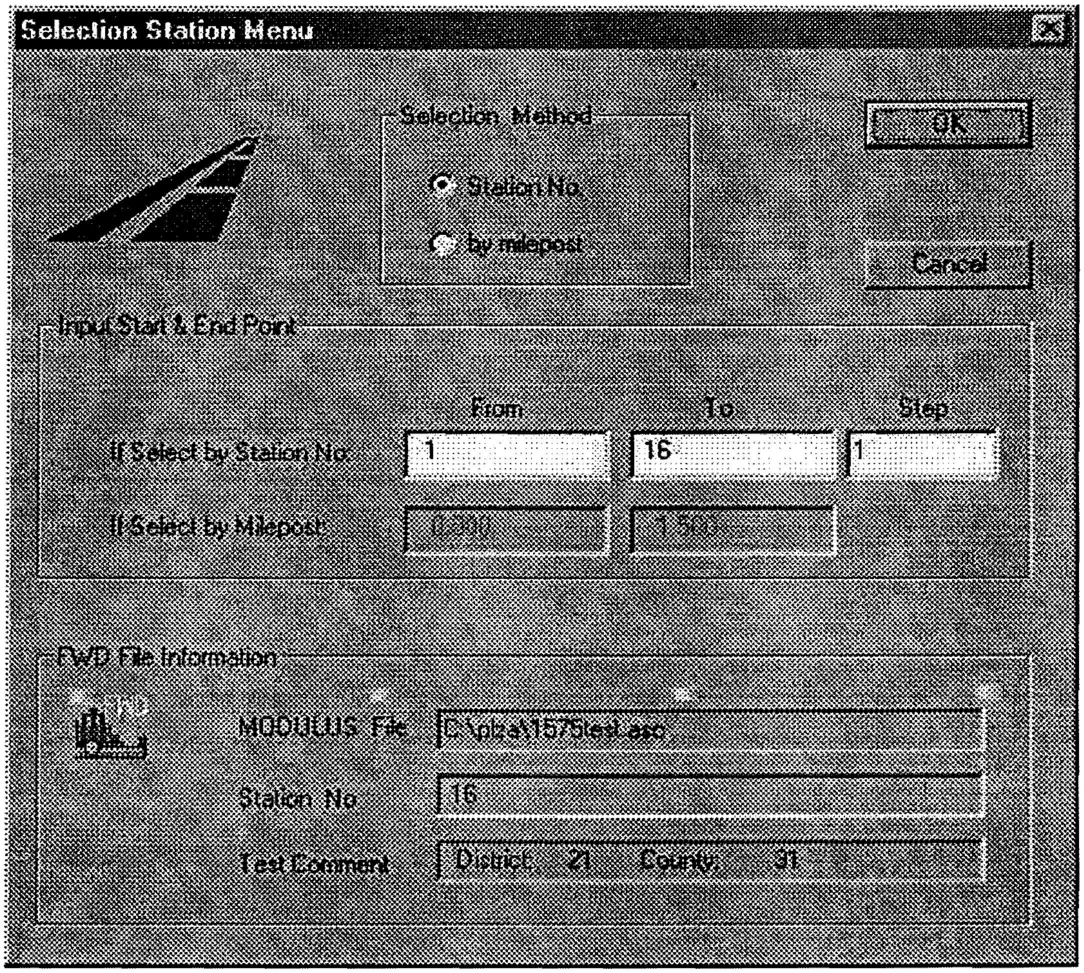


Figure 5. Dialog Box for Selecting FWD Data to Analyze in PLZA.

Note that the station numbers refer to the order in which the deflection data are written in the MODULUS output file. If the selection method is by station number, you specify the beginning and ending station numbers that define the range of locations to analyze in the program. This option also allows you to specify the analysis frequency by entering a step size in the dialog box shown in Figure 5. For the example given, the load-zoning analysis will use the backcalculated layer moduli at each of 16 stations where FWD data were collected and make predictions of pavement life at each of these locations. If a step size of two was specified, then the analysis would be made for every other station.

The range of locations to analyze may also be defined by entering the beginning and ending milepost limits. Click on the ***by milepost*** option of the dialog box and type in the beginning and ending milepost limits in the ***From*** and ***To*** fields, respectively, of the dialog box. By default, the program will show the milepost limits that cover the entire range of data in the MODULUS output file. You may choose these limits to analyze all locations where FWD deflections were measured or type in different limits corresponding to the interval within the section or route that you want to analyze. After specifying the analysis interval and frequency, click on the ***OK*** button of the dialog box to continue with the program. The screen given in Figure 6 is then displayed. This figure shows the pavement layering as read from the MODULUS output file. The following information is given:

1. layer thicknesses;
2. the modulus search range used in the backcalculations, as defined by the minimum and maximum moduli values specified for each layer; and
3. the Poisson's ratio of each layer.

No user input is required in the screen shown in Figure 6. However, it does provide information that is used in the PLZA program to predict pavement response under surface wheel loads, specifically the layer thicknesses and Poisson's ratios. By looking at the minimum and maximum values specified for the layer modulus, the user is also able to establish whether any of the pavement layer moduli were fixed in the backcalculations. In the example given in Figure 6, the surface layer modulus was fixed at a value of around 350 ksi when the FWD data were analyzed using MODULUS. This is because the surface is only

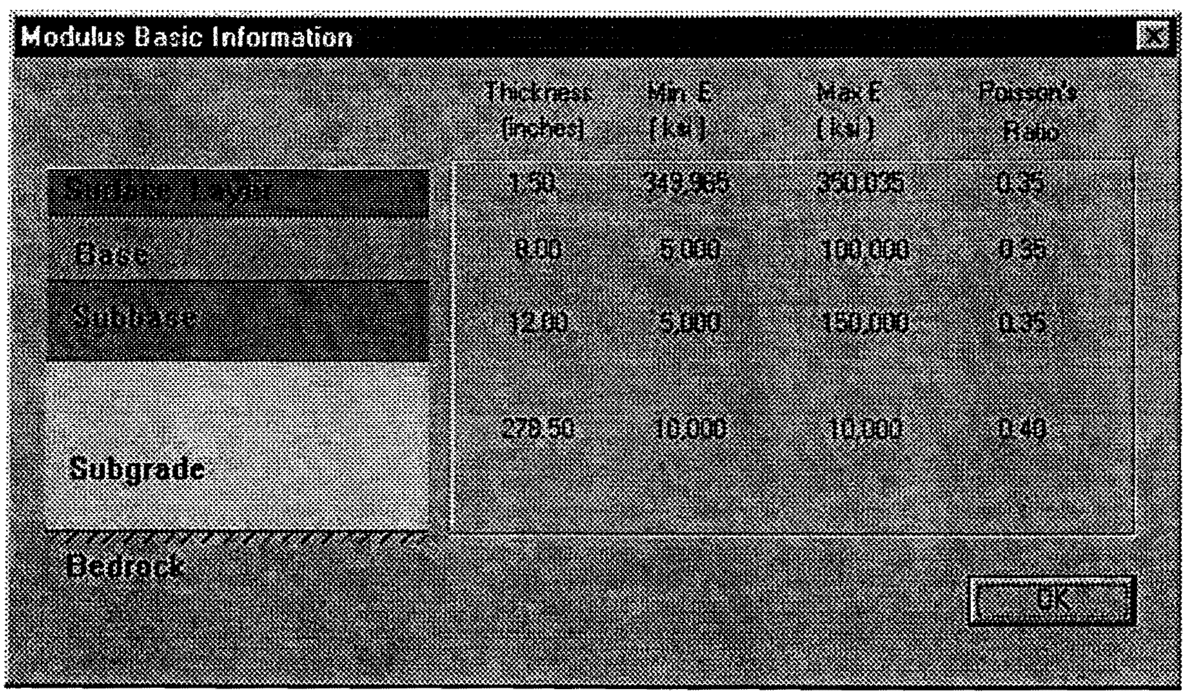


Figure 6. Pavement Layering Information Read from the MODULUS Output File.

1.5 in thick, as shown in Figure 6. For thin-surfaced pavements, the predicted surface deflections are relatively less sensitive to changes in the surface modulus based on layered elastic theory which underlies the MODULUS program. Thus, the surface modulus is typically fixed to a reasonable value in the backcalculation of layer moduli from surface deflections taken on thin-surfaced pavements. While this may be appropriate for this application, the predicted service life is influenced, to a significant degree, by the surface modulus because of its effect on the predicted service life. In fact, the surface modulus is an independent variable in the Asphalt Institute equation used in PLZA for predicting service life based on fatigue cracking.

Figure 7 illustrates the effect of surface modulus on service life predictions from the Asphalt Institute equations for fatigue cracking and rutting. The data shown were obtained from a layered elastic analysis of a three-layer flexible pavement with a 2-in surface, where the surface modulus was varied from 200 to 1000 ksi, and all the other factors were held constant. Figure 7 shows that the service life predictions, in terms of allowable 18-kip single axle load applications, are significantly influenced by the surface modulus. Thus, it is important (for load-zoning analysis) that the surface modulus is assigned a value (during the backcalculation) appropriate for the particular mix and pavement temperature at which the FWD data were collected.

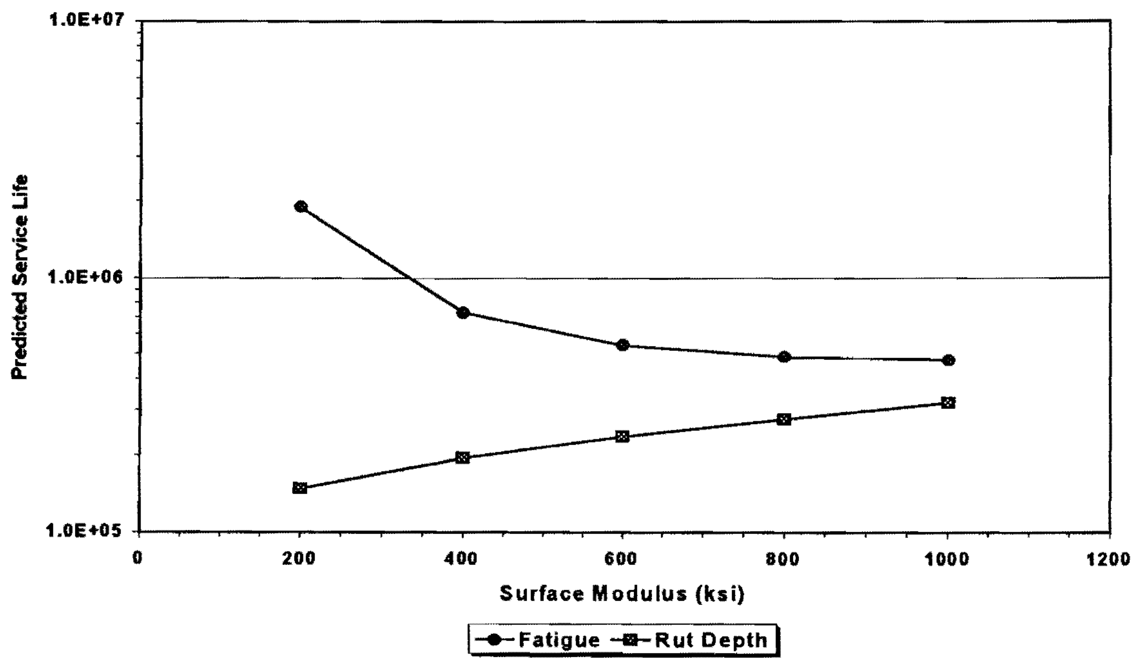


Figure 7. Illustration of Effect of Surface Modulus on Predicted Service Life.

After viewing the information in Figure 6, click on the *OK* button to leave this screen. The next window (Figure 8) allows the user to view the following information on each FWD test location selected in the dialog box given in Figure 5:

1. measured sensor deflections, R1 to R7;
2. backcalculated layer moduli, E1 to E4;
3. absolute error per sensor (Err/Sens) from the backcalculation; and
4. predicted depth to bedrock (DB).

The above information is read from the MODULUS output file and displayed by the PLZA program. You can go through each selected FWD test location using the buttons located on the right side of the window. Clicking on ***First*** displays the data for the first FWD station you selected. ***Prev*** displays the data for the previous station (relative to the current station that is displayed), while ***Next*** displays the data for the following station. ***Last*** displays the data for the last station in the range of locations specified by the user for the analysis.

The screen in Figure 8 also permits the user to correct the backcalculated layer moduli to a reference temperature of 75 °F. If you want a temperature correction done on the

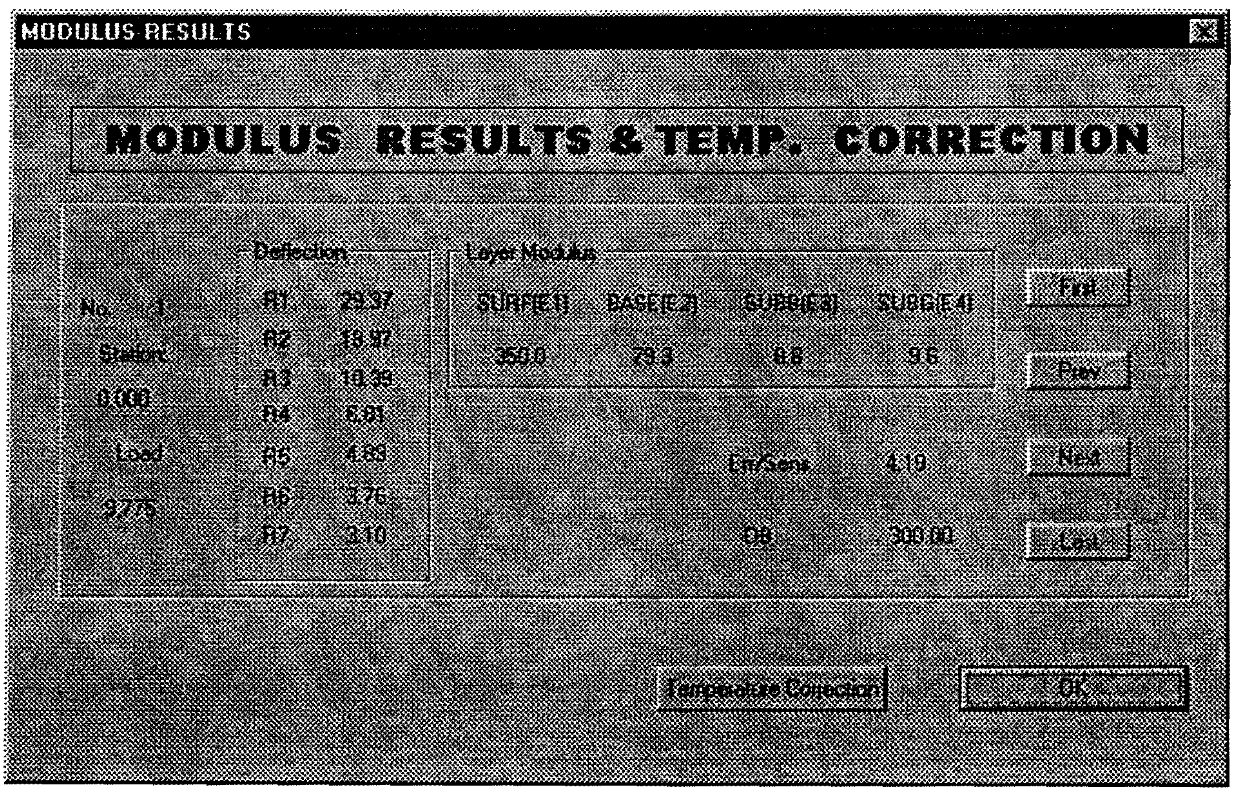


Figure 8. Window for Viewing FWD Data on Selected Test Locations.

MODULUS results, click on the ***Temperature Correction*** button in Figure 8. This will display the dialog box in Figure 9. In this screen, you enter the pavement temperatures in °F at the beginning and ending stations of the interval to be analyzed. A linear interpolation is then done in the computer program to estimate the pavement temperatures at the time of testing for the stations within the beginning and ending limits specified in Figure 9. These pavement temperatures are then used with the following equation to determine a correction factor (*CF*) that is applied to the backcalculated asphalt concrete modulus at a given station to correct its value to the reference temperature of 75 °F:

$$CF = \frac{(T_{FWD})^{2.81}}{185{,}000} \tag{2}$$

where T_{FWD} is the pavement temperature in °F at the time of FWD testing. For the purpose of temperature correction, the analysis interval specified in Figure 5 may further be subdivided into subsections to better characterize the pavement temperature variation at the time of the

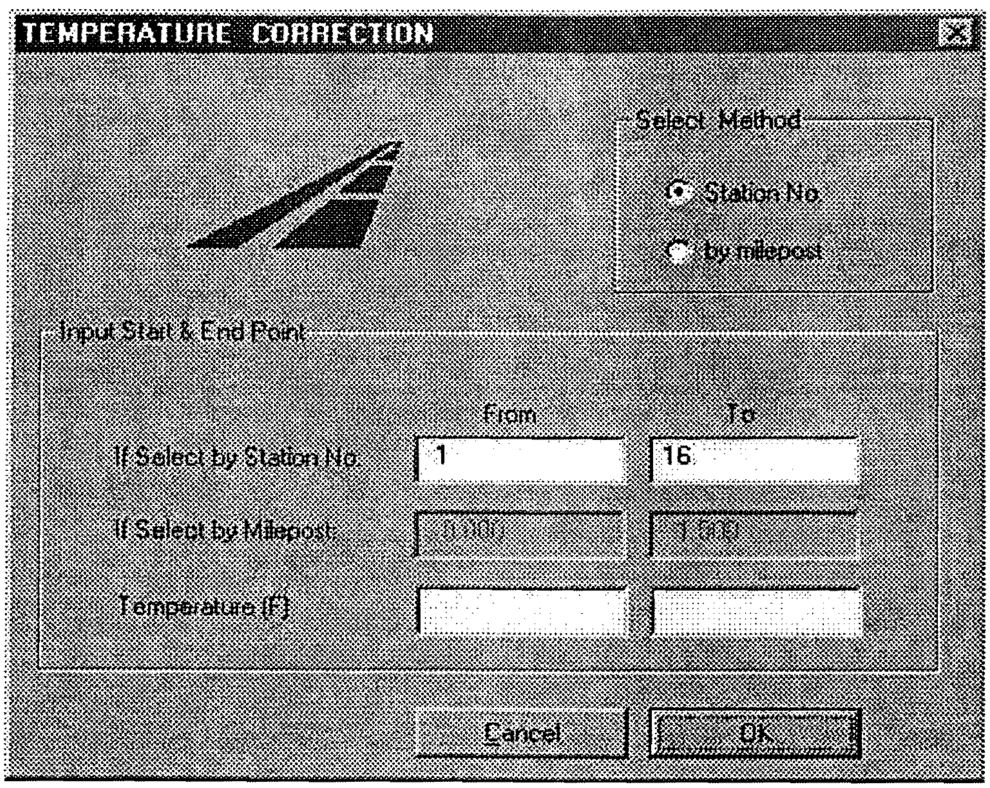


Figure 9. Temperature Correction of Asphalt Concrete Modulus.

FWD tests. This is accomplished by specifying the beginning and ending locations of the subsections and the corresponding pavement temperatures at these locations in the dialog box given in Figure 9. After specifying the temperature range for a given subsection, click on the ***OK*** button in Figure 9 to go back to the screen in Figure 8. You may then view from this screen the corrected asphalt concrete (AC) moduli for the subsection. To establish the temperature variation for another subsection, click again on the ***Temperature Correction*** button in Figure 8. This will bring back the screen in Figure 9 where you may enter the temperature range for another subsection. Then, click on ***OK*** to view the temperature corrected AC moduli from the screen shown in Figure 8. Keep repeating this sequence until the temperature correction for all subsections you want established is completed. At that point, the user-interface screen in Figure 8 will be active. Click on the ***OK*** button of this screen to proceed to the next step.

The screen shown in Figure 10 will then be displayed. On this screen, you specify the K_2 and K_3 values that define the stress dependency of the pavement materials in the route or segment to be analyzed. By default, the value of these coefficients is zero, corresponding to a linear elastic material. PLZA allows you to model stress-dependent materials by specifying the appropriate K_2 and K_3 values. The ranges of these coefficients for a number of base and subgrade materials used in Texas are given in Tables 2 and 3. After specifying the

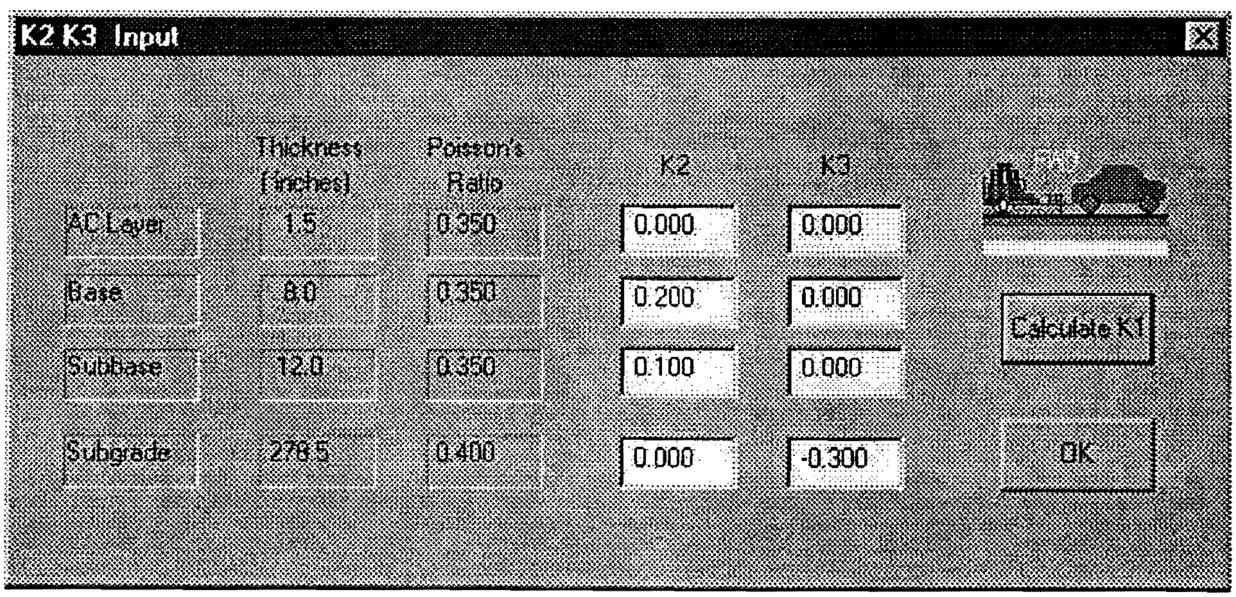


Figure 10. User-Interface Screen for Specifying K_2 and K_3 Values.

Table 2. Laboratory Test Values of K_2 and K_3 for Some Base Materials (Glover and Fernando, 1995).

Material Type	K_2			K_3		
	- opt.	at opt.	+ opt.	- opt.	at opt.	+ opt.
Caliche	1.18	0.83	0.19	0.00	0.00	0.00
Iron Ore Gravel	0.60	0.49	0.56	0.00	0.00	0.00
Shell Base	1.10	0.60	0.78	0.00	0.00	0.00
Crushed Limestone	0.90	0.90	-	-0.33	-0.33	-
Average	0.95	0.71	0.51	-0.33	-0.33	0.00
Std. Dev.	0.22	0.17	0.24	0.00	0.00	0.00

Table 3. Laboratory Test Values of K_2 and K_3 for Some Subgrade Materials (Glover and Fernando, 1995).

Material Type	K_2			K_3		
	- opt.	at opt.	+ opt.	- opt.	at opt.	+ opt.
Sand	0.44	0.51	0.40	0.00	0.00	-0.03
Sandy Gravel	0.63	0.67	-	-0.10	-0.28	-
Lean Clay	0.00	0.32	0.10	-0.27	0.10	-0.55
Fat Clay	0.66	1.25	0.66	-1.47	-0.50	-0.17
Silt	1.19	0.52	0.50	-0.11	-0.20	-0.10
Averages for Sandy Materials	0.53	0.59	0.40	-0.05	-0.14	-0.03
Std. Dev. for Sandy Materials	0.09	0.08	0.00	0.05	0.14	0.00
Averages for Clayey Materials	0.62	0.70	0.42	-0.62	-0.20	-0.27
Std. Dev. for Clayey Materials	0.49	0.40	0.24	0.61	0.24	0.20

coefficients for each layer, click on the ***Calculate*** K_1 button to estimate the K_1 values. This is done for each FWD station through layered elastic analysis using the specified K_2 and K_3 values, backcalculated layer moduli, and the FWD load used in the backcalculation. After the K_1 coefficients are calculated, a message box appears on screen notifying the user of the completion of this step. Click on the K_1 ***Calculation Finished*** button of the message box, and then on the ***OK*** button of the screen in Figure 10 to get back to the Main Menu of PLZA.

At this point, the material parameters and layer thicknesses have been specified or determined. To establish the need for load restrictions, click on the ***Evaluate Reliability*** button of the Main Menu in Figure 11. The menu shown in Figure 12 is displayed. The buttons in this menu are used for the following purposes:

1. to define truck traffic characteristics (***Input Design Load*** and ***Input Traffic Information***),
2. to evaluate the need for load restrictions (***Evaluate Reliability***),
3. to display and save the results from the evaluation (***List Results*** and ***Write Results to File***), and
4. to get a hard copy of the output (***View & Print Output File***).

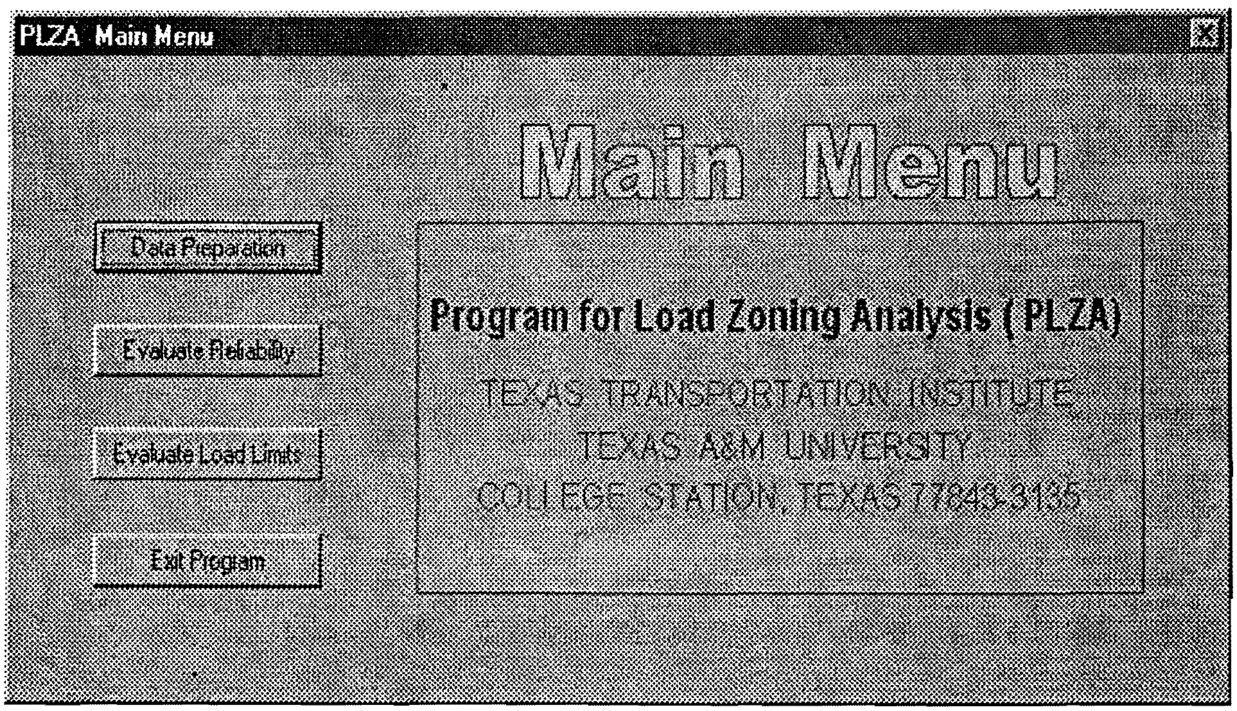


Figure 11. PLZA Main Menu after Data Preparation Step.

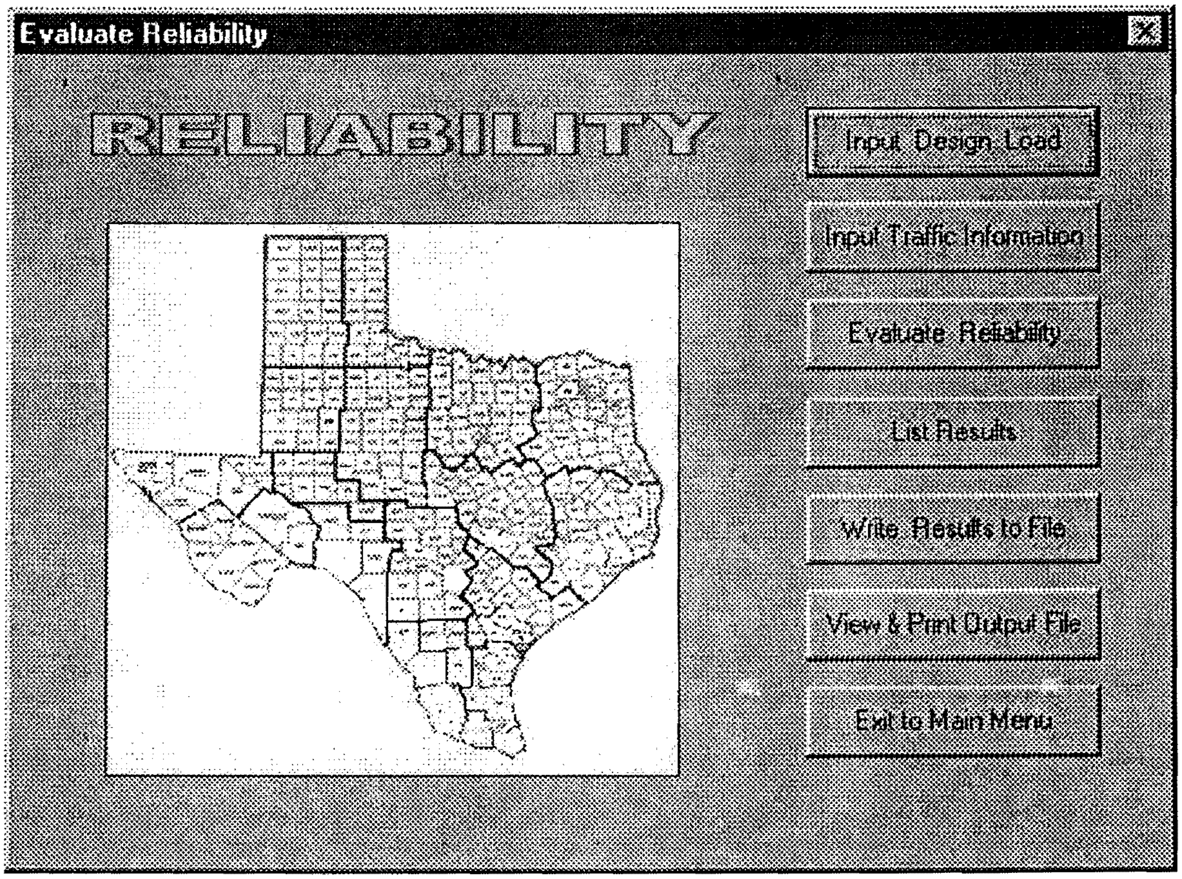


Figure 12. The Evaluate Reliability Menu in PLZA.

The truck traffic characteristics that are input to PLZA define the load geometry, load magnitudes, and the cumulative number of load applications during the prescribed design period. By clicking on the ***Input Design Load*** button of the menu in Figure 12, the user may specify the load geometry and load magnitudes for the analysis. The required data, shown in Figure 13, are the:

1. tire contact pressure,
2. dual tire spacing,
3. spacing between axles of a tandem axle group,
4. design single axle load, and
5. design tandem axle load.

The design axle loads that are input in Figure 13 should correspond to magnitudes that, in your judgment, characterize the truck traffic using the route. If axle load distribution data are available, these design loads may correspond to averages of the single and tandem

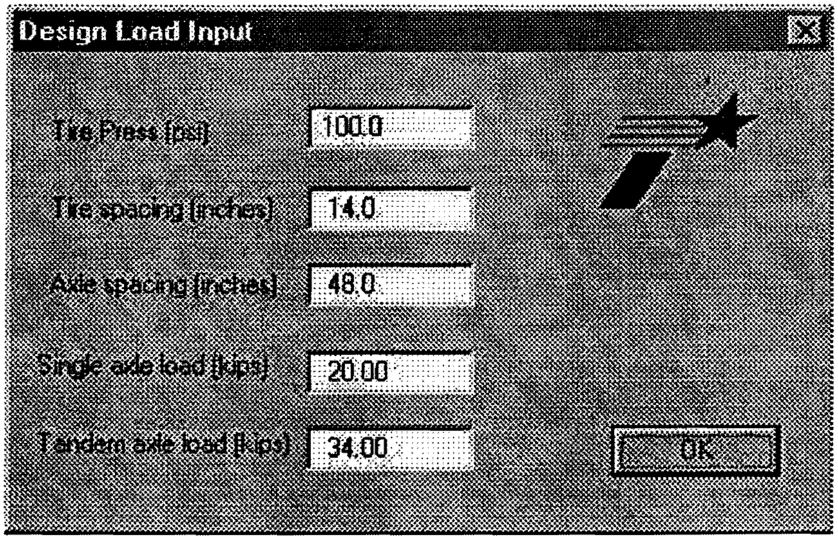


Figure 13. Screen for Entering Data on Load Geometry and Magnitudes.

axle loads weighted by the number of load applications. They may also correspond to selected percentiles of the single and tandem axle load distributions, or to the legal single and tandem axle load limits if your aim is to establish whether the route can carry truck traffic at the legal limits for the design period of interest. This design period is defined in the user-interface screen given in Figure 14 that is accessed by clicking on the ***Input Traffic Information*** button of Figure 12. The traffic information entered in Figure 14 is used to establish the cumulative single and tandem axle load applications during the prescribed design period. In order to calculate the cumulative axle load applications, the following data are required:

1. beginning and ending ADT values,
2. length of design period,
3. directional factor,
4. percent trucks in the traffic stream,
5. average number of axle groups per truck,
6. percent of axle groups that are singles, and
7. percent of axle groups that are tandems.

To illustrate the meaning of the average axles per truck in Figure 14, assume that the trucks using a given route consist of conventional tractor-semitrailers (3S2s) and single unit

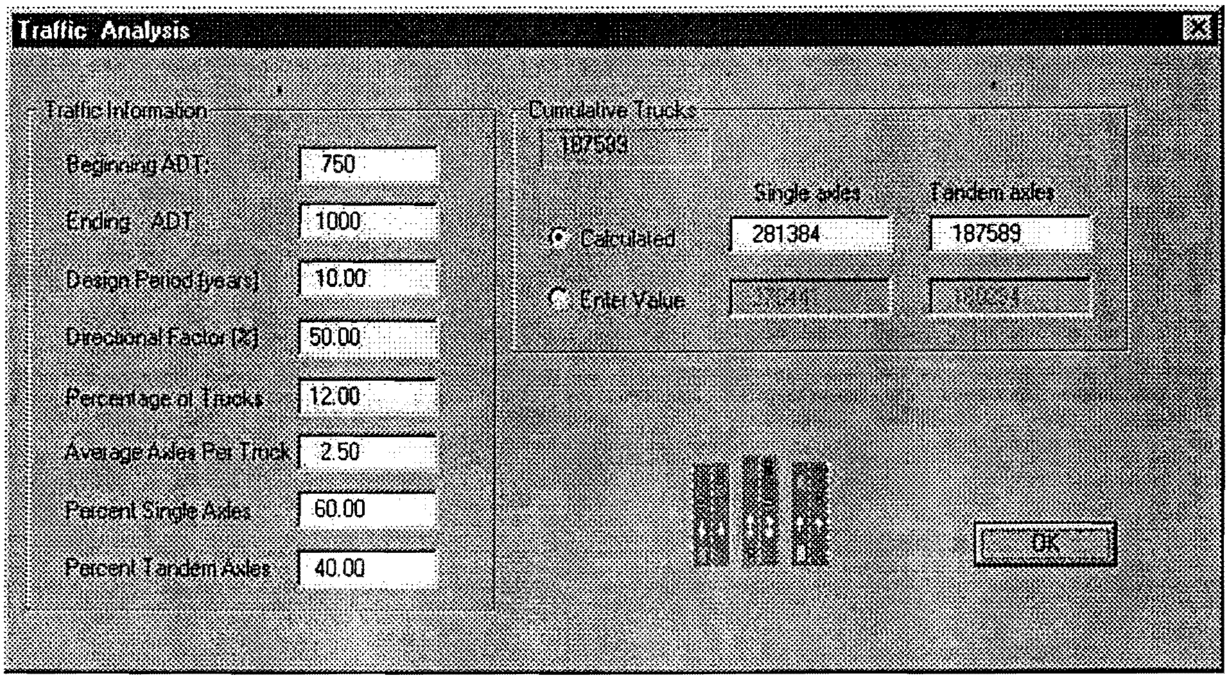


Figure 14. Input Screen for Establishing Cumulative Axle Load Applications.

trucks with tandem drive axles (3As). If the distribution of trucks is 75 percent 3S2s and 25 percent 3As, then the average number of axle groups per truck is calculated as 2.75, as shown in the following:

Table 4. Calculation of the Average Number of Axle Groups per Truck.

Truck category *(1)*	Number of axle groups *(2)*	Percentage of truck distribution *(3)*	Average number of axle groups for truck category *(2) x (3)/100*
3S2	3	75	2.25
3A	2	25	0.50
Average number of axle groups per truck			2.75

The cumulative number of single and tandem axle load applications calculated from the traffic data entered in Figure 14 incorporate a traffic growth factor consistent with the specified beginning and ending ADTs, and the duration of the design period. In lieu of calculating the cumulative load applications, Figure 14 also permits the user to specify these numbers directly. To do this, simply click on the ***Enter Value*** option of the screen and type in the cumulative number of load applications for both single and tandem axles. When done, click on the *OK* button to go back to the menu given in Figure 12. At this point, all input data to evaluate the need for load restrictions have been specified. To run the analysis, click on the ***Evaluate Reliability*** button of Figure 12. The user will then be asked to specify the limit on the number of iterations available to the program to achieve convergence for stress-dependent moduli. This limit is specified by choosing one of the options shown in Figure 15. By default, the maximum number of iterations is set at 1000. Note that this is only an upper limit. The program may actually take a much smaller number of iterations to achieve convergence, and for problems where all layers are characterized as linear elastic, no iterations are made.

Once the limit is set in Figure 15, the evaluation begins. Each FWD test location is analyzed as indicated in Figure 16, which shows how much of the evaluation is complete at any given time. During this evaluation, the following calculations are made:

1. At each selected FWD test location, the allowable number of load repetitions are determined using the Asphalt Institute equations for fatigue cracking and rutting. These predictions are made for both the design single and tandem axle loads defined in the analysis. The service life based on fatigue cracking, $(N_f)^c$, is predicted from the equation:

$$(N_f)^c = 7.9488 \times 10^{-2} \left(\frac{1}{\varepsilon_{ac}}\right)^{3.29} \left(\frac{1}{E_{ac}}\right)^{0.854} \tag{3}$$

where ε_{ac} = tensile strain at the bottom of the asphalt surface layer, and
E_{ac} = asphalt concrete modulus.

The service life based on rutting, $(N_f)^r$, is determined from:

$$(N_f)^r = 1.365 \times 10^{-9} \left(\frac{1}{\varepsilon_{sg}}\right)^{4.477} \tag{4}$$

where ε_{sg} is the vertical compressive strain at the top of the subgrade. In the program, the strains induced under loading are determined at a number of lateral offsets beneath the wheel loads. These positions correspond to the outside tire

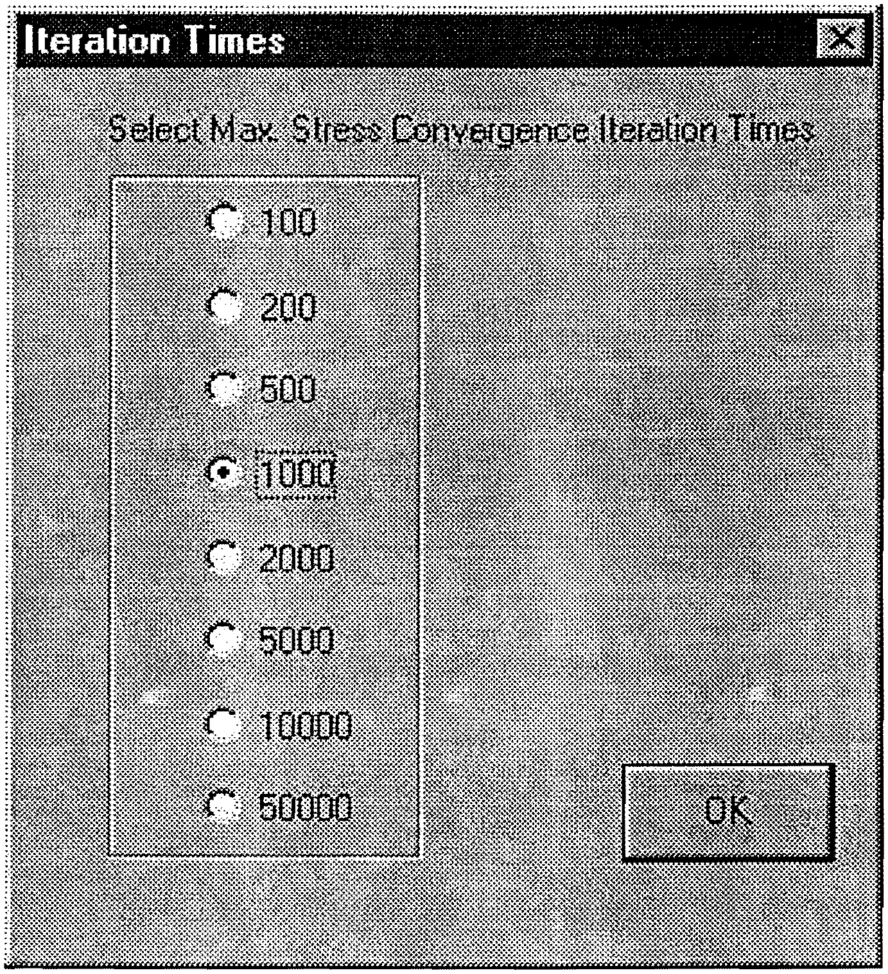


Figure 15. Screen to Specify the Maximum Number of Iterations for Convergence of Stress-Dependent Moduli.

edge, middle of a tire, inside tire edge, and midway between the dual tires for a single axle configuration. For a tandem axle assembly, the strains are also predicted at these lateral offsets beneath the dual tires and at a distance corresponding to half the axle spacing. The maximum predicted asphalt tensile strain and subgrade vertical compressive strain are used in PLZA to predict the allowable number of repetitions of the design axle loads.

2. The ratio of the expected number of yearly load applications to the allowable number of repetitions prior to failure is computed for each axle configuration (single and tandem). This ratio is an estimate of the life consumed per year of the design period for the given axle configuration and load, and for the given failure criterion (fatigue cracking or rutting). Assuming Miner's hypothesis, the

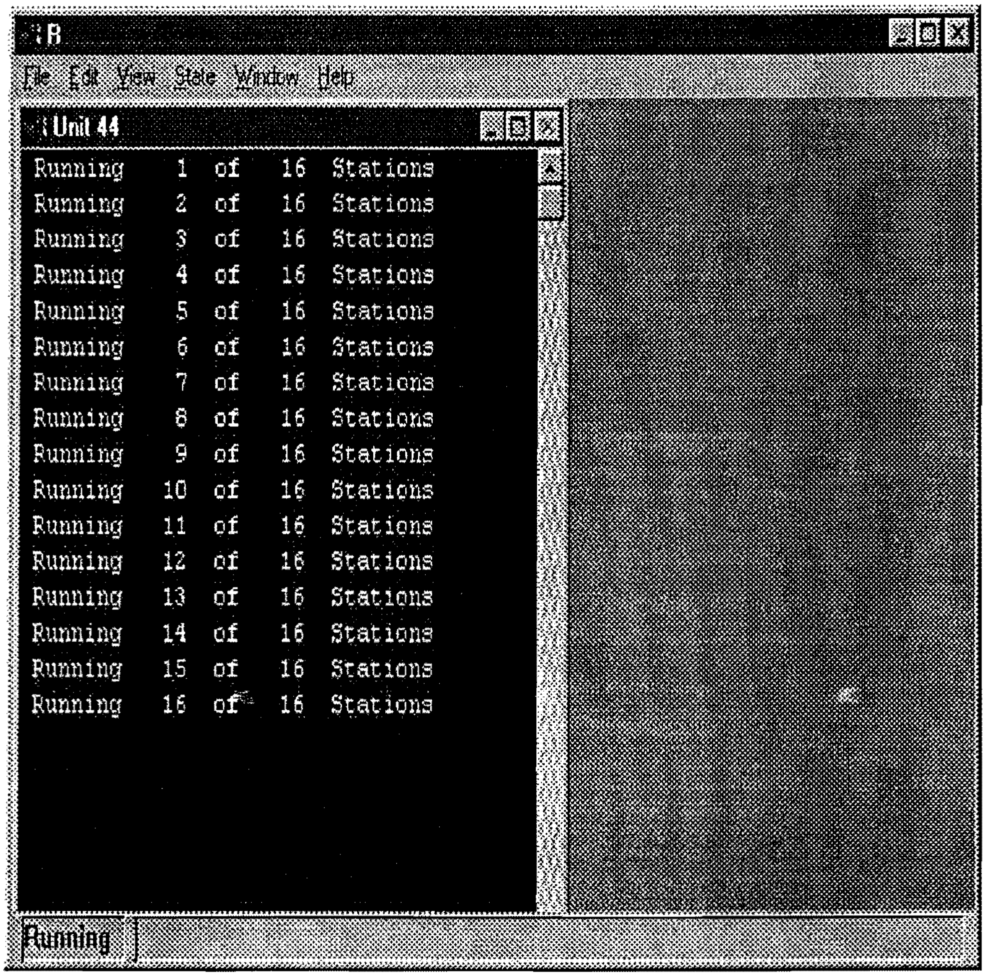


Figure 16. Display Screen Showing Completion of Analysis for Each FWD Station.

computed damage ratios for both axle configurations are summed to determine the yearly service life consumption for each failure criterion. Thus, at each selected FWD station, predictions of service life (in years) are determined.

3. The service life predictions for the route or segment analyzed are then used to compute the probability P_{fail} that the service life is less than the design period. Pavement reliability R is then evaluated as $1 - P_{fail}$.

The reliability from PLZA is used to establish the need for load restrictions on the route or segment analyzed. This computed reliability is compared with the desired or target value which may be tied to the roadway functional classification. For low-volume farm-to-market roads typical of most load-zoned roads in Texas, a desired reliability level within the range of 60 to 80 percent may be appropriate to establish the need for load zoning. On the other hand, existing load-zoned roads that have been upgraded through rehabilitation or reconstruction may require a higher level of reliability, within the range of 70 to 90 percent, particularly if the improvements were made in anticipation of an increase in the level of use of the given route.

The service life predictions are plotted on screen for both fatigue cracking and rutting criteria. Figure 17 illustrates the output from the evaluation of pavement reliability. The circles in the figure are the predicted service lives based on cracking while the squares are the predictions based on rutting. For comparison, the specified design period is also plotted as a horizontal line.

For reporting purposes, an upper limit of 40 years is imposed on the performance predictions. However, in evaluating reliability, the actual values of the predicted service lives are used. The chart in Figure 17 may be printed by clicking on ***File*** at the top of the figure and selecting the ***Print*** option (Figure 18). For identification purposes, the name of the MODULUS ASCII file is printed at the top of the chart, along with the date and time of the analysis. In addition to printing, the chart may be saved as a bitmap file by using the ***Save*** option within the ***File*** function. This graphics file may later be imported into a document reporting the results of the load-zoning analysis.

To clear the chart from the screen, double click on it as instructed at the bottom right of the figure. The reliability statistics will then be displayed, as illustrated in Figure 19. The minimum of the computed statistics is reported as the pavement reliability. This should be compared with the desired reliability level to determine whether load restrictions are necessary on the route evaluated.

In addition to the chart, the results for each FWD station may be viewed using the ***List Results*** option of the reliability analysis menu given in Figure 12. The information provided for each station is shown in Figure 20 which illustrates the screen displayed after clicking on ***List Results*** of the menu in Figure 12. For each FWD station, the following information is provided:

1. layer moduli backcalculated from FWD deflections,
2. K_1 coefficients backcalculated from the layer moduli and the K_2 and K_3 coefficients specified by the user,
3. service life predictions for both fatigue cracking and rutting criteria, and
4. the prescribed design period.

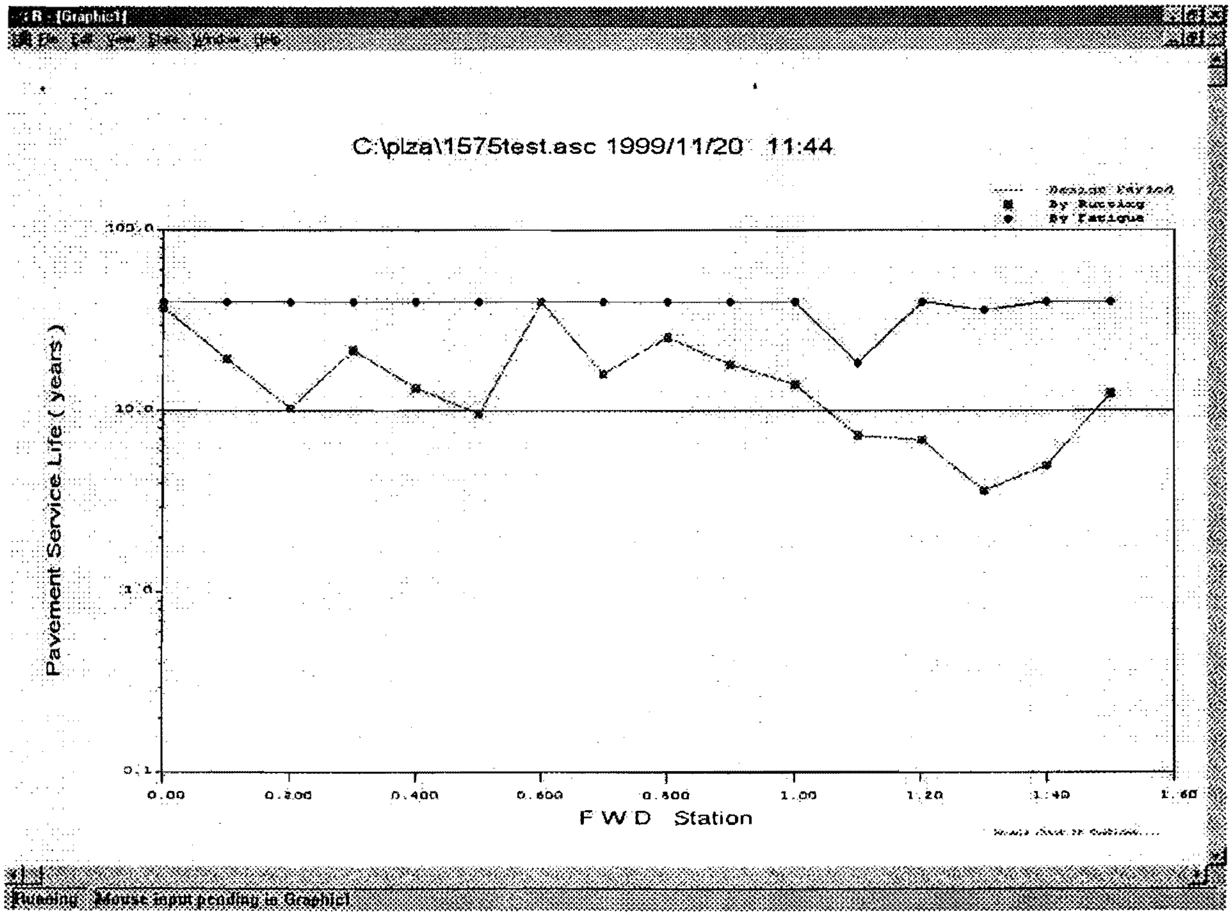


Figure 17. Plot of Performance Predictions from the Reliability Analysis.

The user may view the results for individual stations using the ***First***, ***Last***, ***Previous***, and ***Next*** buttons of Figure 20, which function as described previously. There is also an output field labeled ***Result*** which shows whether the pavement at the given location is adequate to handle the expected traffic loadings based on the performance predictions. If the pavement is predicted to fail during the prescribed design period, a message is displayed which shows the predicted mode of failure (fatigue cracking or rutting) at the given FWD test location.

The ***Other Info*** button in Figure 20 may be used to view other data that are common to all FWD stations selected for the analysis. These other data are identified in Figure 21. For each pavement layer, the thickness, Poisson's ratio, and K_2 and K_3 values are displayed on the screen.

To save the results from the reliability analysis, click on the ***Write Results to File*** button of the menu given in Figure 12. A dialog box will be displayed for the user to specify

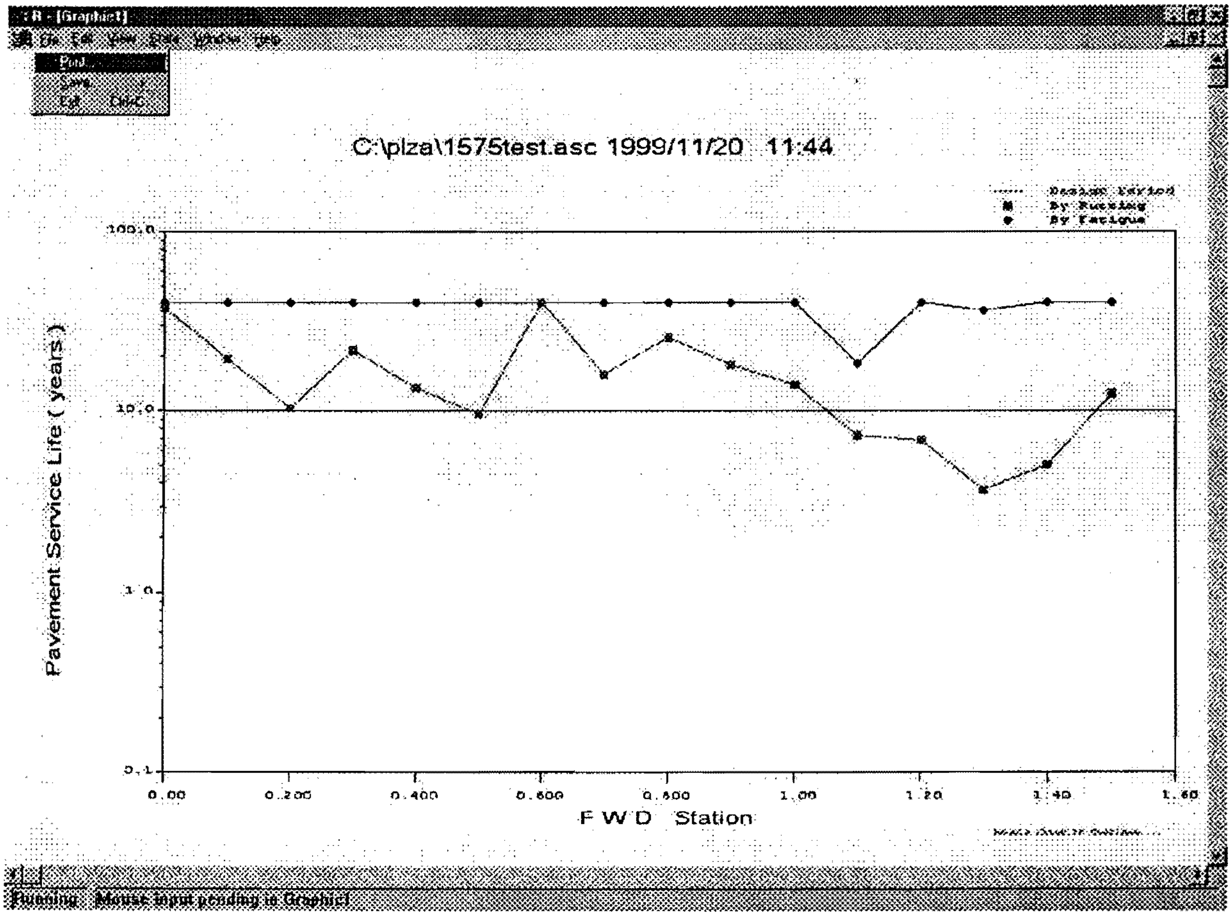


Figure 18. Using the *File* Function to Print or Save the Reliability Analysis Chart.

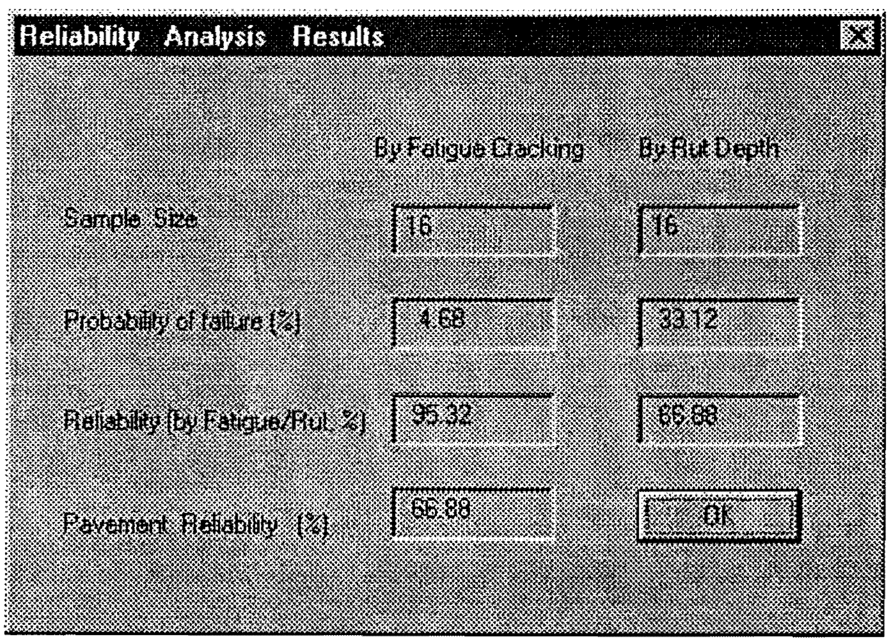


Figure 19. Screen Showing Computed Reliability Statistics.

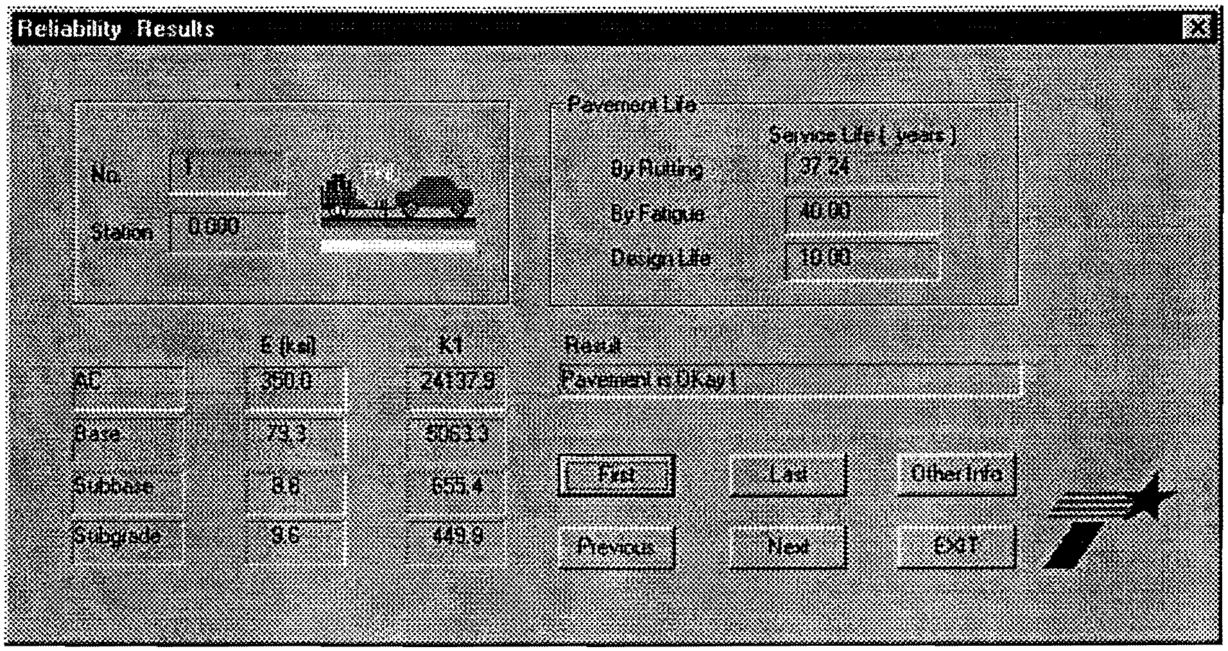


Figure 20. Data Displayed on Each FWD Station in the *List Results* Option.

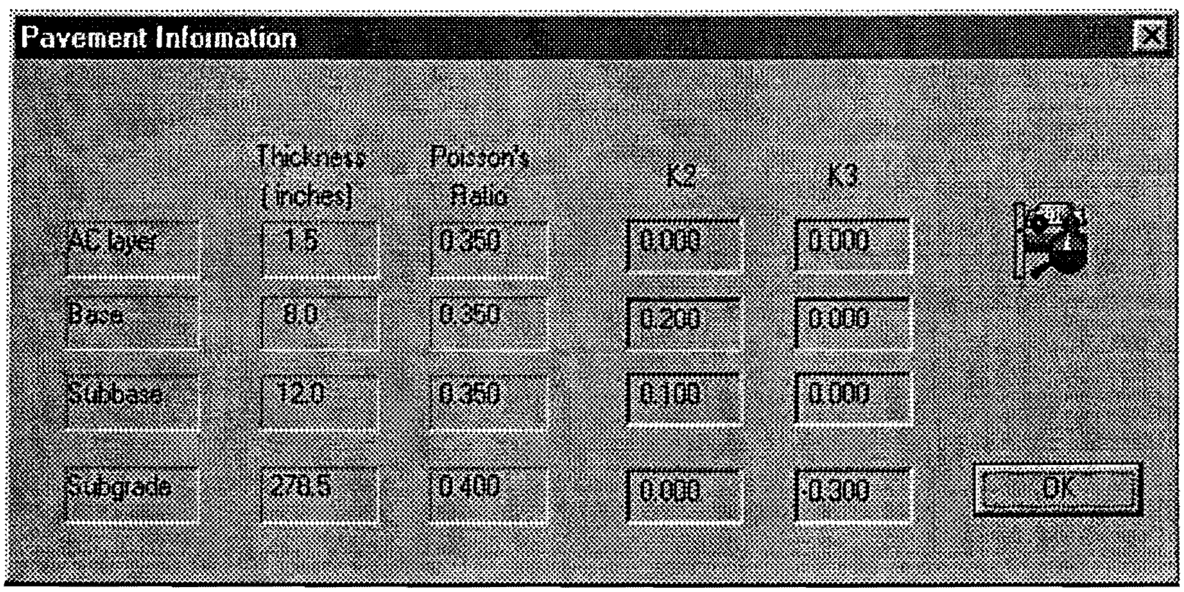


Figure 21. Pavement Data Common to All FWD Stations Displayed under the *List Results* Option.

the name of the output file. By default, the output file is given the name of the MODULUS ASCII file, concatenated with the characters *REL*, as illustrated in Figure 22. The default file extension is *OUT*. After the output file is written to disk, it may be viewed on screen using the ***View & Print Output File*** option of the reliability analysis menu in Figure 12. The window illustrated in Figure 23 is then displayed. If this window happens to be displayed in the background after clicking on the ***View & Print Output File*** button, simply click on any part of the window to bring it to the foreground.

At the top of the screen, the name of the MODULUS ASCII file and the date and time of analysis are reported to help identify a particular output. In addition, the following input data are echoed for verification purposes:

1. pavement layer thicknesses,
2. the K_2 and K_3 parameters for each layer,
3. the number of FWD test locations analyzed,
4. the load geometry (dual tire spacing and axle spacing),
5. tire contact pressure, and
6. traffic data.

From the reliability analysis, the following results are also reported:

1. the computed reliability levels for both fatigue cracking and rutting criteria;
2. the reliability of the existing pavement, which is the minimum of the computed reliability statistics for fatigue cracking and rutting;
3. the number of test locations along the route where the pavement structure is predicted to be adequate for the specified axle loadings;
4. as applicable, the number of test locations where the pavement may experience failure within the prescribed design period based on fatigue cracking and/or rutting criteria; and
5. the backcalculated layer moduli, estimated K_1 values, and predicted service lives for the different FWD test locations analyzed.

You may use the vertical scroll bar of the output display window in Figure 23 to scroll up and down the output file. In addition, you may print the file by clicking on the ***Print File*** button to the right of the window. If you want to use a particular printer, click on the ***Select Printer*** button before printing the output file. You will then be presented with the printer

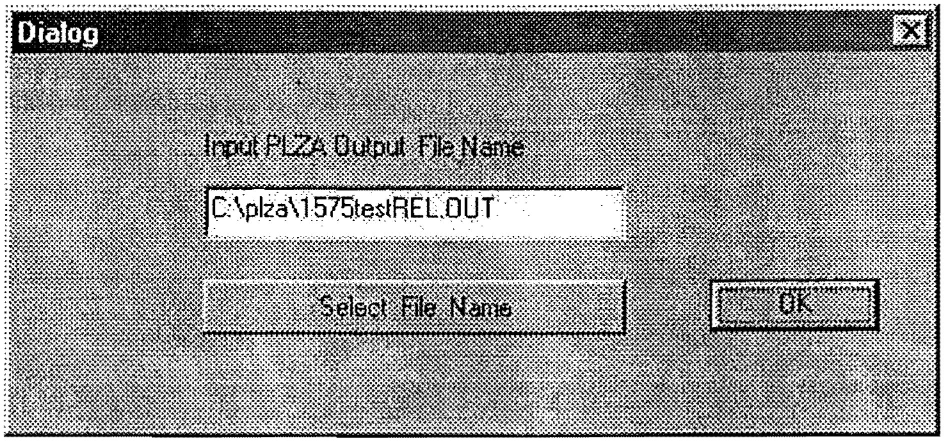
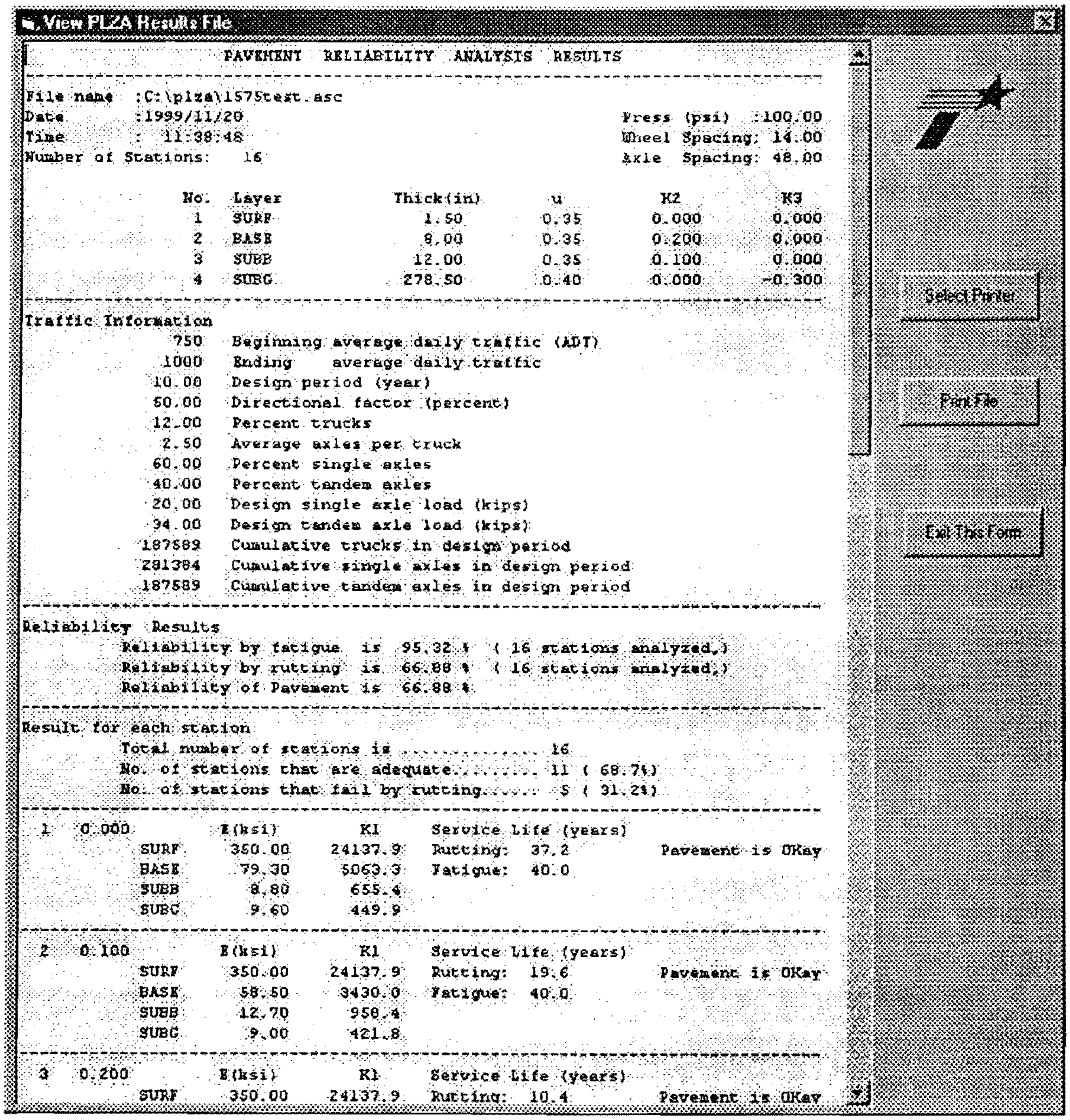


Figure 22. Dialog Box to Save Results from the Reliability Analysis.




```
                    PAVEMENT  RELIABILITY  ANALYSIS  RESULTS
--------------------------------------------------------------------------------
File name  :C:\plza\1575test.asc
Date       :1999/11/20                                    Press (psi)   :100.00
Time       :  11:38:48                                    Wheel Spacing: 14.00
Number of Stations:   16                                  Axle  Spacing: 48.00

                No.  Layer          Thick(in)      u        K2        K3
                 1   SURF             1.50       0.35     0.000     0.000
                 2   BASE             8.00       0.35     0.200     0.000
                 3   SUBB            12.00       0.35     0.100     0.000
                 4   SUBG           278.50       0.40     0.000    -0.300
--------------------------------------------------------------------------------
Traffic Information
               750   Beginning average daily traffic (ADT)
              1000   Ending    average daily traffic
             10.00   Design period (year)
             50.00   Directional factor (percent)
             12.00   Percent trucks
              2.50   Average axles per truck
             60.00   Percent single axles
             40.00   Percent tandem axles
             20.00   Design single axle load (kips)
             34.00   Design tandem axle load (kips)
            187589   Cumulative trucks in design period
            281384   Cumulative single axles in design period
            187589   Cumulative tandem axles in design period
--------------------------------------------------------------------------------
Reliability Results
          Reliability by fatigue  is  95.32 %  ( 16 stations analyzed.)
          Reliability by rutting  is  66.88 %  ( 16 stations analyzed.)
          Reliability of Pavement is  66.88 %
--------------------------------------------------------------------------------
Result for each station
          Total number of stations is ............... 16
          No. of stations that are adequate......... 11 ( 68.7%)
          No. of stations that fail by rutting...... 5 ( 31.2%)
--------------------------------------------------------------------------------
  1  0.000         E(ksi)        K1      Service Life (years)
           SURF    350.00    24137.9    Rutting:  37.2         Pavement is OKay
           BASE     79.30     5063.3    Fatigue:  40.0
           SUBB      8.80      655.4
           SUBG      9.60      449.9
--------------------------------------------------------------------------------
  2  0.100         E(ksi)        K1      Service Life (years)
           SURF    350.00    24137.9    Rutting:  19.6         Pavement is OKay
           BASE     58.50     3430.0    Fatigue:  40.0
           SUBB     12.70      958.4
           SUBG      9.00      421.8
--------------------------------------------------------------------------------
  3  0.200         E(ksi)        K1      Service Life (years)
           SURF    350.00    24137.9    Rutting:  10.4         Pavement is OKay
```

Figure 23. Viewing the Output File from the Reliability Analysis.

dialog box in Figure 24, from where you may view a list of printers defined for your computer, and select the device you want to use. You may also vary the printer settings within this dialog box. Simply go over the available options and make your selections. When done, go back to the output display window in Figure 23 and print the results by clicking on the ***Print File*** option.

Figure 25 shows an example of the printed output that may be generated from evaluating the need for load restrictions using the PLZA program. Should the results show that load restrictions are necessary on the route evaluated, the applicable axle load limits corresponding to the desired or target level of reliability are determined using the ***Evaluate Load Limits*** option of the Main Menu in Figure 11. The application of this program function is described in the succeeding chapter.

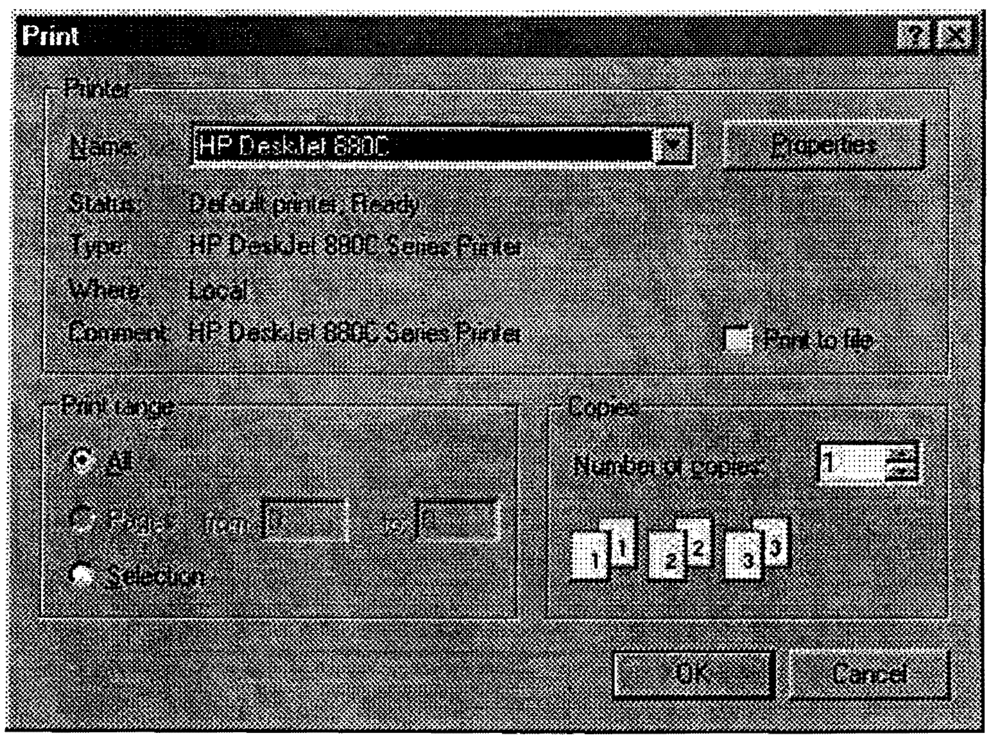


Figure 24. Printer Dialog Box.

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PAVEMENT RELIABILITY ANALYSIS RESULTS

```
File name  :C:\plza\1575test.asc
Date       :1999/11/19                                  Press (psi)   :100.00
Time       :  17:30:50                                  Wheel Spacing: 14.00
Number of Stations:   16                                Axle  Spacing: 48.00
```

No.	Layer	Thick(in)	u	K2	K3
1	SURF	1.50	0.35	0.000	0.000
2	BASE	8.00	0.35	0.200	0.000
3	SUBB	12.00	0.35	0.100	0.000
4	SUBG	278.50	0.40	0.000	-0.300

Traffic Information

750	Beginning average daily traffic (ADT)
1000	Ending average daily traffic
10.00	Design period (year)
50.00	Directional factor (percent)
12.00	Percent trucks
2.50	Average axles per truck
60.00	Percent single axles
40.00	Percent tandem axles
20.00	Design single axle load (kips)
34.00	Design tandem axle load (kips)
187589	Cumulative trucks in design period
281384	Cumulative single axles in design period
187589	Cumulative tandem axles in design period

Reliability Results

Reliability by fatigue is 95.32 % (16 stations analyzed,)
Reliability by rutting is 66.88 % (16 stations analyzed,)
Reliability of Pavement is 66.88 %

Result for each station

Total number of stations is 16
No. of stations that are adequate......... 11 (68.7%)
No. of stations that fail by rutting...... 5 (31.2%)

```
 1  0.000          E(ksi)       K1     Service Life (years)
           SURF    350.00   24137.9    Rutting:  37.2        Pavement is OKay
           BASE     79.30    5063.3    Fatigue:  40.0
           SUBB      8.80     655.4
           SUBG      9.60     449.9
-------------------------------------------------------------------------------
 2  0.100          E(ksi)       K1     Service Life (years)
           SURF    350.00   24137.9    Rutting:  19.6        Pavement is OKay
           BASE     58.50    3430.0    Fatigue:  40.0
           SUBB     12.70     958.4
           SUBG      9.00     421.8
-------------------------------------------------------------------------------
 3  0.200          E(ksi)       K1     Service Life (years)
           SURF    350.00   24137.9    Rutting:  10.4        Pavement is OKay
           BASE     45.00    2778.1    Fatigue:  40.0
           SUBB      7.90     586.7
           SUBG      8.00     374.9
-------------------------------------------------------------------------------
 4  0.300          E(ksi)       K1     Service Life (years)
           SURF    350.00   24137.9    Rutting:  21.6        Pavement is OKay
           BASE     65.60    4157.1    Fatigue:  40.0
           SUBB      8.90     668.3
           SUBG      8.70     407.7
-------------------------------------------------------------------------------
 5  0.400          E(ksi)       K1     Service Life (years)
           SURF    350.00   24137.9    Rutting:  13.5        Pavement is OKay
           BASE     43.60    2616.9    Fatigue:  40.0
           SUBB      9.40     697.7
           SUBG      8.90     417.1
```

Texas Transportation Institute   Print Time:11/20/99 11:55PM   Page: 1

Figure 25. Sample Printout of Reliability Analysis Results.

Texas Department of Transportation

PAVEMENT RELIABILITY ANALYSIS RESULTS

6	0.500		E(ksi)	K1	Service Life (years)	
		SURF	350.00	24137.9	Rutting: 9.7	Fails by rutting
		BASE	37.50	2221.6	Fatigue: 40.0	
		SUBB	9.20	681.3		
		SUBG	8.50	398.3		
7	0.601		E(ksi)	K1	Service Life (years)	
		SURF	350.00	24137.9	Rutting: 40.0	Pavement is OKay
		BASE	93.10	5265.9	Fatigue: 40.0	
		SUBB	21.00	1635.0		
		SUBG	10.40	487.4		
8	0.699		E(ksi)	K1	Service Life (years)	
		SURF	350.00	24137.9	Rutting: 16.2	Pavement is OKay
		BASE	43.10	2571.0	Fatigue: 40.0	
		SUBB	9.70	717.2		
		SUBG	9.50	445.2		
9	0.800		E(ksi)	K1	Service Life (years)	
		SURF	350.00	24137.9	Rutting: 25.5	Pavement is OKay
		BASE	46.80	2647.5	Fatigue: 40.0	
		SUBB	14.00	1035.4		
		SUBG	10.80	506.1		
10	0.900		E(ksi)	K1	Service Life (years)	
		SURF	350.00	24137.9	Rutting: 18.1	Pavement is OKay
		BASE	41.40	2313.9	Fatigue: 40.0	
		SUBB	15.30	1143.7		
		SUBG	10.00	468.6		
11	1.001		E(ksi)	K1	Service Life (years)	
		SURF	350.00	24137.9	Rutting: 13.9	Pavement is OKay
		BASE	51.10	3208.8	Fatigue: 40.0	
		SUBB	8.10	604.7		
		SUBG	8.30	389.0		
12	1.100		E(ksi)	K1	Service Life (years)	
		SURF	350.00	24137.9	Rutting: 7.3	Fails by rutting
		BASE	27.50	1563.4	Fatigue: 18.5	
		SUBB	10.10	741.1		
		SUBG	8.80	412.4		
13	1.202		E(ksi)	K1	Service Life (years)	
		SURF	350.00	24137.9	Rutting: 6.9	Fails by rutting
		BASE	41.90	2534.6	Fatigue: 40.0	
		SUBB	9.30	704.0		
		SUBG	7.20	337.4		
14	1.301		E(ksi)	K1	Service Life (years)	
		SURF	350.00	24137.9	Rutting: 3.7	Fails by rutting
		BASE	29.20	1883.5	Fatigue: 36.3	
		SUBB	5.20	386.4		
		SUBG	6.50	304.6		
15	1.401		E(ksi)	K1	Service Life (years)	
		SURF	350.00	24137.9	Rutting: 5.1	Fails by rutting
		BASE	34.50	2226.2	Fatigue: 40.0	
		SUBB	5.70	424.2		
		SUBG	6.80	318.7		
16	1.500		E(ksi)	K1	Service Life (years)	
		SURF	350.00	24137.9	Rutting: 12.4	Pavement is OKay
		BASE	40.30	2424.8	Fatigue: 40.0	
		SUBB	8.90	658.8		
		SUBG	8.90	417.1		

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Figure 25. Sample Printout of Reliability Analysis Results (Continued).

CHAPTER III

EVALUATING AXLE LOAD LIMITS

Figure 26 shows the menu for evaluating axle load limits in the PLZA program. There are six options available from this menu:

1. ***Input Minimum Reliability***,
2. ***Input Load***,
3. ***Run Load Limit Program***,
4. ***Write Results to File***,
5. ***View & Print Output File***, and
6. ***Exit to Main Menu***.

The first two options are used to establish the minimum reliability required of the route, the design single and tandem axle loads, and the cumulative axle load applications for each axle configuration. The third option runs the analysis to determine the axle load limits that satisfy the prescribed level of reliability. When this analysis is completed, the results may be saved, viewed, and printed using Options 4 and 5. The steps in the load-limit evaluation are further described in the following sections.

INPUT SCREENS FOR LOAD-LIMIT ANALYSIS

Before load limits may be evaluated, the user should first specify the minimum reliability required of the route. This is done by clicking on the ***Input Minimum Reliability*** button of the Load Limit menu in Figure 26. The user-interface screen in Figure 27 will then be displayed, which shows the computed reliability levels for both fatigue and rutting criteria and the existing pavement reliability. The sample size reported in the figure refers to the number of FWD stations along the route that were used in calculating the existing pavement reliability.

To establish load limits for the route, specify on the user-interface screen shown in Figure 27 the minimum reliability level that you want to achieve. Obviously, this must be greater than the existing pavement reliability. Otherwise, load restrictions will not be

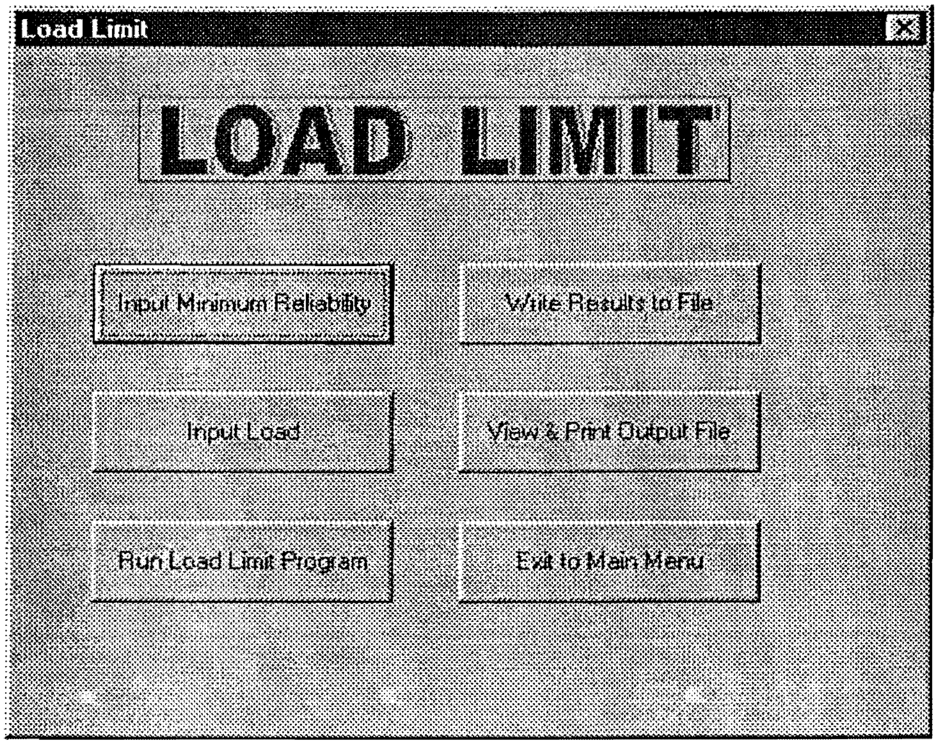


Figure 26. Menu for Evaluating Axle Load Limits.

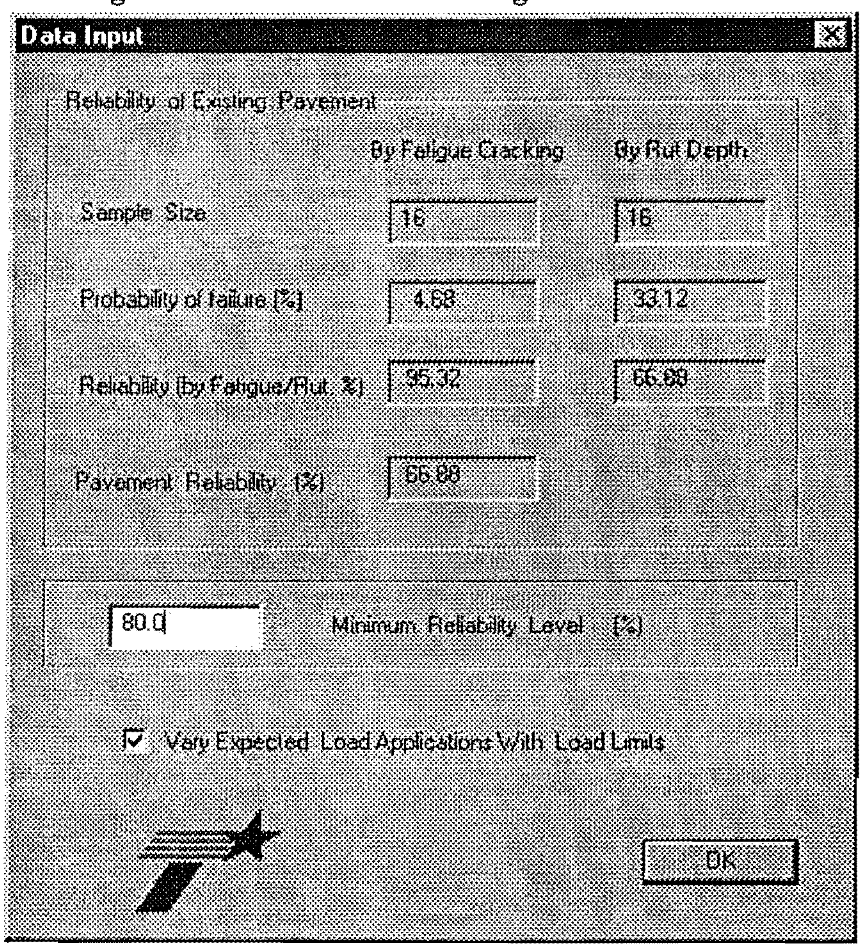


Figure 27. Data Input Screen to Specify Minimum Reliability Level.

necessary. The program will then determine the single and tandem axle loads that satisfy the prescribed reliability.

The check box below the user-interface screen in Figure 27 provides the option of varying the load applications with the axle load limits. If this box is checked, the cumulative axle load applications are adjusted assuming that:

1. The total payload carried by trucks using the route remains constant; and
2. The ratio of single to tandem axle load applications is maintained.

Thus, for lower load limits, the number of applications will increase since truckers will have to make more trips to move the same total payload. Conversely, the cumulative load repetitions will decrease if axle load limits are raised.

The default setting in the program is to vary the axle load applications with changes in axle load limits. If you do not want to do this in the analysis, simply click on the check box to deselect this option. Under this assumption, lowering the load limits means that less payload may be moved on the given roadway. This implies that to carry the same payload, truckers must find alternative routes.

The cumulative axle load applications used in the analysis are defined by clicking on the ***Input Load*** button of the menu in Figure 26. This will bring up the screen shown in Figure 28. The data displayed on this screen are those which were used in the last evaluation made of axle load limits. Note that the traffic information need not necessarily correspond to the same traffic data specified in the most recent reliability analysis. If you want to use the traffic data from this analysis, simply click on the ***Use Reliability Traffic Data*** button at the bottom of the screen in Figure 28. This will update the traffic information so that the data are the same as those specified in the most recent reliability analysis. In addition, the cumulative axle load applications will be updated so that the values displayed correspond to the traffic information.

The traffic data, design axle loads, and cumulative axle load applications in Figure 28 may be changed by the user. Thus, you may specify values for the cumulative load applications that are different from those calculated using the traffic data. In this case, the cumulative load applications will have the label *User Input* in the load-limit analysis output. The data in Figure 28 may also be different from the corresponding data used in the previous reliability analysis. For consistency, the load-limit analysis first computes the reliability of the

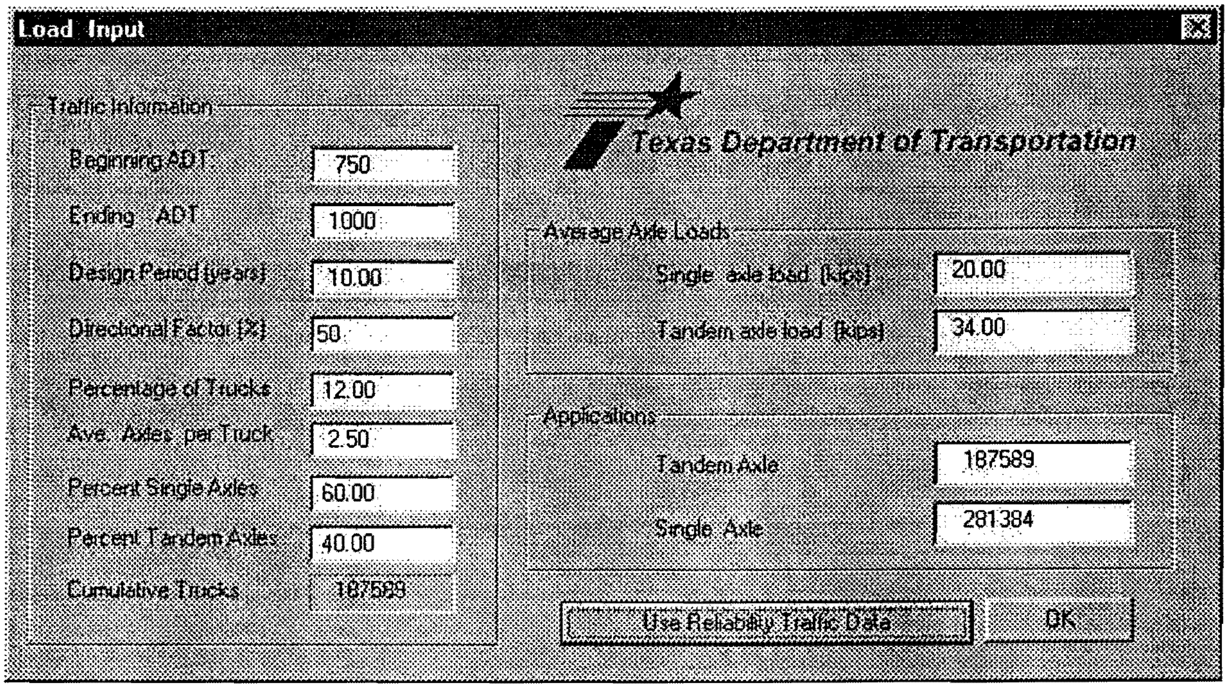


Figure 28. Menu to Specify Traffic Data and Design Axle Load Magnitudes and Repetitions for the Load-Limit Analysis.

existing pavement for the given data in Figure 28. If this reliability is less than the prescribed minimum, then an evaluation of axle load limits is made. Otherwise, the axle load limits reported are the same as the specified design axle loads in Figure 28.

RUNNING THE LOAD-LIMIT ANALYSIS

To evaluate the axle load limits for the prescribed level of reliability and the specified load parameters, click on ***Run Load Limit Program*** in the menu given in Figure 26. You will then be prompted for the settings of two parameters that control the number of iterations the program goes through to find a set of axle load limits that satisfy the prescribed minimum reliability. These two parameters are specified in the screen shown in Figure 29. One parameter is the tolerance between the calculated reliability and the required minimum. If the former differs from the latter by more than this tolerance, another iteration is made until the magnitude of the difference is within the tolerance specified in Figure 29. By default, this parameter is set to half of a percent.

The other parameter controls the number of iterations to achieve stress compatible moduli values when one or more pavement layers are characterized as nonlinear. This

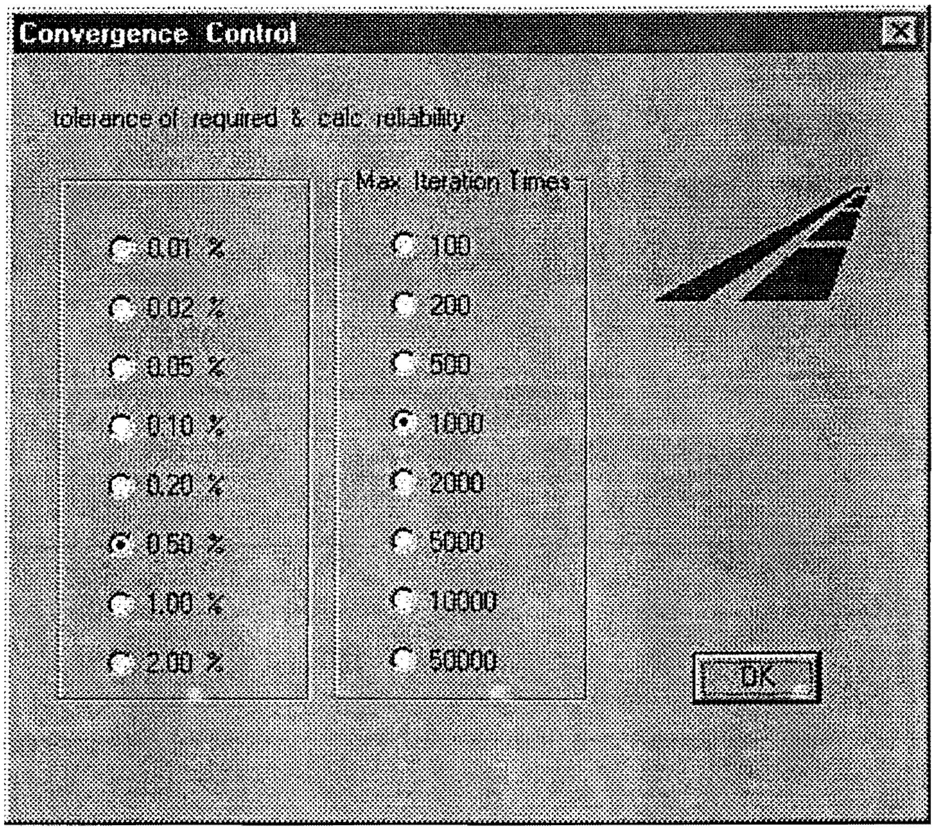


Figure 29. Screen to Specify Run Parameters to Control Number of Iterations in the Load-Limit Analysis.

parameter was explained in the previous chapter. By default, the limit on the number of iterations for convergence of stress dependent moduli is 1000.

To proceed with the analysis, click on the *OK* button of the menu in Figure 29. The trial wheel loads for each iteration are displayed on screen during the analysis, along with the corresponding level of reliability. Figure 30 illustrates the run-time screen of the load-limit analysis. At the top of the screen, the *Start Time* is reported in 24-hour (military time) format. In addition, the start time for the current iteration (*Run Start*) is given, along with the execution time, in minutes, of the previous iteration (*Last run*). When the analysis is complete, the program reports the time at completion (*End Time*) and displays an estimate of the total execution time in a message box, as illustrated in Figure 30. The computed axle load limits are displayed at the bottom of the screen, along with the reliability level corresponding to these limits. At the end of the analysis, you may return to the Load Limit menu by clicking on the ***Return to Menu*** button of the message box. From there, you may save and print the results of the last analysis.

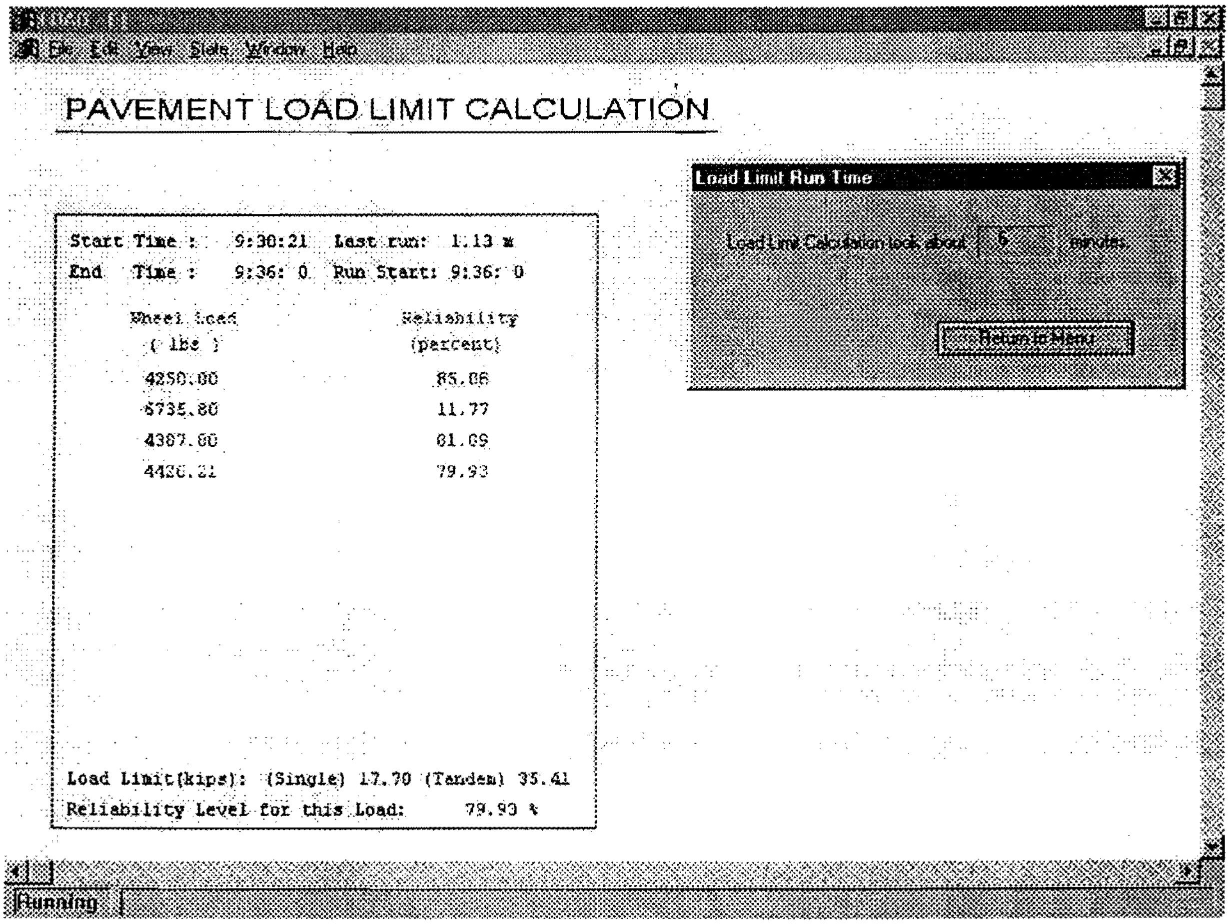


Figure 30. Run-Time Screen Displayed During Load-Limit Analysis.

SAVING AND PRINTING LOAD-LIMIT ANALYSIS RESULTS

To save your results from the last run, click on ***Write Results to File*** in the Load Limit menu. A dialog box will then be displayed for you to specify the name of the output file. By default, this name is formed by concatenating the MODULUS ASCII file name with the characters *LOD*, as illustrated in Figure 31. In this figure, the MODULUS ASCII file is identified as *C:\PLZA\1575TEST*. The default extension for the output file is *OUT*. You may accept the default output file name or type in a new name in the input field of the dialog box in Figure 31. Alternatively, you may click on ***Select File Name*** in the box to look at the files on your computer's hard disk and select an existing file to write the output to.

After saving the results to a file, you may view this file on screen by clicking on the ***View & Print Output File*** button of the Load Limit menu. The screen shown in Figure 32 will be displayed (you may have to click on the output screen to bring it to the foreground). At the top of the screen, the name of the MODULUS ASCII file and the date and time of

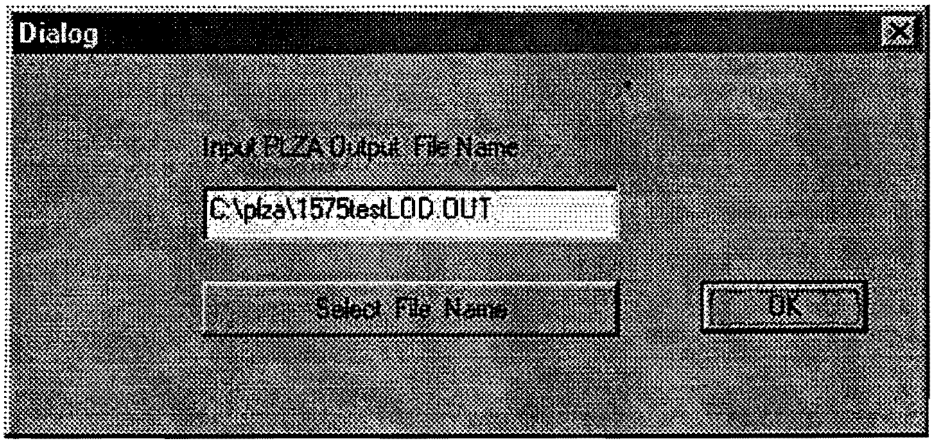


Figure 31. Dialog Box for Specifying Name of Output File for Load-Limit Analysis.

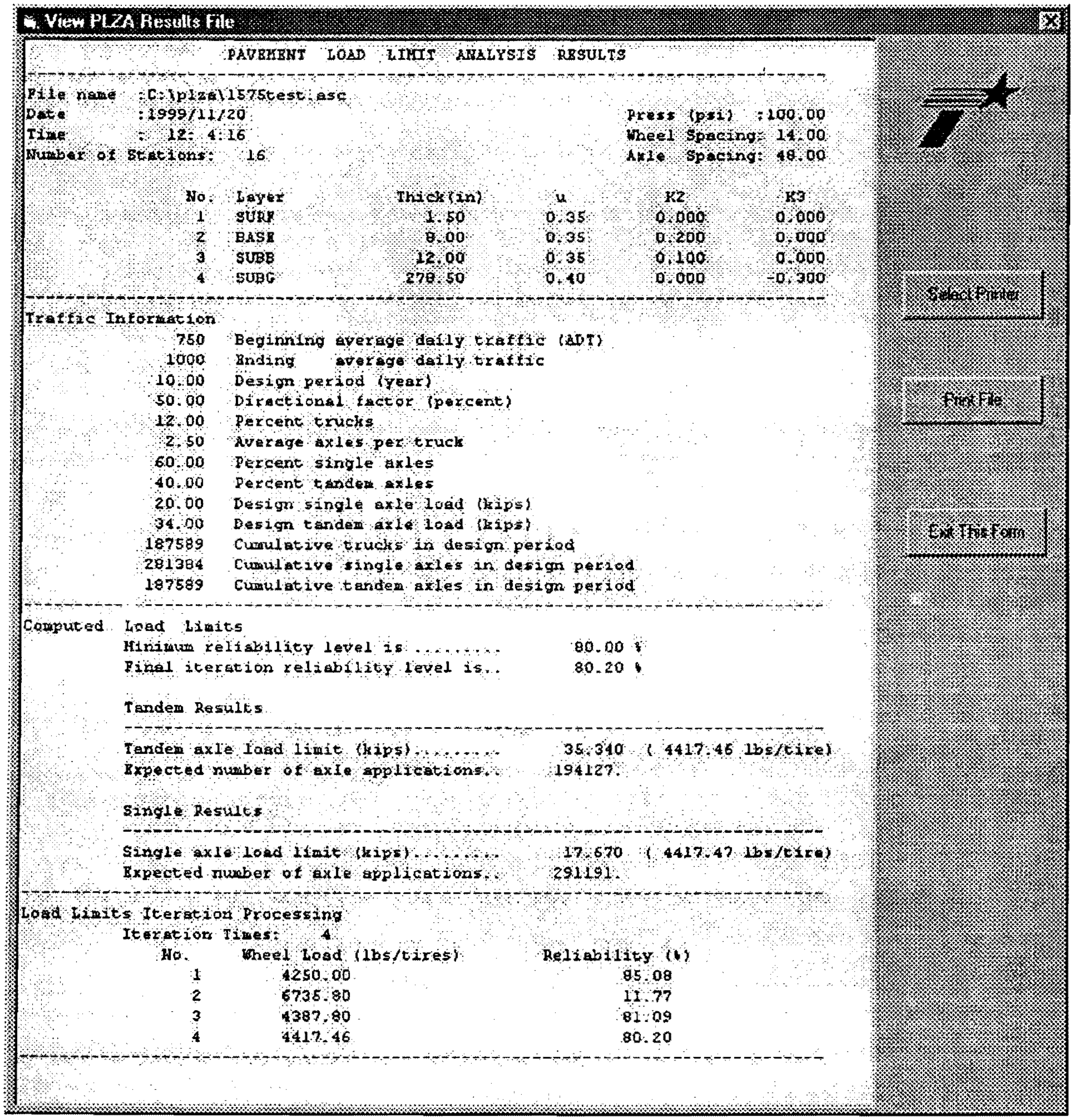
analysis are reported to help identify a particular output. In addition, the following data that were input to the analysis are reported:

1. pavement layer thicknesses,
2. the K_2 and K_3 parameters for each layer,
3. the number of FWD test locations analyzed,
4. the load geometry (dual tire spacing and axle spacing),
5. tire contact pressure,
6. traffic data, and
7. the minimum required reliability for evaluating axle load limits.

From the analysis, the following results are also reported:

1. the reliability level corresponding to the computed axle load limits,
2. the applicable axle load limits and the estimated cumulative number of applications for each axle load, and
3. the results from the iterations made during the analysis.

You may print the output displayed by clicking on the ***Print File*** button. This will print the output to the default printer. You may select another printer by clicking on the ***Select Printer*** button of the screen shown in Figure 32. This will bring up the dialog box shown previously in Figure 24, from which you can specify another printer and change printer settings as desired. After you have made your selections, click on the ***OK*** button of the printer dialog box to return to the output screen in Figure 30. Then click on ***Print File*** to get a hard copy of the load-limit analysis results. Figure 33 illustrates a sample printout from the program.



View PLZA Results File

```
                    PAVEMENT  LOAD  LIMIT  ANALYSIS  RESULTS
------------------------------------------------------------------------------
File name   :C:\plza\1575test.asc
Date        :1999/11/20                              Press (psi)   :100.00
Time        :  12: 4:16                              Wheel Spacing: 14.00
Number of Stations:  16                              Axle  Spacing: 48.00

              No.  Layer       Thick(in)      u        K2        K3
               1   SURF          1.50       0.35     0.000     0.000
               2   BASE          8.00       0.35     0.200     0.000
               3   SUBB         12.00       0.35     0.100     0.000
               4   SUBG        278.50       0.40     0.000    -0.300
------------------------------------------------------------------------------
Traffic Information
            750   Beginning average daily traffic (ADT)
           1000   Ending    average daily traffic
          10.00   Design period (year)
          50.00   Directional factor (percent)
          12.00   Percent trucks
           2.50   Average axles per truck
          60.00   Percent single axles
          40.00   Percent tandem axles
          20.00   Design single axle load (kips)
          34.00   Design tandem axle load (kips)
         187589   Cumulative trucks in design period
         281384   Cumulative single axles in design period
         187589   Cumulative tandem axles in design period
------------------------------------------------------------------------------
Computed  Load  Limits
         Minimum reliability level is .........      80.00 %
         Final iteration reliability level is..      80.20 %

         Tandem Results
         ---------------------------------------------------------------------
         Tandem axle load limit (kips).........     35.340  ( 4417.46 lbs/tire)
         Expected number of axle applications..    194127.

         Single Results
         ---------------------------------------------------------------------
         Single axle load limit (kips).........     17.670  ( 4417.47 lbs/tire)
         Expected number of axle applications..    291191.
------------------------------------------------------------------------------
Load Limits Iteration Processing
         Iteration Times:    4
            No.     Wheel Load (lbs/tires)        Reliability (%)
             1          4250.00                        85.08
             2          6735.80                        11.77
             3          4387.80                        81.09
             4          4417.46                        80.20
------------------------------------------------------------------------------
```

Select Printer

Print File

Exit This Form

Figure 32. Window for Viewing and Printing Load-Limit Analysis Results.

Texas Department of Transportation

PAVEMENT LOAD LIMIT ANALYSIS RESULTS

File name :C:\plza\1575test.asc

Date	:1999/11/19	Press (psi)	:100.00
Time	: 17:37:42	Wheel Spacing:	14.00
Number of Stations:	16	Axle Spacing:	48.00

No.	Layer	Thick(in)	u	K2	K3
1	SURF	1.50	0.35	0.000	0.000
2	BASE	8.00	0.35	0.200	0.000
3	SUBB	12.00	0.35	0.100	0.000
4	SUBG	278.50	0.40	0.000	-0.300

Traffic Information

750	Beginning average daily traffic (ADT)
1000	Ending average daily traffic
10.00	Design period (year)
50.00	Directional factor (percent)
12.00	Percent trucks
2.50	Average axles per truck
60.00	Percent single axles
40.00	Percent tandem axles
20.00	Design single axle load (kips)
34.00	Design tandem axle load (kips)
187589	Cumulative trucks in design period
281384	Cumulative single axles in design period
187589	Cumulative tandem axles in design period

Computed Load Limits

Minimum reliability level is .... 80.00 %

Final iteration reliability level is.. 80.20 %

Tandem Results

Tandem axle load limit (kips)......... 35.340 (4417.46 lbs/tire)

Expected number of axle applications.. 194127.

Single Results

Single axle load limit (kips)......... 17.670 (4417.47 lbs/tire)

Expected number of axle applications.. 291191.

Load Limits Iteration Processing

Iteration Times: 4

No.	Wheel Load (lbs/tires)	Reliability (%)
1	4250.00	85.08
2	6735.80	11.77
3	4387.80	81.09
4	4417.46	80.20

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Figure 33. Sample Printout of Load-Limit Analysis Results.

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APPENDIX

FORMATS OF PLZA RUN-TIME FILES

FILES CREATED AFTER DATA PREPARATION STEP

PLZ1.INP (Figure A1)

1. First record - number of FWD test locations selected for analysis, and name of MODULUS output file containing backcalculated layer moduli for the route or segment under investigation. This MODULUS output file is used as input to the PLZA software;
2. For each FWD test location, the following data are given:
   a) number of pavement layers and distance of test location from start of FWD measurements (one record);
   b) then, for each pavement layer, the following data are given (one record per layer): backcalculated layer modulus, Poisson's ratio, layer thickness, and K_2 and K_3 coefficients. For the surface layer, the pavement temperature is given as the last entry of the record if temperature corrections were specified. Otherwise, the text *No Correct* is written at the end of the record;
   c) FWD load and plate radius.

PLZ1.OUT (Figure A2)

1. First record - number of FWD test locations selected for analysis;
2. For each FWD test location, the following data are given:
   a) number of pavement layers (one record);
   b) for each layer, the calculated K_1 coefficient is given (one record per layer).

FILES CREATED AFTER RELIABILITY ANALYSIS

PLZ2.INP (Figure A3)

1. First record - number of FWD test locations selected for analysis;
2. For each FWD test location, the following data are given:

```
 16     C:\PLZA\1575test.asc
              4       0.000
350000.0      0.35     1.50  0.0000   0.0000  No Correct
 79300.0      0.35     8.00  0.0000   0.0000
  8800.0      0.35    12.00  0.0000   0.0000
  9600.0      0.40   278.50  0.0000   0.0000
    9775   5.91
       4        0.100
350000.0      0.35     1.50  0.0000   0.0000  No Correct
 58500.0      0.35     8.00  0.0000   0.0000
 12700.0      0.35    12.00  0.0000   0.0000
  9000.0      0.40   278.50  0.0000   0.0000
    9827   5.91
       4        0.200
350000.0      0.35     1.50  0.0000   0.0000  No Correct
 45000.0      0.35     8.00  0.0000   0.0000
  7900.0      0.35    12.00  0.0000   0.0000
  8000.0      0.40   278.50  0.0000   0.0000
    9644   5.91
```

Figure A1. Illustration of PLZ1.INP File Showing Data for First Three Stations.

```
       16
        4
24137.93
5468.965
606.8965
662.0690
        4
24137.93
4034.483
875.8621
620.6896
        4
24137.93
3103.448
544.8276
551.7241
```

Figure A2. Illustration of PLZ1.OUT File Showing Data for First Three Stations.

```
       16
        4      0.000
 350000.0       0.35       1.50   24137.9      0.000      0.000
  79300.0       0.35       8.00    5469.0      0.000      0.000
   8800.0       0.35      12.00     606.9      0.000      0.000
   9600.0       0.40     278.50     662.1      0.000      0.000
   4500.0     100.00      14.00     48.00
        4      0.100
 350000.0       0.35       1.50   24137.9      0.000      0.000
  58500.0       0.35       8.00    4034.5      0.000      0.000
  12700.0       0.35      12.00     875.9      0.000      0.000
   9000.0       0.40     278.50     620.7      0.000      0.000
   4500.0     100.00      14.00     48.00
        4      0.200
 350000.0       0.35       1.50   24137.9      0.000      0.000
  45000.0       0.35       8.00    3103.4      0.000      0.000
   7900.0       0.35      12.00     544.8      0.000      0.000
   8000.0       0.40     278.50     551.7      0.000      0.000
   4500.0     100.00      14.00     48.00
```

Figure A3. Illustration of PLZ2.INP File Showing Data for First Three Stations.

a) number of pavement layers and distance of test location from start of FWD measurements (one record);

b) then, for each pavement layer, the following data are given (one record per layer): backcalculated layer modulus, Poisson's ratio, layer thickness, and K_1, K_2, and K_3 coefficients;

c) wheel load for standard 18-kip single axle, tire contact pressure, dual tire spacing, and axle spacing (one record).

PLZ2B.OUT (Figure A4)

1. First record - number of FWD test locations analyzed;
2. For each FWD test location, the following data are given:
   a) run number (one record);
   b) for each axle configuration, the following data are given (one record per axle type, i.e., single/tandem, beginning with the single axle): maximum horizontal strain at the bottom of the surface layer, maximum vertical strain at the top of the subgrade, and surface layer modulus.

```
        16
         1
4.0738618E-05
4.2144323E-04
 350000.0
5.0113227E-05
3.6449565E-04
 350000.0
         2
8.8575238E-05
4.8348421E-04
 350000.0
9.7830853E-05
4.1859440E-04
 350000.0
         3
1.2834750E-04
5.5600022E-04
 350000.0
1.4048496E-04
4.7870236E-04
 350000.0
```

Figure A4. Illustration of PLZ2B.OUT File Showing Data for First Three Stations.

PLZ2B.$$$ (annotated file illustrated in Figure A5)

1. First record - number of FWD test locations analyzed;
2. For each FWD test location, the following data are given:
   a) predicted number of allowable applications of design single axle load based on fatigue cracking and rutting criteria (one record);
   b) predicted number of allowable applications of design tandem axle load based on fatigue cracking and rutting criteria (one record);
3. Expected cumulative applications of design single axle load during design period (one record);
4. Expected cumulative applications of design tandem axle load during design period (one record);
5. Length of design period (one record);
6. Number of FWD test locations where the predicted horizontal strain at the bottom of the surface layer is tensile. (Note that for thin surface layers overlying a stiff base and/or subgrade, the predicted horizontal strain may be compressive. In this instance, no

```
        16   No. of stations analyzed
 0.4062E+09  0.1763E+07    1 fatigue & rut
 0.2055E+09  0.3376E+07    2 fatigue & rut
 0.3155E+08  0.9531E+06    1 fatigue & rut
 0.2275E+08  0.1817E+07    2 fatigue & rut
 0.9313E+07  0.5098E+06    1 fatigue & rut
 0.6918E+07  0.9965E+06    2 fatigue & rut
 0.8325E+08  0.1016E+07    1 fatigue & rut
 0.5519E+08  0.1944E+07    2 fatigue & rut
 0.7333E+07  0.6658E+06    1 fatigue & rut
 0.5523E+07  0.1314E+07    2 fatigue & rut
 0.3874E+07  0.4862E+06    1 fatigue & rut
 0.2923E+07  0.9624E+06    2 fatigue & rut
 0.7595E+09  0.2648E+07    1 fatigue & rut
 0.4022E+09  0.4840E+07    2 fatigue & rut
 0.6723E+07  0.8046E+06    1 fatigue & rut
 0.5106E+07  0.1602E+07    2 fatigue & rut
 0.8656E+07  0.1307E+07    1 fatigue & rut
 0.6538E+07  0.2580E+07    2 fatigue & rut
 0.5169E+07  0.9386E+06    1 fatigue & rut
 0.3867E+07  0.1830E+07    2 fatigue & rut
 0.1775E+08  0.6644E+06    1 fatigue & rut
 0.1307E+08  0.1293E+07    2 fatigue & rut
 0.1086E+07  0.3859E+06    1 fatigue & rut
 0.9279E+06  0.7740E+06    2 fatigue & rut
 0.6714E+07  0.3320E+06    1 fatigue & rut
 0.4924E+07  0.6354E+06    2 fatigue & rut
 0.1599E+07  0.1745E+06    1 fatigue & rut
 0.1251E+07  0.3471E+06    2 fatigue & rut
 0.3159E+07  0.2413E+06    1 fatigue & rut
 0.2347E+07  0.4755E+06    2 fatigue & rut
 0.5195E+07  0.6133E+06    1 fatigue & rut
 0.3934E+07  0.1220E+07    2 fatigue & rut
  281384.000000000        Expected cumulative single axle loads
  187589.000000000        Expected cumulative tandem axle loads
  10.0000000000000        Design period (years)
        16   No. of FWD stations with fatigue pred.
 3.877873853364533E-002  0.961221261466355       Pfail and Rel. (fatigue)
        16   No. of FWD stations with rutting pred.
 0.208756407287774       0.791243592712226       Pfail and Rel. (rutting)
```

Figure A5. Sample Illustration of PLZ2B.$$$ File.

fatigue prediction using the Asphalt Institute equation is made. The predicted service life based on fatigue cracking is simply set to a high number, 10^{30});

7. Predicted probability of failure and reliability based on fatigue cracking (one record);
8. Number of FWD test locations used in computing the reliability based on rutting (one record);
9. Predicted probability of failure and reliability based on rutting (one record).

PLZ2B.NF (annotated file illustrated in Figure A6)

1. First record - number of FWD test locations analyzed;
2. For each FWD test location, the following data are given:
   a) predicted number of allowable applications of design single axle load based on fatigue cracking and rutting criteria (one record);
   b) predicted number of allowable applications of design tandem axle load based on fatigue cracking and rutting criteria (one record);
3. Expected cumulative applications of design single axle load during design period (one record);
4. Expected cumulative applications of design tandem axle load during design period (one record);
5. Length of design period (one record);
6. Average of fatigue life predictions at FWD stations analyzed. (The average of the logarithms, base 10, of the fatigue life predictions is first determined. Then, the antilog of this average is taken and reported in this record. This procedure is also used for the statistics based on rutting);
7. Standard deviation of fatigue life predictions at FWD stations analyzed (one record);
8. Probability of failure based on fatigue cracking (one record);
9. Pavement reliability based on fatigue cracking (one record);
10. Average of service life predictions based on rutting (one record);
11. Standard deviation of service life predictions based on rutting (one record);
12. Probability of failure based on rutting (one record);
13. Pavement reliability based on rutting (one record).

PLZ2C.DI (Figure A7)

1. First record - number of FWD stations analyzed and length of design period;
2. For each FWD test location, the predicted service lives (in years) are reported for fatigue cracking and rutting criteria (one record per station). Note that these predictions are based on Miner's hypothesis of cumulative damage to combine the effects of single and tandem axle loads.

```
        16
   406206380.968676          1762692.66451830              1
   205505829.775271          3376267.45202003              2
   31550766.5348997          953133.856017946              1
   22751077.4330115          1817039.40397345              2
   9312641.41977118          509838.725591060              1
   6917757.16622947          996505.886600281              2
   83247978.0240557          1015512.15324460              1
   55189907.4323075          1944126.03649500              2
   7332713.84698670          665781.523998097              1
   5522836.26620900          1314137.91340361              2
   3873827.41586589          486172.507786631              1
   2923257.60152167          962444.533216397              2
   759512970.292216          2647983.35751327              1
   402214358.657272          4840294.55328580              2
   6722999.23631784          804554.533902696              1
   5105892.83252846          1601512.57136562              2
   8656198.57352796          1307093.73373951              1
   6538036.82537720          2580187.47508039              2
   5168784.94215976          938617.132244851              1
   3867386.01395413          1829901.08070492              2
   17748848.9127682          664434.811301469              1
   13069235.0189965          1292619.76340140              2
   1085660.93873784          385937.734821040              1
   927893.906320808          773984.157259346              2
   6714479.92387372          331967.285205132              1
   4924243.18569192          635350.392241316              2
   1599421.22393885          174476.900928176              1
   1250614.55633607          347052.582815683              2
   3158533.88127519          241298.785525592              1
   2346754.39426645          475470.482799597              2
   5194769.08659147          613349.928743495              1
   3934407.38216804          1219729.70006067              2

Expected number of single axle loads:        281384.
Expected number of tandem axle loads:        187589.
Design period (years):  10.00

Average fatigue life (log based, years):     222.6216
Std. dev. of fatigue life (log based, years):        5.8007
Probability of failure by fatigue cracking: 0.038779
Reliability of pavement based on fatigue cracking: 0.961221

Average rut life (log based, years):      17.7211
Std. dev. of rut life (log based, years):       2.0253
Probability of failure by rutting: 0.208756
Reliability of pavement based on rut depth criterion : 0.791244
```

Figure A6. Sample Illustration of PLZ2B.NF File.

```
          16    10.0000000000000
  6228.48110928071          46.4696740250362
  582.623874489389          25.0967081479972
  174.421752684791          13.5106905909503
  1475.13447212175          26.7683187544277
  138.236395303382          17.6870954881242
  73.0949142482353          12.9251922946560
  11949.2853843723          68.9563831409993
  127.236750973830          21.4191804449183
  163.402446621545          34.7248543177264
  97.1397467366583          24.8571399319806
  331.047696586125          17.5865339859348
  21.6755813829277          10.2937876626349
  124.996821647542          8.74983633166480
  30.6818023555992          4.64414335504111
  59.1637528207158          6.40756127008725
  98.1875600145365          16.3248941876300
```

Figure A7. Sample Illustration of PLZ2C.DI File.

FILES CREATED AFTER LOAD-LIMIT ANALYSIS

PLZ4.OUT

This file has the same format as PLZ2B.OUT. However, the data correspond to the allowable single and tandem axle loads that satisfy the required minimum reliability level.

PLZ4.$$$ (annotated file)

The format of this file is the same as PLZ2B.$$$. However, the data in the file correspond to the allowable single and tandem axle loads that satisfy the required minimum reliability level.

PLZ4.NF (annotated file)

This file has the same format as PLZ2B.NF. However, the data correspond to the allowable single and tandem axle loads that satisfy the required minimum reliability level.

PLZ4.DI

The format of this file is the same as PLZ2C.DI. However, the data in the file correspond to the allowable single and tandem axle loads that satisfy the required minimum reliability level. In addition, the first record in the file only reports the number of FWD stations analyzed.

TRUCKS.$$$ (annotated file illustrated in Figure A8)

This file shows the total payload carried by trucks using the route, computed from the equation:

$$Payload = P_s\, n_s + P_t\, n_t \tag{A1}$$

where

P_s	=	design single axle load;
P_t	=	design tandem axle load;
n_s	=	expected cumulative applications of design single axle load; and
n_t	=	expected cumulative applications of design tandem axle load.

In addition, P_s, P_t, n_s, and n_t are reported in the record following the payload. If the option to vary the axle load applications with changes in axle load limits is used, TRUCKS.$$$ will also have the predicted cumulative load applications per axle configuration. In this instance, the following data will be reported for each iteration of the load-limit analysis (one record per iteration): single axle load, tandem axle load, predicted cumulative single axle load applications, and predicted cumulative tandem axle load applications.

LOADLIM.$$$ (annotated file illustrated in Figure A9)

1. First record - required minimum reliability level for the load-limit analysis;
2. Second record - allowable single axle load and the expected number of cumulative applications;
3. Third record - allowable tandem axle load and the expected number of cumulative applications; and
4. Fourth record - pavement reliability in percent.

The above data are also written to the output file where the results from the load-limit analysis were saved by the user.

LOADLIM.ITE (Figure A10)

This file shows the wheel load and the corresponding predicted pavement reliability for each iteration of the load-limit analysis. This information is also reported in the output file where the results from the analysis were saved by the user.

```
Record of estimated axle load applications:

Total payload (kips):       12005706.

 20.00  34.00     281384.     187589.
 17.00  34.00     302665.     201776.
 26.94  53.89     190969.     127312.
 18.34  36.69     280493.     186995.
 18.86  37.73     272750.     181833.
 19.00  38.01     270743.     180495.
```

Figure A8. Sample Illustration of TRUCKS.$$$ File.

```
 67.0000000000000
 20.00000       281384.000000000      Allow. single axle load
 34.00000       187589.000000000      Allow. tandem axle load
 66.8788084431811          Reliability (percent)
```

Figure A9. Sample Illustration of LOADLIM.$$$ File.

```
     4250.000          91.763
     6735.796          20.558
     4585.951          84.668
     4716.145          81.258
     4751.104          80.285
```

Figure A10. Sample Illustration of LOADLIM.ITE File