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TEXAS STATE DEPARTMENT OF HIGHWAYS AND PUBLIC TRANSPORTATION

Pavement Design System

PART I

FLEXIBLE PAVEMENT DESIGNER'S MANUAL

Highway Design Division
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Revised May 1983

Revised May 1983

PREFACE

The purpose of this manual is to provide the pavement designer of the Texas State Department of Highways and Public Transportation with the necessary tools for utilizing the Flexible Pavement Design System. This system includes three computer programs and the equipment necessary to develop inputs for these programs.

This manual was compiled by the Roadway Section (now designated as the "Pavement Design Section") in coordination with Research Study 123, "A System Analysis of Pavement Design and Research Implementation." The following research reports are the basis for this manual:

123-2	"A Recommended Texas Highway Department Pavement Design System User's Manual"
123-1	"A Systems Approach Applied to Pavement Design and Research"
123-8	"A Sensitivity Analysis of Flexible Pavement System FPS2"
32-11	"A Systems Approach to the Flexible Pavement Design Problem"
32-12	"An Empirical Equation for Predicting Pavement Deflections"
32-13	"Flexible Pavement Performance Related to Deflections, Axle Applications, Temperature and Foundation Movements"
101-1F	"An Asphaltic Concrete Overlay Design Subsystem"
123-15	"FPS-11 Flexible Pavement System Computer Program Documentation"
123-18	"Probabilistic Design Concepts Applied to Flexible Pavement System Design"

Questions concerning this manual should be addressed to the Pavement Design Section of the Highway Design Division. As they become desirable, revisions to the Manual will be made by the Pavement Design Section. Numbered Manuals in three-ring binders will be issued only to key personnel who have attended the FPS school conducted by the Highway Design Divison. These designers will be automatically furnished revisions by the Pavement Design Section. Additional bound copies of the Manual will be available. The bound Manuals will not be numbered nor will revisions be issued.

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ABSTRACT

This Manual provides instructions to personnel of the Texas State Department of Highways and Public Transportation for collecting, developing, and processing data for the "THD Flexible Pavement Design System." Included in the Manual are coding instructions for one main program and two subsidiary programs.

The pavement design system provides for generation of several initial design strategies for new pavement construction as well as several overlay strategies for existing pavements. These strategies are listed in order of increasing total cost.

Stiffness Coefficients are used to characterize the materials to be used in new pavement construction, and the Surface Curvature Index is used to characterize existing pavement structures. Uncertainty in the predicted pavement life is treated so that the designer may select various confidence levels.

KEY WORDS: Pavement, Design, Manual, Dyanflect.

CHAPTER 1. INTRODUCTION

The objective of the "THD Flexible Pavement Designer's Manual" is to provide instructions for personnel of Texas State Department of Highways and Public Transportation (SDHPT) to design flexible pavements using the systems approach.

This design system uses Dynaflect deflections to determine material properties and the computer for making numerous calculations. At the present time, this system has three computer programs which are frequently used. This Manual provides instructions for using the FPS program and the subsidiary programs, STIFFNESS COEFFICIENTS and PROFILE ANALYSIS. The latter two programs are discussed in Appendices B and C. The FPS program is discussed in this chapter.

Deflection-Based Structural Subsystem

This section will attempt to explain why and how Dynaflect deflections are used in this system.

In Research Project 32, "Application of AASHO Road Test Results to Texas Conditions," it was found that the original "AASHO Interim Guide for Flexible Pavements" could not be satisfactorily used to design pavements in Texas. This was because of the difficulty in developing material coefficients, as used in the Interim Guide, for the materials and environments encountered in Texas.

The development of a new pavement life equation (or serviceability loss equation) was started because of this difficulty . Work began on the following premise:

> "The wheel load stress acting in the pavement, particularly the tensile stress in the bottom of the asphaltic concrete layer, is believed to be approximately proportional to the curvature of the surface produced by the load."

Professor Scrivner, in his work in Project 32, was able to correlate performance with pavement deflections at the Road Test. A method of predicting deflections in pavement was then sought. No way was found for predicting a pavement deflection with suitable accuracy from laboratory tests. This made it necessary to find a method of field testing (Ref. 1).

The Dynaflect was selected to make the necessary deflection measurements for the following reasons:

1. Pavement deflection curvature can be easily measured with the Dynaflect as described in Appendix A.
2. The Dynaflect equipment was readily available at that time.
3. A large number of measurements can be made economically.
4. Nondestructive testing of pavement materials in situ can be made.

Using the Dynaflect, an empirical equation was developed by means of a statistically designed field experiment. A description of the field facility is contained in Research Report 32-9 (Ref. 2). The equation in the FPS program is used for estimating surface curvature index (SCI) from the design stiffness coefficients (A_s) and layer thickness (D). This equation is also used in a reverse manner to calculate stiffness coefficient of material in place. However, it has been found that the deflection equation can only be used to estimate stiffness coefficients of the pavement and subgrade (A_p and A_s) of a simple two-layer structure.

If the pavement above subgrade level consists of only two layers -- a surfacing and a base layer -- and if the surfacing layer is relatively thin, say, less than 10% of the base thickness, then the composite coefficient A_p obtained in this manner may be taken as a fair estimate of the in situ coefficient of the predominant base material. On the other hand, the value of the subgrade coefficient (A_s) is believed to be largely independent of the make-up of the pavement, and can be taken as a fair estimate of the subgrade stiffness regardless of the composition of the overlaying layers.

Specific recommendations for measuring stiffness coefficients for both subgrade and paving materials will be made in Chapters 6 and 10.

The use of deflection in the ACP Overlay Design Mode is a more specific case and will be discussed in Chapter 9.

General Description of the FPS Program

The FPS System is based on the following general premise: It is the aim of the design engineer to provide, from available materials, a pavement that can be maintained above a specified level of serviceability, over a specified period of time, with a specified reliability, at a minimum overall total cost (Ref. 3).

The computer program, FPS, provides for selecting a complete pavement design strategy. Such a strategy calls for action now (initial construction) and future action(s) (overlays, reconstruction, or maintenance). For a given design analysis, initial construction cost as well as future costs are computed for various design strategies. Future costs consist of future overlay costs, user costs during overlaying, maintenance costs, and salvage value. It is important to note that these costs are considered and that they are discounted to present value by use of the input interest rate.

The FPS program is written in two parts. One is for designing a new flexible pavement structure or completely rebuilding an existing flexible pavement structure. The second part is for the special case where an ACP overlay will be the only initial construction. Hereafter, these parts of the program will be referred to as the "Flexible Pavement Design Mode" and the "ACP Overlay Design Mode," respectively. The flexible Pavement Design Mode was developed in Research Project 32 at the Texas Transportation Institute (Ref. 3) and the ACP Overlay Design Mode was developed in Research Project 101 at the Texas State Department of Highways and Public Transportation (Ref. 4).

In order to understand the FPS program, it is necessary to know generally how the input data are handled and design strategies are calculated. For both the Flexible Pavement Design Mode and the ACP Overlay Design Mode, the input data are read and printed out. The computer proceeds to calculate and store all of the possible initial construction designs for all combinations of materials being considered. These designs are computed over the range of thickness specified for each material. For the special case of the ACP Overlay Design Mode, only one material, the overlay material, is considered for initial construction.

Figure 1.1 is a Summary Flow Chart of FPS (Ref. 5) that illustrates how the program checks each initial design against its constraints to determine all feasible design strategies. This flow chart is applicable to both the Flexible Pavement Design Mode and ACP Overlay Design Mode. The following is a discussion of Figure 1.1.

As seen in Figure 1.1, the program checks each design against the restraints of funds available and maximum initial thickness. If either of these restraints is not met, this initial design is not feasible and the program considers the next design in the same way.

If these first two restrictions are met, the design life of the initial construction is calculated. If the initial design life does not meet the re-

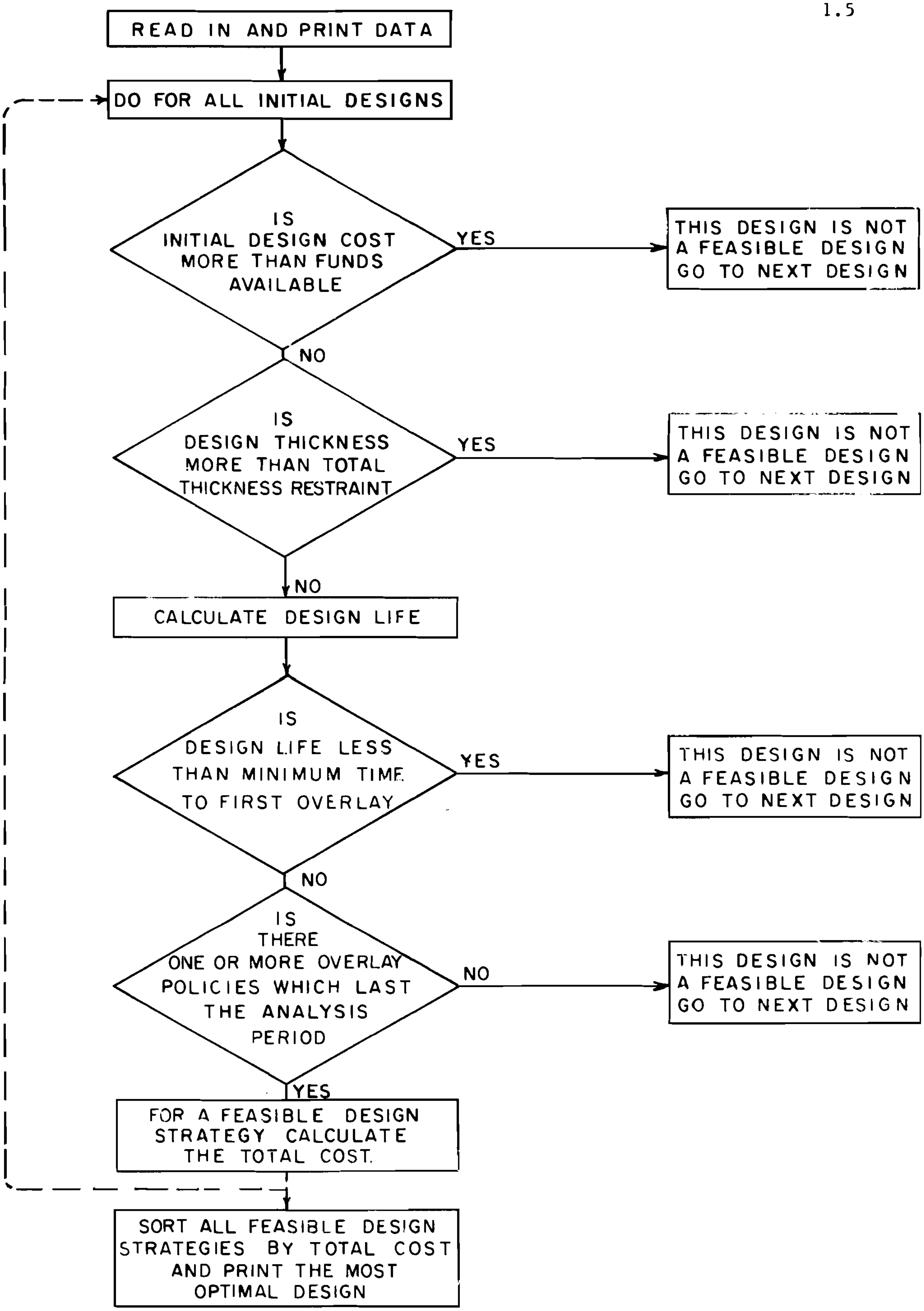

Figure 1.1 SUMMARY FLOW CHART ILLUSTRATING MECHANICS OF THE FPS PROGRAM

straint of the minimum time to first overlay, the program discards this design and proceeds to the next.

If the restraint of the minimum time to first overlay is met, then the program checks to see if there are any overlay strategies which last the analysis period. In order to make these checks the program has to calculate the design life of each overlay thickness for all combinations of overlay strategies. There can be a large number of possible strategies for each initial design.

Total cost is then calculated for each feasible design strategy. This includes the cost of the following: initial construction, overlays including user cost, and maintenance. The program then considers the next initial design and repeats this procedure until all possible design strategies are either discarded or designated as feasible. These strategies are sorted by total cost and a set of design strategies are printed in order of increasing total cost as is illustrated and discussed in Chapter 11.

Pavement Design Process

In this system the pavement design process for either of the two design modes can be thought of as a three-part process. As shown in Figure 1.2, the three parts are: (1) obtaining inputs for the FPS* program, (2) computing with the FPS program, and (3) selecting the best pavement design strategy. Chapters 2 through 10 attempt to explain in detail the selection and coding of inputs that are needed for submitting an FPS problem. Computations with the FPS program are made by submitting the code sheets to the Automation Division, File D-19 (Ref. 6). The FPS program can also be run using remote computer terminals. Instructions to do this must be obtained from D-19. Chapter 11 discusses selection of a pavement design strategy. Reasons for selecting a particular design strategy are discussed and an example problem is presented.

*The FPS computer program inputs have been numbered using the integer number to identify the card and the decimal number the input, i.e. (5.2) indicates Card No. 5 Input No. 2.

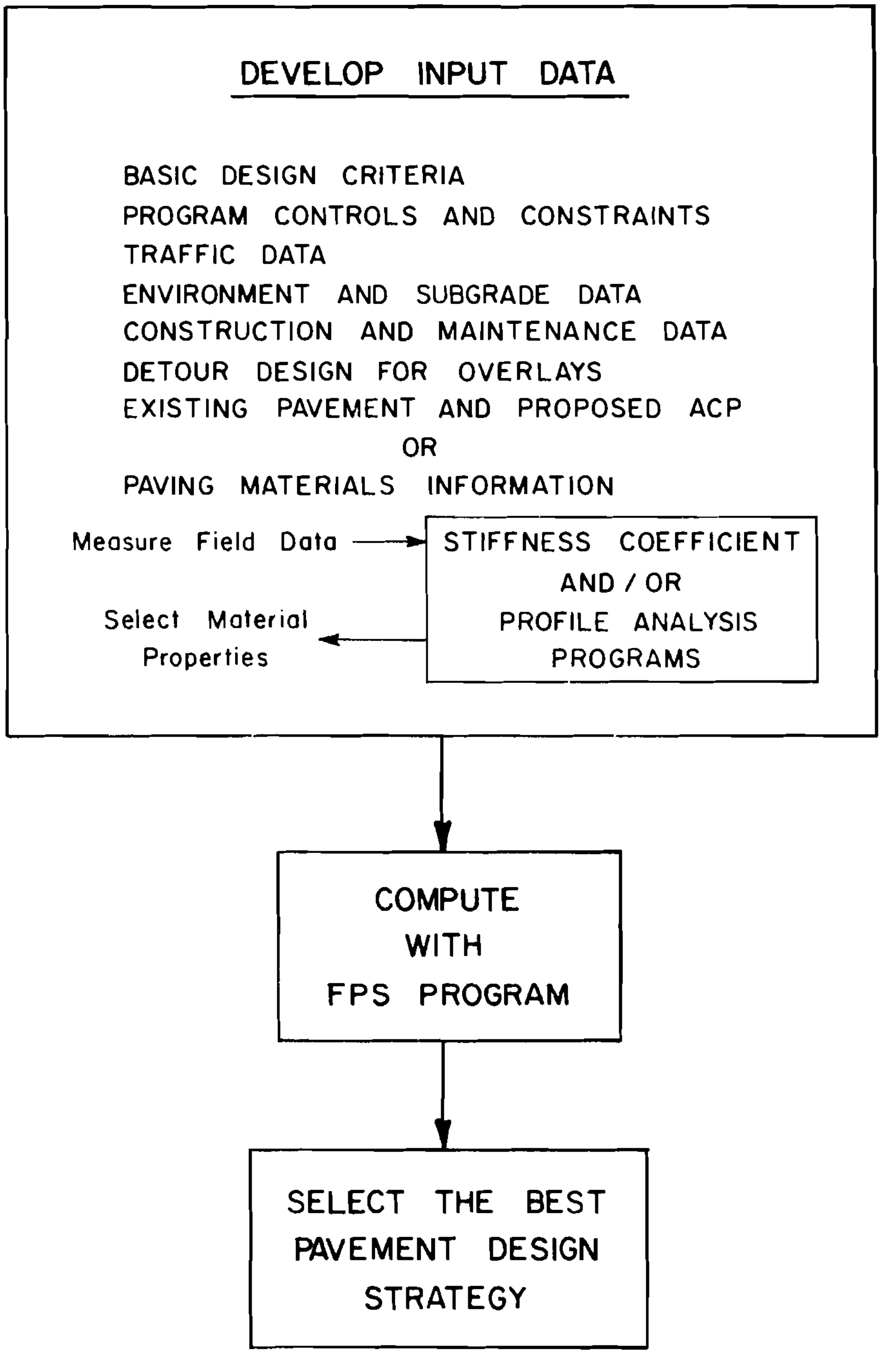

Figure 1.2 PAVEMENT DESIGN PROCESS

CHAPTER 1A. LIMITATIONS OF THE FPS SYSTEM

The FPS program is an attempt to model or simulate the overall pavement process including considerations of design, initial construction, traffic applications, environmental inputs to the system, routine maintenance, overlaying and finally salvaging the remaining value at the end of the analysis cycle. It should be understood that while the program considers the overall problem in its entirety more completely than any analysis package in use today it utilizes some gross over-simplifications in order to do this. Additionally, many pavement considerations still have not been included in the program. For example, frost heave is totally ignored.

The omission and over-simplifications can result in design blunders of some severe consequences, if not controlled. As discussed in Chapter 11, engineering judgment will now and always be required as a first line of defense against such blunders. Such judgment is of course fallible (as are all human endeavors). A corollary defense lies in the utilization of specifications on material properties that are based on much experience.

As specific areas or regions of calculations are identified wherein the program calculates incorrect answers, the simplest control seems to be to prohibit the program from calculating or seeking solutions in these regions.

One of the important simplifications used in the program lies in the assumption that a smaller deflection means smaller stresses or strains and therefore longer life. Notice that no measures of strength of materials are considered. The following simplification of stress-state considerations in pavements is necessary to explain the recommended constraints at the end of this chapter.

Critical Stresses or Strains in Pavements

It has long been recognized that critical stresses in rigid pavements are bending stresses or tensile stresses at the bottom of the slab. Virtually all design methods are aimed at keeping this stress low or the strength high.

In flexible pavements either shear stresses or compressive stresses* have been recognized as being critical for a long time. Current popular practice seems to be to control vertical compressive stresses on top of subgrades and shear stresses (triaxial) in flexible base materials.

In semi-rigid** pavements there seems to be no consensus of analysis on critical stresses. Semi-rigid pavement is defined for usage in this Manual to be those pavements that get their strengths from cohesive bonds between particles. This would generally imply all chemically stabilized materials (asphalt, lime, cement, or others). It appears that whenever such materials are placed over materials that are flexible (untreated) they must be considered to act as rigid or slab-like materials and the critical stresses are tensile.

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* It is now recognized that strains may be more critical than stresses. The reader need not be concerned. He may replace stresses with strains and not change the meaning of the text.

** This terminology is not satisfactory but one is forced to use it because popular usage of the term rigid pavements means portland cement concrete pavements.

Comparison of Critical Stresses With the Deflection-Based Performance Model

Compressive stresses on subgrades are highly correlated to vertical surface deflections. Such surface deflections are in turn correlated to the Surface Curvature Index as used in the FPS program. For most cases the resulting FPS solutions seem compatible with experience as far as compressive and/or shear strains are concerned. Two minor exceptions can occur.

Since FPS uses number of repetitions of an equivalent wheel load, it is possible for the program to generate solutions that are dangerous relative to compressive stresses on the subgrade materials when numbers of applications of equivalent wheel loads are small.

> It is recommended that designers check all FPS solutions with Figure 16, Flexible Base Design Chart and Figure 17, Thickness Reduction Chart for Stabilized Layers of Test Method Tex-117-E contained in the SDHPT Manual of Testing Procedures. Estimated subgrade triaxial classes and cohesiometer values should be accurate enough for this check. Since the FPS solution will be based upon 18 Kip single axle load applications, a load frequency design factor of one should be used. It is necessary to perform this check only on soil materials (subgrade and sand-clay subbases).

It is also possible for FPS to generate solutions that have dangerous shear stress levels on base materials similar to the above.

> It is recommended that the designer not permit FPS to consider unstable base materials without adequate cover. Experience with previous usage of the materials coupled with a triaxial evaluation can be utilized to control this program.

Tensile stresses in the bottom of semi-rigid pavement layers should be closely correlated with the Surface Curvature Index as utilized in the

FPS program. According to most theories, such stresses increase very rapidly with a decrease in thicknesses as such slabs become relatively thin. Experience with FPS has also indicated that the program has a tendency to predict too long a life for thin semi-rigid slabs.

Therefore, when using FPS it is recommended that the thickness of semi-rigid layers be constrained as follows:

Design Wheel Load in Pounds	Minimum Thickness of Semi-Rigid Layers
4,000 - 5,999	5"
6,000 - 8,999	6"
9,000 - 11,999	7"
12,000 - 16,000	8"

Several program controls which are explained in the following chapters can be utilized to do this. This thickness can be composed of composite slabs such as asphaltic concrete plus black base or asphaltic concrete plus soil cement so long as the designer assures that a strong bond between the layers is obtained.

In Texas, thin membrane surfaces placed upon flexible pavements will be in compression under wheel loads most of the time. It is important that such membranes be kept thin, be composed of a mix design such that they are as flexible as possible, and that they not leak water into underlying layers.

It is therefore recommended that the thickness of thin surfaces when placed upon flexible pavements (untreated) be restricted to two inches or less.

It is anticipated that recommendations about other problem areas will be added to this chapter as needed.

CHAPTER 2. PROJECT IDENTIFICATIONS AND COMMENTS

Although the inputs in this Chapter have no effect on computed design solutions, their importance to the Engineer for future identification cannot be overemphasized. As more use is made of the "THD Flexible Pavement Design System," the need for thorough project identification and comments will become increasingly important.

Figure 2.1 illustrates the PROJECT IDENTIFICATION code sheet. Each input is self-explanatory. These inputs provide the Engineer a way to classify each computer run in his use of the Pavement Design System. Input 1.1, Problem number, allows the designer to further identify each individual run. An example is the time when a designer wishes to make more than one computer run, varying one or more of the inputs, in his efforts to evaluate different design strategies on the same stretch of roadway, that is, the same County, Highway, Control, and Section. These PROJECT IDENTIFICATION inputs are echo-printed on each computer output as shown on Figures 11.1 and 11.2

The PROJECT COMMENTS code sheet, Figure 2.2, functions in much the same manner as the PROJECT IDENTIFICATION code sheet. The comments are also echo-printed as shown on Figure 11.1. The program provides for up to seven comment cards for each individual run. Although each card is separated between columns 41 and 42 on the code sheet, the computer printout of these comments is as if these two columns were side by side and not separated. The first function of the comment cards is to let the designer identify each individual problem for his own benefit or for the benefit of anyone else who may be interested in a particular problem. Equally important, the comments also enable him to

PROJECT IDENTIFICATION

1.0	Card type	0 1	1 2
1.1	Problem number		3 4 5
1.2	District		6 7
1.3	County		8 9 10 11 12 13 14 15 16 17 18 19 20 21
1.4	Control		22 23 24 25
1.5	Section		26 27
1.6	Highway		28 29 30 31 32 33 34 35 36 37
1.7	Date		38 39 40 41 42 43 44 45
1.8	IPE		46 47 48 49

Figure 2.1 PROJECT IDENTIFICATION
CODE SHEET

PROJECT COMMENTS

Card Type

0	2
1	2

3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41

42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80

0	2
1	2

3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41

42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80

0	2
1	2

3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41

42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80

0	2
1	2

3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41

42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80

0	2
1	2

3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41

42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80

0	2
1	2

3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41

42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80

0	2
1	2

3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41

42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80

Figure 2.2 PROJECT COMMENTS
CODE SHEET

support and document his basic reasons for making these specific calculations. The designer may use up to seven comment cards.

CHAPTER 3. BASIC DESIGN CRITERIA

An important group of inputs to the FPS program has been termed Basic Design Criteria. They determine the overall quality of pavement service and the reliability with which this quality will be provided to the pavement user. The Basic Design Criteria that have been quantified in FPS to date are: Length of analysis period (3.1), Minimum time to the first overlay (3.2), Minimum time between overlays (3.3), Minimum serviceability index (3.4), Design confidence level (3.5), and Interest rate (3.6). Figure 3.1 is an example code sheet for these inputs.

Pavement performance in FPS is represented by the serviceability index concept as proposed in HRB Bulletin 250, pp. 40-58 (Ref. 7). Figure 3.2, A Performance Curve for One Pavement Design Strategy, illustrates the first four Basic Design Criteria inputs. Minimum serviceability level (3.4) specifies the quality of pavement service, Length of analysis period (3.1) draws a time boundary on the analysis, Minimum time to and between overlays (3.2 & 3.3) limits the number of traffic interruptions to perform overlays. Design confidence level (3.5) provides the reliability with which the above-mentioned quality is provided.

BASIC DESIGN CRITERIA

3.0 Card type	0 3	1 2
3.1 Length of analysis period (years)	☐ ☐	4 5
3.2 Minimum time to first overlay (years)	☐ ☐	9 10
3.3 Minimum time between overlay (years)	☐ ☐	14 15
3.4 Minimum serviceability index	☐ • ☐	19 20 21
3.5 Design confidence level	☐	23
3.6 Interest rate (%)	☐ • ☐	25 26 27

Figure 3.1 BASIC DESIGN CRITERIA
CODE SHEET

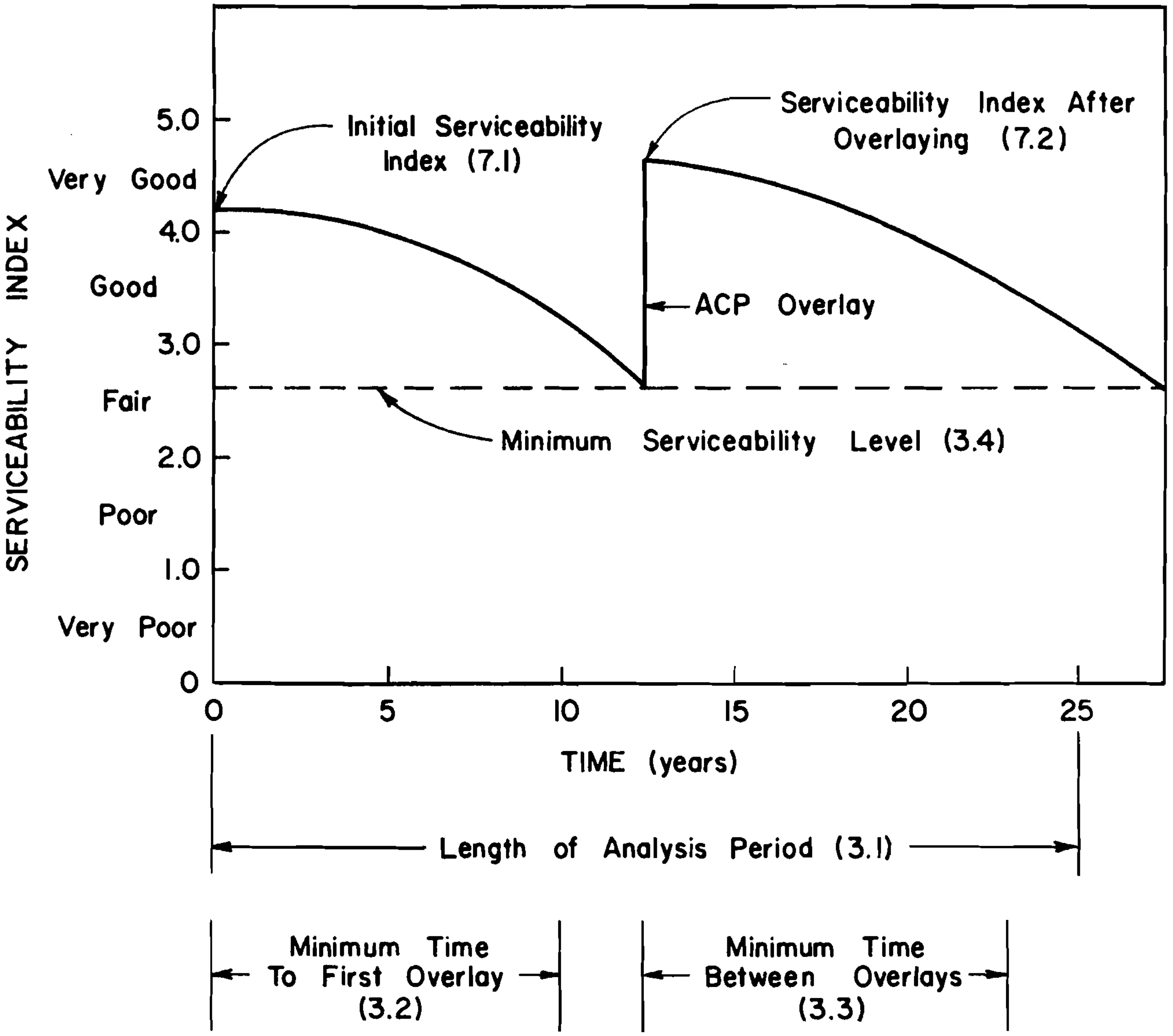


Figure 3.2 A PERFORMANCE CURVE FOR ONE PAVEMENT DESIGN STRATEGY

3.1 Length of analysis period

Generally speaking, the pavement designer should base his pavement design analysis on a period that is no longer than he expects the geometric design to remain adequate.

The following recommendations are given for this input:

a. For Interstate Funded Highways use a twenty-year analysis period beginning with the date of anticipated approval of PS & E by the Federal Highway Administration.

b. For other important 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.

c. For Farm or Ranch to Market Highways use a ten-year analysis period.

d. For temporary connections, detours, and other short life expectancy pavements use an analysis period that equals the expected life of the pavement.

e. For all other facilities (most highways) use twenty years.

3.2 Minimum time to the first overlay

This input specifies the minimum time the initial design must last. This input has no meaning in the ACP Overlay Mode of FPS and should be left blank. Its choice in the Flexible Pavement Design Mode depends essentially upon four considerations.

First, if funds are limited for initial construction, it is possible to build a pavement of only limited initial life. However, this consideration has been provided for in FPS through another input (4.3) and should not affect the designer's choice of Minimum time to the first overlay on the first try at designing the pavement for a project. Conversely, funds may be provided only for initial construction and no overlaying funds will be available during the analysis period. In this case, the designer must specify that the Minimum time to the first overlay (3.2) equal to the Length of analysis period (3.1).

A second consideration may be termed the "public" consideration. Having to overlay a pavement too soon after construction can be quite unpopular with the traveling public. For this reason initial designs should be specified to last a "reasonable" minimum length of time.

The third consideration is that the state of technology in dealing with heaving soils is currently such that it may be wholly uneconomical or technically impossible to provide a very long-lived initial design where such soils are encountered. It is recommended that the designer ignore the heaving soil conditions in specifying the Minimum time to the first overlay (3.2) on the first try at designing the pavement for a project.

The fourth consideration is one of economics. On some highways it can be more economical to maintain the required serviceability level by using frequent overlays rather than by investing in an expensive initial design.

> After considering all the above it is recommended that on the initial design attempt, a Minimum time to the first overlay (3.2) of six years be used. If, because of limited available funds or extensive swelling activity, this results in no solutions or unacceptable solutions the six years must be relaxed and additional calculations made.

3.3 Minimum time between overlays

This input has the same effect in the ACP Overlay Mode of operation as the Minimum time to the first overlay (3.2) has in the Flexible Pavement Design Mode. Its effect is essentially negligible in the Flexible Pavement Design Mode.

> It is therefore recommended that six years be used for both modes with the same exceptions applying as stated in the Minimum time to the first overlay (3.2) recommendations.

3.4 Minimum serviceability index

As stated earlier this input specifies the quality of pavement service to be provided. It appears that smoothness is of primary importance to highway users in defining quality even though other things such as friction, noise level, and appearance are important. The smoothness and friction required (or the roughness and slickness prohibited) are a function of the speed the driver is traveling.

> It is therefore recommended that a Minimum serviceability index (3.4) of 3.0 be used on highways with "Legal Posted Speeds" in excess of 45 mph and 2.5 for those posted 45 mph or less. If signal spacing, stop signs, dips, etc. prevent drivers from operating faster than 20 mph the Minimum serviceability index (3.4) may be relaxed to 2.0.

3.5 Design confidence level

This variable controls the reliability with which the specified quality of pavement service will be satisfied. Its choice should depend largely upon the consequences of failing to provide the specified quality throughout the indicated analysis period. As an example, suppose one highway carrying 28,000 vehicles per lane per day must be overlaid or reconstructed prematurely. The consequences will be much more severe if it does not have continuous frontage roads or some other convenient detour with sufficient capacity available. (The designer is cautioned to remember that the FPS program takes into account user costs for planned future ACP overlays).

The problems arising because of failure to provide the specified quality throughout the analysis period depend upon the type of repair required to restore serviceability, the relative amount of traffic using the facility during this repair, and the availability of a detour route for this traffic.

The designer must specify confidence levels by coding a letter A, B, C, D, E, F or G. The reliability (probability of success) increases with each succeeding letter - A being the lowest reliability and G the highest.

It is recommended that the guidelines shown in Table 3.1 be used in selecting the Design confidence level.

TABLE 3.1

GUIDELINES FOR SELECTING THE DESIGN CONFIDENCE LEVEL

	The highway will remain rural throughout the analysis period	The highway is or will become urban before the end of the analysis period
The highway will be operating at greater than 50% of capacity sometime within the analysis period	C or D	E
The highway will be operating at less than 50% of capacity throughout the analysis period	C	D or E

3.6 Interest rate

Interest rate is used in FPS 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 needed monies to perform these various operations at the appropriate time. Although this money is not literally being invested by the Department, this concept is necessary to have a valid comparision of 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.

> It is therefore recommended that a value of 7% be used in FPS until significant changes in interest rates develop.

CHAPTER 4. PROGRAM CONTROLS AND CONSTRAINTS

As used in this Manual, a program control may be defined as a value assigned to an input which will have the effect of limiting or controlling the number of feasible designs or the formatted output and program running time. The value of these inputs may be set by the designer as he desires to control the program. A constraint may be defined as an input with a fixed value which the designer cannot change for a particular project and it may limit the number of feasible designs. Some of the inputs in this chapter act either as controls or constraints in the program. If the designer has a choice in selecting the inputs, they act as program controls; otherwise, they may act as constraints. Figure 4.1 is an example code sheet.

PROGRAM CONTROLS AND CONSTRAINTS

4.0	Card type	0 4	1 2
4.1	Problem type: 1 = new pavt. const., 2 = ACP overlay	☐	4
4.2	Number of summary output pages (8 designs/page)	☐	6
4.3	Max. funds available per S.Y. for initial const. ($)	☐ ● ☐ ☐	8 9 10 11
4.4	Maximum total thickness of initial construction (inches)	☐ ☐ ● ☐	13 14 15 16
4.5	Maximum total thickness of all overlays (inches)	☐ ☐ ● ☐	18 19 20 21

Figure 4.1 PROGRAM CONTROLS AND CONSTRAINTS CODE SHEET

4.1 Problem type

This input is strictly a program control and specifies the type of problem that is being considered. New Pavement Construction Mode is indicated by coding a 1 for this variable. The ACP Overlay Mode is specified when a 2 is coded for this variable.

4.2 Number of summary output pages

This input is used exclusively as a program control. The computer program lists a summary of the least cost design strategies. Eight design strategies are contained on each summary page. The designer should indicate, up to three, the number of these pages that he desires.

4.3 Maximum funds presently available per S.Y. for initial construction

This input can act either as a constraint or as a control. When the designer is limited by the funds that he can specify, this input may be a constraint. However, if enough funds are available, the designer can select a realistic amount, in which case this input becomes a control in the program. Decreasing this input decreases the amount of calculations. Therefore, if this input is merely being used to control the number of feasible designs, the designer should be careful not to decrease the maximum funds presently available to such a value that it becomes a constraint. If it acts as a constraint when not intended to be one, the least cost design strategy may be missed.

4.4 Maximum total thickness of initial construction (inches)

This input should be no greater than the total maximum thickness for the individual layers. If the designer is restricted to a fixed total thickness of initial construction, this input may act as a constraint and result in a solution less than optimal or in no solution; otherwise, it acts as a control. Again, when using it as a control only to limit calculations, the designer should be careful not to reduce the thickness to the point that it acts as a constraint.

4.5 Maximum total thickness of all overlays (inches)

This input can be used as a constraint or as a control in the program. The maximum overlay thickness is usually determined by the geometrics of the cross section. Although the program computes and includes the cost of a level-up quantity equal to a one-half inch thickness of asphaltic concrete pavement in each overlay, no structural value is attributed to the level-up and the pavement thickness is not considered to be increased. The level-up is assumed to be necessary to smooth up the unevenness of the pavement. This level-up thickness(es) is not considered in testing for this constraint/control in the program.

CHAPTER 5. TRAFFIC DATA

Some of the inputs in this chapter should be obtained from Planning Survey Division, File D-10, SDHPT. For services available from that Division, the reader is referred to their manual, Chapter IV (Ref. 8). Figure 5.1 is an example code sheet for traffic data.

5.1 and 5.2 ADT* at the beginning and at the end of 20 years

Average Daily Traffic (ADT) for both the beginning and at the end of 20 years is used in two places in the program.

First, they are included in the traffic equation to determine the distribution of equivalent 18 Kip Single Axle Loads (18 KSA) as a function of time.

Second, they are used for the calculation of traffic delay cost during overlay construction. Traffic delay cost increases with an increase in ADT. Beyond a traffic volume of between 1350 and 1500 vehicles per hour in one lane during overlay construction, the computed cost of traffic delay is exceptionally high because the assumed lane capacity has been exceeded.

ADT is assumed to increase uniformly from the beginning to the end of the analysis period.

---

* Both directions.

TRAFFIC DATA

5.0 Card type ______ 0 5 — 1 2

5.1 ADT at the beginning of the analysis period (veh./day) ______ ☐☐☐☐☐☐● — 5 6 7 8 9 10 11

5.2 ADT at the end of 20 years (veh./day) ______ ☐☐☐☐☐☐● — 15 16 17 18 19 20 21

5.3 One-drctn. cumulative 18 KSA at the end of 20 years ______ ☐☐☐☐☐☐☐☐● — 23 24 25 26 27 28 29 30 31

5.4 Avg. approach speed to the overlay zone (mph) ______ ☐☐ — 34 35

5.5 Avg. speed through overlay zone (overlay direction) (mph) ______ ☐☐ — 39 40

5.6 Avg. speed through overlay zone (non-overlay direction) (mph) ______ ☐☐ — 44 45

5.7 Percent of ADT arriving ea. hr. of construction ______ ☐●☐ — 49 50 51

5.8 Percent trucks in ADT ______ ☐☐ — 54 55

Figure 5.1 TRAFFIC DATA
CODE SHEET

5.3 The 20 year cumulative 18 KSA

The "One Direction Accumulated Number of Equivalent 18 Kip Single Axle Loads" for a 20-year period is furnished by the Planning Survey Division, File D-10. It is assumed to accumulate proportionally to the rate of accumulation of total traffic. The traffic equation, as modeled in the program, converts this input to the correct value for the analysis period being used (Ref. 3 pp. 26). When ADT is increasing with time, as is the general case, the 18 KSA accumulation curve is concave upward (more 18 KSA occur during the last half of the analysis period than the first). If the ADT is decreasing, the opposite is true.

Before coding the remaining inputs (5.4 thru 5.8) in this chapter the user is referred to Chapter 8 of this Manual.

5.4 Average approach speed to the overlay zone (mph)

This input is used to compute cost of delaying traffic during overlay operations. It is assumed that all vehicles approach the overlay area at the same speed, called the "approach speed," and upon leaving this restricted zone the vehicles return to the approach speed. See Figure 5.2.

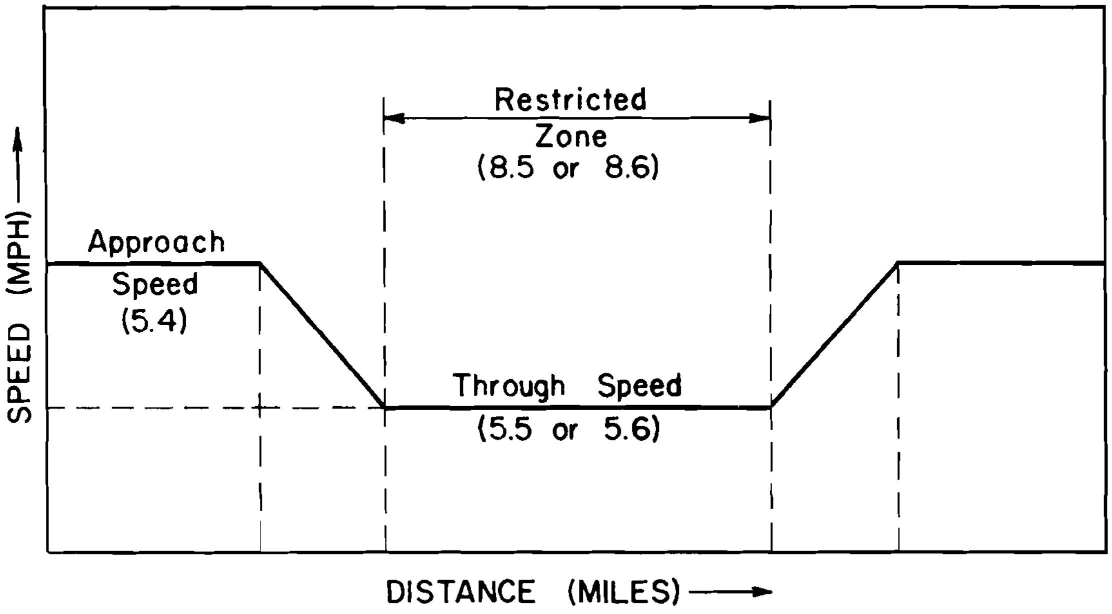


Figure 5.2 SPEED PROFILE FOR VEHICLES WHICH ARE NOT STOPPED BUT ARE SLOWED DURING OVERLAY

5.5 and 5.6 Average speed through overlay zone (overlay and non-overlay direction) (mph)

During overlay operations vehicles must travel through the restricted zone at reduced speeds called the "through speed overlay direction" and "through speed non-overlay direction." It is assumed that vehicles maintain these speeds throughout the restricted zone. See Figure 5.2.

5.7 Percent of ADT arriving each hour of construction

The average percent of ADT which arrives each hour of overlay construction is used in calculating user cost during overlay construction. In order to predict this value, the Planning Survey Division (D-10) will have to be furnished the time of day that construction will occur.

An excellent reference showing how traffic varies hourly is D-10's Annual Report, "Permanent Traffic Recorder Data" (Ref. 9). In the absence of better information, the designer may assume that the proportion of average daily traffic that will pass through the overlay area each hour of the day that overlay takes place is 0.06 for rural highways and 0.05 for urban highways.

5.8 Percent trucks in ADT

This input is used to select the appropriate cost and capacity tables built in the program. Highways carrying more trucks in ADT will have higher user costs during overlay operations because the cost of stopping and slowing down of trucks is higher than that of passenger cars.

CHAPTER 6. ENVIRONMENT AND SUBGRADE

This chapter deals with those factors unique to a particular location that affect pavement performance and over which the designer has no control. Figure 6.1 is an example code sheet.

6.1 District temperature constant

This input represents the increased susceptibility of asphaltic concrete to cracking under traffic in cold weather. For use in the computer program a value for this input has been computed for each District based on weighted mean values of the high and low daily temperatures over a ten-year period (Ref. 3). Values are given in Table 6.1.

TABLE 6.1 DISTRICT TEMPERATURE CONSTANTS

Dist.	Temp. Const.	Dist.	Temp. Const.	Dist.	Temp. Const.	Dist.	Temp. Const.	Dist.	Temp. Const.
1	21	6	23	11	28	16	36	21	38
2	22	7	26	12	33	17	30	22	31
3	22	8	26	13	33	18	26	23	25
4	9	9	28	14	31	19	25	24	24
5	16	10	24	15	31	20	32	25	19

ENVIRONMENT AND SUBGRADE

6.0	Card type	0 6	1 2
6.1	District temperature constant	☐ ☐	4 5
6.2	Swelling probability	☐ ● ☐ ☐	9 10 11 12
6.3	Potential vertical rise (inches)	☐ ☐ ● ☐	13 14 15 16
6.4	Swelling rate constant	☐ ● ☐ ☐	19 20 21 22
6.5	Subgrade stiffness coefficient	☐ ● ☐ ☐	24 25 26 27

Figure 6.1 ENVIRONMENT AND SUBGRADE CODE SHEET

6.2 Swelling probability

At present, three constants are used to calculate the reduction of the serviceability index with time due to swelling clay and other non-traffic causes of serviceability loss. The first constant, Swelling probability (6.2), is a fraction between 0 and 1 which represents the proportion of the project length which is likely to experience swell. This suggests that swelling clay must be present, and that local conditions must be conducive to swelling. Cuts, grade points, bridge approaches, grass root grade lines, and choppy fills seem to be more of a problem than uniform fills. Local experience must be input for this value until more definite guidelines can be developed.

6.3 Potential vertical rise

The potential vertical rise, PVR, is a measure of how much the surface of the bed of clay can rise if it is supplied with all the moisture it can absorb. PVR can either be estimated in a particular locality from the total amount of differential heave the designer (or maintenance personnel) would expect to observe over a long period of time, or by using Texas Test Method, Tex-124-E (Ref. 10). Extremely bad clay may have a PVR in the order of ten to twenty inches.

For highways that have been in existence for some time, the remaining potential for swelling should be reduced by the amount of swell that has already occurred. How much has occurred will depend on the age of the roadbed and the swell rate constant which is discussed in the next section. Figure 6.2 provides a multiplier (ratio) to apply to the original PVR if the swell rate constant and age of an existing road are known.

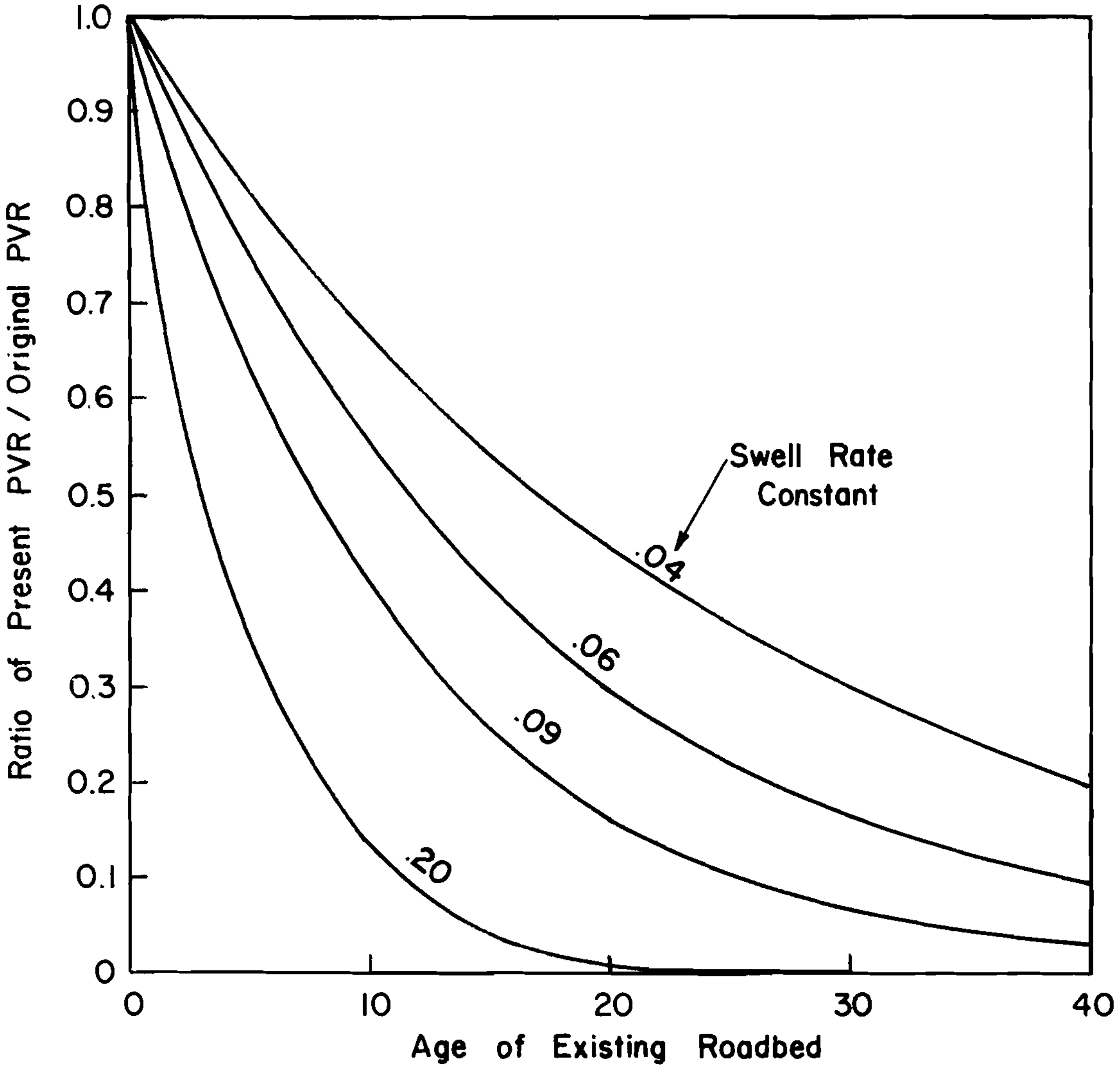


Figure 6.2: CHART FOR ESTIMATING PVR FOR AN EXISTING ROAD

6.4 Swelling rate constant

The swelling rate constant is used to calculate how fast swelling takes place. This constant lies between .04 and 0.20. It is larger when the soil is cracked and open, and when a large moisture supply is available due to poor drainage, high rainfall, underground seeps, or other sources of water. When drainage conditions are good or the soil is tight the swelling rate constant becomes smaller.

The nomograph in Figure 6.3 gives a method of selecting this input based upon the judgment of the designer of local soil and moisture conditions.

Figure 6.4 shows the effects (in the absence of traffic) for three values of PVR and two values of the swelling rate constant on the performance curve. For the curves shown the swelling probability used is 1.0. The effect of other values of swelling probability can be evaluated considering that this input is used solely as a multiplying modifier on PVR in the program. For example, a swelling probability of 0.10 and PVR of 10 inches is exactly equal in the program to a swelling probability of 1.0 and a PVR of one inch.

The loss in serviceability attributed to swelling for each performance period is printed out (See Figures 11.4 and 11.7) so that the designer can check to see if his inputs predict the expected performance. If not, he will want to adjust the inputs to obtain the expected serviceability loss.

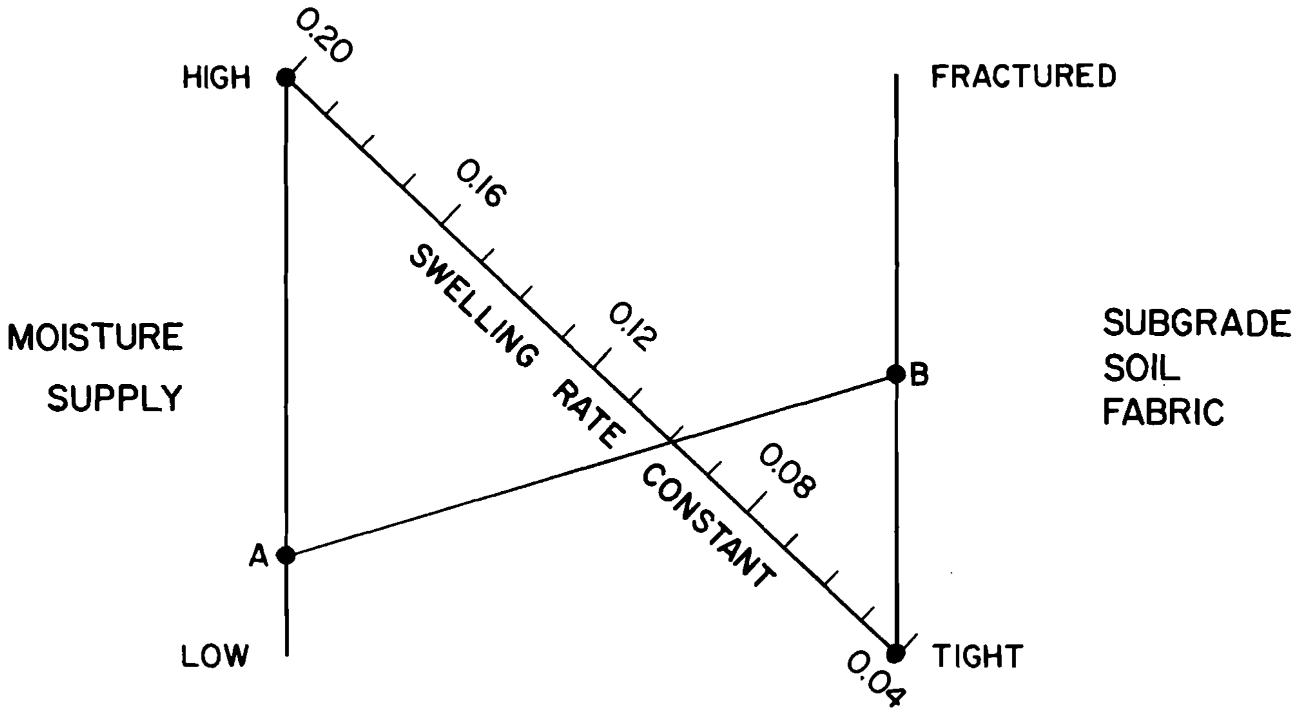


Figure 6.3: NOMOGRAPH FOR SELECTING SWELLING RATE CONSTANT

NOTES: a) LOW MOISTURE SUPPLY:

Low Rainfall
Good drainage

b) HIGH MOISTURE SUPPLY

High Rainfall
Poor drainage
Vicinity of culverts, bridge abutments, inlet leads

c) SOIL FABRIC CONDITIONS

Self explanatory

d) USE OF THE NOMOGRAPH

1) Select the appropriate moisture supply condition which may be somewhere between low and high (such as A).
2) Select the appropriate soil fabric (such as B).
3) Draw a straight line between the selected points (A to B).
4) Read SWRATE from the diagonal axis (read 0.10).

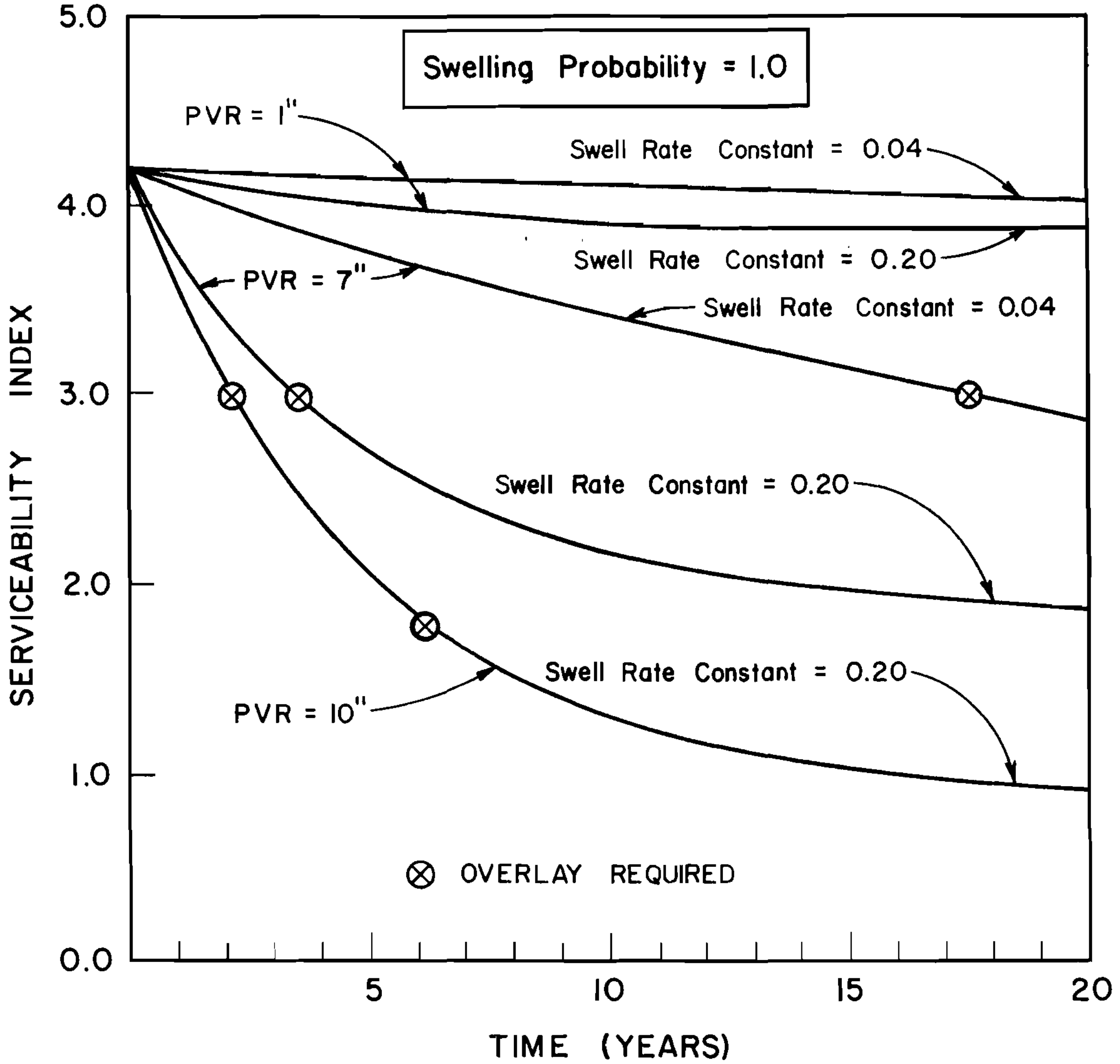


Figure 6.4: PERFORMANCE CURVES ILLUSTRATING SERVICEABILITY LOSS NOT CAUSED BY TRAFFIC

6.5 Subgrade stiffness coefficient

Reference is given to the section "Deflection Based Structural Subsystem" in Chapter 1. That section explains why Dynaflect deflections are used to determine stiffness coefficients.

When determining subgrade stiffness coefficients, two different types of problems are encountered: (1) "existing pavement" to be reworked, and (2) "new locations" where a pavement is to be built on new location. In each case it is important that the changes in subgrade be detected.

The problems of an "existing pavement" are ideal situations for using the Dynaflect. A profile of deflections can be made along the outside wheel path of both directions of traffic. With the aid of the computer, the stiffness coefficients of the subgrade of the pavement can be calculated for the entire profile. As discussed in Chapter 1, the subgrade stiffness coefficient (A_s) is believed to be independent of the make-up of the pavement, and can be taken as a good estimate of subgrade strength. Calculation of stiffness coefficients can be made as discussed in Appendix B.

A "new location" presents a more complicated problem with the first step in solving the problem, since it is similar to current methods of determining subgrade changes. In this step, the designer needs to determine what type subgrades are present and where changes in subgrade occur. This can be done by utilizing any of several aids including laboratory testing; geologic, pedologic, and topographic maps; aerial photographs; and engineering experience. After the Engineer has isolated different types of subgrades,existing pavements with similar subgrades should be chosen to measure deflections with the Dynaflect and to determine stiffness coefficients. Measurements selected in an unbiased manner should be made for each design subgrade section.

When selecting test sections from an existing pavement, consideration should be given to simulating the proposed section as close as possible. Some features to consider are as follow:

1. Fill or cut section
2. Crest or sag of vertical curve
3. Drainage conditions
4. Curbed or uncurbed section
5. Trenched or nontrenched
6. Paved or unpaved shoulders
7. Age of pavement.

For both existing pavements and new pavements the average values of A_s for each design section should be used. Weaker than average subgrade has been taken care of internally by the FPS program as discussed in Chapter 3, Input 3.5.

Design sections for A_s can be established, as discussed in Appendix C, with the aid of the PROFILE ANALYSIS program. Design section can also change for a number of reasons such as changes in traffic, geometrics, swelling clay values or any other physical change. Separate problems should be made for all these design changes with a new average value of A_s for each section involved.

CHAPTER 7. CONSTRUCTION AND MAINTENANCE DATA

This chapter deals with construction variables as well as variables used in computing maintenance costs. Figure 7.1 is an example code sheet.

7.1 Initial serviceability index

This input depends on the materials used and construction practices. Initial serviceability indices have a statewide average of about 4.2. Surface treatments may be near 3.8 and a very smooth ACP or CRCP might be as high as 4.8. See Figure 3.2.

CONSTRUCTION AND MAINTENANCE DATA

7.0	Card type	0 7	1 2
7.1	Initial serviceability index	☐ ● ☐	4 5 6
7.2	Serviceability index after overlaying	☐ ● ☐	9 10 11
7.3	Minimum overlay thickness (inches)	☐ ● ☐	14 15 16
7.4	Overlay construction time (hrs/day)	☐ ☐	19 20
7.5	Asph. conc. compacted density (tons/C.Y.)	☐ ● ☐ ☐	24 25 26 27
7.6	Asph. conc. production rate (tons/hr)	☐ ☐ ☐	28 29 30
7.7	Width of each lane (feet)	☐ ☐	34 35
7.8	First year cost of routine maintenance (dollars/lane - mile)	☐ ☐ ☐ ● ☐ ☐	38 39 40 41 42 43
7.9	Annual incremental increase in maintenance cost (dollars/lane - mile)	☐ ☐ ☐ ● ☐ ☐	44 45 46 47 48 49

Figure 7.1 CONSTRUCTION AND MAINTENANCE DATA CODE SHEET

7.2 Serviceability index after overlaying

In general, the serviceability index after an overlay is about the same as that of initial construction. In this design system it must be specified by the Engineer. See Figure 3.2.

7.3 Minimum overlay thickness

The minimum overlay thickness will usually be determined by the aggregate gradation specified for future overlays. The program automatically adds a one-half-inch level-up to this thickness when determining overlay costs. The level-up is added to restore serviceability and is not considered a part of the structure when strength is calculated.

7.4 Overlay construction time (hrs/day)

The expected number of hours per day that overlay operations will take place is coded for this input. It is used in calculating the number of cars that will be delayed when overlaying is done, which in turn will affect the traffic delay cost.

7.5 Asphaltic concrete compacted density (tons/c.y.)

This input is used to calculate how long it will take to place an overlay and therefore the number of cars that will be delayed. It affects the traffic delay cost.

7.6 Asphaltic concrete production rate (tons/hr)

This input is used to calculate the time it will take to place the overlay and the number of cars that will be delayed due to overlaying. It affects the traffic delay cost.

7.7 Width of each lane (feet)

This input is used in the program to calculate the rate of overlaying and consequently how many vehicles have to be slowed down or delayed due to the work being performed.

7.8 First year cost of routine maintenance (dollars/lane-mile)

The average cost of routine maintenance for the first year after initial or overlay construction should be coded for this input. As an example, the first year cost of routine maintenance statewide varies from $25 to $50 per lane-mile. It is assumed that these expenditures are paid at the beginning of the year. See Figure 7.2.

7.9 Annual incremental increase in maintenance cost (dollars/lane-mile)

The annual incremental increase in routine maintenance cost during each year after initial or overlay construction is assumed to increase at a uniform rate. As an example, the annual incremental increase in routine maintenance costs in Texas varies from $10 to $30 per lane-mile. See Figure 7.2.

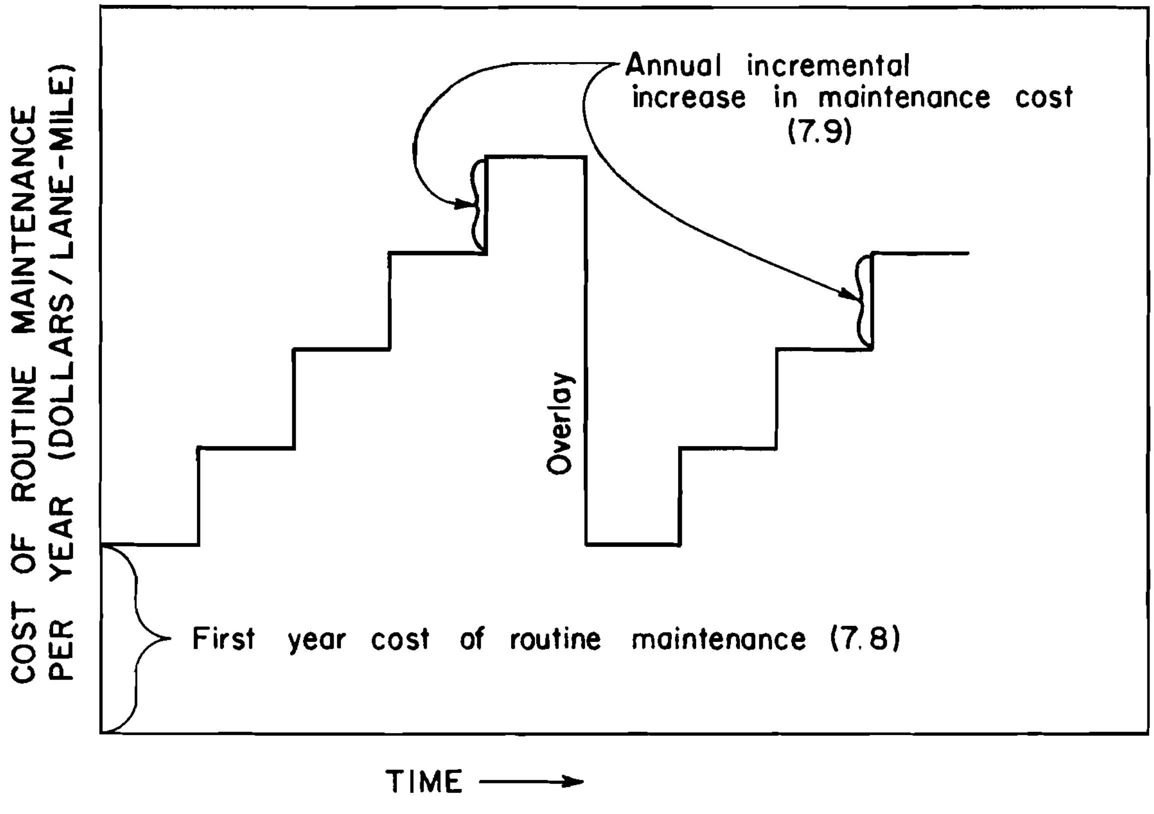


Figure 7.2 MAINTENANCE COST CALCULATIONS IN FPS

CHAPTER 8. DETOUR DESIGN FOR OVERLAYS

This chapter discusses the methods of handling traffic during overlay operations. The method used depends mainly on highway geometrics, especially the number of lanes, the type median (if any), and the presence or absence of paved shoulders, frontage roads, or other alternate routes. The main function of the inputs in this chapter is to model detours for overlay operations in order to predict user cost during overlay operations. Figure 8.1 is an example code sheet.

8.1 Detour model used during overlaying

The program provides for five different methods of handling traffic during overlay operations. See Figures 8.2 through 8.6. The first two methods of detouring traffic, Figures 8.2 and 8.3, are for two-lane roads (with or without shoulders) and the other three methods are for roads with four lanes or more. The designer must decide which type of detouring method will be used when ACP overlays are made upon the proposed project. The model number selected must be coded for this input.

DETOUR DESIGN FOR OVERLAYS

8.0	Card type	0 8	1 2
8.1	Detour model used during overlaying	☐	4
8.2	Total number of lanes of the facility	☐ ☐	5 6
8.3	Number of lanes open in the overlay direction	☐	8
8.4	Number of lanes open in the non-overlay direction	☐	10
8.5	Distance traffic is slowed (overlay direction) (miles)	☐ ● ☐	12 13 14
8.6	Distance traffic is slowed (non-overlay direction) (miles)	☐ ● ☐	17 18 19
8.7	Detour distance around the overlay zone (miles)	☐ ● ☐	22 23 24

Figure 8.1 DETOUR DESIGN FOR OVERLAYS CODE SHEET

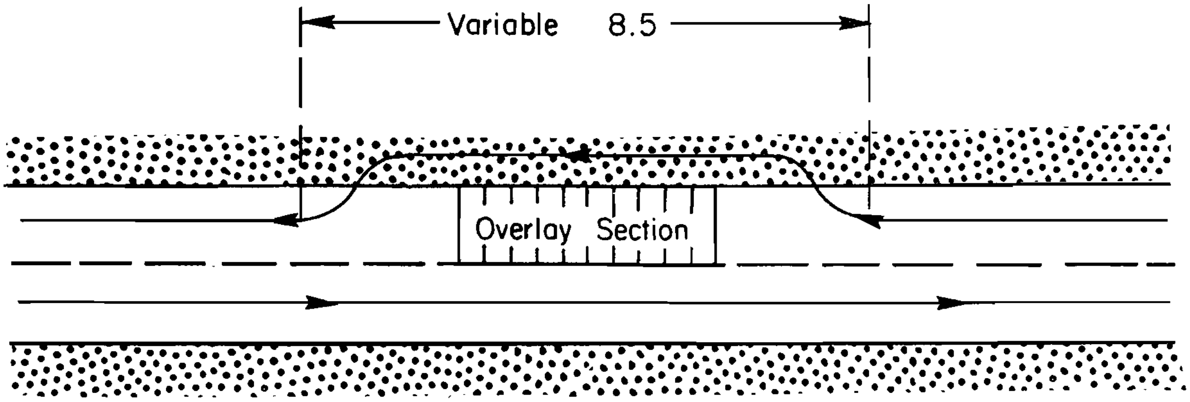


Figure 8.2 DETOUR MODEL NO.1

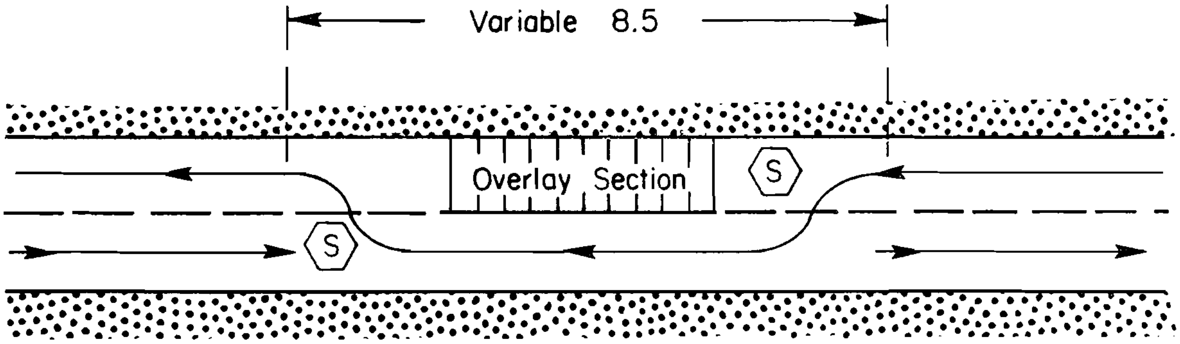


Figure 8.3 DETOUR MODEL NO.2

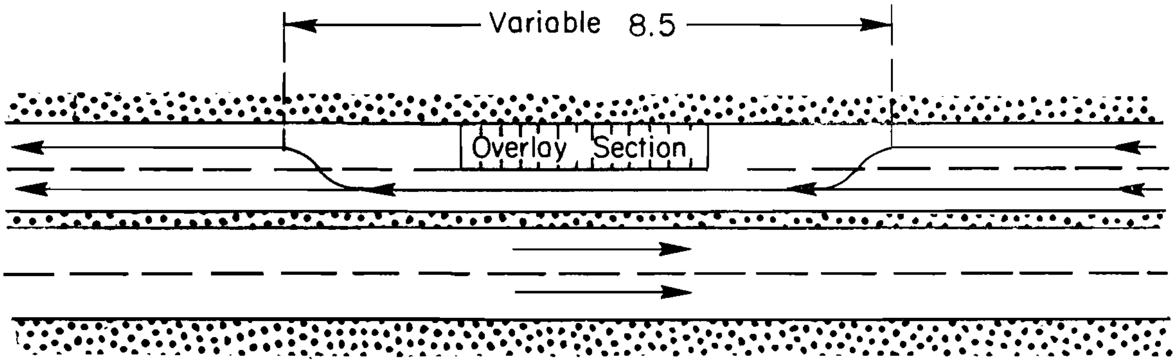


Figure 8.4 DETOUR MODEL NO.3

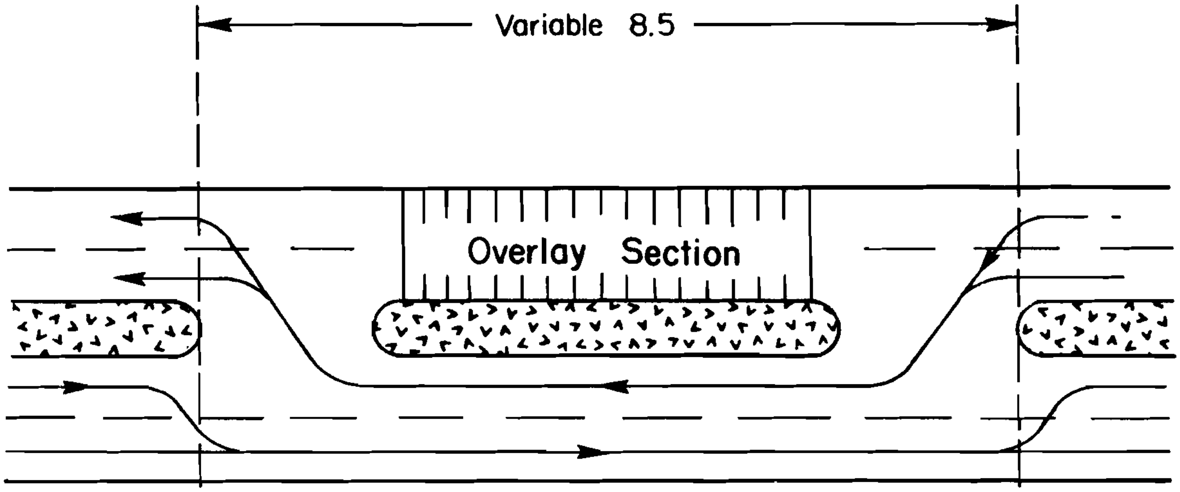


Figure 8.5 DETOUR MODEL NO.4

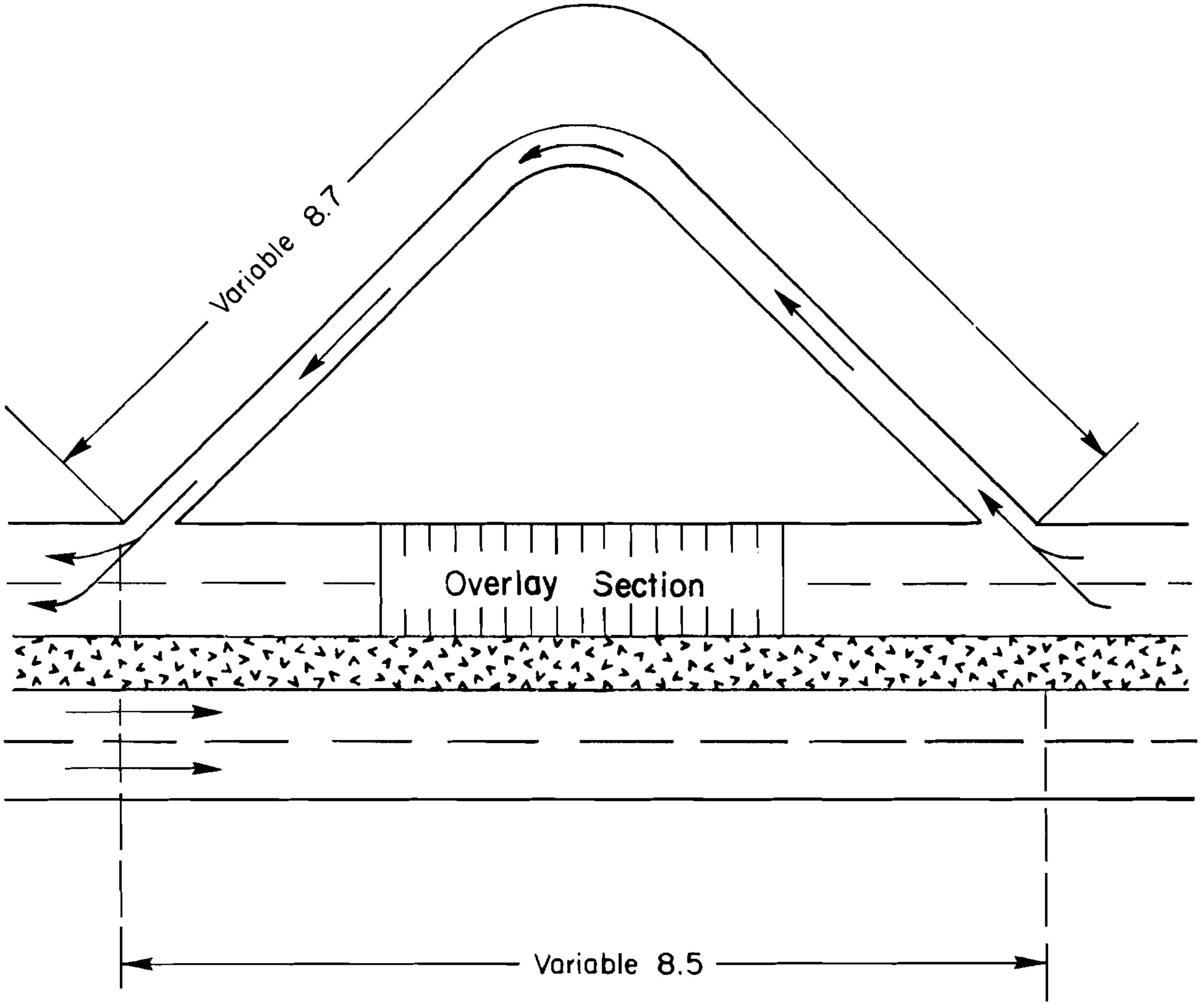


Figure 8.6 DETOUR MODEL NO.5

8.2 Total number of lanes of the facility

This total is for main lanes only and is used in determining traffic delay cost during overlay operations.

8.3 and 8.4 Number of lanes open in the overlay and non-overlay direction

These two inputs, number of open lanes in the overlay and non-overlay direction, depend upon the method of handling traffic and the number of lanes of the highway.

8.5 and 8.6 Distance traffic is slowed in the overlay and non-overlay direction

These two inputs are used in calculating the time that vehicles are delayed due to overlay operations. The units used for these inputs are miles. See Figure 5.2.

8.7 Detour distance around the overlay zone

In some cases during overlay operations, a special detour has to be built to handle traffic. At other times, traffic is directed along an alternate route. Detour Model 5 is used for these two cases. The length in miles of this detour is coded for this input. This input should be left blank unless Detour Model 5 is used.

CHAPTER 9. EXISTING PAVEMENT AND PROPOSED ACP

This chapter contains instructions so that the pavement designer may use the THD Pavement Design System to design asphaltic concrete overlays for existing flexible pavement roadways. The inputs are applicable only to the ACP Overlay Design Mode.

Such overlays may be made for a variety of reasons. They include correcting slipperiness, bad appearance, roughness, leaking surfaces, and strengthening the pavement structure by adding additional thickness of high quality material. Prior to deciding to use the overlay design subsystem described herein, the Pavement Designer should determine why he is placing an overlay. The design system does not consider the skid resistance, appearance, or sealing function of overlays. If these are considerations, they must be handled independently by the designer in making final design selections. The design subsystem for overlays does attempt to handle or design for the leveling and strengthening functions of overlays. Some of the inputs to the design subsystem are used to design for one problem and some for the other. It is imperative that the designer anticipate which type of problem or combination of the two he is trying to overcome so that he may correctly select some of the key inputs.

The roughness problem exhibits itself in the following ways throughout the State. In areas with swelling clays, pavements are almost continually being leveled with either heavy maintenance patches or asphaltic concrete overlays. In other areas, particularly those with high water tables along the Coast or in river flood plains, combinations of both swell and settlement create level-up problems. In some places these conditions are compounded by extremely non-uniform conditions that lead to traffic compaction following construction.

All of these conditions are handled in the program with the "swelling clay" inputs, discussed in Chapter 6. In addition to the swelling clay constants, the designer must input the amount of asphaltic concrete to be used for level-up on the initial overlay.

Strengthening overlays are placed to combat cracking. This cracking may result from fatigue; shrinkage due to drying, temperature changes, or chemical changes; and combinations of these. The cracks themselves are seldom directly the cause of loss of service of the pavement. Frequently, however, intrusion of moisture through them results either in loss of support by weakening of the underlying materials or pumping of the underlying materials. In some locations with some pavement structures, cracks have not resulted in deterioration of the pavement structure.

Cracks frequently reflect through ACP overlays. If the designer desires to try to prevent reflective cracking, he must select a minimum thickness overlay which he thinks will prevent reflective cracking on the particular roadway in question.

Occasionally,a designer may be tempted to use an overlay to solve problems of instability in an existing roadway. This instability, resulting either from too thin a pavement structure on a weak subgrade or weak layers of pavement, rarely can be cured with an economical asphaltic concrete overlay. Such problems should be cured by reconstruction of the pavement structure.

In summary, before using the ACP Overlay Design Mode, the designer should determine (1) that an asphaltic concrete overlay is a solution to his problem, (2) the type of problem or problems that he is trying to solve,and then carefully select the key inputs to fit the particular problem. Figure 9.1 is an example code sheet for these inputs.

EXISTING PAVEMENT AND PROPOSED ACP

9.0	Card type	0 9	1 2
9.1	SCI of the existing pavement	☐ ● ☐ ☐ ☐	3 4 5 6 7
9.2	The standard deviation of SCI	☐ ● ☐ ☐ ☐	8 9 10 11 12
9.3	The composite thickness of the existing pavement (inches)	☐ ☐ ● ☐	13 14 15 16
9.4	In-place cost/comp. - C.Y. of proposed ACP ($)	☐ ☐ ● ☐ ☐	18 19 20 21 22
9.5	Proposed ACP's salvage value as % of original cost	☐ ☐ ☐ ☐	23 24 25 26
9.6	In-place value of existing pavement/comp. - C.Y. ($)	☐ ☐ ● ☐ ☐	29 30 31 32 33
9.7	Existing pavement's salvage value as % of present value	☐ ☐ ☐ ☐	34 35 36 37
9.8	Level-up required for the first overlay (inches)	☐ ● ☐	41 42 43

Figure 9.1 EXISTING PAVEMENT AND PROPOSED ACP
CODE SHEET

9.1 SCI of the existing pavement

The Dynaflect is used to make a deflection profile along the roadway. The measurements are recorded on the STIFFNESS COEFFICIENTS Code Sheets. The deflection parameter, SURFACE CURVATURE INDEX (SCI for short), is used to characterize the existing pavement.

From the recorded deflection measurements, the SCI may be computed directly by substracting the deflection at Geophone 2 from the deflection at Geophone 1, or the STIFFNESS COEFFICIENTS Code Sheets may be submitted to the Computer Center for processing. The profile of SCI's is then analyzed using the PROFILE ANALYSIS PROGRAM as described in Appendix C.

9.2 The standard deviation of SCI

The standard deviation of SCI can be obtained from the output of the PROFILE ANALYSIS PROGRAM as shown in Appendix C. If PROFILE ANALYSIS is not run, a standard deviation is printed for the entire design project on the output of the STIFFNESS COEFFICIENT PROGRAM as shown in Appendix B. Uncertainty is increased as the standard deviation is increased. This uncertainty will cause the program to calculate shorter pavement lives and higher costs.

9.3 The composite thickness of the existing pavement (inches)

This input is not necessary for the program to optimize for least cost. It is included so that the Engineer can get a better estimate of overall cost and document the existing conditions for future reference.

9.4 In-place cost/comp.-C.Y. of proposed ACP ($)

This cost along with the thickness determines construction cost.

9.5 Proposed ACP's salvage value as % of original cost

The salvage value of ACP usually runs approximately 10% - 30% of the original construction cost. A detailed discussion of salvage value is given in Chapter 10 under input 10.8.

9.6 In-place value of existing pavement/comp. - C.Y. ($)

This input is not necessary for the program to optimize for least cost. It is included to get a better estimate of overall cost and document existing conditions.

9.7 Existing pavement's salvage value as a % of present value

This is another input that is included to get a better value for overall cost and it is not necessary for optimization. A detailed discussion of salvage value is given in Chapter 10 under input 10.8.

9.8 Level-up required for the first overlay (inches)

The designer must input the amount of asphaltic concrete level-up to be used for the initial overlay. On future overlays one-half inch is placed by the program for level-up. In both cases, level-up is given no structural value because of its variable initial thickness.

CHAPTER 10. PAVING MATERIAL INFORMATION

This chapter discusses the inputs that are necessary for each pavement layer not including the subgrade, when the Flexible Pavement Design Mode is being used. Figure 10.1 is an example code sheet. One of these code sheets must be filled in for each material that is to be considered in the design. Note that the success of this design system in computing the optimal design strategy depends entirely upon the designer's inputting the optimal materials for consideration.

TEXAS HIGHWAY DEPARTMENT
FLEXIBLE PAVEMENT DESIGN SYSTEM
FPS - 11

PAVING MATERIAL INFORMATION

10.0 Card type ________ [1] [0] (1 2)

10.1 Layer designation number ________ [ ] (4)

10.2 Letter code of material ________ [ ] (8)

10.3 Name of material ________ [ ] (12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29)

10.4 In-place cost/comp. - C.Y. ($) ________ [ ][ ][●][ ][ ] (31 32 33 34 35)

10.5 Stiffness coefficient ________ [ ][●][ ][ ] (40 41 42 43)

10.6 Min. allowable thickness of initial const. (inches) ________ [ ][ ][●][ ][ ] (47 48 49 50 51)

10.7 Max. allowable thickness of initial const. (inches) ________ [ ][ ][●][ ][ ] (55 56 57 58 59)

10.8 Material's salvage value as % of original cost ________ [ ][ ][ ][ ] (62 63 64 65)

10.9 Check ________ [ ] (80)

Figure 10.1 PAVING MATERIAL INFORMATION CODE SHEET

10.1 Layer designation and 10.2 Letter code of material

It is important that the Engineer provide information about all available materials for the program to consider.

Each construction material that is input to the computer program must be accompanied by a layer designation number which indicates the layer in which the material will be used. Each material is also assigned a unique letter code so that the material can be identified in the output summary table. The layer numbering is done in sequence from top to bottom. Surfacing materials are 1, base materials are 2, etc. The subgrade is not numbered.

This scheme allows alternative materials to be used in each layer of the design. For example, the Engineer may want to consider two or more base materials. The surface material would be designated by the number "1", each base material would be designed by the number "2". The program is written so that all combinations of materials are analyzed with the stipulation that no two materials with the same designation number are used in the same design, and no higher numbered layer is used above a lower numbered layer.

Example:

1A = Surfacing

2B = Base

2C = Base

3D = Subbase

Designs Combinations Considered:

1A	1A	1A	1A	1A
Subg.	2B	2B	2C	2C
	Subg.	3D	Subg.	3D
		Subg.		Subg.

10.3 Name of material

A maximum of 13 letters and numbers can be used to describe the material of each layer.

10.4 In place cost/comp. - C.Y. ($)

The in-place costs of materials determine the cost of initial construction, cost of overlay construction, and salvage return. A change in the cost of any material may result in a different optimal design for that combination.

10.5 Stiffness coefficients

These are important variables of design because of their functions of representing structurally the materials in the solution process.

With deflections and composite pavement thickness as inputs, stiffness coefficients can be computed from an empirical deflection equation (Ref. 1). The computer program STIFFNESS COEFFICIENTS, which solves these equations, is discussed in Appendix B. Average value for stiffness coefficient should be input for each material to be used in design. Weaker-than-average materials have been taken care of internally by the FPS program as discussed in Chapter 3.

Base Material Coefficients: For deflection measurements to determine the stiffness coefficients of base materials, the designer should choose a number of existing pavements that have (a) relatively thin surfacing materials, (b) base material(s) similar to the material(s) proposed for the new pavement, and (c) little or no subbase. To be avoided for use in determining coefficients are base materials which have not reached moisture equilibrium,and base materials in badly deteriorated pavements. Stiffness Coefficients may also be obtained from measurements made in other Districts. D-8PD should be contacted if this information is desired.

Subbase Material Coefficients: The same procedure discussed previously for base material should be used for determining subbase material coefficients when such materials are found as base materials in existing projects. For weak subbases, such as sand-clays and lime-treated subgrades that never appear as the predominant part of a pavement structure, it is necessary to extrapolate the stiffness coefficients from those found in subgrade materials. It is felt that such subbases have about the same stiffness as good subgrades (non-rock), and poor base materials.

ACP Surfacing Materials: In most cases stiffness coefficients for thin layer surfacing materials cannot be determined from deflection measurements because of boundary conditions imposed in developing the deflection equations. Based on work in Research Project 32, which developed the equation, work in Research Project 101, and experience gained in measuring base material coefficients in the field, it is recommended that a stiffness coefficient of 0.96 be used for asphaltic concrete surfacing.

10.6 and 10.7 Min. and Max. allowable thickness of initial const. (inches)

These inputs determine the range of thickness to be considered for each material. The minimum and maximum values should be carefully selected to prevent thicknesses which are impractical to construct. Wide ranges of thicknesses will cause excessive computation time.

10.8 Material's salvage value as % of original cost

For salvage purposes the engineer should estimate the value of each material at the end of the analysis period and convert this value to a percent of its original construction value. For example, a granular base material may retain 80% of its originally invested value, while only 30% of the value of asphaltic concrete may be usable at the end of the analysis period. The present worth of the salvaged materials is used in comparing total costs of alternate designs. It should be remembered that this value has been discounted for the entire length of the analysis period. It may be a negative value. Table 10.1 gives recommended guideline percentages for different materials.

In Table 10.1 the percentages are lower for roads with lower geometric standards anticipating that the pavement may be relocated by the end of the analysis period because of geometric deficiencies. They are also lower for materials that deteriorate with time.

For situations where existing pavement materials are re-used, the percentage values in the table should be adjusted upward to reflect the true salvage values as multiples of the value of re-used materials, and not simply as multiples of the cost of making these values re-usable. For example, the cost of using an existing granular base material might only be one-fourth of its cost in new construction. In such a situation the table percentage should be multiplied by 4.0 (the ratio of new construction cost to cost of using the existing material).

10.9 Check

This input checks the number of materials for a given problem. A number 1 (one) must be coded for all material cards except the last card which must have a 0 (zero).

Table 10.1 Salvage Value 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. Subbase (lower part of pavement structures)	30	25	20	55	50	45	80	75	70	95	90	85
2. Granular Base Material	20	15	10	40	35	30	60	55	50	80	75	70
3. Treated Base (with Asphalt, Lime, Cement)	25	10	0	35	20	10	45	30	20	55	40	30
4. Asphalt Surface	15	0	0	25	10	0	35	20	10	45	30	10

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.

CHAPTER 11. INTERPRETATION OF OUTPUT

This chapter explains how to interpret the output of the FPS program. The output can be divided into three parts as follows:

1. Summary of the input data,
2. Summary of the least-cost design strategy for each combination of materials, and
3. Summary of the best design strategies in order of increasing total cost.

Summary of the input data. This section of the output listing prints out all of the inputs (see Figures 11.1 and 11.2 Input Data). The designer should check this list.

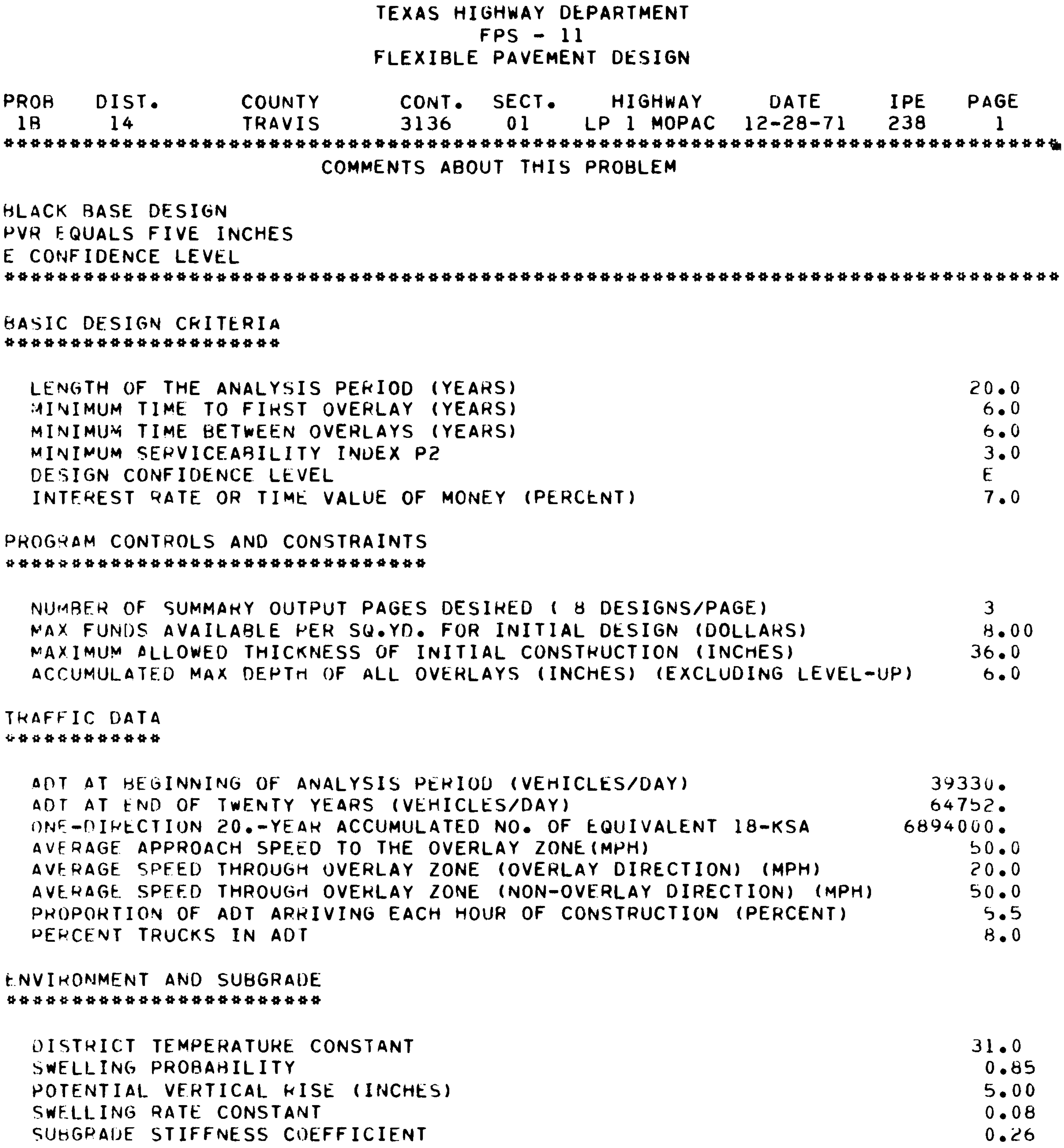
Summary of the least-cost design strategy for each combination of materials. The purpose of this section is to have detailed information on the least-cost design strategy for each combination of materials. This sheet (see Figures 11.3 - 11.6, Examples of Optimal Design Strategy) is divided into the following subsections:

a. Inputs: With each material used in the combination, the cost, the stiffness, thickness restriction, and the salvage value are listed.

b. Optimal Design Strategy: This subsection prints the optimal design strategy for this combination of materials. The serviceability loss due to swelling clay is also output. This is included so that the designer can further check the coding of variables 6.2 thru 6.4.

c. Cost Breakdown: This Table gives a cost listing for the design strategy. With the exception of initial construction cost, it is important to note that the other costs have been discounted to their present worth.

d. Active Restrictions: This subsection gives a list of boundary restrictions that are active and, therefore, affect the solution of the problem. It is very important that the Engineer check the validity of these restrictions. If they are not valid, he should re-examine the problem coding and relax the restrictions that are causing this situation.



```
                              TEXAS HIGHWAY DEPARTMENT
                                      FPS - 11
                              FLEXIBLE PAVEMENT DESIGN

PROB   DIST.      COUNTY      CONT.  SECT.    HIGHWAY     DATE      IPE    PAGE
 1B     14        TRAVIS      3136    01    LP 1 MOPAC  12-28-71    238      1
********************************************************************************
                          COMMENTS ABOUT THIS PROBLEM

BLACK BASE DESIGN
PVR EQUALS FIVE INCHES
E CONFIDENCE LEVEL
********************************************************************************

BASIC DESIGN CRITERIA
*********************

  LENGTH OF THE ANALYSIS PERIOD (YEARS)                                     20.0
  MINIMUM TIME TO FIRST OVERLAY (YEARS)                                      6.0
  MINIMUM TIME BETWEEN OVERLAYS (YEARS)                                      6.0
  MINIMUM SERVICEABILITY INDEX P2                                            3.0
  DESIGN CONFIDENCE LEVEL                                                    E
  INTEREST RATE OR TIME VALUE OF MONEY (PERCENT)                             7.0

PROGRAM CONTROLS AND CONSTRAINTS
********************************

  NUMBER OF SUMMARY OUTPUT PAGES DESIRED ( 8 DESIGNS/PAGE)                   3
  MAX FUNDS AVAILABLE PER SQ.YD. FOR INITIAL DESIGN (DOLLARS)                8.00
  MAXIMUM ALLOWED THICKNESS OF INITIAL CONSTRUCTION (INCHES)                36.0
  ACCUMULATED MAX DEPTH OF ALL OVERLAYS (INCHES) (EXCLUDING LEVEL-UP)        6.0

TRAFFIC DATA
************

  ADT AT BEGINNING OF ANALYSIS PERIOD (VEHICLES/DAY)                     39330.
  ADT AT END OF TWENTY YEARS (VEHICLES/DAY)                              64752.
  ONE-DIRECTION 20.-YEAR ACCUMULATED NO. OF EQUIVALENT 18-KSA          6894000.
  AVERAGE APPROACH SPEED TO THE OVERLAY ZONE(MPH)                           50.0
  AVERAGE SPEED THROUGH OVERLAY ZONE (OVERLAY DIRECTION) (MPH)              20.0
  AVERAGE SPEED THROUGH OVERLAY ZONE (NON-OVERLAY DIRECTION) (MPH)          50.0
  PROPORTION OF ADT ARRIVING EACH HOUR OF CONSTRUCTION (PERCENT)             5.5
  PERCENT TRUCKS IN ADT                                                      8.0

ENVIRONMENT AND SUBGRADE
************************

  DISTRICT TEMPERATURE CONSTANT                                             31.0
  SWELLING PROBABILITY                                                       0.85
  POTENTIAL VERTICAL RISE (INCHES)                                           5.00
  SWELLING RATE CONSTANT                                                     0.08
  SUBGRADE STIFFNESS COEFFICIENT                                             0.26
```

Figure 11.1 SUMMARY OF INPUT DATA

```
                              TEXAS HIGHWAY DEPARTMENT
                                      FPS - 11
                              FLEXIBLE PAVEMENT DESIGN

PROB   DIST.       COUNTY       CONT.  SECT.    HIGHWAY      DATE      IPE    PAGE
 1B     14         TRAVIS       3136    01    LP 1 MOPAC  12-28-71    238      2

                             INPUT DATA CONTINUED


CONSTRUCTION AND MAINTENANCE DATA
*********************************

  SERVICEABILITY INDEX OF THE INITIAL STRUCTURE                                4.2
  SERVICEABILITY INDEX P1 AFTER AN OVERLAY                                     4.0
  MINIMUM OVERLAY THICKNESS (INCHES)                                           1.0
  OVERLAY CONSTRUCTION TIME (HOURS/DAY)                                        7.0
  ASPHALTIC CONCRETE COMPACTED DENSITY (TONS/C.Y.)                             1.26
  ASPHALTIC CONCRETE PRODUCTION RATE (TONS/HOUR)                              75.0
  WIDTH OF EACH LANE (FEET)                                                   12.0
  FIRST YEAR COST OF ROUTINE MAINTENANCE (DOLLARS/LANE-MILE)                 100.00
  ANNUAL INCREMENTAL INCREASE IN MAINTENANCE COST (DOLLARS/LANE-MILE)         10.00

DETOUR DESIGN FOR OVERLAYS
**************************

  TRAFFIC MODEL USED DURING OVERLAYING                                         3
  TOTAL NUMBER OF LANES OF THE FACILITY                                        6
  NUMBER OF OPEN LANES IN RESTRICTED ZONE (OVERLAY DIRECTION)                  1
  NUMBER OF OPEN LANES  IN RESTRICTED ZONE (NON-OVERLAY DIRECTION)             3
  DISTANCE TRAFFIC IS SLOWED (OVERLAY DIRECTION) (MILES)                       1.00
  DISTANCE TRAFFIC IS SLOWED (NON-OVERLAY DIRECTION) (MILES)                   0.0
  DETOUR DISTANCE AROUND THE OVERLAY ZONE (MILES)                              0.0

PAVING MATERIALS INFORMATION
****************************

            MATERIALS             COST     STR.     MIN.     MAX.   SALVAGE.
   LAYER CODE        NAME        PER CY   COEFF.   DEPTH    DEPTH     PCT.
     1     A   A LT. WT. ACP     21.42     0.96     1.00     1.00    30.00
     2     B   ACP               15.48     0.96     1.50     1.50    30.00
     3     C   BLACK BASE        13.93     0.90     4.50    10.00    40.00
     4     D   CRUSHED STONE      4.40     0.60    10.00    18.00    75.00
     5     E   LIME TREATED SUBG  2.40     0.40     6.00     6.00    90.00
```

Figure 11.2 SUMMARY OF INPUT DATA
(CONTINUED)

```
                              TEXAS HIGHWAY DEPARTMENT
                                     FPS - 11
                              FLEXIBLE PAVEMENT DESIGN

 PROB   DIST.      COUNTY      CONT.  SECT.    HIGHWAY     DATE      IPE    PAGE
  1B     14        TRAVIS      3136    01    LP 1 MOPAC  12-28-71    238      4

 FOR THE 2 LAYER DESIGN WITH THE FOLLOWING MATERIALS--
         MATERIALS              COST    STR.     MIN.    MAX.   SALVAGE
LAYER CODE        NAME         PER CY  COEFF.   DEPTH   DEPTH    PCT.
  1     A   A LT. WT. ACP      21.42    0.96     1.00    1.00    30.00
  2     B   ACP                15.48    0.96     1.50    1.50    30.00
            SUBGRADE                    0.26


   THE CONSTRUCTION RESTRICTIONS ARE TOO BINDING TO OBTAIN A STRUCTURE
   THAT WILL MEET THE MINIMUM TIME TO THE FIRST OVERLAY RESTRICTION.
```

Figure 11.3 SUMMARY OF THE LEAST COST DESIGN STRATEGY FOR EACH COMBINATION OF MATERIALS

```
                                  TEXAS HIGHWAY DEPARTMENT
                                          FPS - 11
                                  FLEXIBLE PAVEMENT DESIGN

  PROB    DIST.       COUNTY       CONT.   SECT.    HIGHWAY      DATE      IPE    PAGE
   18      14         TRAVIS       3136     01    LP 1 MOPAC  12-28-71    238      5

  FOR THE 3 LAYER DESIGN WITH THE FOLLOWING MATERIALS--
          MATERIALS                COST    STR.     MIN.     MAX.   SALVAGE
 LAYER CODE       NAME            PER CY  COEFF.   DEPTH    DEPTH     PCT.
   1     A  A LT. WT. ACP         21.42    0.96     1.00     1.00    30.00
   2     B  ACP                   15.48    0.96     1.50     1.50    30.00
   3     C  BLACK BASE            13.93    0.90     4.50    10.00    40.00
            SUBGRADE                       0.26


    THE CONSTRUCTION RESTRICTIONS ARE TOO BINDING TO OBTAIN A STRUCTURE
    THAT WILL MEET THE MINIMUM TIME TO THE FIRST OVERLAY RESTRICTION.
```

Figure 11.4 SUMMARY OF THE LEAST COST DESIGN STRATEGY FOR EACH COMBINATION OF MATERIALS (CONTINUED)

```
                              TEXAS HIGHWAY DEPARTMENT
                                      FPS - 11
                              FLEXIBLE PAVEMENT DESIGN

 PROB   DIST.      COUNTY      CONT.  SECT.    HIGHWAY     DATE      IPE    PAGE
  18     14        TRAVIS      3136    01    LP 1 MOPAC  12-28-71    238      6

 FOR THE 4 LAYER DESIGN WITH THE FOLLOWING MATERIALS--
         MATERIALS            COST    STR.    MIN.    MAX.   SALVAGE
LAYER CODE       NAME        PER CY  COEFF.  DEPTH   DEPTH    PCT.
  1     A  A LT. WT. ACP     21.42    0.96    1.00    1.00   30.00
  2     B  ACP               15.48    0.96    1.50    1.50   30.00
  3     C  BLACK BASE        13.93    0.90    4.50   10.00   40.00
  4     D  CRUSHED STONE      4.40    0.60   10.00   18.00   75.00
           SUBGRADE                   0.26

  4   THE OPTIMAL DESIGN FOR THE MATERIALS UNDER CONSIDERATION--
       FOR INITIAL CONSTRUCTION THE DEPTHS SHOULD BE
              A LT. WT. ACP          1.00 INCHES
              ACP                    1.50 INCHES
              BLACK BASE             4.50 INCHES
              CRUSHED STONE         15.00 INCHES
       THE LIFE OF THE INITIAL STRUCTURE =  9.58 YEARS
       THE OVERLAY SCHEDULE IS
              2.50 (INCH(ES) (INCLUDING 0.5 INCH LEVEL-UP) AFTER  9.58 YEARS.

       TOTAL LIFE =  20.26YEARS

       SERVICEABILITY LOSS DUE TO SWELLING CLAY IN EACH PERFORMANCE PERIOD IS
              (1)  0.762
              (2)  0.380

       THE TOTAL COSTS PER SQ. YD. FOR THESE CONSIDERATIONS ARE
              INITIAL CONSTRUCTION COST          4.815
              TOTAL ROUTINE MAINTENANCE COST     0.225
              TOTAL OVERLAY CONSTRUCTION COST    0.756
              TOTAL USER COST DURING
                      OVERLAY CONSTRUCTION       0.281
              SALVAGE VALUE                     -0.724
              TOTAL OVERALL COST                 5.353


       NUMBER OF FEASIBLE DESIGNS EXAMINED FOR THIS SET --       34


         AT THE OPTIMAL SOLUTION,THE FOLLOWING
         BOUNDARY RESTRICTIONS ARE ACTIVE--
                  1. THE MINIMUM DEPTH OF LAYER  1
                  2. THE MAXIMUM DEPTH OF LAYER  1
                  3. THE MINIMUM DEPTH OF LAYER  2
                  4. THE MAXIMUM DEPTH OF LAYER  2
                  5. THE MINIMUM DEPTH OF LAYER  3
```

Figure 11.5 SUMMARY OF THE LEAST COST DESIGN STRATEGY FOR EACH COMBINATION OF MATERIALS (CONTINUED)

```
                           TEXAS HIGHWAY DEPARTMENT
                                   FPS - 11
                           FLEXIBLE PAVEMENT DESIGN

 PROB   DIST.      COUNTY      CONT.  SECT.    HIGHWAY      DATE     IPE   PAGE
  1B     14        TRAVIS      3136    01    LP 1 MOPAC  12-28-71    238     7

 FOR THE 5 LAYER DESIGN WITH THE FOLLOWING MATERIALS--
        MATERIALS            COST    STR.    MIN.    MAX.   SALVAGE
LAYER CODE      NAME        PER CY  COEFF.  DEPTH   DEPTH    PCT.
  1    A  A LT. WT. ACP     21.42    0.96    1.00    1.00   30.00
  2    B  ACP               15.48    0.96    1.50    1.50   30.00
  3    C  BLACK BASE        13.93    0.90    4.50   10.00   40.00
  4    D  CRUSHED STONE      4.40    0.60   10.00   18.00   75.00
  5    E  LIME TREATED SUBG  2.40    0.40    6.00    6.00   90.00
          SUBGRADE                   0.26

  5   THE OPTIMAL DESIGN FOR THE MATERIALS UNDER CONSIDERATION--
       FOR INITIAL CONSTRUCTION THE DEPTHS SHOULD BE
              A LT. WT. ACP        1.00 INCHES
              ACP                  1.50 INCHES
              BLACK BASE           4.50 INCHES
              CRUSHED STONE       15.00 INCHES
              LIME TREATED SUBG    6.00 INCHES
       THE LIFE OF THE INITIAL STRUCTURE = 11.70 YEARS
       THE OVERLAY SCHEDULE IS
               1.50 (INCH(ES) (INCLUDING 0.5 INCH LEVEL-UP) AFTER 11.70 YEARS.

       TOTAL LIFE =  23.79YEARS

       SERVICEABILITY LOSS DUE TO SWELLING CLAY IN EACH PERFORMANCE PERIOD IS
              (1)  0.865
              (2)  0.346

       THE TOTAL COSTS PER SQ. YD. FOR THESE CONSIDERATIONS ARE
              INITIAL CONSTRUCTION COST          5.215
              TOTAL ROUTINE MAINTENANCE COST     0.230
              TOTAL OVERLAY CONSTRUCTION COST    0.396
              TOTAL USER COST DURING
                        OVERLAY CONSTRUCTION     0.511
              SALVAGE VALUE                     -0.771
              TOTAL OVERALL COST                 5.581


       NUMBER OF FEASIBLE DESIGNS EXAMINED FOR THIS SET --      33


         AT THE OPTIMAL SOLUTION,THE FOLLOWING
         BOUNDARY RESTRICTIONS ARE ACTIVE--
                    1. THE MINIMUM DEPTH OF LAYER  1
                    2. THE MAXIMUM DEPTH OF LAYER  1
                    3. THE MINIMUM DEPTH OF LAYER  2
                    4. THE MAXIMUM DEPTH OF LAYER  2
                    5. THE MINIMUM DEPTH OF LAYER  3
                    6. THE MINIMUM DEPTH OF LAYER  5
                    7. THE MAXIMUM DEPTH OF LAYER  5
```

Figure 11.6 SUMMARY OF THE LEAST COST DESIGN STRATEGY FOR EACH COMBINATION OF MATERIALS (CONTINUED)

It should be pointed out that the optimal design for a combination of materials is the least cost for a number of possible design strategies for that combination.

Summary of the best design strategies in order of increasing total cost: The purpose of this section of the output listing is to give the Engineer an overall view of the best design strategies in order of increasing total cost. Figures 11.7 - 11.8 are example summaries.

Selection of best strategy: The final decision of selecting the best design strategy must be made using engineering judgment with the help of the FPS program. This has always been the case in engineering design and will remain so until all uncertainties can be quantified and formulated. In making his decision, the Engineer should consider things that are not accounted for in the FPS program.

To name a few possible considerations, the following list is given:

1. A design strategy with a number of future overlays could be chosen because of anticipated skid problems, or for repair of anticipated thermal cracking.
2. A thick stabilized layer might be chosen over a nonstabilized layer because of moisture or frost problems.
3. A higher cost design might be chosen because of limited funds for future work or maintenance.
4. Some designs might be eliminated because of a limited supply of local materials.

These types of considerations may be used by the Engineer to choose the best design from the computer output. For example, consider choosing a design from the computer output shown in Figures 11.7 and 11.8.

```
                            TEXAS HIGHWAY DEPARTMENT
                                    FPS - 11
                            FLEXIBLE PAVEMENT DESIGN

PROB   DIST.      COUNTY      CONT.  SECT.    HIGHWAY     DATE     IPE   PAGE
 1B     14        TRAVIS      3136    01    LP 1 MOPAC  12-28-71   238     8
                      SUMMARY OF THE BEST DESIGN STRATEGIES
                        IN ORDER OF INCREASING TOTAL COST

                         1      2      3      4      5      6      7      8
********************************************************************************
MATERIAL ARRANGEMENT    ABCD   ABCD   ABCD   ABCDE  ABCDE  ABCD   ABCDE  ABCDE
INIT. CONST. COST      4.81   5.12   5.20   5.21   4.91   5.28   4.99   5.30
OVERLAY CONST. COST    0.76   0.42   0.42   0.40   0.76   0.42   0.76   0.40
USER COST              0.28   0.46   0.44   0.51   0.47   0.37   0.39   0.51
ROUTINE MAINT. COST    0.22   0.23   0.23   0.23   0.22   0.23   0.22   0.23
SALVAGE VALUE         -0.72  -0.74  -0.72  -0.77  -0.76  -0.70  -0.74  -0.75
********************************************************************************
TOTAL COST             5.35   5.49   5.58   5.58   5.60   5.61   5.62   5.68
********************************************************************************
NUMBER OF LAYERS        4      4      4      5      5      4      5      5
********************************************************************************
LAYER DEPTH (INCHES)
     D(1)              1.00   1.00   1.00   1.00   1.00   1.00   1.00   1.00
     D(2)              1.50   1.50   1.50   1.50   1.50   1.50   1.50   1.50
     D(3)              4.50   4.50   5.50   4.50   4.50   6.50   5.50   5.50
     D(4)             15.00  17.50  15.00  15.00  12.50  12.50  10.00  12.50
     D(5)                                   6.00   6.00          6.00   6.00
********************************************************************************
NO.OF PERF.PERIODS      2      2      2      2      2      2      2      2
********************************************************************************
PERF. TIME (YEARS)
     T(1)              9.6   11.2   11.1   11.7   10.2   10.8    9.9   11.7
     T(2)             20.3   22.3   22.0   23.8   21.9   21.0   21.2   23.8
********************************************************************************
OVERLAY POLICY(INCH)
(INCLUDING LEVEL-UP)
     O(1)              2.5    1.5    1.5    1.5    2.5    1.5    2.5    1.5
********************************************************************************
SWELLING CLAY LOSS
 (SERVICEABILITY)
    SC(1)              0.76   0.84   0.84   0.87   0.79   0.82   0.78   0.87
    SC(2)              0.38   0.34   0.34   0.35   0.38   0.34   0.38   0.35
********************************************************************************
```

Figure 11.7 SUMMARY OF THE BEST DESIGN STRATEGIES IN ORDER OF INCREASING TOTAL COST

```
                          TEXAS HIGHWAY DEPARTMENT
                                   FPS - 11
                          FLEXIBLE PAVEMENT DESIGN

PROB    DIST.        COUNTY        CONT.  SECT.     HIGHWAY      DATE       IPE    PAGE
 1B     14           TRAVIS        3136    01     LP 1 MOPAC  12-28-71     238      9
                       SUMMARY OF THE BEST DESIGN STRATEGIES
                         IN ORDER OF INCREASING TOTAL COST

                                  9       10       11       12       13       14       15       16
*****************************************************************************************************
MATERIAL ARRANGEMENT            ABCD     ABCD     ABCDE    ABCD     ABCDE    ABCD     ABCD     ABCD
INIT. CONST. COST               4.51     4.90     5.38     4.98     4.60     4.59     5.36     5.75
OVERLAY CONST. COST             0.87     1.13     0.42     1.13     1.56     1.67     0.76     0.40
USER COST                       0.84     0.26     0.49     0.19     0.26     0.27     0.48     0.50
ROUTINE MAINT. COST             0.21     0.22     0.23     0.22     0.22     0.22     0.22     0.23
SALVAGE VALUE                  -0.66    -0.75    -0.73    -0.73    -0.79    -0.74    -0.73    -0.72
*****************************************************************************************************
TOTAL COST                      5.76     5.76     5.79     5.79     5.85     6.01     6.10     6.15
*****************************************************************************************************
NUMBER OF LAYERS                 4        4        5        4        5        4        4        4
*****************************************************************************************************
LAYER DEPTH (INCHES)
     D(1)                       1.00     1.00     1.00     1.00     1.00     1.00     1.00     1.00
     D(2)                       1.50     1.50     1.50     1.50     1.50     1.50     1.50     1.50
     D(3)                       4.50     5.50     6.50     6.50     4.50     5.50     7.50     8.50
     D(4)                      12.50    12.50    10.00    10.00    10.00    10.00    10.00    10.00
     D(5)                                         6.00              6.00
*****************************************************************************************************
NO.OF PERF.PERIODS               3        2        2        2        2        2        2        2
*****************************************************************************************************
PERF. TIME (YEARS)
     T(1)                        7.6      9.3     11.4      8.6      8.3      7.1     10.2     11.6
     T(2)                       13.6     22.9     22.8     21.1     24.3     20.4     22.0     23.5
     T(3)                       20.2
*****************************************************************************************************
OVERLAY POLICY(INCH)
(INCLUDING LEVEL-UP)
     O(1)                        1.5      3.5      1.5      3.5      4.5      4.5      2.5      1.5
     O(2)                        1.5
*****************************************************************************************************
SWELLING CLAY LOSS
 (SERVICEABILITY)
    SC(1)                       0.65     0.74     0.85     0.71     0.69     0.62     0.79     0.86
    SC(2)                       0.29     0.45     0.34     0.45     0.53     0.53     0.38     0.35
    SC(3)                       0.20
*****************************************************************************************************


          THE TOTAL NUMBER OF FEASIBLE DESIGNS CONSIDERED WAS          67
```

Figure 11.8 SUMMARY OF THE BEST DESIGN STRATEGIES IN ORDER OF INCREASING TOTAL COST (CONTINUED)

(1) The designer decides the first 13 designs do not differ significantly in total cost and he will select one design from these 13.

(2) The designer prefers designs that include a layer of lime stabilized subgrade. The reason for this might be that the effect of swelling clay is reduced and it will provide a working table for construction. This leaves for consideration designs 4, 5, 7, 8, 11 and 13.

(3) Design No. 13 is undesirable because of thicker future overlays which will reduce the effectiveness of planned curbs.

(4) For material E (crushed stone) the optimum lift thickness for construction is 6 inches. Of the five remaining designs this makes designs No. 5 and 8 more desirable.

(5) The designer chooses design No. 8 over No. 5 based on the previous performance of pavements in his purview. As an additional check, the engineer finds that his chosen initial design strategy also meets the Texas Triaxial Design procedure standards (Ref. 11).

Another influencing factor in selecting the best design strategy occurs when the project has been designed in sections. For example, there may be two or more subgrades each of which has had an FPS run made or more frequently two SCI sections have been designed for overlays. In these cases the designer must select from the various possible strategies an overall strategy which he considers the best for the project. This is discussed in more detail in Chapter 3 of Ref. 3.

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3. Scrivner, F. H., W. M. Moore, W. F. McFarland, and Gary R. Carey, "A Systems Approach to the Flexible Pavement Design Problem," Research Report 32-11, Texas Transportation Institute, Texas A & M University, College Station, Texas, October, 1968.

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5. Hudson, W. Ronald, B. Frank McCullough, F. H. Scrivner, and James L. Brown, "A Systems Approach Applied to Pavement Design and Research," Research Report 123-1, Highway Design Division Research Section, Texas Highway Department; Texas Transportation Institute, Texas A & M University; Center for Highway Research, The University of Texas at Austin, 1969.

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12. Scrivner, F. H., and W. M. Moore, "An Electro-Mechanical System for Measuring the Dynamic Deflection of a Road Surface Caused by an Oscillating Load," Research Report 32-4, Texas Transportation Institute, Texas A & M University, College Station, Texas, December, 1964.

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15. Alder, Henry L., and Edward B. Roessler, Introduction to Probability and Statistics, University of California, W. H. Freeman and Company, San Francisco, 1964.

16. Orellana, Hugo E., "FPS-11 Flexible Pavement System Computer Program Documentation", Research Report 123-15, Texas Highway Department; Texas Transportation Institute, Texas A&M University; and the Center for Highway Research, The University of Texas at Austin, October 1972.

17. Darter, Michael I. and W. Ronald Hudson, "Probabilistic Design Concepts Applied to Flexible Pavement System Design", Research Report 123-18, Texas Highway Department; Texas Transportation Institute, Texas A&M University; and the Center for Highway Research, The University of Texas at Austin, May 1973.

APPENDIX A

FIELD MEASUREMENTS

APPENDIX A. FIELD MEASUREMENTS

In this design system the Dynaflect* is used for measuring deflections on existing highways. A description of the Dynaflect and examples of its use have been published previously (Refs. 2, 3, 12 and 13). Counter-rotating eccentric masses provide a total live load of 1000 lbs. (500 lbs. up, 500 lbs. down) which is applied at 8 cps to the pavement through two steel wheels spaced 20 inches apart. Deflections are sensed by means of sensors normally arranged on the pavement surface as shown in Figure A.1. These sensors register the vertical amplitude, in thousandths of an inch (or mils), of the motion of the pavement.

A deflection basin of the type illustrated in Figure A.2 results from the Dynaflect loading. The deflection variables important to this design system are deflections W1 and W2, and surface curvature index, SCI. These are illustrated in the Figure.

The SDHPT has two Dynaflects (1966 Model) that are available to any District. A Dynaflect should be requested in advance to insure availability as well as aid in scheduling for statewide use. D-10R will furnish one man to operate the Dynaflect vehicle and the District will be required to furnish men to record data and provide traffic protection.

For traffic handling and consistency it is suggested that the deflection be measured with the Dynaflect load wheels near the outside wheel path.

* Registered Trademark, Remco Highway Products, Fort Worth, Texas.

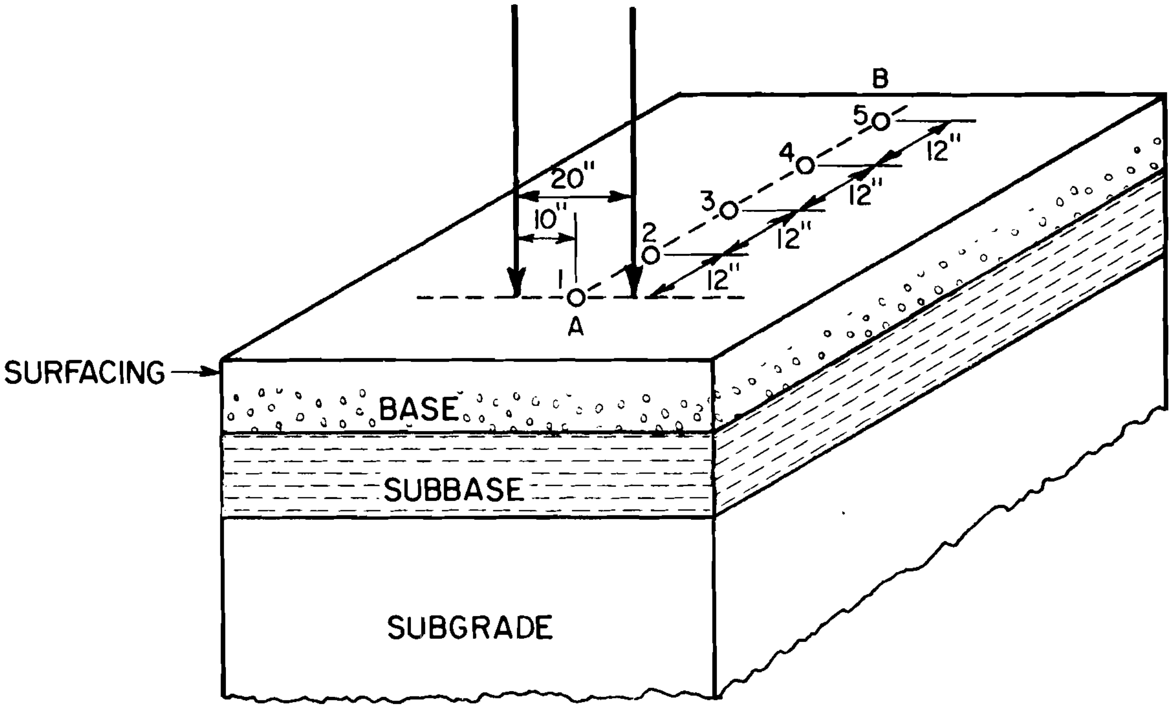


Figure A.1: POSITION OF DYNAFLECT SENSORS AND LOAD WHEELS DURING TEST. VERTICAL ARROWS REPRESENT LOAD WHEELS. POINTS NUMBERED 1 THROUGH 5 INDICATE LOCATION OF SENSORS.

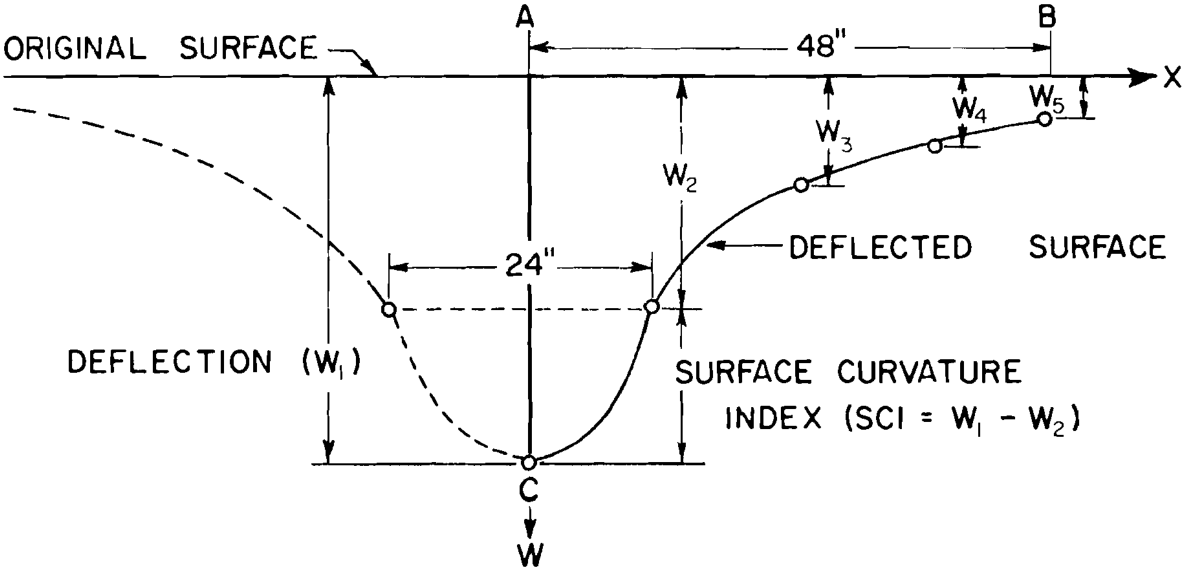


Figure A.2: TYPICAL DEFLECTION BASIN RECONSTRUCTED FROM DYNAFLECT READINGS. ONLY HALF OF BASIN IS MEASURED. SCI IS THE DEFLECTION VARIABLE USED TO REPRESENT THE DESIGN.

APPENDIX B

STIFFNESS COEFFICIENT PROGRAM

Rev. April 10, 1973
Rev. June 9, 1975

APPENDIX B. STIFFNESS COEFFICIENT PROGRAM

With Dynaflect deflections and composite pavement thickness, stiffness coefficients can be computed from an empirical equation (Ref. 1). The computer program "STIFFNESS COEFFICIENT" solves this equation and prints out stiffness coefficients for both pavement (AP2) and subgrade (AS2). In addition, SCI's and standard deviations of both SCI's and stiffness coefficients are printed out.

The inputs for this program are coded on two types of code sheets labeled "DYNAFLECT DEFLECTION DATA." The code sheets are Form 1112-1 Rev. 5/75 and Form 1112-2 Rev. 5/75.

The program contains a plot option. When the plot option is specified the program will generate a series of deflection basin plots for W1-W5 (Geophones 1-5) at each location where measurements have been taken. If the user desires a few plots at specific locations, he should resubmit only those data cards that he wants plotted. The plotter can plot approximately 3 plots per minute, and D-19 charges $1 per minute for plotter time. For specific details about charges, the user should contact D-19. For an explanation of the plot see Figure 1.

If the user wants to get a plot from previously keypunched data, he can do so by inserting a card with 999YES keypunched in Cols. 1-6. This card should be the first card for each section that he wants plotted. The user should check carefully the answers for evidence of input data errors.

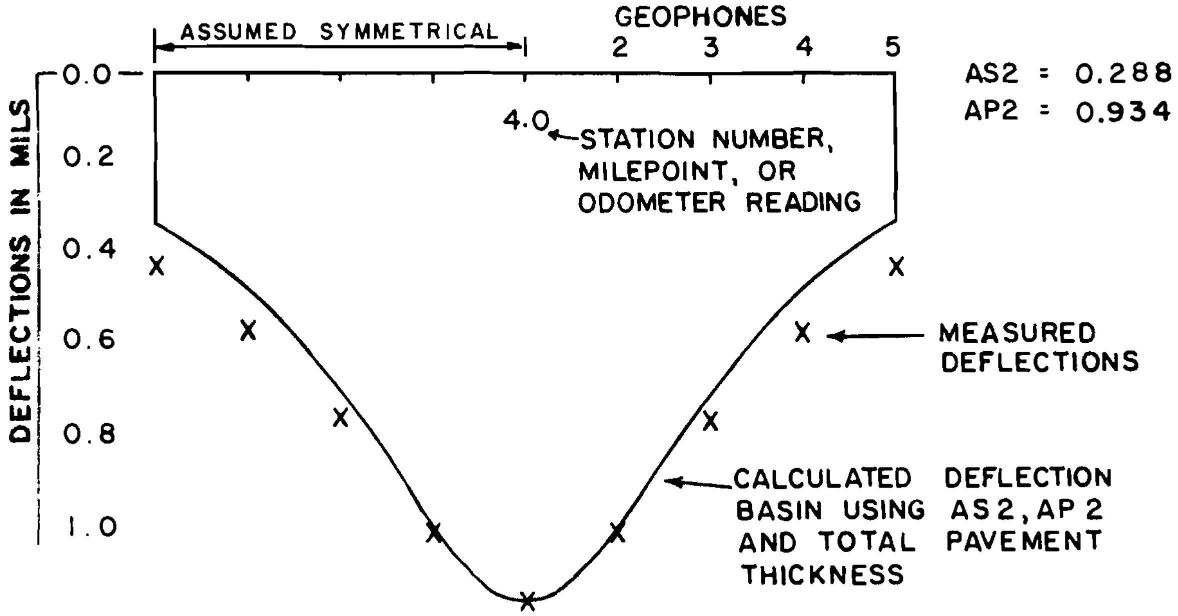
When submitting a problem the cards should be stacked in sequence (010, 020, 030, 040). If another card 020 is needed, only card No. 020 should be keypunched from the code sheet and inserted behind the previously keypunched card No. 020. When coding or keypunching a second 020 card, do not code or keypunch cards 010 and 030 from the code sheet.

CODING INSTRUCTIONS

Card 010 - PROJECT IDENTIFICATION

This card should be the first card for each problem submitted.

Cols.	
1-3	Precoded
4-32	Used for identification purposes; headings are self-explanatory.
33-39	PPSN is the "Pavement Performance Section Number." The PPSN is the same number as the construction section number used in the Skid-System.
40-42	Plot Option. If a plot is desired, code YES. If no plot is desired, code NO.



EXPLANATION OF DEFLECTION
BASIN PLOT

Figure 1

43-47 **Total Pavement Depth.** This information MUST always be coded. It is used to compute the Stiffness Coefficients (AS2 and AP2).

46-57 **Reasons for Measurement**

Code

IN for Inventory
SS for Special Studies
DS for FPS or RPS Pavement Design
EX for Experimental Work
OD for Overlay Design

58-79 **Comments**

Any comments the user wishes to make.

Card No. 020 - EXISTING PAVEMENT

The data on this card is for informational purposes and is optional. The layer thickness is not used for computations. It is suggested that the user complete this card to document the existing pavement structure.

Card No. 030 - GENERAL LOCATION INFORMATION

There are three No. 030 CARDS. The first card is a description of a key feature or the distance from a key feature where the job begins. The second card is a description of a key feature preferably near the mid-point of the section. The third card is a description of a key feature where the job section ends. Key features may be mile posts, bridge ends, intersections of state-maintained highways, or railroad crossings.

Cols.

1-3 **Precoded**

4 **"W" or "O" Milepoints**

Code a "W" to indicate increasing RI-1 Milepoints.

Code an "O" to indicate decreasing RI-1 Milepoints.

NOTE: RI-1 are the D-10 straight line Road Inventory Logs or records.

5-6 **Direction of Travel**

Code

E - East
W - West
N - North
S - South
SE - Southeast
SW - Southwest
NE - Northeast
NW - Northwest

7-8 Lane Position. Distance in feet from the right side of the lane being measured.

9 Lane

Code an "A" - First lane from center line

Code a "B" - Second lane from center line

Code a "C" - Third lane from center line

10-17 Location. The station number or odometer reading should be recorded in these fields. If stations are recorded, column 14 should have a "+" (plus); otherwise, a "." (decimal) should be coded.

18-54 Physical Description of Location

See description of No. 030 CARDS

55-60 Milepoint

The RI-1 Milepoint at each key feature

Card No. 040 - DATA CARDS

Cols.

1-3 Precoded

4-22 The information in these fields are for identification of the data, same as Control, Section, PPSN, Month, Day and Year of Card No. 010.

23-30 Location

Either the station number or the odometer reading is recorded in this field at the position where the measurement is being taken. In Col. 27 code a "+" (plus) for station location or a "." (decimal) for other types of location.

31-55 Dynaflect Reading

The Geophone reading with its respective multiplier should be coded in this field (Geophones 1 thru 5).

56-60 Time

The hour of the day at which the measurement is being taken should be coded in this field.

61-80 **Remarks**

Only pertinent remarks about the measurements taken should be written in this field.

The following pages contain example code sheets, computer output and plots. A glossary of terms for the output is included in the computer printout.

NOTE: D-19 will mail the plots to the user.

TEXAS HIGHWAY DEPARTMENT
≠ DYNAFLECT DEFLECTION DATA

CARD NO. 010 – PROJECT IDENTIFICATION

Card No.	Dist.	County	Control	Section	Highway	PPSN	Plot Option
010	20	CHAMBERS	2242	02	FM 2354	1525450	NO
1 2 3	4 5	6 7 8 9 10 11 12 13 14 15 16 17 18 19	20 21 22 23	24 25	26 27 28 29 30 31 32	33 34 35 36 37 38 39	40 41 42

* Total Pav. Depth	Month	Day	Year	Dynaflect	Reason for Measurement	Comments
6•75	05	06	75	29	IN	EXAMPLE PROBLEM
43 44 45 46 47	48 49	50 51	52 53	54 55	56 57	58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79

≠ The cards should be stacked in sequence.

* Total pavement depth must always be coded, it is used to calculate AS2 and AP2.

** CARD NO. 020 – EXISTING PAVEMENT

	Type of Material		Layer Thick. (in.)	
020	SURFACE TREATMENT	4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23	0.75	24 25 26 27
1 2 3	FLEX BASE SAND-SHELL	28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47	6.00	48 49 50 51
	SUBBASE SOIL	52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71	7.00	72 73 74 75

** Card No. 020 can be coded as many times as needed.

CARD NO. 030 GENERAL LOCATION INFORMATION

	"W" or "O" Milepoints	Direction of Travel	Lane Position	Lane
030	O	NE	4	A
1 2 3	4	5 6	7 8	9

Location	Physical Description of Location	Milepoint
59.700	FROM-JUNCTION OF FM 1405	11•317
	MP 10	10•000
63.490	TO-END OF SECTION	8•019
10 11 12 13 14 15 16 17	18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54	55 56 57 58 59 60

Form 1112-1 Rev. 5/75

TEXAS HIGHWAY DEPARTMENT
DYNAFLECT DEFLECTION DATA

CARD NO. 040 - DATA CARDS

Card No.	Cont.	Sect.	Month	Day	Year	PPSN
040	2242	02	05	06	75	1525450
1 2 3	4 5 6 7	8 9	10 11	12 13	14 15	16 17 18 19 20 21 22

Location	DYNAFLECT READING Sc	1	Sc	2	Sc	3	Sc	4	Sc	5	Time	Remarks
23 24 25 26 27 28 29 30	31 32	33 34 35	36 37	38 39 40	41 42	43 44 45	46 47	48 49 50	51 52	53 54 55	56 57 58 59 60	61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80
59.800	6.4	.30	4.4	.30	9.0	.10	4.8	.10	5.8	.10		NEAR INTERSECTION
60.100	5.6	.30	3.6	.30	6.9	.10	4.9	.10	5.6	.10		IN SLIGHT CURVE
60.400	7.1	.30	4.1	.30	7.2	.10	6.6	.10	4.2	.10		IN CURVE NEAR ROAD
60.700	5.0	.30	3.3	.30	6.9	.10	6.0	.10	4.7	.10		IN CURVE
61.000	4.0	.30	6.9	.10	4.4	.10	6.0	.10	3.8	.10		IN CURVE
61.300	8.1	.30	5.7	.30	4.0	.30	3.8	.30	9.6	.10		IN DIP
61.600	8.9	.30	6.1	.30	4.0	.30	3.7	.30	8.7	.10		DRIVEWAY INT.
61.900	7.7	.30	5.1	.30	3.3	.30	9.0	.10	7.8	.10		JUST PAST RD INT
62.200	7.0	.30	4.7	.30	8.7	.10	6.6	.10	4.9	.10		JUST PAST RD INT
62.500	6.3	.30	4.6	.30	9.3	.10	8.4	.10	7.2	.10		IN CURVE
62.800	6.9	.30	4.6	.30	9.3	.10	8.7	.10	6.9	.10		IN CURVE DRIVEWAY
63.100	5.9	.30	3.9	.30	7.8	.10	7.2	.10	6.0	.10		JUST PAST PLANT ENTR
63.422	7.9	.30	5.0	.30	9.6	.10	9.3	.10	7.8	.10		JUST PAST RD INT

Form 1112-2 Rev. 5/75

Sheet 2 of 2

```
                                TEXAS HIGHWAY DEPARTMENT

                              DISTRICT 20 -DESIGN SECTION

               DYNAFLECT DEFLECTIONS AND CALCULATED  STIFFNESS COEFFICIENTS

                             THIS PROGRAM WAS RUN - 06-04-75

************************************************************************************

                          PROJECT IDENTIFICATION

DIST.      COUNTY      CONT. SECT.  PPSN    HIGHWAY    DATE    DYNAFLECT
 20       CHAMBERS     2242   02   1525450  FM 2354  05-06-75     29

        REASONS FOR MEASUREMENTS AND COMMENTS      TOTAL PAV DEPTH
               IN - EXAMPLE PROBLEM                     6.75 INCHES

************************************************************************************

                             EXISTING PAVEMENT

                   MATERIAL TYPE        LAYER THICK.(IN)

                SURFACE TREATMENT           0.75
                FLEX BASE SAND-SHELL        6.00
                SUBBASE SOIL                7.00

************************************************************************************

                       GENERAL LOCATION INFORMATION

           DIRECTION OF TRAVEL IS NO. EAST OPPOSITE MILEPOINTS
           MEASUREMENTS ARE  4 FEET FROM THE RIGHT SIDE OF LANE A

           DESCRIPTION OF LOCATION            ODOMETER READING  MILEPOINT
    FROM-JUNCTION OF FM 1405                          59.700        11.317
    MP 10                                                           10.000
    TO-END OF SECTION                                 63.490         8.019

************************************************************************************
```

```
DIST.     COUNTY      CONT.  SECT.   FROM     HIGHWAY     DATE     DYNAFLECT
 20       CHAMBERS    2242    02   1525470    FM 2354   05-06-75     29

                                  DYNAFLECT DATA

ODOMETER   W1     W2     W3     W4     W5     SCI    AS2   AP2      REMARKS

  60.700  1.500  0.990  0.690  0.600  0.470  0.510  0.26  0.79  IN CURVE
  61.000  1.200  0.690  0.440  0.600  0.380  0.510  0.29  0.59  IN CURVE
  61.300  2.430  1.710  1.200  1.140  0.960  0.720  0.22  0.90  IN DIP
  61.600  2.670  1.830  1.200  1.110  0.870  0.840  0.22  0.85  DRIVEWAY INT.
  61.900  2.310  1.530  0.990  0.900  0.780  0.780  0.23  0.79  JUST PAST RD INT
  62.200  2.100  1.410  0.870  0.660  0.490  0.690  0.23  0.81  JUST PAST RD INT
  62.500  1.890  1.380  0.930  0.840  0.720  0.510  0.23  0.99  IN CURVE
  62.800  2.070  1.380  0.930  0.870  0.690  0.690  0.24  0.80  IN CURVE DRIVEWAY
  63.100  1.770  1.170  0.780  0.720  0.600  0.600  0.25  0.79  JUST PAST PLANT ENT
  63.422  2.370  1.500  0.960  0.930  0.780  0.870  0.24  0.71  JUST PAST RD INT

AVERAGES  2.031  1.359  0.899  0.837  0.674  0.672  0.24  0.80
STANDARD DEVIATION                           0.136  0.02  0.10
NUMBER OF POINTS IN AVFRAGE =  10


    W1-5  DEFLECTIONS AT GEOPHONES 1,2,3,4,&5
    SCI   SURFACE CURVATURE INDEX ( W1 MINUS W2)
    AS2   STIFFNESS COEFFICIENT OF THE SUBGRADE
    AP2   STIFFNESS COEFFICIENT OF THE PAVEMENT
```

TEXAS HIGHWAY DEPARTMENT
‡ DYNAFLECT DEFLECTION DATA

CARD NO. 010 — PROJECT IDENTIFICATION

Card No.	010	1 2 3
Dist.	25	4 5
County	DICKENS	6 7 8 9 10 11 12 13 14 15 16 17 18 19
Control	0132	20 21 22 23
Section	01	24 25
Highway	US 82EB	26 27 28 29 30 31 32
PPS	UNKNWN	33 34 35 36 37 38 39
Plot Option	YES	40 41 42
* Total Pav. Depth	12•00	43 44 45 46 47
Month	03	48 49
Day	12	50 51
Year	75	52 53
Dynaflect	29	54 55
Reason for Measurement	EX	56 57
Comments	THIS IS AN EXAMPLE	58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79

‡ The cards should be stacked in sequence.

* Total pavement depth must always be coded, it is used to calculate AS2 and AP2.

** CARD NO. 020 - EXISTING PAVEMENT

Card No.	Type of Material		Layer Thick. (in.)	
020 (1 2 3)	ASPH CONC PAVEMENT	4–23	1.50	24 25 26 27
	ASPH STAB BASE	28–47	2.50	48 49 50 51
	FLEXIBLE BASE	52–71	8.00	72 73 74 75

** Card No. 020 can be coded as many times as needed.

CARD NO. 030 GENERAL LOCATION INFORMATION

Card No.	030	1 2 3
"W" or "O" Milepoints	W	4
Direction of Travel	E	5 6
Lane Position	4	7 8
Lane	A	9

Location	Physical Description of Location	Milepoint
0.000	FROM- FM 2941	2•269
1.011	MILE POST 10	2•300
2.000	TO- DICKENS-KING COUNTY LINE	3•300
10 11 12 13 14 15 16 17	18–54	55 56 57 58 59 60

Form 1112-1 Rev. 5/75

TEXAS HIGHWAY DEPARTMENT
DYNAFLECT DEFLECTION DATA

CARD NO. 040 - DATA CARDS

Card No. (1–3)	Cont. (4–7)	Sect. (8–9)	Month (10–11)	Day (12–13)	Year (14–15)	PPSN (16–22)
040	0132	01	03	12	75	UNKNØWN

Location	DYNAFLECT READING										Time	Remarks
	Sc	1	Sc	2	Sc	3	Sc	4	Sc	5		
23–30	31–32	33–35	36–37	38–40	41–42	43–45	46–47	48–50	51–52	53–55	56–60	61–80
0.000	25	30	48	10	27	10	53	03	39	03		
1.011	36	30	21	10	34	03	22	03	26	01		
2.000	31	30	25	30	34	10	24	10	46	03		

Sheet 2 of 2

Form 1112-2 Rev. 5/75

```
                                TEXAS HIGHWAY DEPARTMENT

                              DISTRICT 25 -DESIGN SECTION

                 DYNAFLECT DEFLECTIONS AND CALCULATED  STIFFNESS COEFFICIENTS

                             THIS PROGRAM WAS RUN - 06-04-75

************************************************************************************

                           PROJECT IDENTIFICATION

DIST.       COUNTY      CONT.  SECT.   PPSN    HIGHWAY     DATE    DYNAFLECT
 25         DICKENS     0132    01   UNKNOWN   US 82EB   03-12-75     29

        REASONS FOR MEASUREMENTS AND COMMENTS      TOTAL PAV DEPTH
              EX -  THIS IS AN EXAMPLE                 12.00 INCHES

************************************************************************************

                              EXISTING PAVEMENT

                   MATERIAL TYPE        LAYER THICK.(IN)

                ASPH CONC PAVEMENT          1.50
                ASPH STAB BASE              2.50
                FLEXIBLE BASE               8.00

************************************************************************************

                        GENERAL LOCATION INFORMATION

           DIRECTION OF TRAVEL IS   EAST     WITH   MILEPOINTS
           MEASUREMENTS ARE  4 FEET FROM THE RIGHT SIDE OF LANE A

           DESCRIPTION OF LOCATION                ODOMETER READING  MILEPOINT
     FROM- FM 2941                                       0.000         2.269
     MILE POST 10                                        1.011         2.300
     TO- DICKNES-KING COUNTY LINE                        2.000         3.300

************************************************************************************

                  PLOTS WERE REQUESTED WITH THIS PROGRAM.

************************************************************************************
```

```
DIST.       COUNTY       CONT.  SECT.   PPSN     HIGHWAY      DATE     DYNAFLECT
 25         DICKENS      0132    01   UNKNOWN    US 82EB    03-12-75      29

                                    DYNAFLECT DATA

ODOMETER    W1      W2      W3      W4      W5      SCI     AS2    AP2        REMARKS

   0.000  0.750   0.480   0.270   0.159   0.117   0.270   0.30   0.51
   1.011  1.080   0.210   0.102   0.066   0.026   0.870   1.15   0.28
   2.000  0.930   0.750   0.340   0.240   0.138   0.180   0.24   0.76

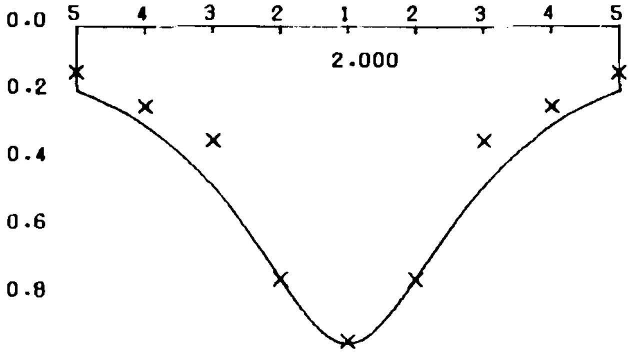
AVERAGES  0.920   0.480   0.237   0.155   0.094   0.440   0.56   0.52
STANDARD DEVIATION                                0.375   0.51   0.24
NUMBER OF POINTS IN AVERAGE =    3


    W1-5  DEFLECTIONS AT GEOPHONES 1,2,3,4,&5
    SCI   SURFACE CURVATURE INDEX ( W1 MINUS W2)
    AS2   STIFFNESS COEFFICIENT OF THE SUBGRADE
    AP2   STIFFNESS COEFFICIENT OF THE PAVEMENT
```

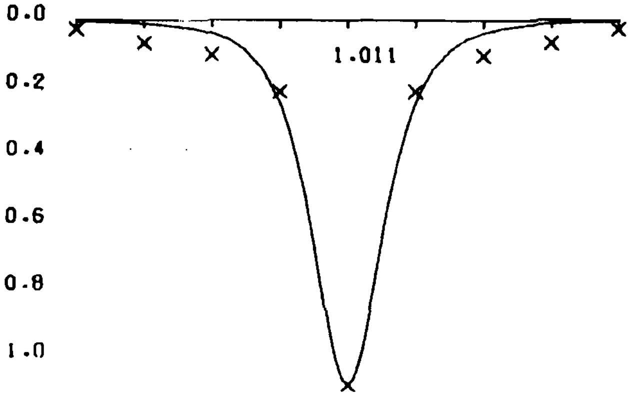
DIST-25 CO- DICKENS CONT-0132-01 US 82EH LA 03-12-75 DYNA-*29
DATE OF RUN - MAY 29, 1975 TOTAL PAVEMENT DEPTH - 12.00 INCHES

LINE TYPES

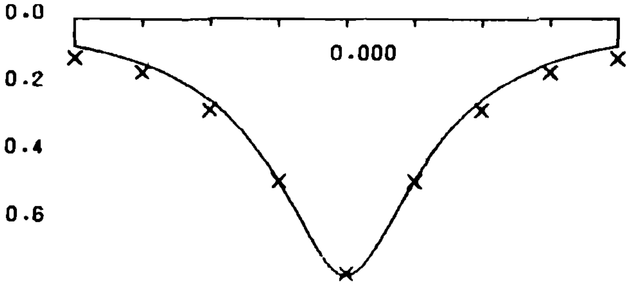
AS2, AP2 ————
AS5, AP5 —●—●—
ES5, EP5 -------
ALTERNATE ES5, EP5 —✦—✦—



AS2 = 0.238
AP2 = 0.760



AS2 = 1.148
AP2 = 0.284



AS2 = 0.296
AP2 = 0.515

APPENDIX C

PROFILE ANALYSIS PROGRAM

APPENDIX C. PROFILE ANALYSIS PROGRAM

The object of this program is to make the necessary calculations to statistically verify the engineer's selection of measured or calculated values, such as SCI, AS2, W1, W2, etc., for design sections. The engineer should plot a profile of these values, i.e., SCI, Stiffness Coefficients, Skid Resistance, etc., on graph paper and visually separate the sections that appear to have significant differences in their measured or calculated values as shown in Figure C.1. The point where the section changes is referred to as a "break point," and these measured or calculated values are coded on a profile analysis code sheet and submitted to the computer center for processing (Ref. 14).

The program uses analysis of variance as discussed in Ref. 15, pp. 253-4, to statistically check for a significant difference between adjacent sections. If any section is found not to be significantly different from its adjacent section, the two sections are combined. Figure C.2 illustrates the statistically different sections as calculated by the program.

The input for this program is coded on a code sheet labeled PROFILE ANALYSIS PROGRAM. Basically this code sheet has three types of cards. Card No. 1 makes provision for district and project identification as well as other remarks appropriate for the section under consideration. Card No. 2 makes provisions for recording the numbers where apparent break points or changes in the measured or calculated values occur. Card No. 3 of the PROFILE ANALYSIS PROGRAM code sheets has four headings. The first heading, "REF. POINTS," is to record, in sequence, the number of measurements. The "STATION" heading makes provision to record the station number at which the measurement was taken. Under the heading "MEASURED OR CALCULATED VALUES" provisions have

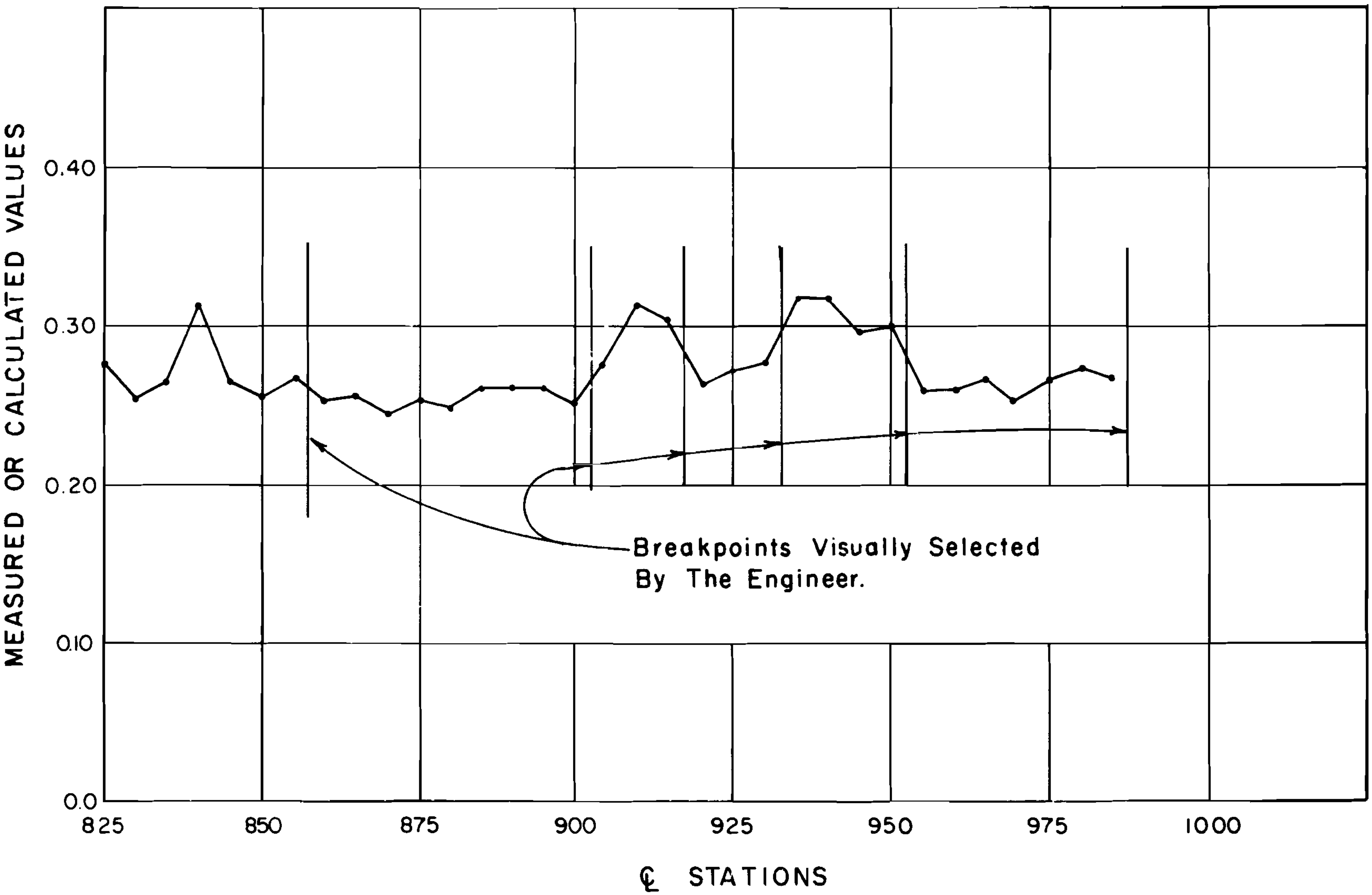


Figure C.1 PROFILE OF DATA

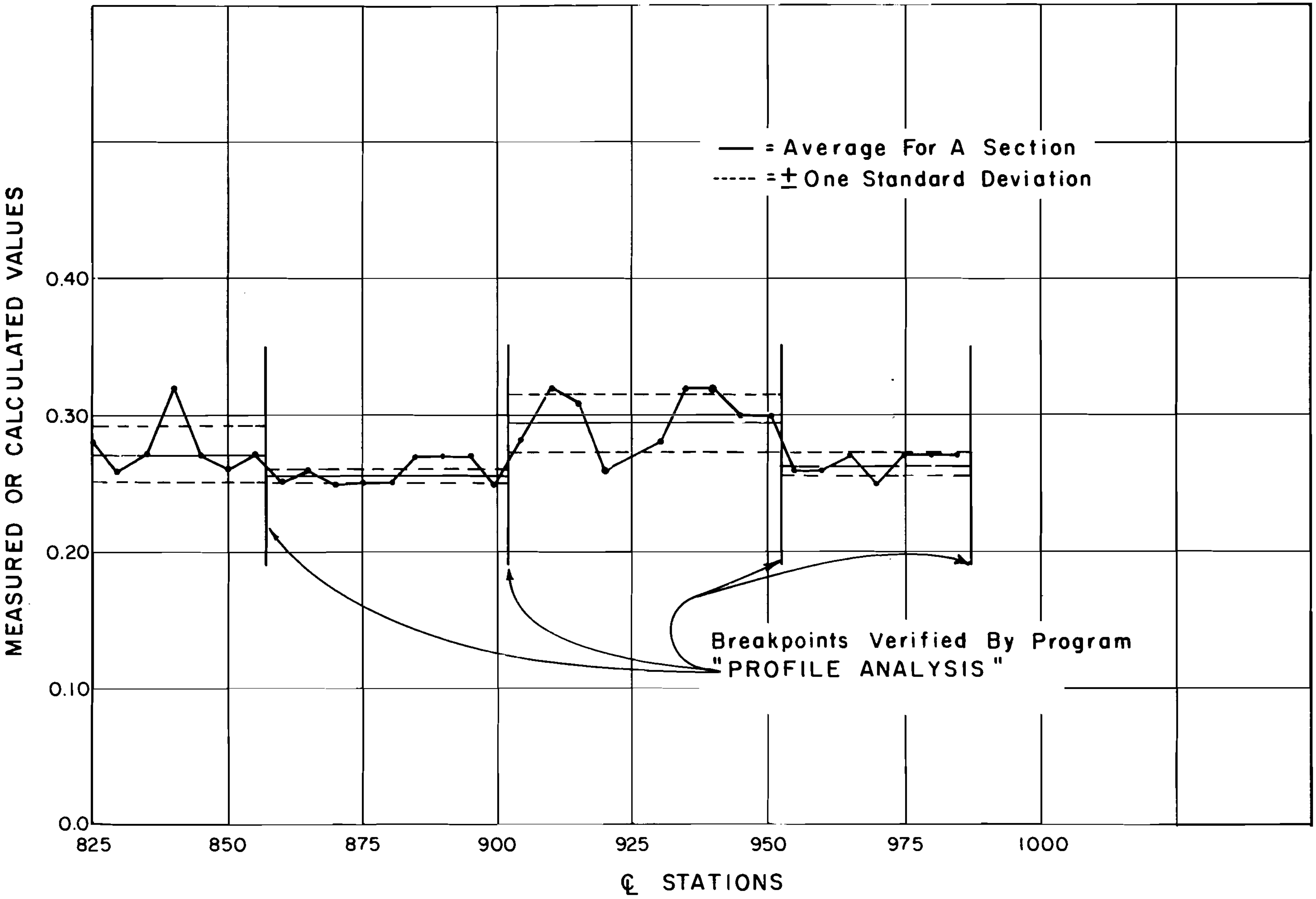


Figure C.2 STATISTICALLY DIFFERENT SECTIONS IN DATA PROFILE been made to record up to four readings for the same station. Under the "AVG" heading the average of the preceding "MEASURED OR CALCULATED VALUES" is to be recorded. Card No. 3 may be repeated as many times as necessary. Example code sheets and output are included in the following pages.

TEXAS HIGHWAY DEPARTMENT

FLEXIBLE PAVEMENT-DESIGN SYSTEM

PROFILE ANALYSIS

CARD NO. 1 - PROJECT IDENTIFICATION

DIST. (4-5)	COUNTY (6-19)	CONTROL (20-23)	SECTION (24-25)	JOB (26-27)	HIGHWAY (28-34)
19	BOWIE	218	1		US 59

DATE (35-42)	NO. OF SECTIONS (43-44)
03/10/72	06

CARD NO. 2 - LAST REF. POINT AT EACH SECTION

1-3	4-6	7-9	10-12	13-15	16-18	19-21	22-24	25-27	28-30
7	16	19	22	26	33				

31-33	34-36	37-39	40-42	43-45	46-48	49-51	52-54	55-57	58-60

CARD NO. 3 - DATA CARDS

REF. POINT	STATION (1-7)	MEASURED OR CALCULATED VALUES NBL	SBL			AVG VALUE (8-12)
1	825+00	.285	.272			0.278
2	830+00	.256				0.256
3	835+00	.264	.268			0.266
4	840+00	.345	.287			0.316
5	845+00	.266				0.266
6	850+00	257	257			0.257
7	855+00	.265	.274			0.270
8	860+00	.249	.257			0.253
9	865+00	.256				0.256
10	870+00	.246				0.246
11	875+00	252				0.252
12	880+00	.250				0.250

C.6

CARD NO. 3 - DATA CARDS

REF POINT	STATION	MEASURED OR CALCULATED VALUES				AVG. VALUE
	1 2 3 4 5 6 7	NBL	SBL	Additional NBL		8 9 10 11 12
13	885+00	.260				0.260
14	890+00	.272	.250			0.261
15	895+00	.266	.256			0.261
16	900+00	.252	.251			0.252
17	905+00		.279			0.279
18	910+00		.315			0.315
19	915+00		.306			0.306
20	920+00		.262			0.262
21	925+00		.271			0.271
22	930+00	.274	.279			0.276
23	935+00	.319	.316			0.318
24	940+00	.320	.313			0.317
25	945+00	.289	.303			0.296
26	950+00		.300			0.300
27	955+00		.260			0.260
28	960+00		.260			0.260
29	965+00		.268			0.268
30	970+00		.253			0.253
31	975+00		.265			0.265
32	980+00		.273			0.273
33	985+00		.269			0.269
	+					.
	+					.
	+					.
	+					.
	+					.
	+					.
	+					.
	+					.
	+					.
	+					.
	+					.
	+					.
	+					.
	+					.

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                              TEXAS HIGHWAY DEPARTMENT

                             PRCFILE ANALYSIS FOR    US 59

                            THIS PROGRAM WAS RUN - 03-30-72

DIST.          COUNTY          CCNT.  SECT.   JOB  HIGHWAY     DATE    NO. OF SECT.
 19             BOWIE           218     1          US 59    03/10/72        6

                               REFERENCE        STA.        INPUT
                                PCINTS                      DATA

                                    1         825+00         0.278
                                    2         830+C0         0.256
                                    3         835+00         0.266
                                    4         840+00         0.316
                                    5         845+00         0.266
                                    6         850+00         0.257
                                    7         855+00         0.270
                                    8         860+00         0.253
                                    9         865+00         0.256
                                   10         870+00         0.246
                                   11         875+00         0.252
                                   12         880+00         0.250
                                   13         885+00         0.260
                                   14         890+00         0.261
                                   15         895+00         0.261
                                   16         900+00         0.252
                                   17         905+00         0.279
                                   18         910+00         0.315
                                   19         915+00         0.306
                                   20         920+00         0.262
                                   21         925+00         0.271
                                   22         930+00         0.276
                                   23         935+00         0.318
                                   24         940+00         0.317
                                   25         945+00         0.296
                                   26         950+00         0.300
                                   27         955+00         0.260
                                   28         960+00         0.260
                                   29         965+00         0.268
                                   3C         970+00         0.253
                                   31         975+00         0.265
                                   32         980+C0         0.273
                                   33         985+00         0.269

 INPUT BREAK PTS. AT     7   16   19   22   26   33
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                              TEXAS HIGHWAY DEPARTMENT

                            PROFILE ANALYSIS FOR    US 59

                           THIS PROGRAM WAS RUN - 03-30-72

DIST.        COUNTY        CONT.  SECT.  JOB  HIGHWAY    DATE   NO. OF SECT.
 19           BOWIE         218     1         US 59    03/10/72       4


                  AVERAGE AND STANDARD DEVIATION FOR DATA DIVIDED
                   INTO GROUPS OF SIGNIFICANT DIFFERENCE


 BREAK POINTS AT      7  16  26  33
       REF. POINTS            AVERAGE           STANDARD         F             F
         LIMITS                  OF             DEVIATION      CALC.         TABLE
       OF SECTIONS            SECTIONS          OF SECTIONS                  VALUE

          1   TO    7          0.273               0.021        6.612         4.600
          8   TO   16          0.255               0.005       30.876         4.450
         17   TO   26          0.294               0.021       13.528         4.540
         27   TO   33          0.264               0.007        0.0           0.0
```