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16. Abstract

This report provides the instructions for a new design procedure for the flexible pavements in Texas. The Texas Flexible Pavement System (TFPS) is developed for the Texas State Department of Highways and Public Transportation (SDHPT) under Study 2-6-86-455. TFPS is a "user-friendly menu driven" computerized design system and represents the latest techniques available in the area of flexible pavement design.

TFPS can evaluate a multi-stage construction (i.e., an initial construction and subsequent overlays and overlay design). The initial construction can consist of:

1. A three layer pavement system (i.e., an asphalt surface on a black base and a granular base).

2. A two-layer pavement system (i.e., an asphalt surface on a granular base or an asphalt surface on a black base).

An overlay is applied when the pavement deteriorates to an intolerable limit. TFPS can also design overlays for an existing pavement. Pavement condition is predicted and failure is defined in terms of serviceability, rut depth, and load induced fatigue cracking.

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THE TEXAS FLEXIBLE PAVEMENT SYSTEM (TFPS),

Volume I, USERS GUIDE

by

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Research Report 455-2
Research Study No. 2-8-86-455

Sponsored by

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IMPLEMENTATION STATEMENT

Implementation of the results of this research is recommended through the adoption of the new Texas Flexible Pavement Design System (TFPS). This design system is a mechanistic approach to pavement design in the determination of average pavement responses associated with each failure mode. It also applies design reliability to two pavement conditions based on mechanistic calculations to represent structural failure modes. Empirical equations are incorporated to predict pavement roughness as a function of traffic, material properties, and the structural analysis of the pavement system.

The new design procedure is developed in a modular format and presented as a computer design program operational in a "user-friendly" format on microcomputers for convenient application to pavement design at district and residency levels. The various program modules are categorized according to four major areas:

a) The generation of input and data management screens as a part of the data input and storage;
b) The generation of pavement design and thickness files in conjunction with the design factorial resulting from the mechanistic analysis;
c) The execution of the mechanistic analysis for new construction and multiple overlays and storage of the results;
d) The printing of the mechanistic analysis, life cycle costs, and pavement input values reflecting the data originally provided by the design engineer.

Flexible pavement design must consider several failure modes, material properties, environmental conditions, wheel loads, material costs, and design criteria among other factors. The design process is extremely complex and stocastic in nature but is simplified through the use of personal computers. The confidence level of the design is controlled by the design engineer through the selection of the desired reliability level. The level of reliability independently affects the level of distress of each failure modes which indirectly affects the life to first overlay. The layer moduli are adjusted during the mechanistic analysis to reflect seasonal variations, cumulative damage, and overlay effects.

Implementation of the design program should be accompanied with further training seminars and design schools oriented towards increasing the understanding of the use of the design program and basic pavement behavior. The program is calibrated in terms of performance and design life for specific pavement structures and varying traffic levels. Further calibration will be necessary to consider additional environmental regions and other material types.

DISCLAIMER

The contents of this report reflect the view of the authors who are responsible for the opinions, findings, and conclusions presented herein. The contents do not necessarily reflect the official view or policies of the Federal Highway Administration or the Texas State Department of Highways and Public Transportation. This report does not constitute a standard, specifications, or regulations.

There is no invention or discovery conceived or first actually reduced to practice in the course of or under this contract, including any art, method, process, machine, manufacture, design or composition of matter, or any new and useful improvement thereof, or any variety of plant which is or may be patentable under the patent law of the United States of America or any foreign country. This report is not intended for construction, bidding, or permit purposes.

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CHAPTER 1 GENERAL DESCRIPTION OF THE PROGRAM

1.1 INTRODUCTION

The Texas Flexible Pavement Design System (TFPS) is a decision support system that assists the pavement design engineer in selecting a cost-effective pavement design strategy. The design strategy is based on life-cycle cost concepts and includes an initial construction, overlay, and routine maintenance to provide a desired quality of initial service over the design period. The system can also analyze overlays on an existing pavement. In the analysis, the performance of each feasible strategy is predicted, and the most suitable is identified based on economic factors. This process compares the total cost (i.e., initial and future costs) of all the feasible options over the analysis period.

The system operates in an "user-friendly" microcomputer environment, and once the program is started, options are selected from a set of menus. The flow diagram in Figure 1 illustrates the general procedure to follow when using the program.

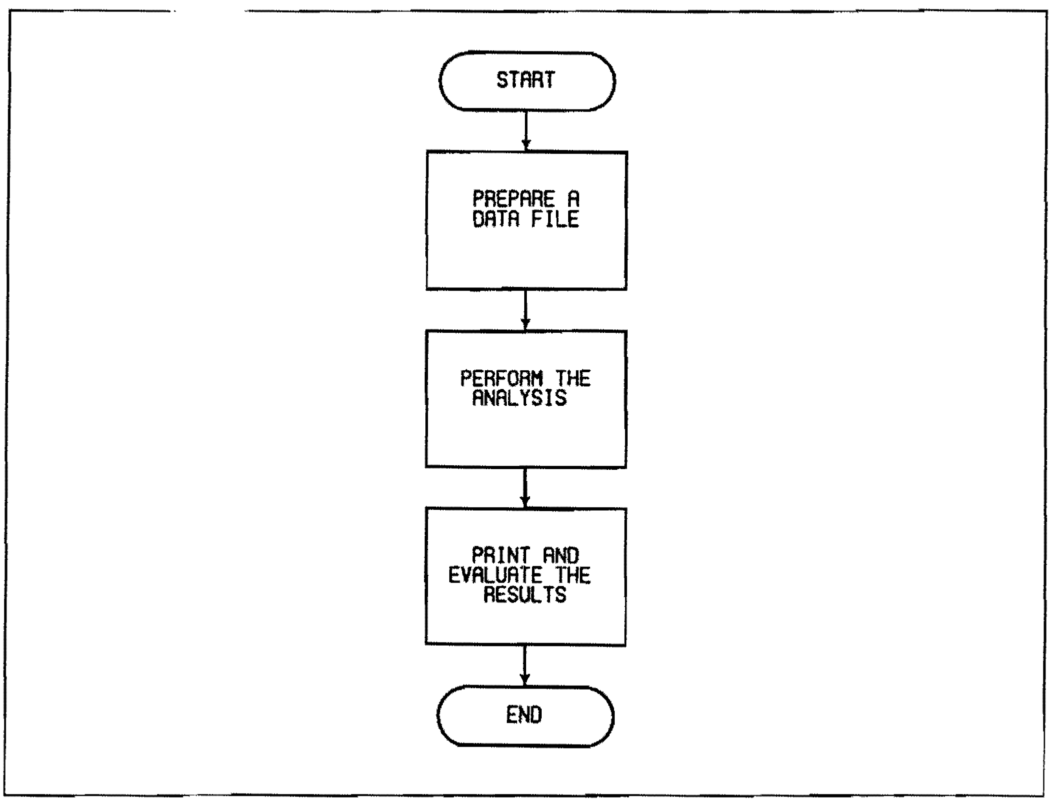

Figure 1. Typical Procedure Using TFPS.

TFPS represents the latest techniques and research available in the area of flexible pavement analysis. Features which make this program unique include:

1. The evaluation of up to 125 different pavement sections in a single run;
2. Seasonal computation of pavement material characteristics, including the effect of moisture and temperature on layer moduli and permanent deformation parameters;
3. Incorporating the depth to a stiff layer (e.g., the bedrock) into structural analysis;
4. Performance predictions based on three kinds of deterioration, i.e., fatigue cracking, rutting, and serviceability;
5. Modified AASHTO Road Test serviceability model in which rut depth variance is used to estimate slope variance;
6. Overlay application analysis to permit maintenance strategy studies;
7. Calculation of expected reduction in service life due to swelling soils; and
8. An economic analysis to compare all feasible design alternatives based on the total present cost over the analysis period.

TFPS can evaluate a multi-stage construction (i.e., an initial construction and subsequent overlays). The initial construction can consist of:

1. A three layer pavement system (i.e., an asphalt surface on an asphalt stabilized [black] base and a granular subbase).
2. A two layer pavement system (i.e., an asphalt surface on a granular base or on an asphalt stabilized [black] base).

An overlay is applied when the pavement deteriorates to an intolerable level. Pavement condition is predicted in terms of serviceability, rut depth, or load-induced fatigue cracking. Although cement treated bases cannot be evaluated at present by the program, they may be included in future versions.

The documentation for the TFPS program is contained in two volumes. This manual, called the "Users Guide", should be read by first time users as well as experienced users seeking additional information about how to use the program. In the first chapter a general description of the program is given. A simplified flow-chart is provided and the important features of the program are explained. The variables used in the program are organized into 11 groups (which correspond to data entry screens). In chapters 2 through 12 each of these groups, the individual variables, how the variables should be obtained, and where the variables are used in the program are discussed. The correct format and range of every variable are also provided.

Appendix A of the Users Guide was prepared as "Quick Start" directions for using the program. It can be used by those familiar with the program to refresh their memory. A typical example problem is provided with <u>all</u> the steps which include supplying the variables, performing the analysis, printing reports, and examining the results.

The second volume [1] contains a detailed description of the elements used in the mechanistic and probabilistic approach. The assumptions and derivations used in the program have also been documented.

1.2 PREPARATION OF A DATA FILE

The first step in analysis is the preparation of a data file. This file contains all information needed by the system to analyze a specific problem. A data file can be prepared in two ways. The data file can be created through a series of data entry screens, described later. The data file must then be saved on the hard disk or a floppy diskette in order to be retrieved in the analysis. The second method is to modify an existing data file. This option can be used if a problem set has been saved and needs to be changed slightly. The old file is retrieved, and with the help of a series of screens, the necessary modifications are made. The modified data is then saved, and the original data set may also be retained if desired. This procedure is also discussed later.

The variables used in TFPS are divided into 11 groups as shown in Table 1. In chapters 2 through 12 the meaning, influence, and process to obtain each variable is discussed.

Table 1. Variable Groups.

Screen Number	Group of Variables	Charter in Users Guide
1	Problem Identification	2
2	Basic Design Criteria	3
3	Traffic Data	4
4	Construction and Maintenance	5
5	Overlay Detour Design	6
6	The Subgrade	7
7	Base and Subbase Layers	8
8	The Surface Layer	9
9	The Overlay	10
10	Swelling Soils	11
11	Transverse & Longitudinal Cracking	12

1.3 THE ANALYSIS

Up to 125 pavement systems can be analyzed. Each pavement system analyzed must have the same initial material properties. The program is run for each set of materials considered by the designer. To determine the optimum strategy, performance is compared to the designer's requirements. For all feasible options, the total present costs are predicted. This process is represented in a simplified flow chart shown in Figure 2. Although the flow chart may appear complex, it demonstrates the logical step-by-step process used in the analysis. Each step is described in detail later. After a few times using the program, the steps become second nature to the designer.

Within the layer thickness limitations set by the designer, a range of possible initial structures is developed. Each of these is analyzed on a seasonal basis to predict their performance under the expected traffic and environmental influences. When the condition of the initial pavement no longer meets the allowable limits set by the designer, an overlay is applied; up to 20 overlays can be analyzed. Various overlays

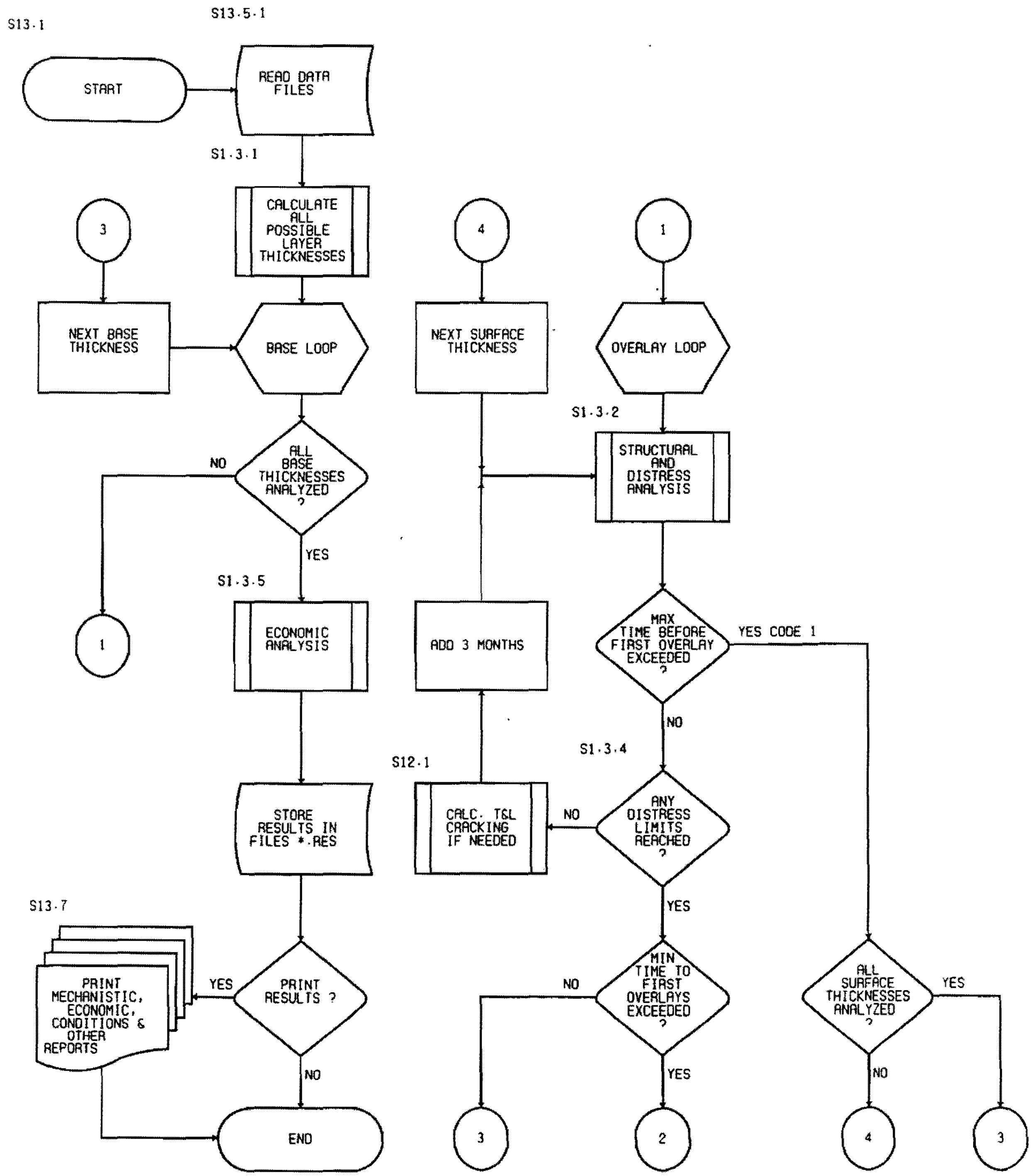

Figure 2. A Flowchart of the Pavement Analysis. (Continued)

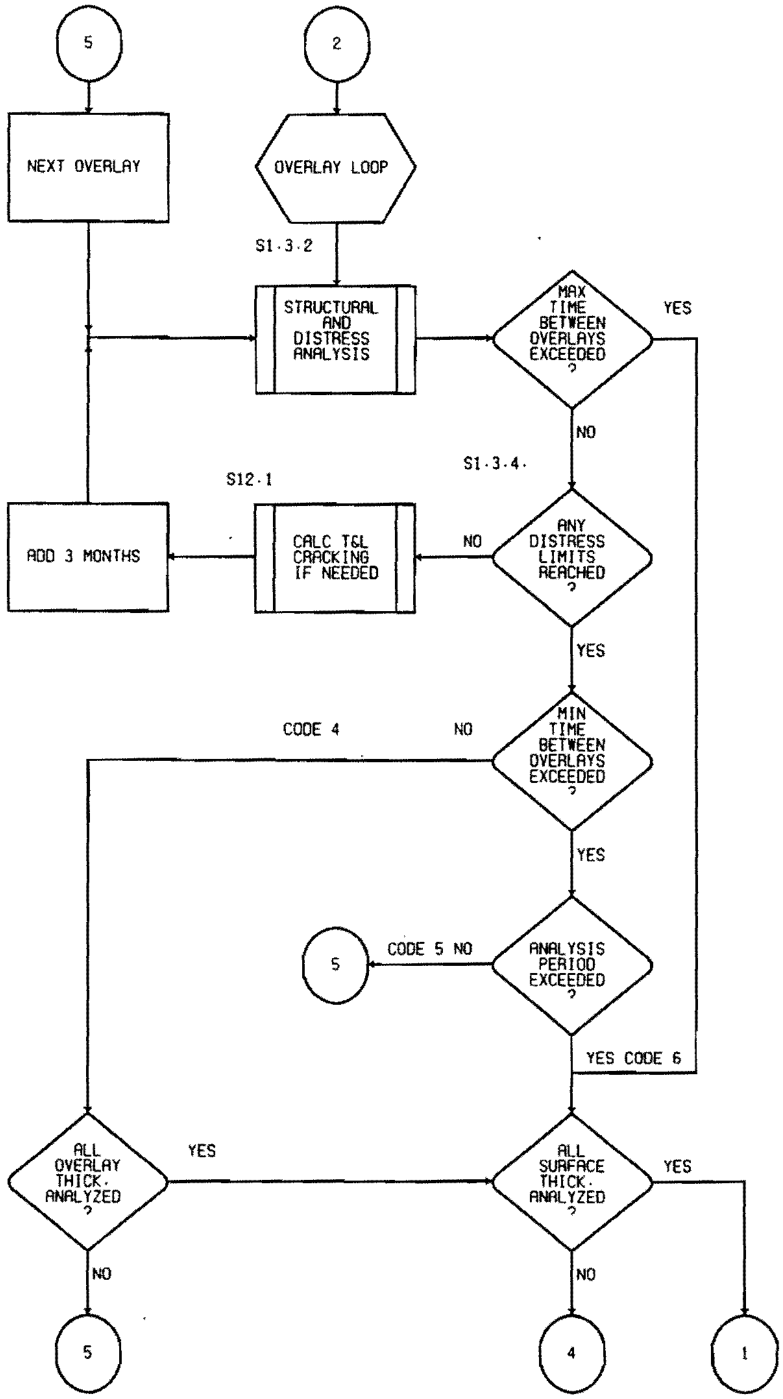

Figure 2. (Continued).

within the selected thickness range are analyzed to obtain overlays that last the remaining time in the analysis period. After all strategies (initial pavement structure and overlays) have been analyzed, the successful strategies (i.e., those that meet the designer's criteria) are subjected to an economic analysis. The design strategy with the lowest estimated total present cost is considered the optimum solution.

In the program three kinds of analysis are conducted. For every pavement structure, a structural and condition analysis are conducted every three months. The three month interval, which is a default setting in the program, conducts the analysis in each of the four seasons of the year. This allows adjustments for the variation in material properties as the seasons change. For every season the structural properties of the layers are calculated. Based on these properties, the strain induced at the bottom of the asphalt layer and the total deflection of the structure under a standard wheel load are computed.

The condition analysis uses three models based on the calculated strain and deflection, as well as the material properties and traffic load in a season, to predict the pavement condition. The condition is predicted in terms of rut depth, area of load-related surface cracking and the level of serviceability. The economic analysis is completed after all the possible structures have been subjected to the structural and condition analysis. The purpose of this analysis is to calculate the total cost of each successful design strategy to select the most cost-effective.

1.3.1 Determining the Structures to be Analyzed

The first step in the analysis process is the determination of the layer thicknesses. As part of the input, the designer defines the minimum and maximum thickness to be considered for each layer. Within these limits the program selects quarter points to define five thicknesses of the base course, the asphalt surface, and the overlay. The increment is, however, limited to one inch for the base and one half inch for the asphalt surface or overlay. This procedure is shown in Figure 3. The procedure used to calculate the layer thicknesses is illustrated by the following example:

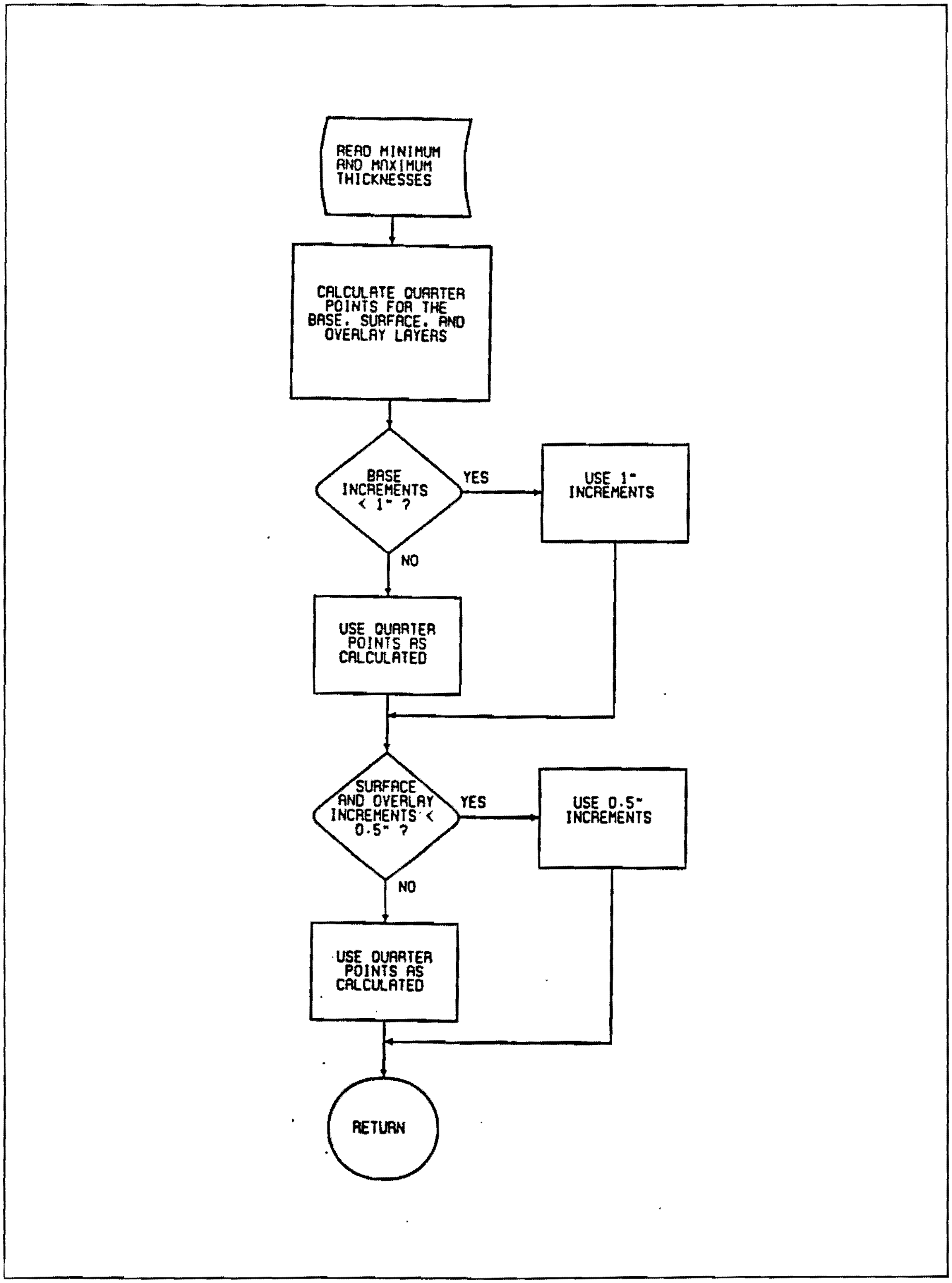

Figure 3. Calculation of the Layer Thicknesses.

A designer decides to analyze a two layer system. This system is comprised of a hot-mix asphaltic concrete surface and flexible base. After the original structure has deteriorated to an unacceptable level, an overlay is planned to rehabilitate the structure.

Based on experience, the design engineer chooses allowable hot-mix asphaltic concrete surface thicknesses between two and four inches, a flexible (granular) base of at least six inches and not exceeding ten inches in thickness, and two inches as minimum with three inches as the maximum thickness for the overlay. When creating the data file the designer sets the following thickness limitations:

Asphalt Overlay	:	Min = 2"	Max = 3"
Asphalt Surface	:	Min = 2"	Max = 4"
Flexible Base	:	Min = 6"	Max = 10"

In the analysis the following thicknesses will be analyzed:

Asphalt Overlay : Quarterpoint increment : (3.0" - 2.0")/4 = 0.25"
But 0.25" < 0.5" therefore use 0.5"
<u>Thicknesses : 2", 2.5", 3"</u>

Asphalt Surface : Quarterpoint increment : (4.0" - 2.0")/4 = 0.50"
Therefore use 0.5"
<u>Thicknesses : 2", 2.5", 3", 3.5" and 4"</u>

Flexible Base : Quarterpoint increment : (10.0" - 6.0")/4 = 1.0"
Therefore use 1.0"
<u>Thicknesses : 6", 7", 8", 9", 10"</u>

These five base, five surface, and three overlay thicknesses can be combined in 5 x 5 x 3 = 75 different ways. The thickest section analyzed would be the 3" + 2" + 10" structure and the thinnest the 2" + 2" + 6" structure. Each of these 75 structures will be analyzed to evaluate their performance.

In the structural analysis, the generated pavement structures will be analyzed in the following order:

1. The pavement structure with the thinnest overlay, thickest asphalt surface, and thickest black base is analyzed first. Therefore, the structure 2" + 4" + 10" is the first candidate structure.
2. If the overlay layer is too weak, the overlay thickness is increased to the next increment. This process is repeated until a suitable candidate overlay thickness is found. Therefore, it is possible to consider all three overlay thicknesses, 2", 2.5", and 3", for a given asphalt stabilized base, and asphalt surface structure.
3. The next candidate structure is determined by decreasing the asphalt overlay thickness to the next thickest increment. For the given example this structure is 2" + 3.5" + 10". The procedure described in Step 2 is used to determine the overlay thickness. The asphalt surface layer thickness is decreased until all possible surface layer increments are analyzed.
4. Once all possible asphalt surface thickness increments are considered, the asphalt stabilized base thickness is decreased to the next thickness increment. According to the example this structure is 2" + 4" + 9". The processes discussed in Steps 1 to 3 are repeated for this structure. The asphalt stabilized base layer thickness is decreased until all possible asphalt stabilized base layer increments are analyzed.

1.3.2. Structural Analysis

In the structural analysis, the response of the pavement structure under a standard wheel load (i.e., 18 kip single axle) is calculated. The response is calculated in terms of strain in the bottom of the asphalt layer and the total deformation of the structure. These two variables are used in the condition analysis to predict performance under repeated traffic. To model the pavement structure, the stiffness or modulus of elasticity of each layer is used. This material property is sensitive to climatical changes and therefore is calculated for each season.

Subgrade

The modulus of elasticity of the subgrade is based on the resilient modulus which is discussed in Chapter 7. The subgrade modulus is normally determined from in place deflection testing. It is sensitive to changes in temperature and soil suction. As the temperature and the soil suction in the subgrade changes through the year, the resilient modulus is adjusted. The subgrade temperature is a function of the air temperature and the thickness of the "insulating" pavement layers. The soil suction depends on the material type, the monthly rainfall, and whether the shoulders of the road are paved [1]. Monthly rainfall and temperature data for each county in Texas are stored in the district data files which are provided with the program.

Granular Base or Subbase

The modulus of elasticity of the granular base or subbase is required. This information can be obtained using the laboratory testing or non-destructive testing.

Asphaltic Layers

The modulus of elasticity of the asphaltic layers (i.e., the asphaltic [black] base, the asphalt surface, and the overlay) is called the stiffness modulus. The Asphalt Institute equation [2], used to calculate this stiffness, considers the influence of temperature on the material. The temperature of the layer, which changes with season, is a function of the air temperature and the depth to the center of the layer. The monthly air temperatures are obtained from the district environmental data files.

Pavement Response Under a Standard Wheel Load

From several thousand pavement structures analyzed on Shell's BISAR program [3], a set of regression equations were developed [1]. An elastic layered program predicts strain at the bottom of the asphalt layer and the total deflection as a function of layer moduli and thickness. The regression equations are used to adjust these for seasonal and degration changes. A constant 18 kip single axle load and tire pressure were used in the analysis and are the basis of the design procedure. Equivalency factors are used to adjust other loading conditions to the design standards.

1.3.3. Condition Analysis

The condition analysis, which is conducted every three months, uses three separate models predicting the accumulation of roughness, load-inducted cracking, and rutting.

Serviceability

In this model, the Present Serviceability Index (PSI), which ranges from 0 (impassible) to 5 (perfect), is used as a measure of overall condition. The PSI after initial construction (or overlay) depends on the quality of construction and is defined by the designer. Every season, the serviceability index is calculated using a regression equation derived from the AASHTO Test results which is described in the accompanying technical report describing the development and implementation of this and the other models [1]. The variables used in the equation are the mean and variance of the rut depth, as well as the mean calculated cracked area.

Fatigue Cracking

The model, used to predict the load-related fatigue cracking in the asphalt layers, is described in detail in the technical report [1]. The tensile strain in the bottom of the asphalt layer is computed. A fatigue law is used to predict the number of load repetitions to failure. By using Miner's law of cumulative damage, the relative accumulated damage can be calculated every three months. The cracked area, percent of wheel path area cracked, is computed based on the expected variance of the cracking damage function.

Rutting

Rutting is a distress associated with permanent deformation in all of the pavement layers and subgrade. It is caused by consolidation or lateral movement of the materials due to traffic loads. In TFPS the calculated rut depth, in inches, is the average permanent deformation in the wheel path as measured under a 4-foot straight edge. The rutting calculations depend upon the number of load applications and the permanent deformation properties of the layers. The rutting subsystem is also explained in the technical report [1].

1.3.4 Evaluating the Pavement Condition

A terminal serviceability, maximum rut depth, and a maximum area of cracked surface area are selected by the design engineer. If <u>any</u> of the three calculated conditions reaches the terminal level, the pavement is considered failed, and the overlay is applied. In the second stage of construction (i.e., after the overlay), the condition of the pavement is again predicted seasonally. When any of three terminal condition criteria are reached, the life of the overlay is assumed to end. If the lives of these two exceed the analysis period, the next design strategy is analyzed. Otherwise, additional overlays are considered prior to analyzing the next strategy. As an example of this procedure, consider the following:

A specific pavement structure is analyzed. The three indicators of pavement condition (i.e., roughness, cracking and rutting), which are calculated seasonally throughout the pavement life, are plotted in Figure 4. The designer has specified the minimum acceptable criteria to be a PSI of 2.5, a maximum cracked area of 600 square feet/1000 square feet of wheel path area, and a maximum average rut depth of 0.6 inches.

As seen in Figure 4 the cracking in the first stage is slow to develop, rutting has developed slightly faster, but the critical criteria for this structure is the roughness (PSI). After 11.5 years the calculated PSI drops to the minimum terminal PSI of 2.5. This is the end of the initial construction period analysis. To rehabilitate the structure, the overlay is applied. In the second stage it is clear that load-related surface cracking is the most critical criteria. After 15.5 years this structure fails due to fatigue cracking. A second overlay is applied at this time. The surface of the second overlay is still in

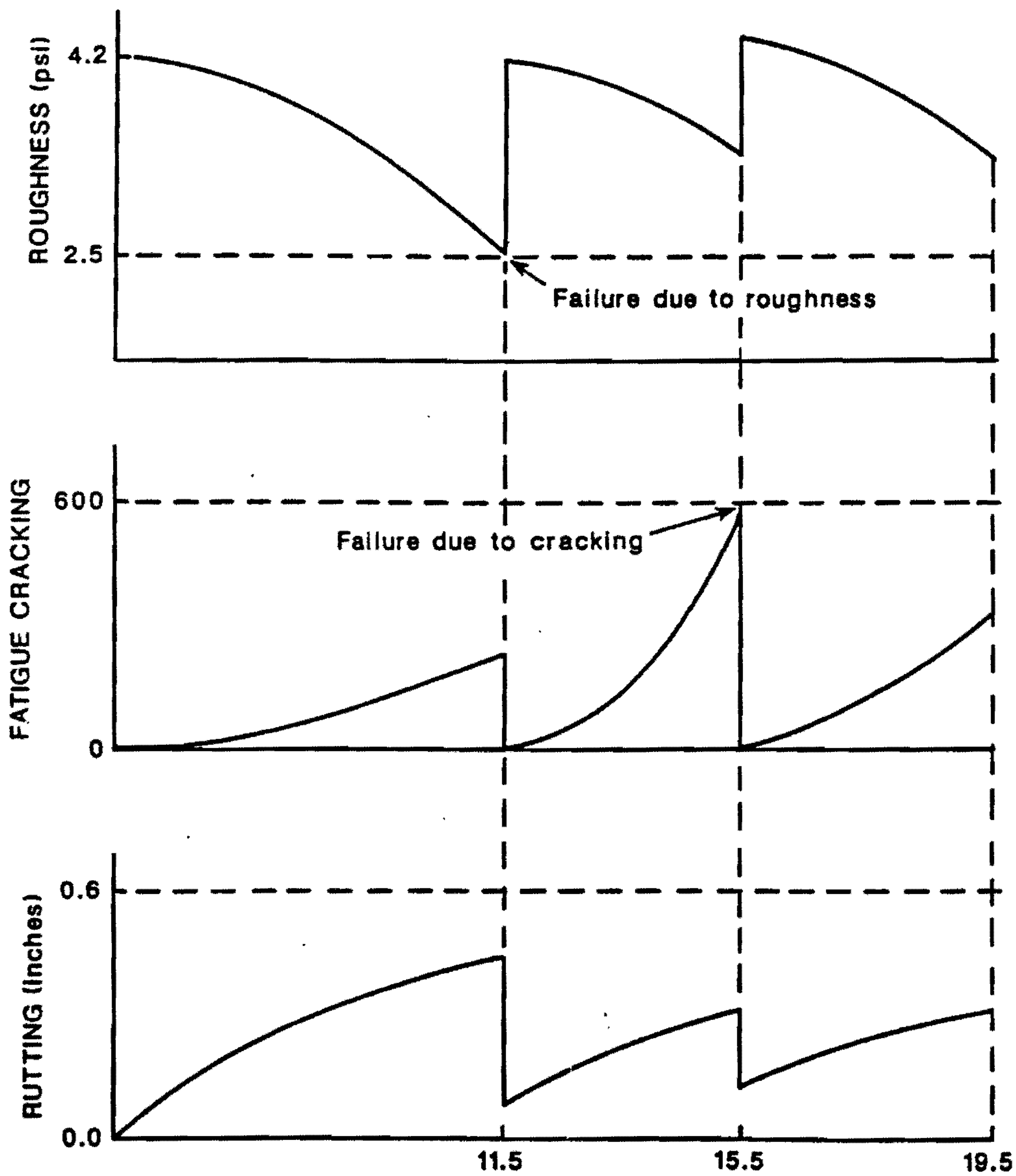

Figure 4. Rehabilitation Due to Excessive Roughness in the First Period and Failing Due to Fatigue Cracking in the Second Period.

acceptable condition at the end of the 20 years analysis period, and the strategy would be considered a feasible solution.

1.3.5 Economic Analysis

The purpose of the economic analysis is to calculate the costs associated with each feasible design strategy. The program calculates the present worth of the following costs over the analysis period.

- Initial Construction Cost
- Routine Maintenance Cost
- Overlay Construction Cost
- Seal Coat Costs
- User Cost Due to Traffic Delays During Overlays
- Salvage Value

After the totals are compared, the design strategy with the lowest total present cost is the preferred solution.

1.4 GETTING STARTED

The following terms and conventions are used throughout this document:

- All characters to be typed are quoted and displayed in boldface. For example, "**TFPS**".
- Special keyboard keys such as ENTER or F1 will be printed in square brackets [ ].
- The word "type" means just type the characters indicated while "enter" means type the characters indicated and then press the [ENTER] key.
- All the entries are shown in uppercase, but entering them in lowercase will yield the same results.

Appendix A is provided as a quick reference. The chapters in the Users Guide provide detailed information on program features and input variables.

1.4.1 INSTALLING OF THE TFPS PROGRAM

To install the TFPS on a hard disk, use the following steps:

1. In the hard disk directory in which you wish to install TFPS, type **"CD\"** to change to the root directory.
2. Make a subdirectory TFPS by typing **"MD TFPS"**.
3. Change the default directory to TFPS by typing **"CD\TFPS"**.
4. Copy all the files from the distribution diskettes to the TFPS subdirectory.

1.4.2 STARTING THE PROGRAM

The program is very simple to start. First, change to the directory that contains the TFPS program files. It is assumed that the program was installed in a directory named TFPS. To start the program;

1. Switch to the proper directory by entering **"CD\TFPS"**.
2. Now type **"TFPS"** and press **"[ENTER]"** to load the program into memory and start it.

After starting the program the MAIN MENU appears. Appendix A is a step-by-step procedure describing each screen.

1.4.3 HELP SCREENS

Help screens for each data entry request are available by pressing **"F1"**. Help screens are available to assist the designer to select the appropriate material characterization from the Unified Classification System for subgrade and granular base type. By entering the percentages of material that passes the No. 200 and No. 4 sieves or by being familiar with the Unified letter symbols the program will automatically input the proper classification. All the other help screens are for information only and will not input values on the data entry screens. The help screens can be exited by pressing **"enter"**.

1.4.4 GETTING AROUND IN THE PROGRAM

The following keys can be used to get around in the program:
[spacebar], [↑], or [↓] to move to an option in the menu.

[F1] Provides help by displaying information pertinent to what you are doing. The help offered is not as complete as the Users Guide, but can be used as a quick reference.

[F2] Sends you back to the top of the screen. This allows you to change data that you just entered.

[ESC] Returns you to the previous menu.

[ENTER] Continue to the next data field.

1.5 HARDWARE AND SOFTWARE REQUIREMENTS

The TFPS program runs on any IBM[1] compatible personal computer fitted with a numeric co-processor. A minimum of 640k Random Access Memory (RAM) and a graphics card to display the screens are also required. Although the program can be operated from a single flexible diskette, operating time is decreased considerably if operated from a hard disk.

The program operates with IBM's PC Disk Operating System (PC DOS) or Microsoft's Disk Operating System (MS[2] DOS). The following files should be in the default drive when running the Program:

1. TFPS.BAT
2. TFP.EXE
3. SGBL.DAT
4. BASESUF.DAT
5. OVERLAY.DAT
6. TABL.RST
7. TAB1.RST
8. OVER.RST
9. UZAN.RST
10. COST.RST
11. COND.RST
12. SORT.RST
13. DISPLAY.COM
14. SCREENS.LTR
15. DIST-1.ENV, DIST-2.ENV,...DIST-25.ENV.

The program was written in Fortran and the Executable file is called TFPS.EXE. DISPLAY.COM and SCREEN.LBR are used to operate the menus and

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[1] IBM is a trademark of International Business Machines Corporation.

[2] MS is a trademark of Microsoft Corporation.

input screens. The batchfile TFPS.BAT will load the DISPLAY.COM into the resident memory and start the program. The three files with the extension DAT are used to save regression constants and other layer related data during the pavement analysis. The analyzed pavement results are saved with the extension RST. These files are not of importance to the user because they are in an unformatted form. After the analysis is completed, the RST-files are retrieved and the reports are printed. The 24 district data files contain the environmental data for each county within the district. This data includes monthly temperature and precipitation data, the average daily solar radiation and the Thornthwaite Moisture Index.

1.6 REPORTS

The program provides two reports to describe the results of the analysis. One report gives the results of the mechanistic analysis. The second report provides information on the cost-effectiveness of feasible strategies. Sample reports are shown in Appendix A.

1.6.1 RESULTS FROM THE MECHANISTIC ANALYSIS

This report contains a summary of the mechanistic results in tabular form. The table columns are described below.

Pavement System: A unique number is assigned to each case analyzed. It is only a means of identification. This identifying number is the same pavement system number used in the second report.

Base Thickness: The base thickness (granular and/or black) is shown in inches for the strategy analyzed for the unique pavement system number.

Surface Thickness: The asphalt concrete pavement surface thickness is shown in inches for the strategy analyzed for the unique pavement system. If an overlay has been added to the surface, indicated in the overlay thickness column, the surface thickness will include the overlay thickness minus the planning depth used in the analysis.

Overlay Thickness: The thickness of the overlay layer is shown in inches.

Time Overlay Failed: The time to overlay failure is shown in years.

Code: A code is assigned to each load case analyzed which describes when the load case failed. The codes are defined as follows:

Code 1 - Maximum allowable time to first overlay was exceeded (i.e., initial performance is larger than allowable by selected criteria).

Code 2 - Minimum time to first overlay not reached (i.e., initial performance is less than allowable by selected criteria).

Code 4 - Minimum time between overlays not exceeded (i.e., overlay performance is less than allowable by selected criteria).

Code 5 - All design criteria met (i.e., this is an acceptable design based on selected criteria).

Code 6 - Analysis period not reached within overlay (i.e., this design did not provide adequate acceptable life to reach the end of the analysis period).

Seal Coats Added: The number of seal coats added as a maintenance action in the life cycle costing is shown. This result is only applicable if the "transverse and longitudinal cracking" option is used.

1.6.2 COST-EFFECTIVENESS ANALYSIS

The second report contains a summary of the performance, condition, and life cycle costing information for the pavement strategies analyzed. The system numbers, used to identify the load cases, are the same as those used in the first report. The results are reported under the headings: Initial Construction, Swelling Soils, Seal Coats, Overlay Number, and Life Cycle Costs.

Initial Construction - Initial Construction refers to the original structure of the pavement before multiple overlays are applied. The time of "failure" of this structure, the failure mode, and the terminal condition of the pavement are described by the calculated PSI, cracked area, and rut depth values.

Swelling Soils - This is an optional analysis in the program. The time to failure number of the original structure due to swelling soils is reported. Swelling soils reduces the serviceability of the pavement and the associated failure mode is serviceability. The reduction in serviceability, because of swelling soils, is not used in the mechanistic analysis.

Seal Coats - This is an optional analysis in the program. The number of seal coats used as a maintenance action are only calculated if the "transverse and longitudinal cracking" option is used. The number of seal coats applied is used in the life cycle costing analysis.

Overlay Number - The overlay number and the time of failure is reported. In addition, the thickness of the overlay and the user defined planing depth is reported.

Life Cycle Costing - The initial construction, overlay construction, seal coat, routine maintenance, traffic delay costs, and salvage value costs for the pavement are reported as the net present worth costs in dollars per square yard (i.e., the costs discounted to time of initial construction).

CHAPTER 2 PROBLEM IDENTIFICATION AND DISTRICT DATA FILES

2.1 PROBLEM IDENTIFICATION

The problem identification parameters have no effect on the computed design solutions. However, their importance to the engineer for future identification purposes can not be overemphasized. For convenience, these identification parameters are printed on the top of each report page. The following parameters are used:

- District
- County
- Problem Number
- Control
- Section
- Job
- Highway
- Date

2.1.1 District and County

Texas is divided into 24 highway districts and 254 counties. The district and county numbers are used to identify the location of the pavement being designed. The county name and county number in each district are available to the designer through the help screens. For every county an environmental data file has been prepared. Once the district and county numbers have been supplied to the program, the appropriate district data file is retrieved. The county name and relevant environmental data are read from these district data files.

2.1.2 Other Identifiers

In an effort to evaluate different design strategies considering several materials, the designer may complete several computer runs. In each run different variables may be used. To identify each run on the same problem, different problem numbers should be used.

The control, section, job, and highway are variables unique to a specific project. Without these variables future identification of the printed results may not be possible.

The date of the analysis is completed can also be recorded. The format of this variable is XX-XX-XX (for example 02-28-89).

2.2 THE DISTRICT DATA FILES

The 24 districts of Texas include 254 counties. The environmental data used by the program for each county data has been stored by district, in the 24 district data files. The designer supplies the district and county number, and the following data are retrieved from the file:

- The county name (See section 2.1.1);
- The monthly air temperatures;
- The lowest monthly averaged minimum daily air temperatures;
- The monthly average rainfall;
- The Thornthwaite Moisture index;
- The Thornthwaite Moisture index range; and
- The Average Annual Solar Radiation.

The typical format of a district data file is shown in Figure 5. The data file for district 24, called **DIST-24.ENV** is used as an example. The format or contents of these files should not be important to the designer since the program stores them and recalls them automatically.

2.2.1 Monthly Average Air Temperature

The monthly average air temperatures are used in the structural analysis of the pavement structures. As the average air temperature varies through the year, the elastic properties of the pavement structure change. The moduli of elasticity of primarily asphaltic layers are temperature dependent. Each layer temperature is influenced by the layer's depth from the surface and the air temperature. If the subgrade temperature is calculated to be below 32°F, the subgrade modulus is assumed to be frozen and is set at 50,000 psi.

2.2.2 The Lowest Monthly Averaged Minimum Daily Air Temperature

The lowest monthly averaged minimum daily air temperature is the lowest of the 12 monthly minimum temperatures. In most counties the

```
DISTRICT NUMBER  24

COUNTY NUMBER      22      BREWSTER
 49.6  53.   60.2  69.2  75.5  80.4  81.   79.5  74.4  66.8  57.3 50.9
 34.   34.   34.   34.   34.   34.   34.   34.   34.   34.   34.   34.
 .5    .5    .4    .4    1.4   1.4   1.8   1.8   2.3   1.6   .5    .4
-31.6    27.7    162.

COUNTY NUMBER      55      CULBERSON
 44.   47.2  54.5  63.6  72.   79.4  80.7  78.5  73.2  63.4  51.8 45.2
 29.   29.   29.   29.   29.   29.   29.   29.   29.   29.   29.   29.
 .5    .3    .2    .2    .5    .9    1.7   2.2   1.7   1.4   .4    .3
-44.1    15.7    188.

COUNTY NUMBER      72      EL PASO
 42.4  46.2  54.1  61.8  70.   78.4  80.8  78.5  72.9  62.6  50.7 43.4
 30.   30.   30.   30.   30.   30.   30.   30.   30.   30.   30.   30.
 .3    .4    .3    0     .2    .7    1.8   1.8   1.2   .7    .3    .4
 -46.6    19.8    198.

COUNTY NUMBER     116      HUDSPETH
 43.7  46.7  53.5  62.   70.2  77.7  79.3  77.2  71.9  62.7  51.2 44.5
 29.   29.   29.   29.   29.   29.   29.   29.   29.   29.   29.   29.
 .4    .4    .3    .2    .5    1.    1.9   2.1   2.1   1.2   .5    .4
-41.7    25.9    193.

COUNTY NUMBER     123      JEFF DAVIS
 42.1  44.   50.4  58.4  65.5  70.6  70.7  68.8  65.   58.5  49.5 43.9
 31.   31.   31.   31.   31.   31.   31.   31.   31.   31.   31.   31.
 .7    .6    .5    .2    1.4   2.1   3.7   4.1   3.    1.7   .7    .4
-11.7    42.8    182.

COUNTY NUMBER     189      PRESIDIO
 45.5  49.   55.7  64.2  71.9  77.7  78.8  76.8  72.3  63.4  52.7 46.1
 31.3  31.3  31.3  31.3  31.3  31.3  31.3  31.3  31.3  31.3  31.3 31.3
 .4    .3    .3    .3    .7    1.7   1.9   2.6   2.1   1.2   .6    .3
-3.4     131.7   175.

               FORMAT:
                County number    County name
                The monthly air temperatures (for 12 months)
                The lowest of the monthly averaged minimum daily air
                temperatures
                The monthly average rainfall (for 12 months)
                Thornthwaite Moisture index
                Thornthwaite moisture Index Range
                Average Annual Solar Radiation
```

Figure 5. The Contents and Format of a Typical District Data File.

lowest temperature occurs during the month of January. This temperature is used in the longitudinal and transverse cracking model which is an optional function of the program discussed in Chapter 11.

2.2.3 The Monthly Average Rainfall (inches)

The monthly average rainfall data are also used to modify the subgrade modulus for seasonal differences. In months with a low rainfall, the soil suction will be relatively high resulting in a higher subgrade modulus. In a wet season, the relative suction will be low, resulting in a lower subgrade modulus.

2.2.4 The Thornthwaite Moisture Index

The Thornthwaite Moisture Index value is read from the district data file. It is an index which is related to the environment of a county [4]. Because the index is related to moisture availability and evaporation potential, moist climates have positive values while dry climates have negative values. Based on the subgrade type, this index, and the monthly precipitation data, the variation in soil suction and the seasonal change in subgrade modulus is calculated.

2.2.5 Average Amplitude of Solar Radiation

The average amplitude of solar radiation is used in the prediction of the transverse and longitudinal cracking. The average amplitude of solar radiation is an indicator of how much energy the sun pours onto the earth's surface. Radiation is measured in Langleys per day.

CHAPTER 3 BASIC DESIGN CRITERIA

3.1 INTRODUCTION

The "Basic Design Criteria" determines the overall quality of pavement service provided to the pavement user. This criteria influences the design outcome of both condition and time. Due to the variability of material properties, layer thicknesses, and traffic, probability concepts are used to ensure a standard level of service at different reliability or certainty levels. The basic design criteria consist of the following variables:

- Length of Analysis Period (years)
- Minimum Life Expected from the Initial Construction (years)
- Maximum Life Expected from the Initial Construction (years)
- Minimum Life Expected from the Overlay (years)
- New Construction (Y or N)
- Minimum Serviceability Index (PSI)
- Maximum Allowable Rut Depth (inches)
- Maximum Allowable Cracked Surface Area (inches)
- Pre-Overlay Planning Depth (inches)
- Reliability code (A,B,C,D or E)
- Speed Category (H,S,I)
- Aggregate Quality (L,M,H)

3.2 TIME RELATED CRITERIA

Within the thickness limits set for each layer (Chapters 8, 9, 10), an analysis is performed on all possible combinations of layer thicknesses. After a structure is analyzed and is found to perform satisfactorily throughout the analysis period, it is considered a feasible design alternative. To limit the outcome of the analysis to realistic options, constraints are placed on the performance periods of both the original construction and the overlay. Because experience has shown that most asphalt pavements will require some type of major rehabilitation within a set number of years, a reasonable maximum performance period should be used. Whenever the performance of a design exceeds this period, it is regarded as a conservative design and is not further investigated. The user has the opportunity to define the minimum number of years any design should last. Time constraints should not be overly restrictive because this will limit feasible pavement design options. Figure 6 (a typical performance curve) shows the five time-related basic design criteria.

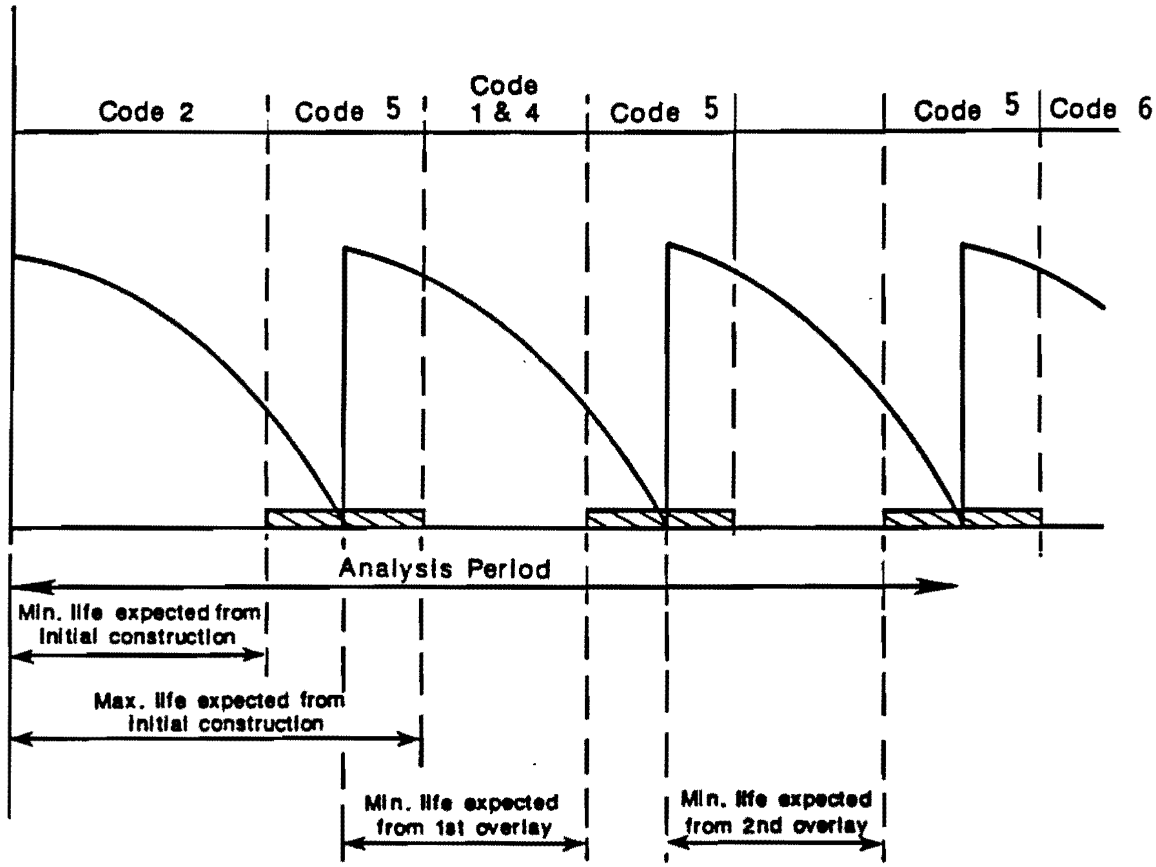
3.2.1 Length of Analysis Period

The analysis period is analogous to the term "design life." It is that length of time that the initial construction and the overlay(s) are expected to perform satisfactorily. It is also the period over which the cost of various alternatives is compared for economic analysis. The analysis period, in general, should not exceed the time the geometric design is expected to remain adequate. However, the analysis period should include the initial construction and one rehabilitation. The following analysis periods are recommended:

- Interstate-funded highways: a thirty-year analysis period from the date of anticipated approval by the Federal Highway Administration.
- Farm- or Ranch-to-Market Highways: use a ten to fifteen year analysis period.
- Temporary connections, detours, and other short life expectancy pavements: use an analysis period that equals the expected life of the pavement.
- For other important (primary and secondary) urban arterial streets and expressways with gradelines such that the pavement will not likely be destroyed (due to alignment revisions) during the analysis period: consideration should be given to a thirty-year analysis period.
- For all other facilities (most highways): use twenty years.

3.2.2 Minimum Life Expected from the Initial Construction

The minimum life expected from the initial construction is the minimum time the initial design must last. The time limit may be controlled by any of the following considerations:



Code 1 - Max. time to first overlay exceeded
Code 2 - Min. time to first overlay not reached
Code 4 - Min. time between overlays not exceeded
Code 5 - Analysis period not reached within overlay
Code 6 - All design criteria met

Figure 6. A Typical Performance Curve.

- The public's perception of how long a new pavement should last. Overlaying a pavement shortly after the initial construction can be very unpopular with the travelling public.
- For this reason, specify a "reasonable" minimum length of time. A range of eight to twelve years is recommended for the minimum life.
- Limiting funds for initial construction may force the designer to build a pavement with limited initial life. When a less expensive initial construction is used, a relatively short minimum time to the first overlay should be specified.
- Heaving soils are often remedied by frequent overlays. The designer should not decrease the minimum period in an effort to accommodate the heaving soils. It is recommended that heaving soils be ignored in specifying the performance periods. Chapter 12 discusses how to address swelling soils.

If restrictive limitations are used, the program may find no feasible solutions. In order to obtain results it may be necessary to shorten the minimum life expected from a design.

3.2.3 Maximum Life Expected from Initial Construction

Maximum life expected from initial construction is the program life expectancy of the pavement. Past performance should be the main factor to influence this variable, but it should not exceed the time period used for the "Length of Analysis Period" above.

3.2.4 Minimum Life Expected from the Overlay

Minimum life expected from the overlay is the shortest period the overlay is expected to last. If the performance time of the overlay is less than this required limit, the alternative will be rejected. The parameters that influence this variable are similar to the minimum time to the first overlay. A minimum time of <u>seven years</u> is recommended. The quantity selected is also used for the time between multiple overlays.

3.3 OVERLAY RELATED CRITERIA

The program can also analyze conditions of an existing pavement to determine the asphalt concrete thickness required for an overlay of the existing pavement surface. Existing conditions of cracking and rutting are utilized along with existing and projected cumulative number of 18 kip single axle loads over the design period by the program in its calculations. A backcalculated modulus of the existing pavement structure should also be used.

3.3.1 New Construction

New Construction (Y or N) tells the computer whether the problem is an initial construction problem or overlay(s) only. Selecting "Y" will cause calculation of a pavement structure for a new roadway plus future overlays required to reach the specified analysis period. Selecting an "N" will cause calculation of an asphalt thickness for overlay(s) only. The value entered for the maximum life expected from the initial construction is considered the age of the existing pavement at the time of the overlay. If an overlay design is chosen, the existing pavement structure must be entered as the thicknesses of base and surface layers. This is completed by entering the same value for the minimum and maximum thicknesses for the base layer (see section 8.2.1) and for the surface layer (see section 9.2.1). Entering an "N" in the "New Construction" line will cause a pop-up screen to appear requesting data for the overlay design. The overlay design criteria consists of the following variables.

3.3.2 Existing Cracking

The existing cracked area in percent of the wheel path area cracked is the observed cracked area of the existing pavement. This information can be found in PES survey data or determined by a distress survey. The system will also calculate the expected cracking. The computer uses the greater of the observed cracked area or the calculated cracked area (see section 3.4.3). The calculated cracked area may include cracking in the hot-mix asphalt concrete which has been covered, or hidden, by seal coats.

3.3.3 Existing Rutting

Existing rutting is the observed rutting depth of the existing pavement. This information can be determined from PES survey data or determined by a distress survey. The system also calculated the expected rutting. If the existing rutting is greater than the calculated rutting, the existing rutting value will be used in the calculations (see section 3.4.2.).

3.3.4 One Direction Cumulative 18 kip ESAL (20 yrs. Traffic from O.L.)

The one direction number of 18 kip single axle loads accumulated over the next twenty years from overlay is used by the program to proportion the traffic loading for the overlay design period. It is used in both the cracking and rutting models. In the overlay design, this is the future traffic applied to the overlay(s) being designed.

3.3.5 ADT at the Beginning and End of 20 Years

The average daily traffic (ADT) at the beginning of the overlay period is the average two-directional traffic volume during a 24 hour period (see section 4.2.1.), expected to be on the pavement at the time the first overlay is to be applied. The ADT at the end of 20 years is the same type of traffic data expected to be on the pavement 20 years after the overlay is applied.

3.3.6 Composite Modulus and Temperature

The program uses the lesser of the measured modulus and the calculated modulus in its computations for overlay(s) of the existing pavement. Non-destructive testing (see section 7.2.5) or laboratory testing on core samples can be used to obtain the measured composite modulus of the existing pavement. The measured modulus is adjusted to 70° F by the program by using the temperature at which the modulus was measured. If the measured modulus is not entered, the calculated modulus will be used.

3.4 CONDITION-RELATED CRITERIA

The TFPS program evaluates potential pavement structures by analyzing three kinds of deterioration: serviceability, cracking, and rutting on a seasonal basis. The user specifies the desired quality of pavement service by selecting a minimum allowable level of serviceability (roughness), a maximum amount of fatigue cracking in square feet per 1000 square feet of wheel path allowable, and a maximum allowable rut depth. When a seasonally-calculated deterioration reaches one of these specified levels, the pavement is considered failed. The user is advised not to use "overly conservative" limits to ensure that the pavement provides the desired service with more certainty. Probability concepts are used to ensure acceptable condition levels are reached for the desired level of certainty (see section 3.5).

3.4.1 Terminal Serviceability

Serviceability is the ability of a pavement to serve the traffic for which it was designed. The measure of serviceability is the Present Serviceability Index (PSI) which ranges from 0 (impassible) to 5 (perfect). In Texas the PSI is calculated from measured roughness or ride. The terminal serviceability index is based on the lowest index that will be tolerated before rehabilitation becomes necessary. Recommended terminal PSI values are shown in Table 2. Figure 7 shows the influence of these variables on a typical performance curve.

Table 2. Recommended Distress Limits for Various Road Classifications.

Road Classification	Terminal Service-ability	Maximum Rut Depth (inches)	Maximum Cracked Area (sq ft/1000 sq ft)
Interstate-Funded Highways	2.5	0.4	400
Important Urban Arterials	2.5	0.4	450
Farm- or Ranch-to-Market Highways	2.2	0.5	500
Low Volume and Other Facilities	2.0	0.6	600

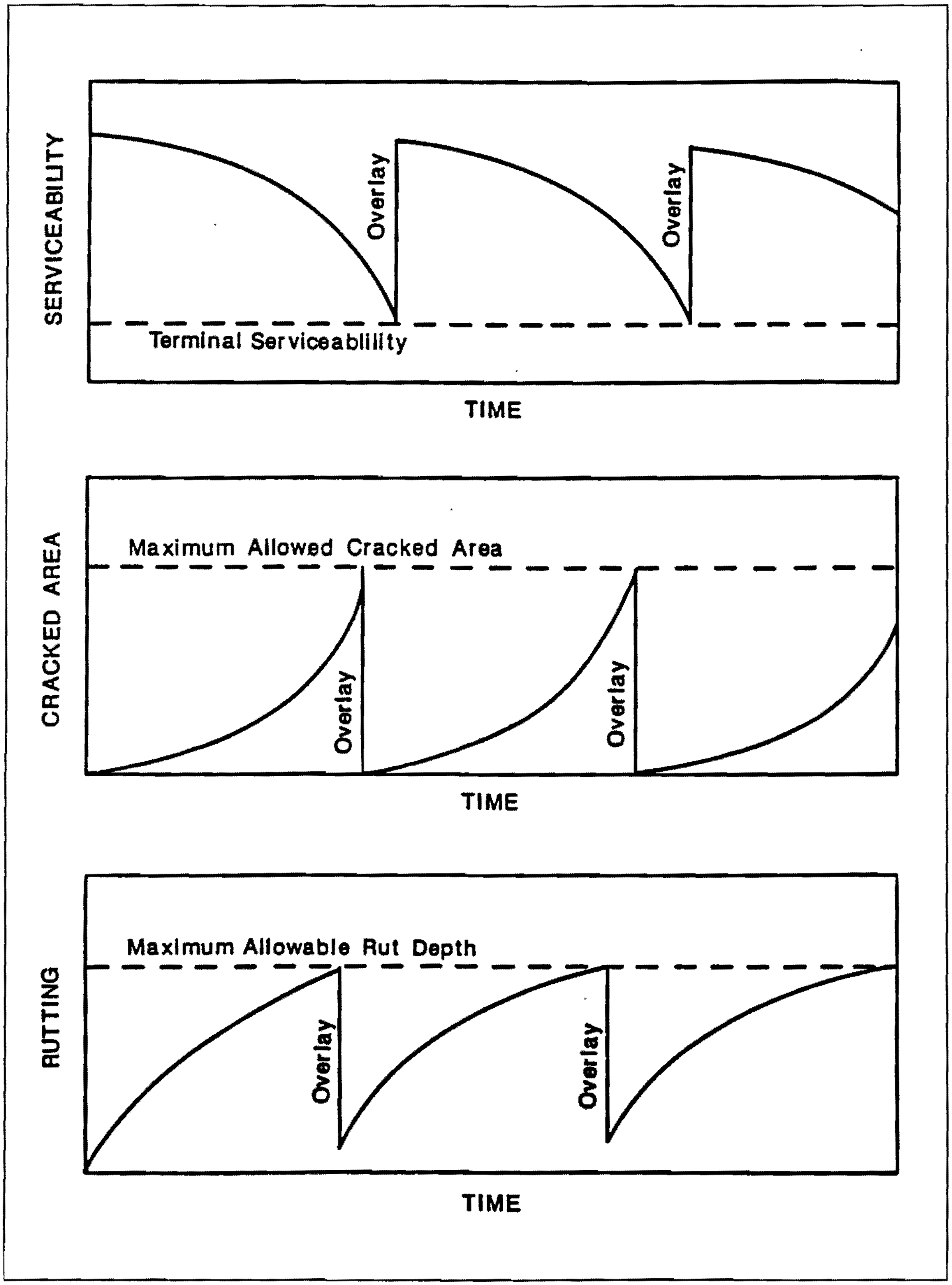


Figure 7. Performance Curves Indicating the Three Modes of Failure.

3.4.2 Maximum Allowable Rut Depth

Rutting is a distress associated with permanent deformation in any or all of the pavement layers or subgrade, usually caused by consolidation or lateral movement of the materials due to traffic loads. In TFPS the calculated rut depth is the expected permanent deformation under a four foot straightedge. If the seasonally-calculated rut depth reaches the maximum rut depth allowable, the pavement will be considered to have failed (see Figure 7). Table 2 provides recommended values for the maximum allowable rut depth for different road classifications.

3.4.3 Maximum Cracked Area Allowable

The maximum cracked area allowable is a limit set on the maximum area of road surface experiencing load-related cracking. This cracking is caused by fatigue failure of the asphalt surface due to traffic loading. The cracked area is calculated in square feet per 1000 square feet of the wheel path. When the seasonally-calculated area reaches the maximum allowable cracked area, the pavement is considered failed (see Figure 7). Table 2 provides recommended values for the maximum cracked area for different road classifications.

3.4.4. Pre-Overlay Planing Depth

The design engineer can include removal of a portion of the existing asphalt before overlaying with asphalt concrete. This may be done to remove the top layer of aged, oxidized asphalt, to improve bond between the new asphalt and the existing asphalt layer or to remove rutting. Also, a curb and gutter section may limit the thickness of the asphalt layer requiring removal of old asphalt before overlaying with new.

The program accounts for the thickness to be removed in the calculations in the overlay mode. The pre-overlay planing depth specified will be subtracted from the existing asphalt layer by the computer, and the reduced thickness of existing asphaltic concrete will be used in calculations to determine overlay thicknesses.

3.5 RELIABILITY

Reliability, as used in the TFPS program, is the probability that all three types of deterioration: cracking, rutting, and serviceability, will remain within permissible levels for each of the stages of analysis. Five reliability codes have been defined to allow the user to vary the confidence level in design. This level of reliability accounts for variance in traffic prediction, materials characterization, layer thickness, performance prediction, and other sources of variability.

3.5.1 Reliability Code

The reliability code is the variable that controls the level of confidence provided a design. The level of reliability is specified using a letter code of A, B, C, D, or E. The reliability increases from A to E, with A being the lowest. As the volume of traffic, difficulty of diverting traffic, and public expectation of availability increases, the risk of not performing to the expected level must be minimized. This can be achieved by selecting a higher reliability code during the design process. Recommended guidelines for reliability codes are shown in Table 3.

Table 3. Recommended Reliability Codes.

Functional Classification	Urban	Rural
Interstate-Funded Highways	E (95%)	D (90%)
Important Urban Arterials	D (90%)	C (85%)
Farm- or Ranch-to-Market Highways	C (85%)	B (70%)
Low Volume and Other Facilities	B (70%)	A (50%)

To illustrate the influence of reliability within the program, the following example is provided:

A typical initial pavement structure in Travis county is analyzed using a reliability code of A, C, and E. For the example only the influence of reliability on the <u>roughness criteria</u> will be illustrated.

The predicted PSI (Present Serviceability Index) and the variance in PSI over the pavement life is listed in Table 4.

Based on the assumption of a normal distribution and a known expected value and its variance [1], it can be shown that the probability of failure is:

Table 4. Predicted PSI and the Variance in PSI Over the Pavement Life.

Years	E[PSI]	Var[PSI]	$E[PSI]-Z_r\ Var[PSI]$		
			Rel. Code A	Rel. Code C	Rel. Code E
0	4.20	0.00	4.20	4.20	4.20
1	3.95	0.40	3.48	3.05	2.71
2	3.93	0.40	3.46	3.03	2.69
3	3.91	0.40	3.44	3.01	2.67
4	3.90	0.40	3.43	3.00	2.66
5	3.87	0.40	3.40	2.97	2.63
6	3.83	0.41	3.36	2.92	2.58
7	3.78	0.41	3.31	2.87	2.53
8	3.72	0.43	3.24	2.79	Fail
9	3.66	0.45	3.16	2.71	
10	3.60	0.47	3.09	2.63	
11	3.54	0.50	3.02	2.54	
12	3.48	0.52	2.95	Fail	
13	3.42	0.55	2.87		
14	3.37	0.57	2.81		
15	3.33	0.59	2.76		
16	3.28	0.61	2.70		
17	3.23	0.63	2.64		
18	3.18	0.65	2.58		
			Fail		

$$P = \text{Prob}\ \{\ F\ (x_i) > F_o\ \} = 1 - R$$

where F_o = failure criteria (e.g., a PSI of 2.5)

$$F_z = F(x_i) - Z_R \ \text{var}\ F(x_i)$$

In Table 4 these F_z values for reliability levels A (Z_R = 0.545), C (Z_R = 1.42), and E (Z_R = 1.955) have also been calculated.

From these results it can be seen that the reliability code is a very sensitive parameter. For the reliability code E the average PSI over the total section is still 3.72 at failure! The above example shows the following expected pavement lives:

Reliability level A : 19.0 years
Reliability level C : 11.4 years
Reliability level E : 7.8 years

3.5.2 Speed Category

The speed category is the variable from which a time of loading is calculated. For a high speed roadway the time of loading will be less than that for a city street. The time of loading is used in the calculation of the viscous component of the total strain of the asphalt layer and will affect the rutting projected for the pavement. Assignment of the variable is dependent upon the speed category of the roadway.

H - Highway
S - Street
I - Intervention

The highway speed should be used for normal design. Street speed can be used for sections experiencing slower or stop and go type traffic. Intersection should be used to check the rutting which might be projected for a section of pavement with controlled intersections.

3.5.3 Aggregate Quality

The aggregate used in the asphalt mix controls the rutting behavior of the mix. In TFPS, the aggregate quality variable is used in the rutting calculation of the program. A low quality aggregate will have more rutting than a high quality aggregate. Aggregate quality is dependent upon the geological properties of rock such as hardness, surface texture, permeability, and how the aggregate reacts with asphalt.

Practically speaking, low quality aggregate is more related to rounded, smooth, non-porous aggregate particles. Field and laboratory results show that asphalt mixtures, containing this type of material, deform much more easily under static and dynamic loads, than similarly graded mixtures containing crushed (manufactured) particles, which can be considered high quality aggregate.

3.6 DATA FORMAT AND LIMITS

The data supplied to the program will not be accepted if they do not meet certain limits. These limits and the correct format for each entry are listed in Table 5. Those items identified with numbers are numeric entries. Those items identified with an X are alphabetic entries.

Table 5. Data Forms and Limits - Basic Design Criteria.

Variable	Format	Minimum	Maximum
Length of Analysis Period	99	1	60
Minimum Life Expected from Initial Construction	99.9	0.1	60.0
Maximum Life Expected from Initial Construction	99.9	0.1	60.0
Minimum Life Expected from Overlay	99.9	0.1	60.0
New Construction	X	-	-
Minimum Serviceability	9.99	1.5	4.0
Maximum Allowable Rut Depth	9.9	0.1	5.0
Maximum Allowable Cracked Surface Area	999	1	999
Pre-Overlay Planing Depth	9.9	0	5.0
Reliability Code	X	-	-
Speed Category	X	-	-
Aggregate Quality	X	-	-
EXISTING OVERLAY DESIGN CRITERIA			
Existing Cracking	999	0	999
Existing Rutting	9.9	0	5.0
One Directional Cumulative 18k SAL (20 years)	99999999	0	99999900
ADT for Beginning of Overlay Period	999999	0	999999
ADT for Ending of Overlay Period	999999	0	999999
Composite Modulus	9999999	0	9999999
Temperature for Composite Modulus	999.9	0	135.0

CHAPTER 4 TRAFFIC DATA

4.1 INTRODUCTION

The traffic-related variables are used in both the condition and cost analysis conducted on the potential pavement structure. In the condition analysis, the traffic characteristics are used to calculate the cumulative traffic loads over any period of time. In the cost analysis, the models calculate the user cost due to the delay of traffic during overlay operations. This cost is influenced by factors such as traffic volume, speed, type of traffic, and the details of the detour. The following variables are used to characterize the traffic:

- ADT at beginning of analysis period (vehicles/day)
- ADT at end of 20 years (vehicles/day)
- Average approach speed to the overlay zone (mph)
- Average speed through overlay zone (overlay direction) (mph)
- Average speed through overlay zone (non-overlay direction) (mph)
- Proportion of ADT arriving each hour of construction (percent)
- Percentage of trucks in ADT
- One direction cumulative 18 kip ESAL at the end of 20 years

Most of the variables above should be obtained from the Transportation Planning Survey Division, File D-10, State Department of Highways and Public Transportation. For services available from this Division, the user is referred to the "Transportation Planning Division Operations Manual" [5].

4.2 TRAFFIC VARIABLES

4.2.1 ADT at the Beginning and End of 20 years

The Average Daily Traffic (ADT) is the average two-directional traffic volume during a 24 hour period. The ADT is used in both the condition and cost analysis. In the condition analysis, it is assumed that the equivalent 18 kip ESAL over the analysis period are distributed proportionally to the average daily traffic. By assuming a uniform increase in traffic volume from the beginning to the end of the analysis based on the changes from the beginning ADT to the ending ADT, the

CHAPTER 4 TRAFFIC DATA

4.1 INTRODUCTION

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- ADT at beginning of analysis period (vehicles/day)
- ADT at end of 20 years (vehicles/day)
- Average approach speed to the overlay zone (mph)
- Average speed through overlay zone (overlay direction) (mph)
- Average speed through overlay zone (non-overlay direction) (mph)
- Proportion of ADT arriving each hour of construction (percent)
- Percentage of trucks in ADT
- One direction cumulative 18 kip ESAL at the end of 20 years

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4.2 TRAFFIC VARIABLES

4.2.1 ADT at the Beginning and End of 20 years

The Average Daily Traffic (ADT) is the average two-directional traffic volume during a 24 hour period. The ADT is used in both the condition and cost analysis. In the condition analysis, it is assumed that the equivalent 18 kip ESAL over the analysis period are distributed proportionally to the average daily traffic. By assuming a uniform increase in traffic volume from the beginning to the end of the analysis based on the changes from the beginning ADT to the ending ADT, the cumulative 18 kip ESAL is predicted at any time during the analysis period. This cumulative traffic loads in 18 kip ESAL's is used to predict pavement deterioration.

In the cost analysis the average daily traffic is used to calculate the traffic delay cost during overlay construction. Traffic delay cost increases with an increase in ADT. Beyond a traffic volume of 1350 to 1500 vehicles per hour per lane during overlay construction, the computed cost of traffic delay is exceptionally high because the assumed lane capacity is assumed to have been exceeded.

4.2.2 The Average Speeds to and through the Overlay

The traffic speeds approaching and through an overlay construction area are used in computing the cost of delaying traffic during overlay construction. It is assumed that all vehicles approach the overlay area at the same speed, called the "approach speed." After leaving this restricted area it is assumed that traffic returns to the approach speed (see Figure 8).

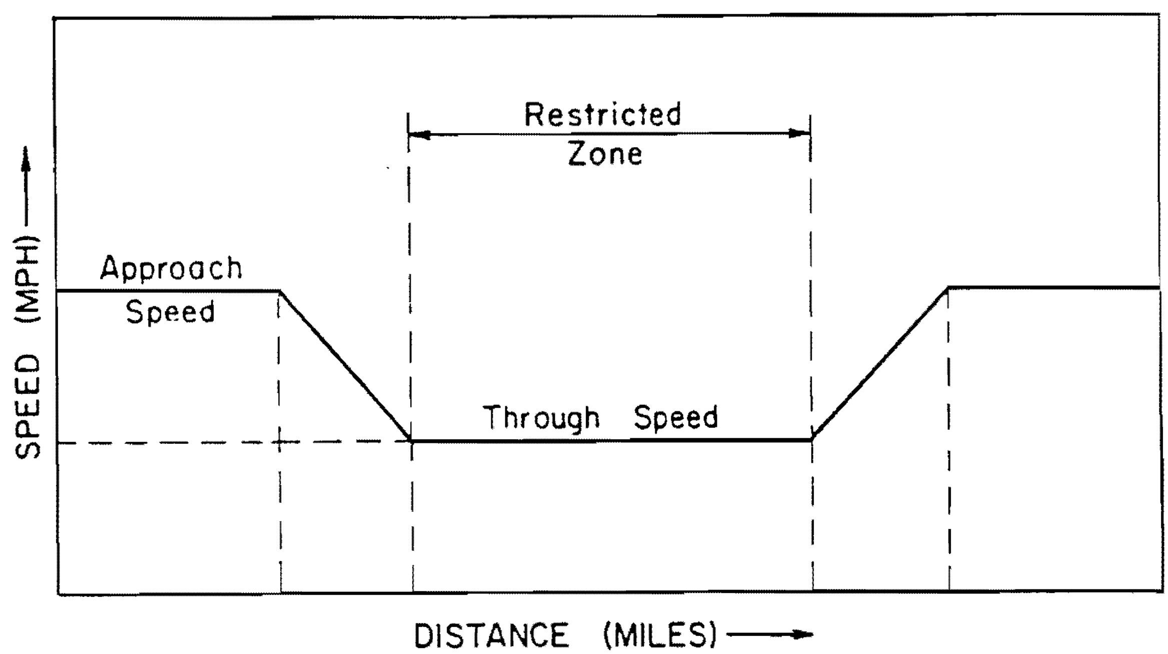

Figure 8. Speed Profile for Unstopped Vehicles During Overlay Construction Operations.

Through the overlay zone the traffic travels at a reduced speed, called the "through speed." Different speeds can be specified in the overlay and non-overlay directions. It is assumed that vehicles maintain these speeds throughout the restricted zone.

4.2.3 Proportion of ADT Arriving Each Hour of Construction

The percent of ADT arriving each hour of overlay construction is used in the calculation of the user cost during the overlay construction. The Transportation Planning Division (D-10) can provide this value if they are given the time of day over which the overlay construction will occur. In the absence of better information, the designer can use 6 percent for rural areas, and 5 percent for urban highways.

4.2.4 Percentage of Trucks in ADT

The percentage of trucks in the average daily traffic is used by the program to select the appropriate delay cost and capacity tables built into the program for the user cost analysis. Because the cost of slowing down or stopping a truck is higher than that for a passenger car, the percentage of trucks have an influence on the delay cost during overlay construction. Highways which carry more trucks in their daily traffic will have higher delay costs.

4.2.5 One Direction Cumulative 18 kip ESAL (20 yrs. Traffic From Initial Construction)

The "One-Directional Number of 18 ESAL Single Axle Loads" accumulated over a 20-year period from initial construction can be obtained from the Planning Survey Division, File D-10. The cumulative traffic load is calculated by assuming that the load distribution is proportional to the traffic distribution. In both the load-induced cracking and rutting models used in this program, the 18 kip ESAL is used as the design load.

4.3 DATA FORMAT AND LIMITS

The data supplied to the program will not be accepted if they are not within certain limits. These limits and the correct format for each entry are listed in Table 6. Those items identified with numbers are numeric entries.

Table 6. Data Format and Limits - Traffic Data.

Variable	Format	Minimum	Maximum
ADT at Beginning of Analysis Period	999999	1	999999
ADT at End of Analysis Period	999999	1	999999
Average Approach Speed to the Overlay	99	1	99
Average approach Speed through Overlay (OD)	99	1	99
Average Approach Speed through Overlay (ND)	99	1	99
Proportion of ADT Each Hour	99.9	1	99.9
Percent of Trucks	99	1	99
One Directional Cumulative 18 kip SAL_{20y}	99999999	1	99999999

CHAPTER 5 CONSTRUCTION AND MAINTENANCE DATA

5.1 INTRODUCTION

This group, called "construction and maintenance data," consists of the following variables:

- Overlay Construction Time (hours/day)
- Asphaltic Concrete Compacted Density (tons/cu. yard)
- Asphaltic Concrete Production Rate (tons/hour)

- Width of each lane (feet)

- Annual Routine Maintenance Cost for the First Period
- Annual Routine Maintenance Cost for the Second Period
- Annual Increase in Maintenance for the First Period
- Annual Increase in Maintenance for the Second Period

- Initial Serviceability Index (PSI)
- Serviceability Index after an Overlay (PSI)

- Interest Rate or Time Value of Money (percent)

5.2 CONSTRUCTION DATA

The construction variables are necessary to calculate the duration of the overlay construction operation. This, in conjunction with the detour design and traffic variables, is used to calculate the number of cars that will be delayed during an overlay operation. If the designer has difficulty in obtaining good estimates for these values, the district construction engineer should be consulted.

5.2.1 Overlay Construction Time

Overlay construction time is the number of hours over which the construction is expected to occur in a typical day. It is used in the economic analysis to calculate the user cost due to the delay of traffic.

5.2.2 Asphaltic Concrete Compacted Density

The compacted density of the asphalt concrete in tons per cubic yard is used to calculate the time it would take to place an overlay. Because of the considerable variation in specific gravity, gradation, and other characteristics of the aggregate, the compacted density varies considerably.

Good estimates can be obtained from the district laboratory or construction records. Typically the compacted density would be between 1.7 and 2.0 tons per cubic yard. For a quick conversion factor remember

$$150 \text{ lb/ft}^3 \cong 2.0 \text{ ton/cubic yard.}$$

5.2.3 Asphaltic Concrete Production Rate

The asphaltic concrete production rate, measured in tons/hour, should be obtained from the district construction engineer. The production rate will depend on the type and capacity of the mixing plant. In certain areas the paving unit or the number of available hauling trucks might be the limiting factor. The overlay lay down rate can be used to calculate the production rate. Suppose, for example, the production rate is known to be one lane mile per day for a 2 inch thick overlay, 12.5 ft wide. The compacted density is 125 lb per cubic feet. The following equation illustrates how to calculate the production rate in tons per hour:

$$\frac{\text{1 lane-mile x 2 in.}}{\text{day}} = \frac{\text{(12.5 ft)(5280 ft/mile)(125/c.ft)(1ft/12in)}}{\text{(2000/ton)(8HR/day)}}$$

$$= 86 \text{ tons/hour}$$

5.2.4 Width of Each Lane (feet)

The width of each lane is used to calculate the rate of construction and consequently how many vehicles have to be slowed down or delayed due to the work being performed. Typically a lane is 12 feet wide.

5.3 MAINTENANCE DATA

The maintenance cost data are used in the program to compare the total cost associated with each design alternative. The best source for this information is the district maintenance engineer. It is assumed that these expenditures are paid at the beginning of the year.

5.3.1 Annual Routine Maintenance Cost for the First Period

The annual routine maintenance cost, in dollars per lane-mile, is the average cost of maintenance for the first year after construction (see Figure 9).

5.3.2 Annual Routine Maintenance Cost for the Second Period

The annual routine maintenance cost for the second period, in dollars per lane-mile, is the average cost of maintenance for the first year after the first and subsequent overlays have been constructed (see Figure 9).

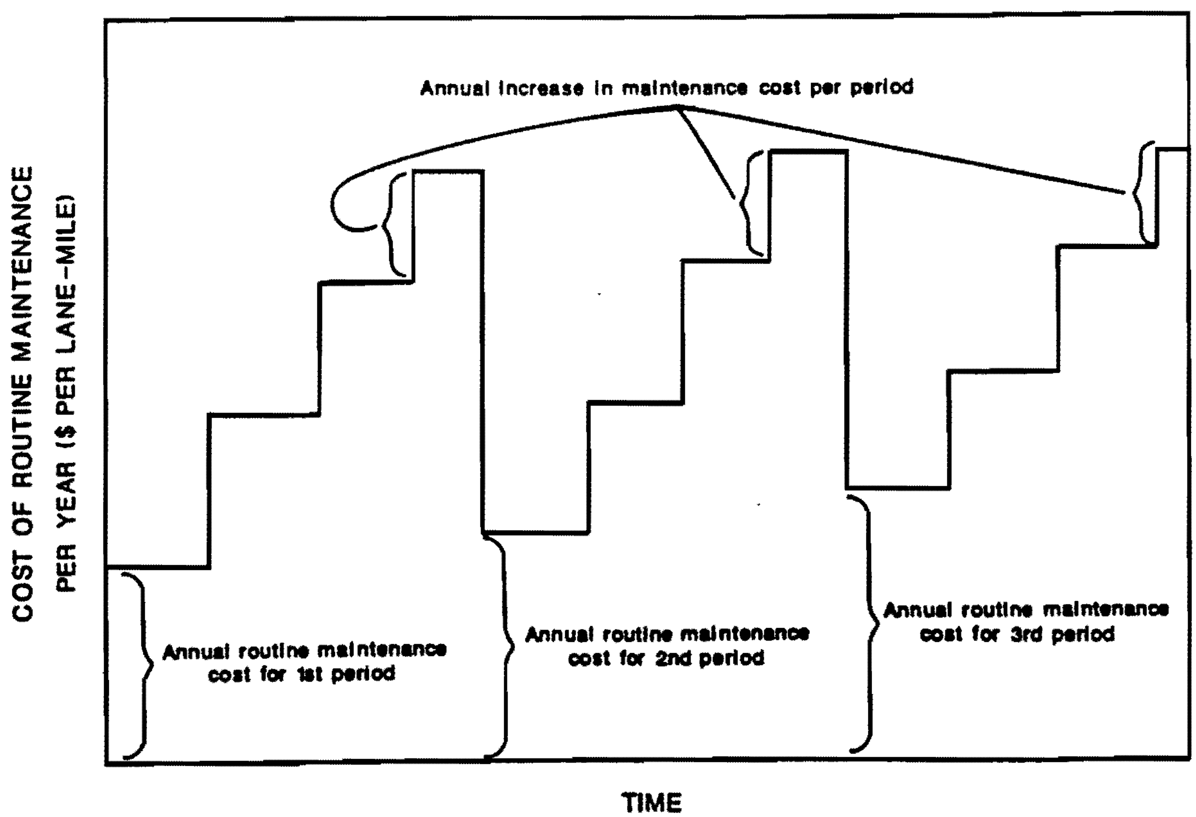

Figure 9. Maintenance Cost Calculations in TFPS.

5.3.3 Annual Increase in Maintenance for the First Period

The annual increase in routine maintenance cost for each year after the initial construction is assumed to increase uniformly. This increase is also in units of dollars per lane-mile (see Figure 9).

5.3.4 Annual Increase in Maintenance for Subsequent Periods

The annual increase in routine maintenance cost for each year after each overlay, in dollars per lane-mile, is assumed to increase uniformly (see Figure 9).

5.4 QUALITY OF CONSTRUCTION

5.4.1 Initial Serviceability Index

The initial serviceability index reflects the "smoothness" of the newly constructed pavement. It depends on the materials used and the construction practices. Initial serviceability indices have a statewide average of about 4.2. For a flexible pavement a PSI of 4.4 is near perfect.

5.4.2 Serviceability Index after an Overlay

The serviceability index after the overlay depends on the quality of the overlay construction. Usually a PSI of 4.2 is used for a flexible overlay analysis.

5.5 TIME VALUE OF MONEY

Interest rate or the time value of money is used in TFPS to discount future expenditures. By discounting these future expenses, the Department realistically invests only that money that should be spent now to provide the pavement service needed. In other words, the amount of the cost shown for overlays, maintenance, and salvage value is the amount of money that would have to be invested at the specified interest rate in order to have the money at the needed time. Although this money is not literally invested by the Department, this concept is necessary to have a valid comparison of the design strategies. It could be considered that this money is being invested in other projects which have a return equal to or greater than the specified interest rate. The present interest rate is in the order of seven percent to nine percent.

5.6 DATA FORMAT AND LIMITS

The data supplied to the program will not be accepted if they are not within certain limits. These limits and the correct format for each entry are listed in Table 7. Those items identified with numbers are numeric entries.

Table 7. Data Format and Limits - Construction and Maintenance Data.

Variable	Format	Minimum	Maximum
Overlay Construction Time	99.9	0.1	24
Asphaltic Concrete Compacted Density	9.99	1	3
Asphaltic Concrete Production Rate	999	1	999
Width of Each Lane	99	3	20
Annual Routine Maintenance (1st period)	999.99	0	999
Annual Routine Maintenance (2nd Period)	999.99	0	999
Annual Increase in Maint. (1st Period)	999.99	0	999
Annual Increase in Maint. (2nd Period)	999.99	0	999
Initial Serviceable Index	9.99	2.5	4.6
Serviceability Index after an Overlay	9.99	2.5	4.6
Interest Rate or Time Value of Money	9.99	0	99

CHAPTER 6 DETOUR DESIGN FOR OVERLAY

6.1 INTRODUCTION

Details of expected detour designs are used to predict the additional user cost caused by overlay construction operations. The method used depends mainly on highway geometrics, especially the number of lanes, the median type (if any), and the presence or absence of paved shoulders, frontage roads, or other alternate routes. In order to model the detour the following variables are used:

- Traffic model used during overlay (1 to 5)
- Number of open lanes in restricted zone (overlay direction)
- Number of open lanes in restricted zone (non-overlay direction)
- Distance traffic is slowed (overlay direction) (miles)
- Distance traffic is slowed (non-overlay direction) (miles)
- Detour distance around the overlay zone (miles)

6.2 DETOUR DESIGN VARIABLES

6.2.2 Traffic Model Used During Overlay

The program provides five methods to handle traffic during overlay operations (see Figures 10a and 10b). Models 1 and 2 are for two-lane roads (with or without shoulders) and the other three models are for roads with four lanes or more. The designer decides on the model to use and then enters the model number (1 through 5).

6.2.3 Number of Lanes Open in Restricted Zone (Overlay and Non-Overlay Direction

The number of lanes open to traffic is used to compute the delay caused to traffic during overlay construction. The number of open lanes depends on the method of handling traffic and the number of lanes available.

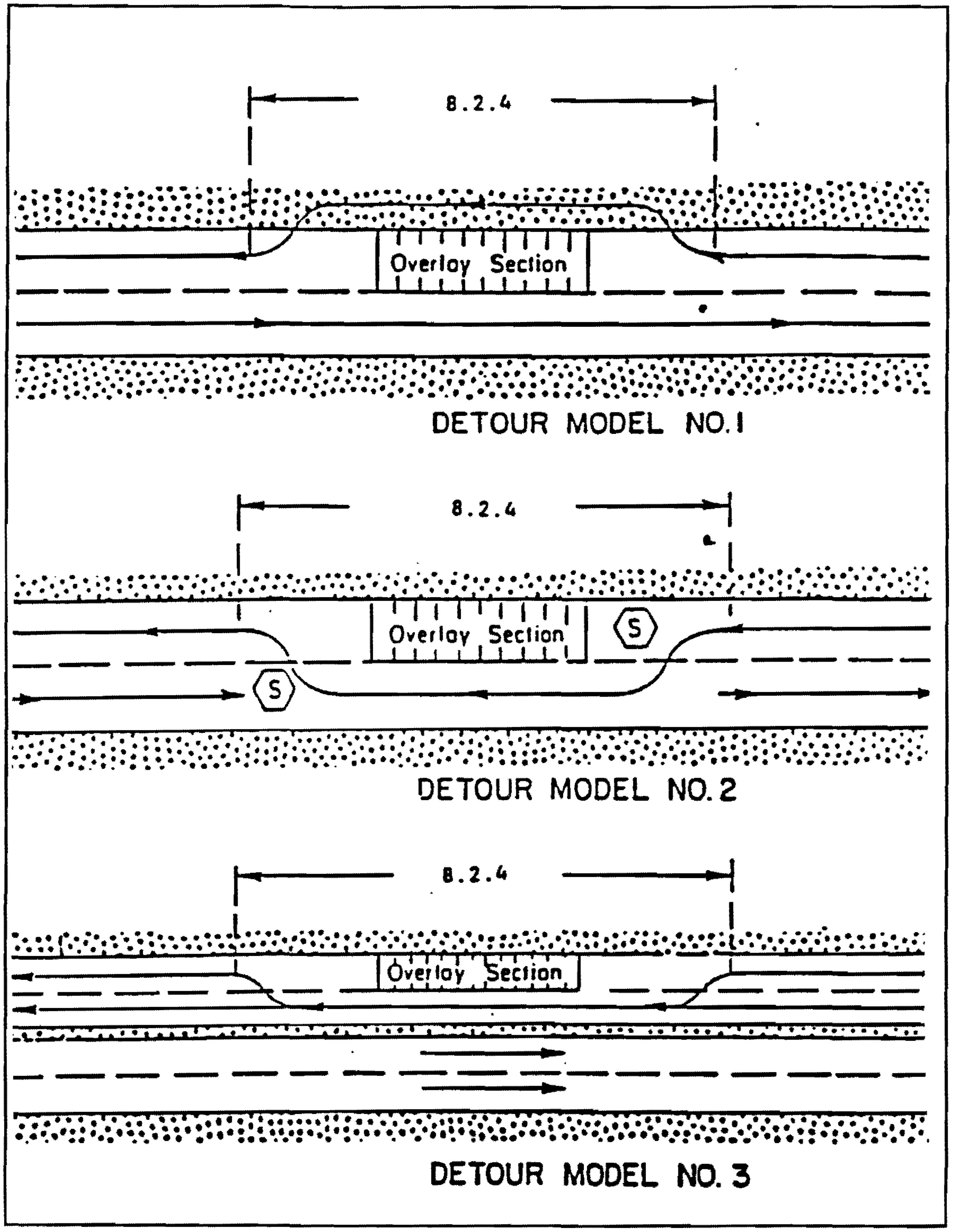

Figure 10a. Detour Models 1, 2, and 3.

design obtaining 3.0 air voids based on 97 percent density (Test Method TEX-207-F) is compacted in the field to 96 percent density, the percent air voids is actually four percent. The district laboratory engineer should be consulted if the designer is not familiar with the air void content expected for the mix which is projected for the project.

Asphalt Content

The percent of asphalt (by weight of mix) is obtained from the mix design and is typically between 3.5 percent and seven percent. The district laboratory engineer should be consulted if the designer is not familiar with the asphalt content expected for the mix which is projected for the project.

8.2.3 The Elastic Modulus at 70 degrees Fahrenheit

In the present version of the program the elastic modulus of the asphalt stabilized base is not a required input. The district laboratories are not equipped to run the dynamic modulus test (ASTM D 3497 [10]), and therefore an equation from the Asphalt Institute is used to predict the modulus from the mix properties and temperature. After all the variables in the "asphalt stabilized base group" have been entered, the calculated modulus is displayed. It cannot be changed by the user.

8.2.4 Construction Cost of the Asphalt Stabilized Base

The cost of the black base requires the initial "in-place" construction cost for an asphalt stabilized base layer in dollars per cubic yard. The most recent cost data available should be used because the best design will be based on a cost analysis. In this cost analysis the initial construction cost is usually the main contribution to the total cost. The district construction engineer should be a good source for this information. Recent construction cost records may also be helpful.

8.2.5 Salvage Value for the Asphalt Stabilized Base

For salvage purposes the engineer should estimate the value of the asphalt stabilized base at the end of the analysis period and convert this value to a percent of its original construction value. The present worth of the salvaged materials is used to compare total costs of alternate designs.

In Table 11 some recommended percentages are shown. The percentages are lower for roads with lower geometric standards anticipating that sections of the road might be relocated by the end of the analysis period due to geometric deficiencies. They are also lower for materials that deteriorate with time.

8.3 THE GRANULAR BASE (OR SUBBASE)

The term "granular base" refers to an unbound flexible base as described in Item 248 of the Standard Specifications for Highways, Streets, and Bridges [9]. The following variables are used to characterize the granular base:

- Minimum Base Thickness (inches)
- Maximum Base Thickness (inches)
- Plasticity Index
- Liquid Limit
- Base Type
- Backcalculated Granular Base Modulus (psi)
- Month in Which Non-destructive Testing Was Done
- Cost of the Base Layer ($/cubic yard)
- Material's Salvage Value as a percent of the Original Cost.

8.3.1 Minimum and Maximum Thicknesses

The minimum and maximum thicknesses are the thinnest and the thickest of the range of granular base thicknesses (in inches) to be considered in the analysis, as discussed in section 1.3.1. In the case of a granular subbase under a black base, only one thickness can be analyzed. These values should be carefully selected to prevent thicknesses which are impractical to construct. The minimum value usually depends on the construction practices and a good source for this information is the district construction engineer. Typically six inches would be a minimum thickness for a granular base. Any realistic maximum

Table 11. Salvage Values as a Percent of Initial Cost.

Percent of Road Meeting Present Design Standards	0% to 25%			25% to 50%			50% to 75%			75% to 100%		
Analysis Period (years)	10	20	30	10	20	30	10	20	30	10	20	30
Type of Material												
1. Granular Subbase	30	25	20	55	50	45	80	75	70	95	90	80
2. Granular Base	20	15	10	40	35	30	60	55	50	80	75	70
3. Asphalt Stabilized Base	20	10	0	35	20	10	40	30	20	55	40	30
4. Asphalt Surface	15	0	0	25	10	0	35	20	10	45	30	10
5. Asphalt Overlay	30	15	5	40	25	15	45	35	25	55	45	35

Suggestion: These percentages may be revised up or down depending on the engineer's best estimate of the value of the material at the end of the analysis period.

thickness can be used. The designer should however be careful not to miss a good design by defining the maximum thickness too thin. It is recommended that the experienced designer should select the expected thickness and then obtain the upper and lower limits by adding and subtracting two or three inches from his expected granular base thickness. A single thickness can also be evaluated by entering the same value for the minimum and maximum thickness.

8.3.2 Plasticity Index (PI)

The PI of the material refers to that range of moisture contents in which the soil will remain in a plastic state while passing from the semisolid to the liquid state. The method to calculate the PI of a soil is described in Texas Test Method Tex-106-E [11]. In the program the PI of the base material is only used to determine the material type if the designer is unfamiliar with the classification system.

8.3.3 Liquid Limit

The liquid limit, which refers to the moisture content at which a soil changes from a plastic to a liquid state, is determined through the procedure described in Texas Test Method Tex-104-E [11]. The liquid limit is also only used in the classification of a soil if the Unified Classification System is not known.

8.3.4 Base Type

The seasonal change in the modulus of elasticity of the granular material depends on the type of base used and the degree of support provided by the subgrade. The granular material, like the subgrade (chapter 7), is characterized by using the Unified Soil Classification System (see Figure 11). In this system the soils are designated by a combination of letter symbols as described in section 7.2.3. Although several of the following material types are unsuitable for use as a base, the following list includes all valid entries.

CH, CL, MH, ML, CL-ML
SC, SM, SP-SC, SW-SC, SP-SM, SW-SM, SP, SW
GC, GM, GW-GC, GP-GC, GW-GM, GP,GM, GP, GW

However, for users unfamiliar with the Unified Classification System, there is an alternative way to characterize the material. This is done through the HELP system. The user is asked to enter the percentage of material passing the No. 200 and No. 4 sieves (Texas Test Method Tex-110-E). Based on these percentages, the liquid limit, and PI, the material is characterized into one of the following material types:

CH, CL, MH, ML,
SP, SC, SM, SP-SC
GC, GM, GP-GC, GP-GM,

When the material type was characterized using the Unified letter symbols it is not necessary to furnish the program with the sieve percentages.

8.3.5 Design Value of Granular Base Modulus

The modulus of the granular base material characterizes the material properties of the base. A backcalculated modulus from Falling Weight Deflectometer tests should be used as the design value whenever possible. If a backcalculated modulus is not known this entry may be omitted. The program will use a modulus calculated using the Corps of Engineers equation. The granular base modulus is used by the program to adjust the internally calculated modulus created by the program. See section 7.2.4 for a description of non-destructive test procedures such as the Falling Weight Deflectometer.

8.3.6 Month in Which Non-destructive Testing Was Done

The granular base modulus changes with the season of year. The month the deflection measurements were taken is used in adjusting the modulus for seasons of the time of year. The user enters the number of the month in which the non-destructive testings were conducted (i.e., 1 for January through 12 for December) from which the granular base modulus was calculated.

8.3.7 Construction Cost of the Base Layer

The cost of the base layer requires the initial "in-place" construction cost for a granular base layer in dollars per cubic yard.

The most recent cost data available should be used because the best design will be based on a cost analysis. In this cost analysis the initial construction cost is usually the main contribution to the total cost. Again the district construction engineer should be a good source for this information. Recent construction cost records may also be helpful.

8.3.8. Salvage Value for the Base

For salvage purposes the engineer should estimate the value of the granular base at the end of the analysis period and convert the value to a percent of its original construction value. The present worth of the salvaged materials is used to compare total costs of alternate designs.

In Table 11 some recommended percentages are shown. The percentages are lower for roads with lower geometric standards anticipating that sections of the road might be relocated by the end of the analysis period due to geometric deficiencies.

8.4 DATA FORMAT AND LIMITS

While entering data into the program, every entry is checked against a minimum and maximum limit. The correct format and limits placed on the base variables are listed in Table 12. Those items identified with numbers are numeric entries. Those items identified with an X are alphabetic entries.

Table 12. Data Format and Limits - Base and Subbase Layers.

Variable	Format	Minimum	Maximum
ASPHALT STABILIZED BASE			
Minimum Asphalt Stabilized Base	99.99	5	25
Maximum Asphalt Stabilized Base	9.9	5	25
Type of Asphalt	99.9	0.1	15
Percent passing #200	99.9	0.1	20
Percent Air Voids	99.9	0.1	20
Asphalt Content	99.9	0	99.99
Construction Cost of Asphalt Stabilized Base	99.9	0	99
Salvage Value of Asphalt Stabilized	99	0	99
GRANULAR BASE or SUBBASE			
Minimum Granular Base Thickness	99.99	5	25
Maximum Granular Base Thickness	99.99	5	25
Plasticity Index	99	0	99
Liquid Limit	99	0	99
Basetype	XX-XX	-	-
Design Value of Granular Base Modulus	999999	5000	1000000

CHAPTER 9 THE SURFACE LAYER

9.1 INTRODUCTION

This chapter addresses the characterization of the layer which is generally the most expensive in the pavement system. The term "asphalt surface" or "hot-mix" refers to a mixture of mineral aggregate and asphaltic cement material as described in Item 340 of the Standard Specification for Highways, Streets and Bridges [9]. The following variables are used to characterize the Surface Layer :

- Minimum Surface Thickness (inches)
- Maximum Surface Thickness (inches)
- Type of Asphalt
- Percent Passing No. 200
- Percent Air Voids
- Asphalt Content
- Elastic Modulus at 70 degrees Fahrenheit (psi)

- Cost of the Surface Layer ($/cubic yard)
- Material Salvage Value as percent of the Original Cost

9.2 SURFACE LAYER VARIABLES

9.2.1 Minimum and Maximum Thicknesses

This requires the range of surface layer thicknesses (in inches) to be considered. The minimum and maximum surface layer thickness are user inputs into the program. The intermediate surface layer thicknesses are determined by the program, as discussed in section 1.3.1. The minimum value usually depends on the construction practices, and a good source for this information is the district construction engineer. Typically 1.5 inches would be an absolute minimum thickness for a surface layer. A minimum value of two inches is recommended. Any realistic maximum thickness can be used. The designer should be careful not to miss a good design by defining the maximum thickness too thin. It is recommended that the experienced designer should select the expected thickness and then obtain the upper and lower limits by adding and subtracting two inches from his surface thickness. It is also possible to only evaluate one thickness by entering the same value as the minimum and maximum thickness. For an overlay design, the existing surface thickness must be entered (see section 3.3.1).

9.2.2 Mix Properties

The mix properties are used by the program to predict the stiffness (dynamic modulus) of the surface layer. The proper source for this information is the mix design conducted in accordance with SDHPT Bulletin C-14 and Test Method-204-F [11]. However, the mix design often follows the pavement design; therefore, estimates of these properties are generally used in the design process. The district construction engineer or the district laboratory should be contacted for the properties of typical mix designs used in the county where the road is to be constructed. Prospective suppliers or contractors might also be a good source for this information.

Type of Asphalt

This variable requires the grade of the asphalt cement based on the viscosity grade. Asphalt grades AC-1.5, 3, 5, 10, 20, and 40 are valid entries. The AC-5, 10, and 20 grades are used most often.

Percent Passing the No. 200 Sieve

This requires the percent of aggregate (by weight or volume) that passes the No. 200 sieve. It is determined through a dry sieve analysis (test method Tex-200-F [11]). The value, typically between one percent and eight percent, should be obtained from the expected mix design.

Percent Air Voids

This requires the percentage of air voids in the mix <u>after compaction</u>. The data can be obtained from the mix design and should be corrected to obtain the voids after compaction. For example, if a mix design obtaining three percent air voids based on 97 percent density (Test Method TEX-207-F) is compacted in the field to 96 percent density, the percent air voids is actually four percent. The district laboratory engineer should be consulted if the designer is not familiar with the air void content expected for the mix which is projected for the pavement being designed.

Asphalt Content

The percent of asphalt (by weight of mix) is obtained from the expected mix design and is typically between four percent and eight percent. The district laboratory engineer should be consulted if the designer is not familiar with the asphalt cement content expected for the mix which is projected for the pavement being designed.

9.2.3 The Elastic Modulus at 70 degrees Fahrenheit

In the present version of the program this is not a required input. The district laboratories are not equipped to run the dynamic modulus test (ASTM D 3497 [10]), and an equation from the Asphalt Institute is used to predict the modulus from the expected mix properties and temperature. The use of this equation is discussed in section 1.3.2. After all the variables in the "surface layer" have been entered, the calculated modulus is displayed. It cannot be changed by the user.

9.2.4 Cost of the Surface Layer

This variable requires the initial "in-place" construction cost for an asphalt surface layer in dollars per cubic yard. The most recent cost data available should be used because the best design will be based on the cost analysis. In this cost analysis the initial construction cost is usually the main contribution to the total cost. The district construction engineer should be a good source for this information. Recent construction cost-records may also be helpful.

9.2.5 Salvage Value for the Surface Layer

For salvage purposes the engineer should estimate the value of the surface layer at the end of the analysis period and convert this value to a percent of the original construction cost of the layer. The present worth of the salvaged materials is used to compare total costs of alternate designs.

In Table 11 some recommended salvage percentages are shown. The percentages are lower for roads with lower geometric standards anticipating that sections of the road might be relocated by the end of the analysis period due to geometric deficiencies. Because asphalt ages and becomes less flexible, the salvage value in this table decreases with time.

9.3 DATA FORMAT AND LIMITS

While entering data into the program, every entry is checked against a minimum and maximum limit. The correct format and limits placed on the surface layer variables are listed in Table 13. Those items identified with numbers are numeric entries.

Table 13. Data Format and Limits - The Surface Layer.

Variable	Format	Minimum	Maximum
Minimum Surface Thickness	99.99	1	25
Maximum Surface Thickness	99.99	1	25
Type of Asphalt	99.9	1.5	40
Percent Passing #200	99.9	0.1	15
Percent Air Voids	99.9	0.1	20
Asphalt Content	99.9	0.1	20
Construction Cost of Surface Layer	99.99	0	99.99
Salvage Value of the Surface Layer	99	0	99

CHAPTER 10 THE OVERLAY

10.1 INTRODUCTION

This chapter is concerned with the characterization of the overlay; up to 20 overlays can be analyzed. The variables are similar to the asphalt surface, discussed in chapter 9. As before, Item 340 of the <u>Standard Specification for Highways, Streets and Bridges</u> [9], is applicable. The following variables are used to characterize the Overlay:

- Minimum Surface Thickness (inches)
- Maximum Surface Thickness (inches)
- Type of Asphalt
- Percent Passing No. 200
- Percent Air Voids
- Asphalt Content
- Elastic Modulus at 70 degrees Fahrenheit (psi)

- Cost of the Surface Layer ($/cubic yard)
- Material Salvage Value as Percent of the Original Cost

10.2 OVERLAY VARIABLES

<u>10.2.1 Minimum and Maximum Thicknesses</u>

This requires the range of overlay thicknesses (in inches) to be considered, as discussed in section 1.3.1. After the initial construction has failed, overlays over the whole range of thicknesses are analyzed. The overlay with the minimum thickness is analyzed first. If it fails before the end of the analysis period is reached, an analysis is performed on the second thickest overlay. This process is repeated until a successful overlay candidate is found. If even the thickest overlay is found unsuccessful, the design strategy is rejected.

The minimum value usually depends on the construction practices and a good source for this information is the district construction engineer. Typically 1.5 inches would be an absolute minimum thickness for a overlay. A minimum value of two inches is recommended. Any realistic maximum thickness can be used. The designer should be careful not to miss a good design by defining the maximum thickness too thin. It is also possible to evaluate one thickness by entering the same value as the minimum and maximum thickness.

10.2.2 Mix Properties

The mix properties are used by the program to predict the stiffness (dynamic modulus) of the overlay. Because the overlay will be constructed in the future, estimates of these values are required. The district construction engineer or the district laboratory should be contacted for the properties of typical mix designs used in the county where the road is to be constructed. Prospective suppliers or contractors might also be a good source for this information.

Type of Asphalt

This variable requires the grade of asphalt cement based on the viscosity grade. Asphalt grades AC-1.5, 3, 5, 10, 20, and 40 are valid entries. The AC-5, 10, and 20 grades are used most often.

Percent Passing the No. 200 Sieve

This requires the percent of aggregate (by weight or volume) that passes the No. 200 sieve. It is determined through a dry sieve analysis (test method Tex-200-F [11]). The value, typically between one and eight percent, should be based on the expected mix design.

Percent Air Voids

This requires the percentage of air voids in the mix after compaction. The data can be obtained from the mix design and should be corrected to obtain the voids after compaction. For example, if a mix design obtaining three percent air voids based on 97 percent density (Test Method TEX-207-F) is compacted in the field to 96 percent density, the percent air voids is actually four percent.

Asphalt Content

The percent of asphalt (by weight of mix) is obtained from the expected mix design and is typically between four percent and eight percent.

10.2.3 The Elastic Modulus at 70 degrees Fahrenheit

In the present version of the program this is not a required input. The district laboratories are not equipped to run the dynamic modulus test (ASTM D 3497 [10]), and an equation from the Asphalt Institute is used to predict the modulus from the expected mix properties and temperature. The use of this equation is discussed in section 1.3.2. After all the variables in the "overlay" have been entered, the calculated modulus is displayed. It cannot be changed by the user.

10.2.4 Cost of the Overlay

This variable requires the "in-place" construction cost for an asphalt concrete overlay in dollars per cubic yard. The most recent cost data available should be used because the best design will be based on the cost analysis. In this cost analysis, the initial construction cost is usually the main contribution to the total cost. Again the district construction engineer should be a good source for this information. Recent construction cost-records may also be helpful.

10.2.5 Salvage Value for the Surface Layer

For salvage purposes, the engineer should estimate the value of the overlay at the end of the analysis period and convert this value to a percent of the original construction cost of the layer. The present worth of the salvaged materials is used to compare total costs of alternate designs.

In Table 11 some recommended salvage percentages are shown. The percentages are lower for roads with lower geometric standards anticipating that sections of the road might be relocated by the end of the analysis period due to geometric deficiencies. Because asphalt ages and becomes less flexible, the overlay salvage values in this table decreases with time.

10.3 DATA FORMAT AND LIMITS

While entering data into the program, every entry is checked against a minimum and maximum limit. The correct format and limits placed on the overlay variables are listed in Table 14. Those items identified with numbers are numeric entries.

Table 14. Data Format and Limits - The Overlay.

Variable	Format	Minimum	Maximum
Minimum Overlay Thickness	99.99	1	25
Maximum Overlay Thickness	99.99	1	25
Type of Asphalt	99.9	1.5	40
Percent Passing #200	99.9	0.1	15
Percent Air Voids	99.9	0.1	20
Asphalt Content	99.9	0.1	20
Construction Cost of Overlay	99.99	0	99.99
Salvage Value of the Overlay	99	0	99

CHAPTER 11 SWELLING SOILS

11.1 INTRODUCTION

This program does not incorporate changes in structural section due to swelling soils. Because an increase in pavement thickness alone will not appreciably decrease the serviceability loss due to swelling soils, it is recommended that pavement thickness be designed and constructed ignoring the swelling nature of the subgrade. An optional model is included in the program that predicts the actual performance life of the pavement if it is built on a swelling soil. The reduction in pavement life due to swelling soils may be used to determine the economical feasibility of alternative measures such as ponding, vertical moisture barriers, or undercutting (all expensive alternatives).

The model used is based on the actual performance of 23 pavements built on expansive soils in central and east Texas [12]. A regression equation was developed that predicts the loss in serviceability as a function of the pavement structure, time, climate, and several subgrade soil properties. In TFPS this equation is used to predict the time before the terminal serviceability is reached. The results are included in printed reports but do not influence the pavement thickness design. If the swelling soils model is included in the analysis, the exchange sodium percentage of the soil and the Thornthwaite Moisture Index range are required.

11.2 SWELLING SOIL VARIABLES

11.2.1 Exchange Sodium Percentage

The Exchange Sodium Percentage (ESP) is a partial indicator of the geological environment in which the clay was deposited and a partial indicator of how erodible and dispersive the soil is. As the ESP increases, the shrink-swell potential of the soil also increases. This increase is caused by the higher potential of the sodium cations in the interlayer positions. In general, it is found that the higher the ESP the more dispersive the soil. The ESP of a subgrade can be determined through tests which have not yet been included in the Texas Standard Test

Methods. In a limited number of county soil reports this Exchange Sodium Percentage has also been recorded. For the designer having difficulty in obtaining the ESP of a soil, the following values may be used as estimates:

- If the roadway is to be constructed in an old river bottom or lake bed, set the exchange sodium percentage equal to one percent.
- For everywhere else set the exchange sodium percentage equal to 16 percent.

11.3 DATA FORMAT AND LIMITS

While entering data into the program, every entry is checked against a minimum and maximum limit. The correct format and limits placed on the swelling soil variables are listed in Table 15. Those items identified with numbers are numeric entries.

Table 15. Data Format and Limits - The Swelling Soils.

Variable	Format	Minimum	Maximum
Consider Swelling Soils (y/n)	X	-	-
Exchange Sodium Percentage	99.99	1	25

CHAPTER 12 TRANSVERSE AND LONGITUDINAL CRACKING

12.1 INTRODUCTION

Throughout the northern parts of Texas, transverse cracking develops in the asphalt surfaces due to thermal-induced expansion and contraction. In TFPS an optional model is incorporated that predicts this cracking. The model allows the designer to incorporate crack maintenance in the total design strategy.

The model is based on a research project conducted on several pavement sections in the Texas Panhandle [13]. From this study, a regression equation was developed that relates several pavement and environment factors to a damage index. This index, calculated every season, is then compared against the designer's specified damage index. Whenever the calculated index exceeds the specified value, crack maintenance is scheduled, and the annual maintenance cost is lowered to that of the first year after construction. It should be noted that this procedure only influences the cost analysis. The structural properties of the pavement are not affected. This model is extremely sensitive to low temperatures, and therefore it should not be expected to affect pavements in the southern parts of the State. The following additional variables are needed to use the model:

- Damage index at failure
- Ring and ball softening point (degree fahrenheit)
- Crack Maintenance Cost ($/lane-mile)

12.2 TRANSVERSE AND LONGITUDINAL CRACKING VARIABLES

12.2.1 Damage Index at Failure

The damage index which is calculated every season is compared to this value. If the calculated index value exceeds this "damage index at failure" crack maintenance is conducted. Typical values can be obtained from Table 16. If, for example, only a medium amount of longitudinal and transverse cracking is allowed, the specified damage index is 1.4.

Table 16. Typical Damage Index.

T & L Cracking Severity	Damage Index
Low	1.0
Medium	1.4
High	1.7

12.2.2 Ring and Ball Softening Point

The Ring and Ball Softening Point (in degrees Fahrenheit) can be obtained from standard Test Method Tex-505-C [11] or the supplier of the asphalt. Typical Values of the Ring and Ball Softening Point are between 108° F for AC-5 and 121° F for AC-20.

12.2.3 Crack Maintenance Cost

The most recent crack maintenance cost data available should be entered. The variable (in dollars per lane-mile) only influences the total cost and the district maintenance engineer is a good source for this information.

12.3 DATA FORMAT AND LIMITS

While entering data to the program, every entry is checked against a minimum and maximum limit. The correct format and limits placed on the "Transverse and Longitudinal Cracking" variables are listed in Table 17. Those items identified with numbers are numeric entries.

Table 17. Data Format and Limits - Transverse and Longitudinal Cracking.

Variable	Format	Minimum	Maximum
Damage Index at Failure	9.9	0	9.9
Ring and Ball Softening Point	999.9	80	135
Crack Maintenance Cost	9999.99	0	9999.99

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APPENDIX A

TFPS QUICK START GUIDE

A1.0 INTRODUCTION

This Appendix to the Users Guide has been designed to familiarize the designer with the design parameters started with TFPS. By following a typical design example, you can familiarize yourself with the features of the program. The following terms and conventions are used throughout this document:

- All characters you are supposed to type are quoted and displayed in boldface. For example, "**TFPS**".
- Special keyboard keys such as ENTER or F1 will be printed in square brackets [ ].
- The word "type" means just type the characters indicated while "enter" means type the characters indicated and then press the [ENTER] key.
- All entries are shown in uppercase, but entering them in lowercase will yield the same results.

This Appendix can also be used as a quick reference once you are familiar with the program. The Users Guide provides detailed information on all program features and variables.

A1.1 INSTALLING OF THE TFPS PROGRAM

To install the TFPS on a hard disk, the following steps may be used:

1. In the hard disk which you wish to have the TFPS installed, enter "**CD**" to change to the root directory.
2. Make a subdirectory TFPS by typing "**MD TFPS**" and pressing [ENTER].
3. Change the default directory to TFPS by typing "**CD\\TFPS**" and pressing [ENTER].
4. Copy all the files from the distribution diskettes to the TFPS subdirectory.

A1.2 GETTING STARTED

The program is very simple to start. First, you need to change to the directory that contains the TFPS program files. It is assumed that the program was installed in a directory named TFPS. To start the program,

1. Switch to the proper directory by entering "**CD\TFPS**".
2. Now type "**TFPS**" and press "**[ENTER]**" to load the program into memory and start it.

A1.3 THE MAIN MENU

After starting the program the MAIN MENU appears. It is shown in Figure A-1.

```
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            TEXAS FLEXIBLE
               PAVEMENT
             DESIGN SYSTEM

               MAIN MENU

         PREPARE A NEW DATA FILE

      MODIFY AN EXISTING DATA FILE

            RUN THE ANALYSIS

          PRINT THE INPUT DATA

           PRINT THE RESULTS

             RETURN TO DOS

  SPACEBAR TO SELECT        ENTER TO VALIDATE
```

Figure A-1. Main Menu.

From this menu the primary program functions can be selected by pressing the "**[SPACEBAR]**" or the cursor-keys ["↓" or "↑"]. Each option leads you to a second level menu. Table A1 describes each of the options available.

Table A1. TFPS Main Menu Options.

Option	Purpose
Prepare a New Data File	Takes you through the process of entering and editing data. The prepared data is saved in a data file (Section A2.0).
Modify an Existing Data File	Provides options to modify the data file by changing any of the input parameters. The changed file is saved for future use (Section A3.0).
Run the Analysis	Starts the actual analysis of a data file. The analysis consists of a structural, condition, and economic analysis as described in the Users Guide (Section A4.0).
Print the Input Data	Prints a report of all the input parameters and their values used in the analysis (Section A5.0).
Print the Results	Prints a summary of the results (Section A6.0).
Return to DOS	Exit from TFPS and returns to DOS.

A2.0 PREPARING A DATA FILE

When you are preparing a data file for the first time you need to select the "Prepare a New Data File" from the Main Menu. Press the **"[SPACEBAR]"** until the first option (i.e., "Prepare a New Data File) is highlighted. Now press **"[ENTER]"**. The Screen shown in Figure A-2 will appear.

*   PREPARE A NEW DATA FILE   *

* REQUIRED PROBLEM INFORMATION *

PROBLEM IDENTIFICATION
BASIC DESIGN CRITERIA
TRAFFIC DATA
CONSTRUCTION AND MAINTENANCE DATA
OVERLAY DETOUR DESIGN

* REQUIRED LAYER INFORMATION *

THE SUBGRADE
BASE AND SUBBASE LAYERS
THE SURFACE LAYER
THE OVERLAY

*   OPTIONAL *

SWELLING SOILS
TRANSVERSE AND LONGITUDINAL CRACKING

RETURN TO THE MAIN MENU

SPACEBAR TO SELECT   ENTER TO VALIDATE

Figure A-2. "Prepare a New Data File" Menu.

A2.1 PREPARE A NEW DATA FILE

The variables used in TFPS are arranged into 11 groups. Every group of variables can be entered through an input-screen which can be selected from the "Prepare a New Data File" Menu. By using the **"[SPACEBAR]"** or the cursor-keys you can select a variable group from this menu.

<u>2.1.1 Project Identification</u>

If you are preparing a data file for the first time, it is recommended that you start with the "Problem Identification" group and then follow through all the Required Information screens. To begin building the data file, use the cursor keys ["↓" or "↑"] until the problem identification selection is highlighted. Now press **"[ENTER]"**. The following screen will appear (Figure A-3):

```
                PROJECT IDENTIFICATION

          DISTRICT NUMBER  -
          COUNTY NUMBER  - -
          COUNTY NAME  - - -

          PROBLEM NUMBER   -
          CONTROL  - - - - -
          SECTION  - - - - -
          JOB  - - - - - - -
          HIGHWAY  - - - - -
          DATE - - - - - - -
          COMMENTS - - - - -

     F1  HELP                      ESC    RETURN TO MENU
     F2  TOP OF THIS SCREEN        ENTER  VALIDATE ENTRY
```

Figure A-3. "Project Identification" Screen.

Since this is the first input screen, let us point out a few features of the new TFPS program:

- You must enter data into fields with a blinking cursor.
- The format of the entry is always displayed at the very bottom of the screen. For example "XX" for the district number.
- Every variable field has an acceptable upper and lower boundary. For example, the district number must be between 1 and 25. The program will not accept any entry outside the defined boundaries.
- At the bottom of every screen is a list of the keys that can assist you while entering data:

[F1] Provides help by displaying information pertinent to the data element on which the cursor is located. The help offered is not as complete as the Users Guide, but it can be used as a quick reminder.

[F2] Sends you back to the top of the screen. This key allows you to change data that you just entered.

[ESC] Returns you to the previous menu.

[ENTER] Continue to the next data field.

Now let's complete the screen.

1. The cursor is blinking in the "District Number" entry box. Supply the district number by typing **"1"**. The cursor will move to the next entry box and a list of all the counties in district **"1"** will be displayed.
2. Select the desired county from the list. As an example, type **"139"**. The county name "LAMAR" will automatically be displayed after the 139 is entered.
3. Type the problem number **"Ex-1"** and **"[ENTER]"**. The enter-key is required because the entry did not fill the entire entry box. If the entire box is filled the cursor will automatically move to the subsequent entry.
4. Type the control number **"1234"**.
5. Type the Section number **"0001"** and press **"[ENTER]"**.
6. Type the Job number **"23"**.
7. Enter the highway number **"US271"**.
8. Type the date **"07-01-90"**.
9. Type the comments: **"EXAMPLE PROBLEM"**.
10. The completed screen is shown below (Figure A-4). If you would like to change any of your entries press the **"[F2]"** key and move through the screen entries to the one which needs attention. If you are satisfied with all the entries on this screen press **"[ENTER]"**. You will return to the "Prepare a New Data File" menu.

```
PROJECT IDENTIFICATION

DISTRICT NUMBER - - - - - - - - 1
COUNTY NUMBER - - - - - - - - - 139
COUNTY NAME - - - - - - - - - - LAMAR

PROBLEM NO. - - - - - - - - - - EX-1
CONTROL - - - - - - - - - - - - 1234
SECTION - - - - - - - - - - - - 01
JOB - - - - - - - - - - - - - - 23
HIGHWAY - - - - - - - - - - - - US 271
DATE  - - - - - - - - - - - - - 09-07-90
COMMENTS:  EXAMPLE PROBLEM  -

F1  HELP                              ESC     RETURN TO MENU
F2  TOP OF THIS SCREEN                ENTER   VALIDATE ENTRY
```

Figure A-4. Completed "Project Identification" Screen.

A2.1.2 Basic Design Criteria

The "Basic Design Criteria" is the second set of information required by the program. Use the **"[SPACEBAR]"** to select this option from the "Prepare a New Data File" menu. When the option is highlighted press **"[ENTER]"**. The "Basic Design Criteria" screen will appear.

The cursor will be blinking in the first entry box. Lets say you need help in selecting upon a design life for this problem. Press the **"[F1]"** key to activate the help feature. A screen with some pertinent information to "Analysis Period" will appear. After you have read this screen, return to the "Basic Design Criteria" screen by pressing **"[ENTER]"**. The help screen will disappear, and you can continue with the entry procedure. The "Maximum Life Expected from the Initial Construction," "New Construction," and the "Pre-Overlay Planing Depth" (mill depth) inputs are only relevant to overlay design. If new construction is specified, these values will be overridden in the TFPS

Program analysis. Thus, continue completing the entry boxes to obtain the completed screen shown in Figure A-5.0. Press **"[ENTER]"** after the last entry to return to the "Prepare a New Data File" menu.

```
                    ** BASIC DESIGN CRITERIA **

Length of Analysis Period - - - - - - - - - - - - - - - - 20 years
Minimum Life Expected from the Initial Construction - - 10.0 years
Maximum Life Expected From the Initial Construction - - 15.0 years
Minimum Life Expected from the Overlay  - - - - - - - -  7.0 years
New Construction (Y or N) - - - - - - - - - - - - - - -  Y
Minimum Serviceability Index  - - - - - - - - - - - - - 2.50 PSI
Maximum Allowable Rut Depth   - - - - - - - - - - - - - 0.4 inches
Maximum Allowable Cracked Surface Area  - - - - - - - - 400sf/1000sf
Pre-Overlay Planing Depth   - - - - - - - - - - - - - - 0.0 inches
Reliability Code (A,B,C,D,E)  - - - - - - - - - - - - -  E
Speed Category (H,S,I)  - - - - - - - - - - - - - - - -  H
Aggregate Quality (L,M,H) - - - - - - - - - - - - - - -  H

        F1  HELP                        ESC     RETURN TO MENU
        F2  TOP OF THIS SCREEN          ENTER   VALIDATE ENTRY
```

Figure A-5.0. Completed "Basic Design Criteria" Screen.

If the design is for the overlay of an existing pavement, enter **"N"** in the fifth input, "New Construction (Y or N)". This will bring up the submenu Figure A-5.1. This screen contains in situ overlay design information. <u>For an overlay design, the existing pavement structure information must be entered as the input values for base and surface layers</u>. This can be achieved by entering the same value for the minimum and maximum thicknesses for the base layer and for the surface layer as well.

```
                 ** OVERLAY DESIGN CRITERIA **

                     - - - - - - - - - - - - - - - - 200 sf/1000 sf
Existing Rutting     - - - - - - - - - - - - - - - - 0.3 inches
One Directional Cumulative 18k ESAL (20 years) - - 2500000
ADT for Beginning of Overlay Period - - - - - - - 22200 veh/day
ADT for Ending of Overlay Period  - - - - - - - - 48600 veh/day
Composite Modulus of Existing ACP - - - - - - - - 40000 psi
Temperature of Composite ACP Modulus  - - - - - - 80.0 degrees F

    F1  HELP                      ESC     RETURN TO MENU
    F2  TOP OF THIS SCREEN        ENTER   VALIDATE ENTRY
```

Figure A-5.1. Completed "Overlay Design Criteria" Screen.

The program will compare the calculated and in situ measured values of cracking, rutting and composite modulus of existing surface layer. Consequently, the maximum value of cracking and rutting, and the minimum value of the surface modulus will be used in the program.

When the screen is completed press **"[ENTER]"**, and you will return to the "Basic Design Criteria" screen. Proceed as above to complete the "Basic Design Screen". <u>(Note: The example problem presented herein is for a new pavement design. If an overlay design is required, the existing layer thicknesses should be used (see section 3.3.1).</u>

A2.1.3 Traffic Data

The next option from the menu is the "Traffic Data". Select this option by using the **"[SPACEBAR]"** and validate your option by pressing **"[ENTER]"**. The "Traffic Data" screen will appear. A completed screen will look similar to Figure A-6.

```
                         ** TRAFFIC DATA **

ADT at the Beginning of the Analysis Period - - - - -  5000 veh/day
ADT at the end of 20 years - - - - - - - - - - - - - 10000 veh/day

Average Approach Speed to the Overlay - - - - - - - - - -   55 mph
Average Speed through the Overlay (overlay direction) - -   35 mph
Average Speed through the Overlay (non-overlay direction) - 45 mph
Proportion of the ADT Arriving Each Hour of Construction    6.0 %
Percent of Trucks in the ADT   - - - - - - - - - - - - - -  18 %

One Directional Cumulative 18 k ESAL (20 yrs)  - - - - - -  8000000
(New Construction - future 20 yrs traffic)
(Existing Overlay only - past 20 yrs traffic)

        F1  HELP                      ESC      RETURN TO MENU
        F2  TOP OF THIS SCREEN        ENTER    VALIDATE ENTRY
```

Figure A-6. Completed "Traffic Data" Screen.

Press **"[ENTER]"** after the last entry to return to the "Prepare a New Data File" menu.

A2.1.4 Construction and Maintenance Data

The construction and maintenance data is the next set of information required by the program. Use the **"[SPACEBAR]"** or ["↑","↓"] to select this option from the "Prepare a New Data File" menu. When the option is highlighted press **"[ENTER]"**. Complete the screen similar to the screen in Figure A-7. After completing the screen, press **"[ENTER]"** to return to the "Prepare a New Data File Menu".

** CONSTRUCTION AND MAINTENANCE **	
Overlay Construction Time (hours/day) - - - - - - - -	8.0 hours/day
Asphaltic Concrete Compacted Density (tons/cu. yard) -	2.00 tons/cy
Asphaltic Concrete Production Rate (tons/hours) - - - -	75 tons/hour
Width of Each Lane (feet) - - - - - - - - - - - - - - - -	12 feet
Annual Routine Maintenance Cost for the First Period -	200.00 $/lane-mile
Annual Routine Maintenance Cost for the Second Period -	250.00 $/lane-mile
Annual Increase in Maintenance Cost for the 1st Period -	45.00 $/lane-mile
Annual Increase in Maintenance Cost for the 2nd Period -	50.00 $/lane-mile
Initial Serviceability Index - - - - - - - - - - - - - - -	4.20
Serviceability Index after an Overlay - - - - - - - - - -	4.20
Interest Rate or Time Value of Money - - - - - - - - - - -	7.5 percent
F1 HELP	ESC RETURN TO MENU
F2 TOP OF THIS SCREEN	ENTER VALIDATE ENTRY

Figure A-7. Completed "Construction and Maintenance" Screen.

A2.1.5 Overlay Detour Design

The next set of required data is called the "Overlay Detour Design" screen. As before, use the **"[SPACEBAR]"** or the cursor keys ["↑" or "↓"] to select this option from the "Prepare a New Data File" menu. To validate your choice press **"[ENTER]"**. Following the same procedure as before, complete the entry screen similar to this (Figure A-8):

```
** DETOUR DESIGN FOR OVERLAYS **

Traffic Model Used During Overlay - - - - - - - - - - - -      3
No. of Open Lanes in Restricted Zone (Overlay Direction) -     1 lane
No. of Open Lanes in Restricted Zone (Non-overlay Direction)   2 lanes
Distance Traffic is Slowed (Overlay Direction) - - - - - -   1.5 miles
Distance Traffic is Slowed (Non-overlay Direction) - - - -   1.2 miles

F1  HELP                        ESC      RETURN TO MENU
F2  TOP OF THIS SCREEN          ENTER    VALIDATE ENTRY
```

Figure A-8. Completed "Overlay Detour Model" Screen.

After you have completed the screen press **"[ENTER]"** and return to the "Prepare a New Data File" Menu.

A2.1.6 The Subgrade

The subgrade related data is the next set of information required by the program. Use the **"[SPACEBAR]"** or ["↑","↓"] to select this option from the "Prepare a New Data File" menu. When "The Subgrade" option is highlighted, press **"[ENTER]"**. The subgrade input screen will appear. Now complete the screen as shown in Figure A-9.

```
** THE SUBGRADE **

Plasticity Index - - - - - - - - - - - - - - - - - - - - 15 percent
Liquid Limit - - - - - - - - - - - - - - - - - - - - - - 40 percent
Type of Subgrade (Unified Soil Classification) - - - CL
Is the Apparent Depth to the Rigid Layer < 30 ft.     N (Y or N)
Modulus of the Subgrade - - - - - - - - - - - - - - - - 10000 psi
Month in Which the Non-Destructive Testing was Done - 5
Paved Shoulders (Y/N) - - - - - - - - - - - - - - - - - Y

F1  HELP                        ESC      RETURN TO MENU
F2  TOP OF THIS SCREEN          ENTER    VALIDATE ENTRY
```

Figure A-9. Completed "Subgrade Information" Screen.

After completing the screen, press **"[ENTER]"** to return to the "Prepare a New Data File" menu.

A2.1.7 Base and Subbase Layers

The next set of entries is for the base and subbase layers. By using the **"[SPACEBAR]"**, select the "Base and Subbase Layers" option from the "Prepare a New Data File" Menu. Validate your choice by pressing **"[ENTER]"**. The Base Configuration Screen (Figure A-10) will appear. This menu offers you a choice of three different pavement structures:

- Only an Asphalt Stabilized Base;
- Only a Granular Base; or
- An Asphalt Stabilized Base with a Granular Subbase.

In this example we will design a pavement with both an asphalt stabilized base and a granular subbase. Use the **"[SPACEBAR]"** to move the highlighted bar to the third option on the menu. Now press **"[ENTER]"**.

```
** CHARACTERIZATION OF THE BASE STRUCTURE **

      Only an Asphalt Stabilized Base
            Only a Granular Base
Asphalt Stabilized Base with a Granular Subbase

SPACEBAR  -  SELECT THE DESIRED BASE STRUCTURE
ENTER     -  VALIDATE THE SELECTION
```

Figure A-10. Base Configuration Menu.

After selecting the "Asphalt Stabilized Base with a Granular Subbase" option from the menu in Figure A-10, the asphalt stabilized base input screen will appear. Use the same input procedure as before, and complete this screen similar to Figure A-11.

** ASPHALT STABILIZED BASE LAYER **	
Minimum Asphalt Stabilized Base Thickness - - - - - - -	5.00 inches
Maximum Asphalt Stabilized Base Thickness - - - - - - -	9.00 inches
Type of Asphalt -	AC 20.0
Percent Passing #200 Sieve - - - - - - - - - - - - - -	5.0 percent
Percent Air Voids - - - - - - - - - - - - - - - - - - -	6.0 percent
Asphalt Content -	5.0 percent
Elastic Modulus at 70° Fahrenheit - - - - - - - - - - -	622000 psi
Construction Cost of the Asphalt Stabilized Base - - -	50.00 $/cu.yard
Salvage Value of the Asphalt Stabilized Base - - - - -	30 percent
F1 HELP	ESC RETURN TO MENU
F2 TOP OF THIS SCREEN	ENTER VALIDATE ENTRY

Figure A-11. Completed "Asphalt Stabilized Base Layer" Screen.

If you would like to change any of your entries press the **"[F2]"** key and then redo the screen. If you are satisfied with all the entries on this screen press **"[ENTER]"**. The granular base screen will appear. Complete the screen similar to this (Figure A-12):

** GRANULAR BASE LAYER **	
Base Thickness -	6.00 inches
Plasticity Index - - - - - - - - - - - - - - - - - - -	0 percent
Liquid Limit -	5 percent
Base Type (Unified Soil Classification) - - - - -	GW
Design Value of Granular Base Modulus - - - - - - -	35000 psi
Month of Granular Base Modulus Design Value - - -	5 month
Construction Cost of the Granular Subbase - - - -	20.00 $/cu. yard
Salvage Value of the Granular Subbase - - - - - - -	55 percent
F1 HELP	ESC RETURN TO MENU
F2 TOP OF THIS SCREEN	ENTER VALIDATE ENTRY

Figure A-12. Completed "Granular Base" Screen.

If you are satisfied with all the entries on this screen press **"[ENTER]"**. You will return to the "Prepare a New Data File" menu.

A2.1.8 The Surface Layer

The surface layer is the next set of information required by the program. Use the **"[SPACEBAR]"** to select this option from the "Create a New Data File" menu. When the option is highlighted press **"[ENTER]"**. The surface layer information screen will appear with the cursor blinking in the first entry box. Complete the screen similar to (Figure A-12)

```
                    ** SURFACE LAYER **

Minimum Surface Thickness - - - - - - - - - - - - - - 2.00 inches
Maximum Surface Thickness - - - - - - - - - - - - - - 3.00 inches

Type of Asphalt - - - - - - - - - - - - - - - - - - - AC 20.0
Percent Passing #200 Sieve  - - - - - - - - - - - - - 5.0 percent
Percent Air Voids - - - - - - - - - - - - - - - - - - 6.0 percent
Asphalt Content - - - - - - - - - - - - - - - - - - - 5.0 percent
Elastic Modulus at 70 degrees Fahrenheit  - - - - - - 622000 psi

Construction Cost of the Surface Layer  - - - - - - - 55.00 $/cu. yard
Salvage Value of the Surface Layer  - - - - - - - - - 20 percent

       F1  HELP                    ESC      RETURN TO MENU
       F2  TOP OF THIS SCREEN      ENTER    VALIDATE ENTRY
```

Figure A-13. Completed "Surface Layer" Screen.

If you would like to change any of your entries press the **"[F2]"** key and then redo the screen. If you are satisfied with all the entries on this screen press **"[ENTER]"**. You will return to the "Prepare a New Data File" menu.

A2.1.9 The Overlay

The Overlay is the next set of information required by the program. Use the **"[SPACEBAR]"** to select this option from the "Create a New Data File" menu. When the option is highlighted press **"[ENTER]"**. The overlay information screen will appear with the cursor blinking in the first entry box. You will notice that the format of this screen is similar to that of the Surface Layer. Complete the screen similar to this (Figure A-14):

```
                    ** THE OVERLAY **

Minimum Overlay Thickness - - - - - - - - - - - - - - 1.00 inches
Maximum Overlay Thickness - - - - - - - - - - - - - - 3.00 inches

Type of Asphalt - - - - - - - - - - - - - - - - - - - AC 20.0
Percent Passing #200 Sieve  - - - - - - - - - - - - - 5.0 percent
Percent Air Voids - - - - - - - - - - - - - - - - - - 6.0 percent
Asphalt Content - - - - - - - - - - - - - - - - - - - 5.0 percent
Elastic Modulus at 70 degrees Fahrenheit  - - - - - - 622000 psi

Construction Cost of the Overlay  - - - - - - - - - - 55.00 $/cu. yard
Salvage Value of the Overlay  - - - - - - - - - - - - 35 percent

       F1  HELP                       ESC      RETURN TO MENU
       F2  TOP OF THIS SCREEN         ENTER    VALIDATE ENTRY
```

Figure A-14. Completed "Overlay" Screen.

If you are satisfied with all the entries on this screen press **"[ENTER]"**. You will be back in the "Prepare a New Data File" Menu. You have now completed all the <u>required</u> data screens.

<u>A2.1.10 Optional Input for Swelling Soils</u>

Swelling Soils is a set of <u>optional information</u> that may be used by the program. This information is used in the program to determine the reduction in pavement life, due to the effect of swelling soils. The reduction in pavement life is not used in the design procedures in the program, but it is recorded in the output as additional information for the user.

If this analysis is desired use the **"[SPACEBAR]"** to select this option from the "Prepare a New Data File" menu. When the option is highlighted press **"[ENTER]"**. The Swelling Soils information shown in

Figure A-15 will appear. Complete the screen and press **"[ENTER]"** to return to the "Prepare a New Data File Menu".

```
                   ** SWELLING SOIL **

SHOULD A SWELLING SUBGRADE BE INCLUDED IN THE ANALYSIS? (Y/N) - Y

EXCHANGE SODIUM PERCENTAGE - - - - - - - - - - - - - - - 16.0 percent

      F1  HELP                       ESC     RETURN TO MENU
      F2  TOP OF THIS SCREEN         ENTER   VALIDATE ENTRY
```

Figure A-15. "Swelling Soils" Screen.

<u>A2.1.11 Optional Input for Transverse and Longitudinal Cracking</u>

Transverse and Longitudinal Cracking is a set of <u>optional information</u> that may be used by the program. This information is used in the program to determine the seal coat cost component in the life cycle cost analysis.

If this analysis is desired, use the **"[SPACEBAR]"** to select this option from the "Prepare a New Data File". When the option is highlighted press **"[ENTER]"**. The transverse and longitudinal cracking information shown in Figure A-16 will appear.

```
          ** TRANSVERSE AND LONGITUDINAL CRACKING **

Should T&L Cracking be induced in the Analysis?  (Y/N) - Y

Damage Index at Failure - - - - - - - - - - - - - 1.0
Ring and Ball Softening Point - - - - - - - - - - 120 Degrees F
Crack Maintenance Cost  - - - - - - - - - - - - - 600.00

      F1  HELP                       ESC     RETURN TO MENU
      F2  TOP OF THIS SCREEN         ENTER   VALIDATE ENTRY
```

Figure A-16. "Transverse and Longitudinal Cracking" Screen.

A2.1.12 Saving the Data File

It should be mentioned that although you have completed all the entry screens, it is still possible to change any of your inputs. Simply reselect the input group from the "Prepare a New Data File" menu, return to the screen, and make the necessary changes. If you are satisfied with all your entry screens, you can return to the Main Menu. Select the "Return to the Main Menu" option and press **"[ENTER]"**. The program will now offer you the opportunity to save the information in a Data File (Figure A-17).

```
                    ** SAVE THE DATA **

             UPDATE THE EXISTING DATA FILE
              SAVE THE DATA IN A NEW FILE
              RETURN WITHOUT SAVING

        SPACEBAR  -  SELECT THE DESIRED OPTION
         ENTER  -  VALIDATE THE SELECTION
```

Figure A-17. "Save Options" Menu.

Because you created a new data file the first option is not applicable. If you select the third option (i.e., "Return Without Saving") <u>you will loose all the data that you have entered</u>. To save the data, select the "Save the Data in a New File" option and press **"[ENTER]"**. You will be prompted for a file name. When deciding on a file name it is important to use a unique name that can be easily identified. It is recommended that the highway number be included in the file name. For example, if you are working on a US 271 problem, and you would like to save it on a floppy diskette, enter A:\US271-A1.DAT. We will save our example problem on the hard drive in a file called "EXAMPLE.DAT". Type **"EXAMPLE.DAT"** and press **"[ENTER]"**. After the file has been saved, the program will once more display the Main Menu (Figure A-1).

A3.0 MODIFY AN EXISTING DATA FILE

Once a file has been prepared, additional materials and designs can be analyzed by changing the appropriate entries in the existing file and running a new analysis. It is relatively simple to change any of the input parameters in an existing data file. Say, for example, you would like to change the cumulative traffic load in the file A:\US271-A1.DAT from eight million to ten million (18 kip SAL).

1. Use the **"[SPACEBAR]"** or the cursor keys **"[↓ or ↑]"** to select the "Modify an Existing Data File" from the Main Menu. When this option is highlighted, press **"[ENTER]"**.
2. The program will prompt for the name of the data file to be modified. Enter **"EXAMPLE.DAT"**. The "Modify an Existing Data File" menu (Figure A-18) will appear.

```
          * MODIFY AN EXISTING DATA FILE *

         * REQUIRED PROBLEM INFORMATION *
              Problem Identification
               Basic Design Criteria
                   Traffic Data
         Construction and Maintenance Data
               Overlay Detour Design

          * REQUIRED LAYER INFORMATION *
                   The Subgrade
              Base and Subbase Layers
                 The Surface Layer
                    The Overlay

                   * OPTIONAL *
                   Swelling Soils
       Transverse and Longitudinal Cracking

            * RETURN TO THE MAIN MENU *

SPACEBAR TO SELECT                  ENTER TO VALIDATE
```

Figure A-18. "Modify an Existing Data File" Menu.

3. Select the appropriate group of data from the menu (Figure A-18). We would like to change a traffic data parameter, therefore use the **"[SPACEBAR]"** to select "Traffic Data". When this option is highlighted, press **"[ENTER]"**. The original set of data (Figure A-6) will appear.
4. Press the **"[ENTER]"** key seven times until the cursor is blinking in the "One Directional cumulative 18k SAL at the end of 20 years" entry box. Now, enter **"10000000"**. You will return to the "Modify an Existing Data File" menu.
5. Now that you have made all the changes, select "Return to the Main Menu" (Use the **"[SPACEBAR]"**). When this option is highlighted, press **"[ENTER]"**. The "Save Options" menu (Figure A-17) will appear.
6. Use the **"[SPACEBAR]"** to select the "Update an Existing Data File" from the menu. Press **"[ENTER]"**. The original file called EXAMPLE.DAT will be updated. You will return to the main menu (Figure A-1). If you wanted to keep the original file, you would select the "Save The Data in a New File," and choose a new file name such as A:\US271-A2.DAT.

A4.0 RUN THE ANALYSIS

Use the **"[SPACEBAR]"** OR ["↑","↓"] to select "Run the Analysis" option, and a screen like Figure A-19 will appear. Type **"Y"** to have the results displayed, and a screen like Figure A-20 will appear. Use **"[SPACEBAR]"** to select the option and press **"[ENTER]"** to run the analysis. After completing the analysis, the main menu (Figure A-1) will display.

** RUN THE ANALYSIS **

AFTER THE ANALYSIS HAS BEEN COMPLETED AN OPTION TO PRINT A SUMMARY OF THE RESULTS WILL BE DISPLAYED

DETAILED RESULTS (ANNUAL PERFORMANCE OF ALL PAVEMENT STRUCTURES ANALYZED) ARE ALSO AVAILABLE

DISPLAY THE DETAILED RESULTS? (Y/N) - - - - - - - - Y

Figure A-19. "Run the Analysis" Screen.

INITIAL CONSTRUCTION
T(1)= 3.00 T(2)= 9.00 T(3)= 6.00 H SPEED E REL LEVEL

YR	MTH	MICRO STRAIN	CRACKING DAMAGE	DAMAGE VARIANCE	CRACKING LAYER1	LAYER2	RUT DEPTH	RUTTING VARIANCE	EPSR	CUMULATIVE 18KSAL
0	0	.00E+00	.00E+00	.00E+00	0.	0.	.00E+00	.11E-02	4.20	.000E+00
0	10	.91E+00	.18E-09	.53E-17	0.	0.	.88E-01	.16E-02	4.10	.227E+06
1	10	.91E+00	.55E-09	.52E-16	0.	0.	.13E+00	.18E-02	4.07	.511E+06
2	10	.91E+00	.58E-09	.57E-16	0.	0.	.15E+00	.20E-02	4.05	.809E+06
3	10	.91E+00	.60E-09	.62E-16	0.	0.	.18E+00	.20E-02	4.03	.112E+07
4	10	.91E+00	.63E-09	.67E-16	0.	0.	.20E+00	.21E-02	4.02	.144E+07
5	10	.91E+00	.65E-09	.73E-16	0.	0.	.22E+00	.21E-02	4.01	.178E+07
6	10	.91E+00	.68E-09	.79E-16	0.	0.	.23E+00	.22E-02	4.00	.213E+07
7	10	.91E+00	.70E-09	.85E-16	0.	0.	.25E+00	.22E-02	3.99	.250E+07
8	10	.91E+00	.73E-09	.91E-16	0.	0.	.26E+00	.23E-02	3.98	.288E+07
9	10	.91E+00	.76E-09	.97E-16	0.	0.	.28E+00	.23E-02	3.97	.327E+07
10	10	.91E+00	.78E-09	.10E-15	0.	0.	.29E+00	.23E-02	3.96	.367E+07
11	10	.91E+00	.81E-09	.11E-15	0.	0.	.30E+00	.23E-02	3.95	.409E+07
12	10	.91E+00	.83E-09	.12E-15	0.	0.	.31E+00	.24E-02	3.95	.452E+07
13	10	.91E+00	.86E-09	.13E-15	0.	0.	.33E+00	.24E-02	3.94	.496E+07
14	10	.91E+00	.88E-09	.13E-15	0.	0.	.34E+00	.24E-02	3.93	.542E+07

CODE=1 15.00 YEARS EXCEEDS THE MAXIMUM TIME BEFORE AN OVERLAY
****

Figure A-20. Detailed Results Screen.

A5.0 PRINT THE INPUT DATA

This option may be used to obtain a hard copy of the input data file (Figure A-21). It is recommended that a copy be kept with the results in the design files for the project. All data entered will be provided by this report.

```
** PRINT THE INPUT DATA **

THE DATA IN THE LAST FILE MODIFIED

OR ANALYZED WILL BE PRINTED


Name of the Engineer - - - -
```

Figure A-21. "Print the Input Data" Screen.

A6.0 PRINT THE RESULTS

This option may be used to print the results. Use **"[SPACEBAR]"** OR ["↑","↓"] to select the option and press **"[ENTER]"**. A screen like Figure A-22 will appear. Simply select the option to print the results.

```
** SUMMARY OF THE RESULTS **
REPORT NO. 1

REPORT NO. 2

REPORT NO. 1 & 2

RETURN TO THE MAIN MENU

REPORT NO. 1 - RESULTS FROM THE MECHANISTIC ANALYSIS
REPORT NO. 2 - THE COST, CONDITION, AND PERFORMANCE OF ALL
               FEASIBLE DESIGN
```

Figure A-22. "Print the Results" Screen.

A6.1 Description of Reports

A6.1.1 Report No. 1

Report number 1 contains a summary of the mechanistic results in tabular form (see Figure A-23). The table columns are described below:

1. Pavement System: A unique number is assigned to each case analyzed. It is only a means of identification. This identifying number is the same pavement system number used in the second report.
2. Base Thickness: The base thickness (granular and/or black) is shown in inches for the strategy analyzed for the unique pavement system number.
3. Surface Thickness: The asphalt concrete pavement surface thickness is shown in inches. If an overlay has been added to the surface, indicated in the overlay thickness column, the surface thickness will include the overlay thickness minus the planing depth used in the analysis.
4. Overlay Thickness: The thickness of the overlay layer is shown in inches.
5. Time Overlay Failed: The time to overlay failure is shown in years.
6. Code: A code is assigned to each load case analyzed which describes when the load case failed. The codes are found at the bottom of the table.
7. Seal Coats Added: The number of seal coats added as a maintenance action in the life cycle costing is shown. This result is only applicable if the "transverse and longitudinal cracking" option is used (refer to section A2.1.11).

STATE OF TEXAS
NEW FLEXIBLE PAVEMENT SYSTEM

NAME OF ENGINEER :

PROB	DIST.	COUNTY	CONT.	SECT.	JOB	HIGHWAY	DATE	PAGE
EX-1	1	LAMAR	1234	01	23	US 271	01-07-92	1

PAVEMENT SYSTEM	GRANULAR BASE THICKNESS (in.)	BL-BASE THICKNESS (in.)	SURFACE THICKNESS (in.)	OVERLAY THICKNESS (in.)	TIME OF OVERLAY (yr.)	TIME OVERLAY FAILED (yr.)	CODE	SEAL COATS ADDED
5 3 0	6.00	9.00	3.00	.00	GT 15.		1	No Seal Coat
5 2 0	6.00	9.00	2.50	.00	GT 15.		1	No Seal Coat
5 1 0	6.00	9.00	2.00	.00	GT 15.		1	No Seal Coat
4 3 0	6.00	8.00	3.00	.00	GT 15.		1	No Seal Coat
4 2 5	6.00	8.00	2.50	1.00	13.3	20.0	6	No Seal Coat
4 1 5	6.00	8.00	2.00	1.00	11.3	20.0	6	No Seal Coat
3 3 5	6.00	7.00	3.00	1.00	11.3	20.0	6	No Seal Coat
3 2 0	6.00	7.00	2.50	.00	9.8		2	No Seal Coat
2 3 0	6.00	6.00	3.00	.00	8.5		2	No Seal Coat
1 3 0	6.00	5.00	3.00	.00	6.3		2	No Seal Coat

Code 1= Thick pavement, Max. time to first overlay exceeded
Code 2= Thin pavement, Min. time to first overlay not reached
Code 3= Thick pavement, Max. time between overlays exceeded
Code 4= Thin overlay, Min. time between overlays not exceeded
Code 5= Analysis period not reached within overlay
Code 6= All design criteria met.

Figure A-23. Report Number 1 - Sample Output.

A6.1.2 Report No. 2

The second report contains a summary of the performance, condition and life cycle costing of the pavement (see Figure A-24). The system numbers, used to identify the load cases, are the same as those used in report number 1. The results are reported under the headings: Initial Construction, Swelling Soils, Seal Coats, Overlay Number and Life Cycle Costs.

1) Initial Construction - Initial Construction refers to the original structure of the pavement before multiple overlays are applied. The time of "failure" of this structure, the failure mode, and the terminal condition of the pavement are described by the calculated PSI, cracked area, and rut depth values.
2) Swelling Soils - This is an optional analysis in the program. The time to failure of the original structure due to swelling soils is reported. Swelling soils reduce the serviceability of the pavement and the associated failure mode is serviceability. The reduction in serviceability, because of swelling soils, is not used in the mechanistic analysis.
3) Seal Coats - This is an optional analysis in the program. The number of seal coats used as a maintenance action are only calculated if the "transverse and longitudinal cracking" option is used. The number of seal coats applied is used in the life cycle costing analysis.
4) Overlay Number - The overlay number and the time of failure is reported. In addition, the thickness of the overlay and the user defined planing depth is reported.
5) Life Cycle Costing - The initial construction, overlay construction, seal coat, routine maintenance, traffic delay costs, and salvage value costs for the pavement are reported as the net present worth costs in dollars per square yard (i.e., the costs discounted to time of initial construction).

```
                    STATE OF TEXAS
                NEW FLEXIBLE PAVEMENT SYSTEM
             LIST OF FEASIBLE DESIGN ALTERNATIVES
NAME OF ENGINEER :
PROB   DIST.  COUNTY           CONT.  SECT.  JOB  HIGHWAY       DATE     PAGE
EX-1     1    LAMAR            1234   01      23   US 271     01-07-92     1
=============================================================================
1  SYSTEM : 4  2  5

   INITIAL CONSTRUCTION       FAILED - 13 YRS  6 MNTHS- RUTTING
     Granular Base    : 6.00 inches     CONDITION : PSI            :     3.84
     Black Base       : 8.00 inches               : Cracked Area :       0.
     Asphalt Surface  : 2.50 inches               : Rut Depth    :      .42
                                        TRAFFIC   :  .485E+07 18kSAL

     Asphalt Overlay  : 1.00 inches

   SWELLING SOILS
     Final Serviceability Reached in 10.6 years

   SEAL COATS
     There is no seal coats predicted

   OVERLAY # 1        MET DESIGN CRITERIA 20 Years
     Asphalt Overlay  : 1.00 inches     CONDITION : PSI            :     3.81
     Mill Depth       :  .00 inches               : Cracked Area :       0.
                                                  : Rut Depth    :      .23
                                        TRAFFIC   :  .804E+07 18kSAL


   LIFE CYCLE COSTS (in present value)
     Initial Construction : 18.26       Overlay Constr. :    .58
     Routine Maintenance  :   .68       Seal Coats      :    .00
     User Costs           :   .02     Salvage Value   :  -1.52   TOTAL   18.02

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

Figure A-24. Report Number 2 - Sample Output.