ROY PARIKH

Flexible Pavement Design Procedures

Pavement Managers Workshop

August 6-8, 1985

Texas State Department of Highways
and Public Transportation

Highway Design Division
Pavement Design Section

FLEXIBLE PAVEMENT DESIGN PROCEDURES

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Pavement Type Definitions

A discussion of pavement design makes it necessary to define the type of pavement being discussed. The two very basic types are "flexible" and "rigid" pavements. Definitions are very general and due to this fact they are varied. A very basic definition of pavement types is as follows:

Flexible - Asphalt Surface
Rigid - Portland Cement Concrete Surface.

These definitions are arbitrary. The flexible pavement may become "slab-like" and assume many of the rigid pavement characteristics. The rigid pavement may lose this rigid posture and behave somewhat like the flexible pavement.

The flexible pavements may be subdivided into two very general areas:

1. Thin Surfaced Flexible Pavements
2. Semi-Rigid and Stabilized Pavements

The thin surfaced flexible pavements may be surfaced with either asphaltic concrete pavement or the surfacing may be single, double or triple surface treatment. The base course for the thin surfaced flexible pavements should be unbound or unstabilized. The key to the thin surfaced flexible pavement is its flexibility. The surfacing layer must be flexible enough to withstand the tensile strains without forming tensile cracks or fatigue cracking. The base material must be unstabilized so that tensile strains are not transmitted upward to the surfacing layer.

The semi-rigid or stabilized pavements are characterized by their thick and rigid surfacing layers. The subbase(s) in this type of pavement are also frequently stabilized. The key thought in this type of pavement is the ability to withstand tensile stresses without premature fatigue failures. This ability to tolerate the tensile stresses is a function of the rigidness and thickness of the surfacing layer(s). With sufficient rigidness and thickness the pavement layer assumes a semi-rigid slab like behavior. This rigid or slab like behavior aids in disipating the wheel load stresses into the base, subbase and subgrade layers.. The semi-rigid layer may actually be composed of several layers. The layers must be bonded together so that shear stresses are transmitted between layers. The layers may be a series of asphaltic concrete layers or there may be a mixture such as asphaltic concrete on cement treated base.

The surfacing layer thickness for the "thin surfaced flexible pavements" and the "semi-rigid and stabilized pavements" and the reasoning for this concept will be discussed in another section of this report.

Definition of Flexible Pavement Design

Pavement design and especially flexible design divides itself into two tasks as follows:

1. Mixture or Materials Design
2. Structure or Thickness Design

Flexible pavement design divides itself into these two tasks but it is not intended to imply that these two tasks can be cleanly separated at the design stage and later joined into a happy reunion on the roadway. There must be interaction between the tasks; the thickness design assumptions must be achievable in the materials design stage and, likewise, the materials design stage must carry out the intent of the thickness design. Specifications are the link between mixtures and thickness design. Specifications are also the means by which both design phases are linked to construction and to maintenance of the pavement.

Figure 1, Pavement Relationships, point out that specifications are the link in the pavement design, construction and maintenance cycle. Also, the interaction or paths between functions is of interest. Obviously, all posssible pathways are not shown.

The objective of this report will be to treat only the structural or thickness design phase of flexible pavement design.

The Life Cycle of a Pavement

The design of pavements is but one of a series of steps in the life cycle of a pavement. During the life cycle of a pavement some of the major events could be as follows:

1. Planning
2. Preliminary Design
3. Programming (Funding)

4. Detailed Design
5. Construction
6. Maintenance
7. Evaluation (Monitoring)

When to Do a Pavement Design

The question of when to do a pavement design is of extreme importance. Inevitably, the need for a pavement design occurs and before an adequate design can be made, other factors may have forced the use of an "estimate" of a pavement structure. Obviously the design must be well established before the programming or funding stage. In the previously noted life cycle of a pavement there are two design stages shown. If this first or preliminary design is inadequate this deficiency will be reflected into all other phases of a pavement's life cycle. The pavement as constructed will be inadequate,maintenance will be excessive, anticipated performance will not be achieved and the cycle returns prematurely to planning. It becomes necessary to anticipate needs and plan for these needs sufficiently in advance of a program call so that the allocated funding may correspond to the future needs of the project. The evaluation or pavement monitoring process should be used as a tool to anticipate both the current and the future needs of an existing pavement.

Flexible Pavement Design Procedures

There are a considerable number of well known flexible pavement design procedures. The key issue is "availability" and "applicability" of these various procedures. The two procedures most readily available to Departmental pavement designers are:

(1) Flexible Pavement Design System (FPS)
(2) Texas Triaxial Design System

The Flexible Pavement Design System (FPS) is the Highway Design Division's official flexible pavement design procedure and as such, this procedure is presented in greater detail in this report.

The Materials and Tests Division, sponsors Test Method Tex-117E, "Triaxial Compression Tests for Disturbed Soil and Base Materials". This test method is generally known as the Texas Triaxial Design System. The Texas Triaxial Design System will also be discussed later in this report. Also an abbreviated version of the Texas Triaxial Design System is recommended in the checking of designs generated by FPS and this will also be presented.

There are of course many other flexible pavement design procedures both theoretical and emperical, that the designer may wish to consider as "second opinion" type of procedures.

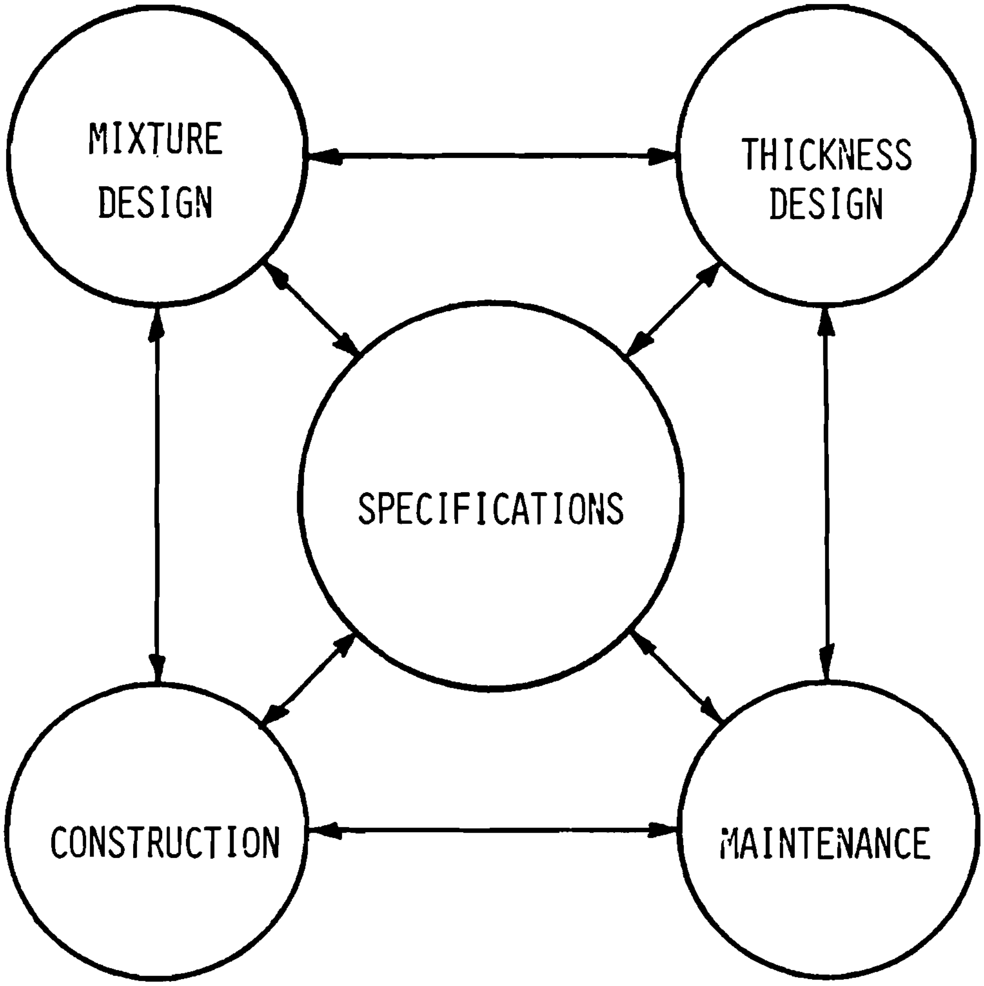

FIGURE 1
Pavement Relationships

FLEXIBLE PAVEMENT DESIGN SYSTEM

FLEXIBLE PAVEMENT DESIGN SYSTEM

Introduction and History

The Flexible Pavement Design System is known in the Department as FPS. The current version is FPS-11, which designates this as the eleventh major version of the system. FPS dates its beginning to the American Association of State Highway Officials (AASHO) Road Test, conducted in Ottawa, Illinois, in the late 1950's and early 1960's. The Test was extensive in its test features and produced design concepts for both flexible and rigid pavements.

The major accomplishment, possibly, of the Road Test was the defining of the serviceability concept or the ability of a pavement to serve traffic for which it was designed. A second important feature defined at the Road Test was the 18-Kip Single Axle load equivalents. This feature allowed mixed traffic to be converted to a uniform common denominator in terms of pavement performance represented by the serviceability concept. By the use of factorial pavement designs the Road Test represented the most comprehensive relationships between performance, structural thickness and traffic loadings available at that time. To date, there have been no further developments that supersede the Road Test.

There was one major flaw in the Road Test concept. The pavement designers in Texas and other states were faced with the problem of extrapolating the AASHO Road Test results to the individual states. The Test results were applicable to one environment, one subgrade, one set of construction materials and one set of construction procedures, all of which were unique to the Road Test site.

In 1962, the Texas Highway Department took a significant step forward in flexible pavement design procedures. The Department contracted with Texas Transportation Institute (TTI) for a research task to adapt findings of the AASHO Road Test to Texas conditions. This task at TTI was under the direction and supervision of Mr. Frank H. Scrivner who had served as Rigid Pavement Research Engineer at the Road Test. Prior to this, he served with the Highway Department in several capacities and his contributions to the flexible pavement design procedures were very substantial.

It became apparent that Texas needed more than a simple extrapolation of Road Test findings to Texas conditions. The Research Report 32-11, "A Systems Approach to the Flexible Pavement Problem," by Scrivner, Moore and McFarland (Ref. 1), published in 1968, pointed out the need for a systems approach as well as implementation of pavement structure design procedure. Climate, maintenance costs, user costs and other items would have to be considered. At about the same time, NCHRP Report 10-1, "Systems Approach to Pavement Design System Formulation, Performance Definition, and Material Characterization," by Dr. W. R. Hudson and others (Ref. 2) was published and dealt with some of the same pavement design-systems approach features researched and reported by Scrivner. Dr. Hudson, currently with the Center for Transportation Research at The University of Texas at Austin, had served as Assistant Rigid Pavement Research Engineer at the AASHO Road Test. He had also been with the Texas Highway Department prior to his joining The University of Texas. Among the other authors of the NCHRP report was Dr. B. F. McCullough, Director of the Center for Transportation Research. He also had a significant period of service with the Texas Highway Department prior to his joining The University of Texas at Austin.

While 1968, was a significant year for publication of research reports of major importance, it was also the year of a cooperative research event. A triumvirate composed of Texas Transportation Institute, Center for Highway Research, and Texas Highway Department, in cooperation with the Federal Highway Administration, undertook a research effort designated as Research Project 123, "A System Analysis of Pavement Design and Research Implementation." Mr. James L. Brown, Engineer of Pavement Design, Highway Design Division, contributed greatly to the coordination of the research effort and to the eventual statewide implementation of FPS.

There were many more people who were significantly involved in the development of a Flexible Pavement Design System through the Project 32 and 123 phase of the effort and a review of research reports for Projects 32 and 123 will make the reader aware of the level of effort involved.

The systems approach flexible pavement design computer program developed by Scrivner in Project 32 was further advanced and became the first official

FPS program designated as FPS-1. "A Systems Approach Applied to Pavement Design and Research" by Hudson, McCullough, Scrivner and Brown was released as Research Report 123-1 in March 1970 (Ref. 3). Their report contained the first FPS series and the program was designated as FPS-3.

The years between 1970 and 1974 were very productive in terms of development and implementation of FPS. By 1972, the FPS family had grown to such an extent that FPS-11 was developed and documented. Research Report 123-20, "Implementation of A Complex Design System" by Buttler and Orellana (Ref. 4), June 1973, documents this effort during the 1970-1973 time period.

The first implementation of FPS was officially started in July 1970 with a pilot training program (Ref. 4). Districts 2, 5, 14, 17 and 19 were the Original Five Districts in the program (Figure 1).

A feedback workshop was held in January, 1971 when users discussed their experience, difficulties, and faults of FPS with the researchers. As a result of this information, the researchers were able to make significant changes in the stochastics or reliability features, revise swelling clay model, addition of overlay mode, and new overlay model.

In June, 1971, the pilot implementation was expanded to include five more Districts: 1, 8, 11, 15, and 21, as noted on Figure 1.

Trial implementation and program debugging of FPS-11 continued until June, 1974 when a statewide implementation of the Flexible Pavement Design System was begun. This consisted of eight regional training schools at various locations about the State. Representatives from three Districts attended each school. At the request of the Federal Highway Administration, an additional school was held in Austin for their Divisional (local), Regional and Washington, D. C. personnel. Out of a total of 244 persons attending the schools, 70 percent were engineers and 30 percent were technicians.

Revision of the Highway Design Division Operations and Procedures Manual in August, 1974, included the Flexible Pavement Design System (FPS) as the recommended flexible pavement design procedure. The Flexible Pavement Designer's Manual provided Departmental personnel with instructions for designing flexible pavements by the systems approach. This is the same manual used in the regional FPS schools. The official title and subsequent revisions of the manual are:

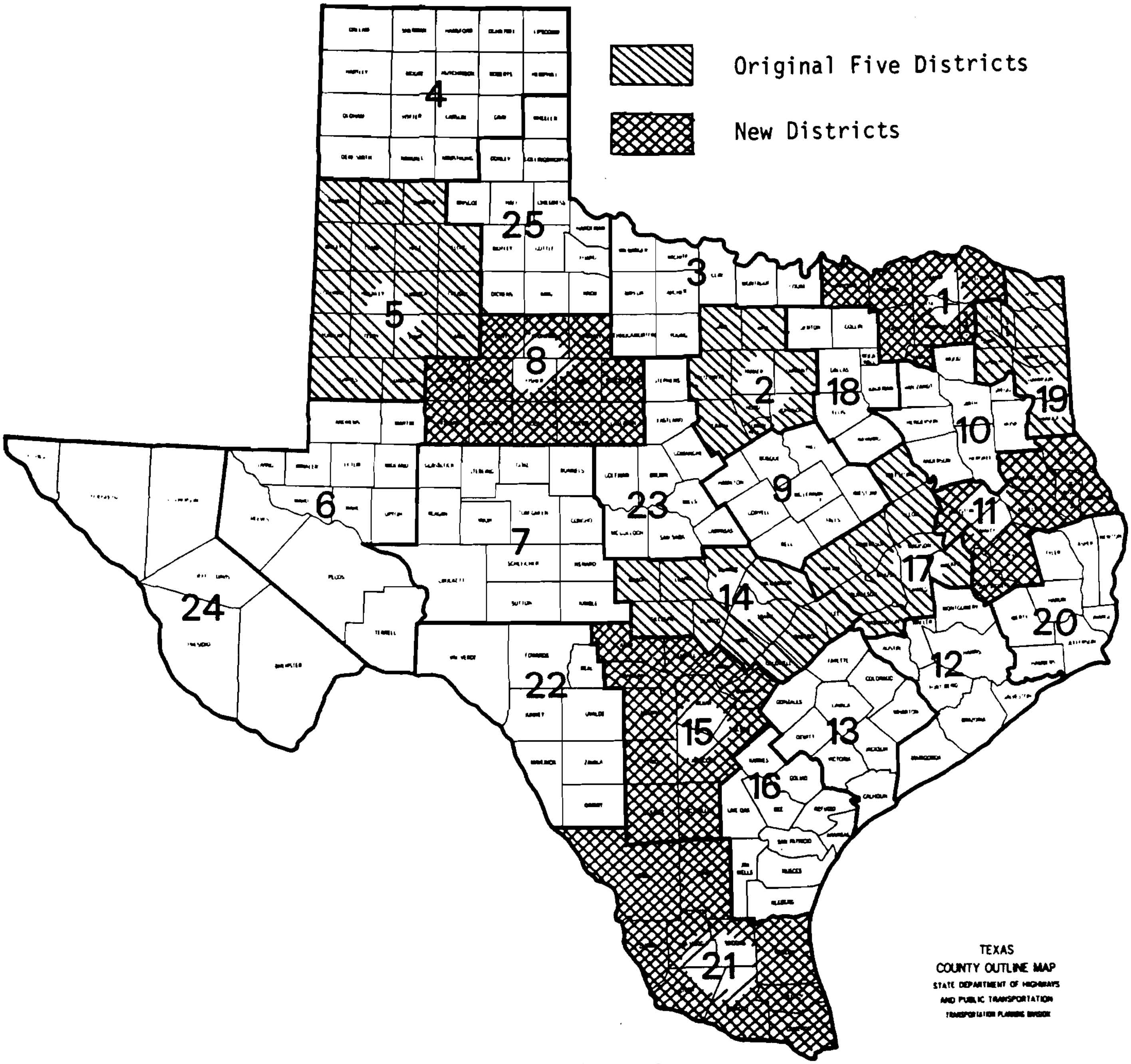

Figure 1
The Ten Participating Districts

Texas State Department of Highways and Public Transportation, Part I, Flexible Pavement Designer's Manual, Highway Design Division, 1972 (Revised through May 1983).

The Districts and Divisions were furnished with two numbered manuals, published in three-ring binders. All other personnel attending the schools received unnumbered bound manuals. Pending changes to the FPS program and manual have made a general reprinting impractical at this time. However, upon request, the Design Division will provide xerox copies of the manual. The Pavement Design Section will also be pleased to give design assistance and training on the FPS program or any other pavement design procedures.

Brief Description

The objective of this report is to give a brief overview of FPS and to point out areas of concern which are not automatically addressed correctly by FPS. The FPS manual has precise and detailed description of the procedure.

The purpose of the FPS system is 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. This objective is accomplished by the designer's use of a group of three computer programs outlined in Figure 2, FPS System Computer Programs. FPS-11, of course, is the chief program; the Stiffness Coefficient Program, and the Profile Analysis Program are subsidiary programs.

The FPS-11 Program has the capability of designing a new flexible pavement (or rehabilitation of an existing pavement structure) or an Asphalt Concrete Pavement overlay for an existing flexible pavement.

The FPS system objective of providing a pavement design "at a minimum overall total cost" is the backbone of the program. The optimization procedure is an optimization of total cost for a given analysis period. Items considered in the total cost optimization are:

1. Initital construction cost,
2. Overlay construction cost,
3. User cost (delay),
4. Routine maintenance cost, and
5. Salvage value.

Sixty-six inputs to the system are provided by the FPS-11 program. These inputs are in ten categories listed below. The parenthetical numbers indicate the inputs on each card or category.

Card No.	Category
1	Project Identification (8)
2	Project Comments (1)
3	Basic Design Criteria (6)
4	Program Controls and Constraints (5)
5	Traffic Data (8)

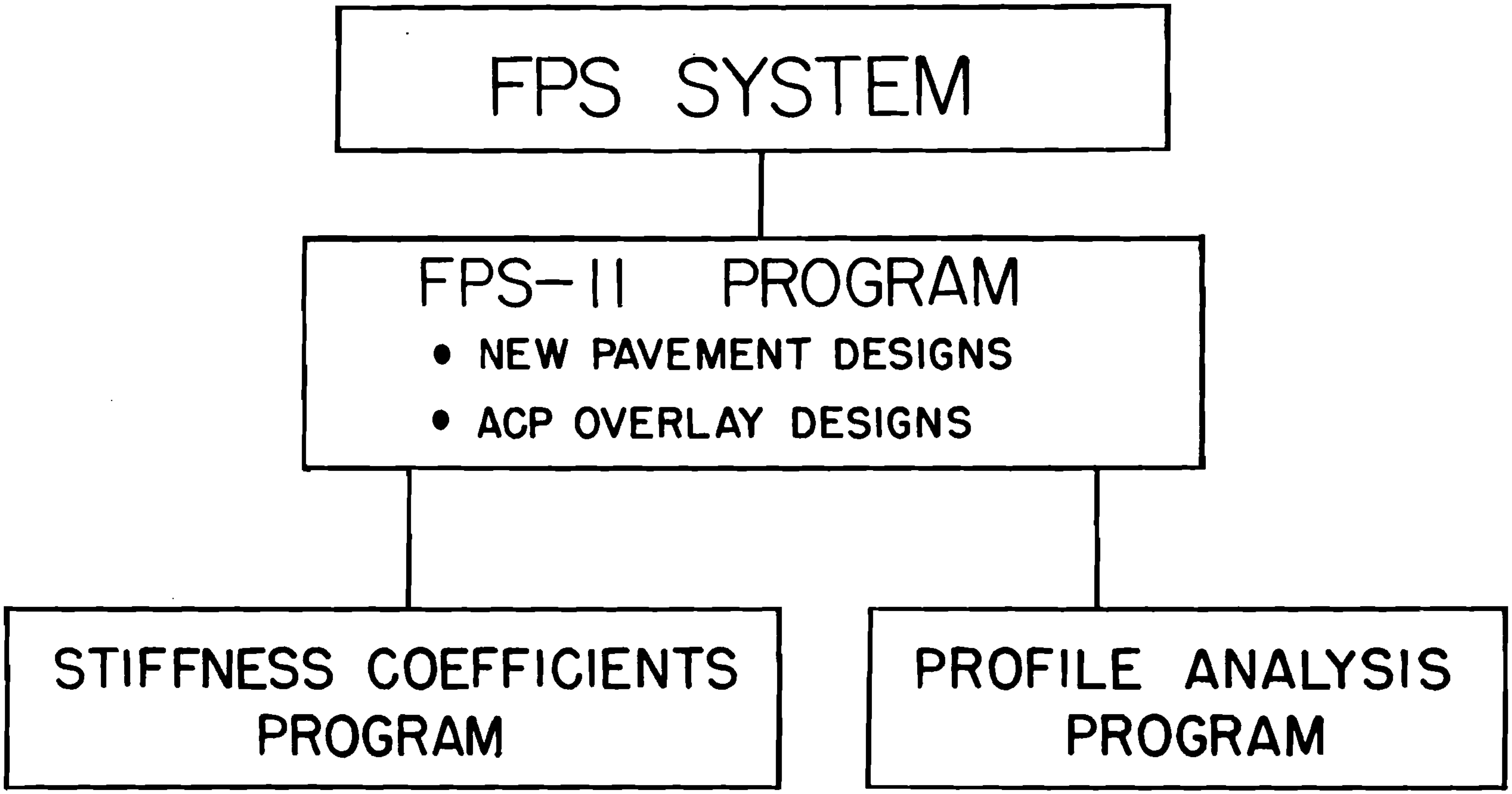

FIGURE 2

FPS SYSTEM COMPUTER PROGRAM

Card No.	Category
6	Environmental and Subgrade (5)
7	Construction and Maintenance Data (9)
8	Detour Design for Overlays (7)
9	Existing Pavement and Proposed ACP (8)
10	Paving Materials Information (9)

A very important feature in training a flexible-pavement designer in the use of the FPS system is the understanding or recognition of the major inputs to FPS. Stated in another way, What are the most sensitive inputs? If pavement design performance is the major objective, then the input items contained in the FPS performance equation should be examined. The performance equation input items are:

1. Serviceability Index
    a. Initital serviceability
    b. Serviceability after ACP overlay
    c. Terminal serviceability
2. Materials Stiffness Coefficients
   (or Surface Curvature Index)
3. Traffic (18-KSA applications)
4. Temperature Constant
5. Swelling Clay Properties

Figure 3, FPS System Performance Equation Concept, gives a blackbox approach to the performance equation. The important feature that the blackbox conveys is that a pavement is started at an initial level of serviceability (smoothness) and, as a function of time, two sets of factors reduce this serviceability. It is interesting to note that swelling clays could destruct a pavement without its exposure to traffic, etc. There is at least one instance where this occurred. A detailed review of the FPS-11 Performance Equation is given in Report 123-15, "FPS-11 Flexible Pavement System Computer Program Documentation," by Orellana (Ref. 5).

One of the best learning procedures for FPS is the sensitivity study (by the user) involving the major inputs. Many applications of sensitivity study are possible, such as traffic versus flexible base thickness, flexible base stiffness coefficient versus flexible base thickness and an endless array of other choices. In all instances, the user must vary only <u>one input</u> and monitor

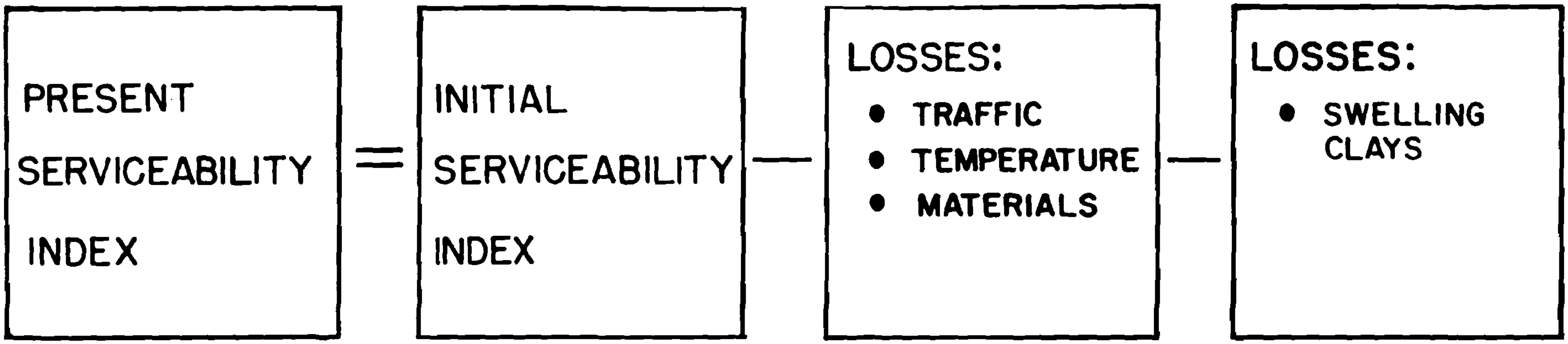

FIGURE 3

FPS SYSTEM

PERFORMANCE EQUATION CONCEPT

the resultant changes in output. If two inputs are simultaneously varied, it will be impossible to determine which one produced the corresponding response. The sensitivity study may be referred to as the "what if" study. What if the subgrade coefficient is changed, the base coefficient, the traffic, etc. But in every instance, only one "what if" should be studied at a time or the response will not be clear. The sensitivity study and the "what if" study appear to be the same except that the sensitivity study is usually better organized and yields better results. With sufficient sensitivity study work in advance, the "what if" question becomes moot at actual design time.

Data Requirements

The two major data item requirements to FPS are the pavement structure and subgrade stiffness information and the traffic data group. In addition to these two groups, there are several items which are not required in the strict sense to use the FPS-11 program but they are needed if a flexible pavement design is to be successful.

Learning everything about an existing pavement structure is a basic beginning. Each pavement structure layer should be identified and its nominal thickness determined. The general condition of the pavement and individual layers is desirable information in that it reveals how various designs and their elements perform under a given environment, traffic, etc.

A soils survey of the probable subgrade material is of design assistance. General soils classification, drainage characteristics and swelling clay potential are necessary items of information. The limits of these features should be established in terms of a relocatable system such as project stationing. When preliminary soils surveys establish that clays with swelling potential are suspected, it becomes almost obligatory to better define the limits of the potential swelling clay areas and to determine their potential vertical rise characteristics. These features relating to the swelling clays are direct and important inputs to the FPS system.

A visual survey of the pavement condition is a spin-off from traveling through the project. Helpful information can usually be gained by a more organized approach to the visual survey. If time is taken to subdivide the project into convenient uniform lengths of known limits, each segment can then be surveyed and major distress elements quantified. For example, the severity of fatigue cracking might be classified as none, slight, moderate, or severe. By defining each severity level, limits of various forms of distress should be more easily quantified. Having the visual condition on a more quantified basis will make it available for comparison with deflection data measurement noted in the following discussion items.

For flexible pavements in Texas the Dynaflect has been an almost exclusive tool for the measurement of pavement surface deflection basins. Appendix B of the FPS manual gives detailed information on the usage of the Dynaflect measurement data for the computation of pavement stiffness coefficients and subgrade stiffness coefficients as well as other items such as the Surface Curvature Index (SCI). A more technical description of the Dynaflect Deflection Equation and its derivation is contained in Research Report 32-12, "An Empirical Equation for Predicting Pavement Deflections" by Scrivner and Moore (Ref. 6).

The need to secure reliable Dynaflect information for the specific job under consideration cannot be over-emphasized. For rehabilitation projects, this securing of Dynaflect data is relatively easy since a pavement exists in the proposed location. Where the proposed project will be on new location the securing of reliable information for the subgrade is more complicated. For the new location it becomes necessary to Dynaflect pavement structures in the vicinity that are also in similar geology and soils classification. The use of assumed pavement materials and subgrade material stiffness coefficients is discouraged. Dynaflect investigations are a rapid and low cost means of materials characterization and their usage are advised.

Traffic data is an item that the pavement designer must obtain from other sources. There are two sources of traffic data and both originate with File D-10, Transportation Planning Division. The more preferable of these methods is by formal request to File D-10 for their "Traffic Analysis for Highway Design" and specifically indicating that this is for pavement design/analysis purposes. As a minimum, D-10 must be advised as to route and limits for which this projection is required. If special developmental features are anticipated within the analysis period, this information should be conveyed with the request. Unless otherwise requested, File D-10 will prepare the projections on the basis of a 20-year analysis period. The second source of traffic data is the Roadway Information System (RIS). Traffic data obtained from RIS is satisfactory for preliminary design purposes but it is not recommended as the sole source of traffic data.

There are some questions as to the adequacy of the present methods of estimating traffic and the amount of data that is available for this purpose. A research project has been proposed to attempt to improve traffic forecasting methods. If there exists any doubt about the traffic furnished by D-10, additional investigation and studies may be warranted.

Dynaflect Deflection Data Analysis

The Dynaflect Stiffness Coefficient Program outlined in Appendix B, Flexible Pavement Designer's Manual, is the basic means of raw Dynaflect data reduction. Figure 4, Dynaflect Deflection Basin, defines the basic deflection information which can be obtained from a Dynaflect measurement. The deflection basin shape, defined by surface deflections W_1 through W_5 is the basic measurement with the Surface Curvature Index (SCI) being directly obtainable by subtracting $W_1 - W_2$. Processed through the Dynaflect Stiffness Program, two other back-calculated data items are obtained. Figure 5, Dynaflect Stiffness Coefficients, outlines the two items. The Composite Pavement Stiffness Coefficient is designated as AP2 and the Subgrade Stiffness Coefficient as AS2. The inability to isolate pavement stiffness coefficients in a multilayer pavement structure has been a major inadequacy in the present version of the Flexible Pavement Design System. In the last several years, there have been several program developments which allow a better determination of coefficients in a multilayer structure. The statewide implementation of these multilayer coefficient programs has been delayed for several reasons. First, their complexity would require a significant implementation effort. Second, the results of these procedures have not been checked out sufficiently to justify their release. Finally, and possibly the most important, is that ongoing research proposes the conversion of FPS to a linear elastic system using elastic moduli as strength inputs. This conversion to elastic moduli inputs has considerable promise, and preliminary indications are that reasonable multilayer elastic moduli determinations can be made from Dynaflect measurements and several other means including laboratory determinations. Simply said, Engineers seem to understand elastic moduli better than stiffness coefficients.

An example of output from the currently available Dynaflect Stiffness Coefficient program in Example 1a through 1d shows the W_1 through W_5, SCI, AS2, and AP2 values previously noted. The overall pavement structure depth is a "must" input for the program to function. The more detailed information provides documentation on the actual pavement structure materials and layer thicknesses.

The shape and magnitude of the Dynaflect deflection basin are indications of the overall pavement structure and subgrade load-carrying capacity. The

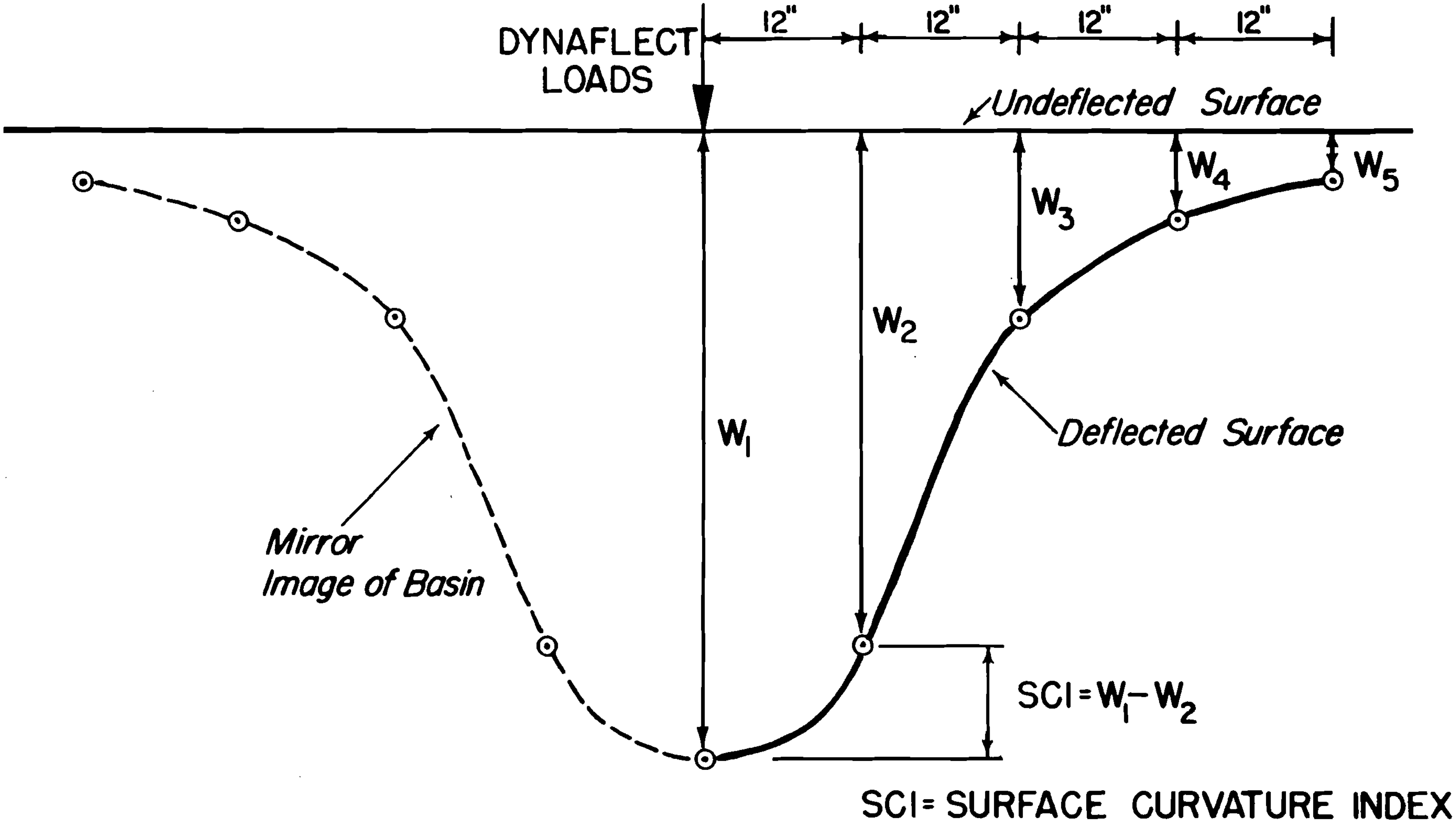

FIGURE 4

DYNAFLECT DEFLECTION BASIN

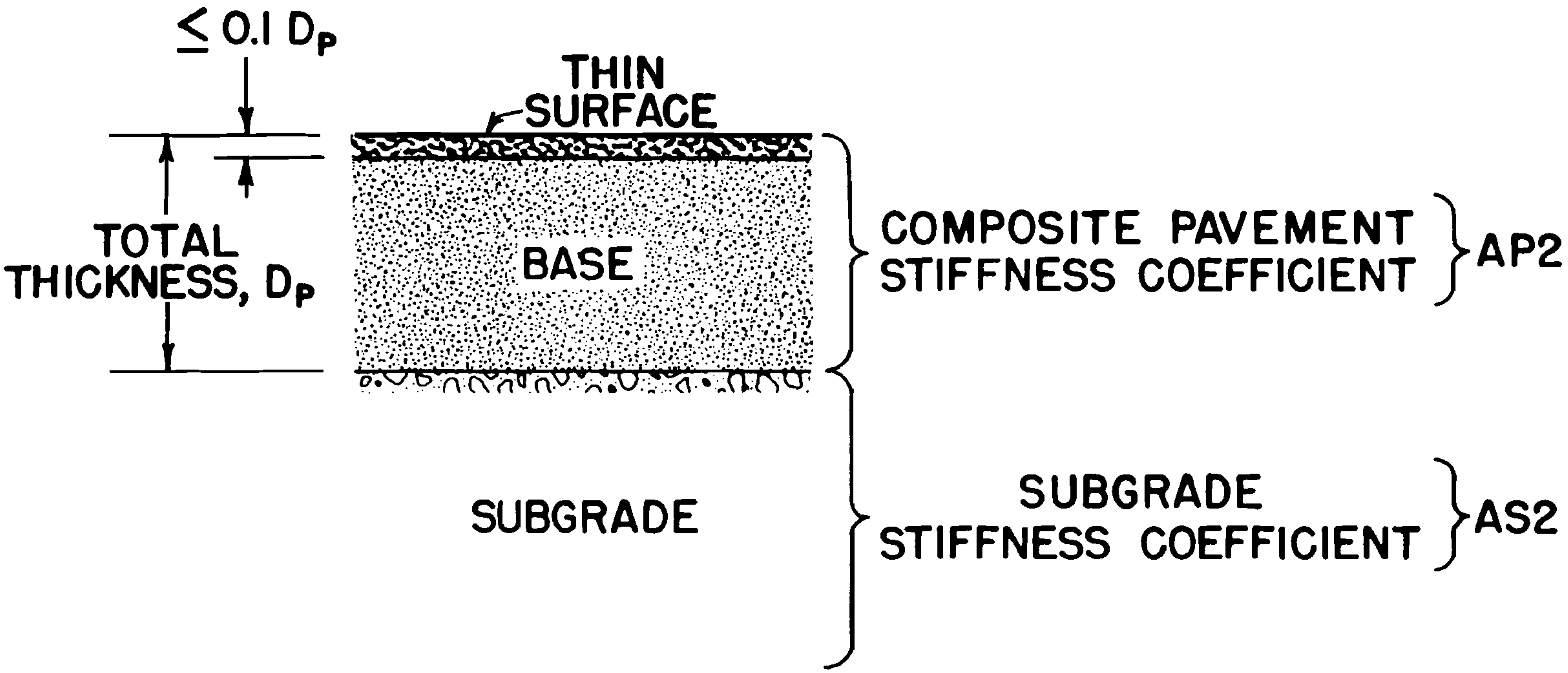

FIGURE 5

DYNAFLECT STIFFNESS COEFFICIENTS

Example 1a

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                                TEXAS HIGHWAY DEPARTMENT

                              DISTRICT 68 -DESIGN SECTION

               DYNAFLECT DEFLECTIONS AND CALCULATED  STIFFNESS COEFFICIENTS

                             THIS PROGRAM WAS RUN - 07-22-82

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

                          PROJECT IDENTIFICATION

DIST.      COUNTY      CONT.  SECT.   PPSN    HIGHWAY     DATE    DYNAFLECT
 68       HARDROCK                            IH 102    05-04-82     48

        REASONS FOR MEASUREMENTS AND COMMENTS      TOTAL PAV DEPTH
               SS -                                    20.10 INCHES

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

                             EXISTING PAVEMENT

                   MATERIAL TYPE        LAYER THICK.(IN)

                HMAC TY D                    1.50
                HMAC TY C                    2.00
                2 CR SURF TR                 0.60
                FB CR LIMESTONE             10.00
                FC SANDY GRAV.               6.00

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

                       GENERAL LOCATION INFORMATION

           DIRECTION OF TRAVEL IS   WEST   OPPOSITE MILEPOINTS
           MEASUREMENTS ARE  3 FEET FROM THE RIGHT SIDE OF LANE L

           DESCRIPTION OF LOCATION           ODOMETER READING  MILEPOINT
    FROM -   NEAR SANDY RIVER BR  MP 48.1
    TO - INTERCHANGE, US 599


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Example 1b

DIST.	COUNTY	CONT.	SECT.	PPSN	HIGHWAY	DATE	DYNAFLECT
68	HARDROCK				IH 102	05-04-82	48

DYNAFLECT DATA

ODOMETER	W1	W2	W3	W4	W5	SCI	AS2	AP2	REMARKS
9711.4	0.580	0.360	0.260	0.210	0.200	0.220	0.30	0.46	0 5/8 0 3/4 0
9711.5	0.310	0.130	0.050	0.020	0.010	0.180	0.45	0.45	0 3/4 0 7/8 0
9711.6	0.230	0.140	0.100	0.070	0.060	0.090	0.35	0.55	0 3/4 0 3/4 0
9711.7	0.330	0.220	0.140	0.090	0.080	0.110	0.31	0.54	0 3/4 0 3/4 0
9711.8	0.310	0.160	0.080	0.040	0.030	0.150	0.37	0.48	0 3/4 0 1/2 0
9711.9	0.220	0.110	0.060	0.040	0.030	0.110	0.41	0.51	0 3/4 0 1/2 0
9712.0	0.260	0.130	0.060	0.030	0.030	0.130	0.40	0.50	0 3/4 0 1/2 0
9712.1	0.320	0.180	0.120	0.080	0.070	0.140	0.35	0.49	0 3/4 0 5/8 0
9712.2	0.290	0.170	0.100	0.060	0.050	0.120	0.35	0.51	
9712.3	0.410	0.270	0.230	0.140	0.130	0.140	0.30	0.51	
9712.4	0.290	0.130	0.070	0.040	0.030	0.160	0.43	0.47	
9712.5	0.290	0.160	0.100	0.070	0.060	0.130	0.36	0.50	MP 47
9712.6	0.290	0.150	0.080	0.060	0.050	0.140	0.38	0.49	
9712.7	0.480	0.320	0.200	0.120	0.080	0.160	0.29	0.50	
9712.8	0.210	0.120	0.070	0.040	0.030	0.090	0.37	0.54	
9712.9	0.330	0.170	0.100	0.060	0.050	0.160	0.37	0.48	
9713.0	0.220	0.120	0.070	0.040	0.030	0.100	0.38	0.53	
9713.1	0.290	0.160	0.120	0.070	0.060	0.130	0.36	0.50	
9713.2	0.160	0.090	0.060	0.030	0.020	0.070	0.39	0.57	S = 45
9713.3	0.220	0.110	0.090	0.040	0.030	0.110	0.41	0.51	
9713.4	0.350	0.160	0.090	0.050	0.050	0.190	0.40	0.45	
9713.5	0.260	0.130	0.080	0.040	0.030	0.130	0.40	0.50	MP 46
9713.6	0.190	0.110	0.070	0.040	0.030	0.080	0.38	0.56	
9713.7	0.260	0.140	0.080	0.050	0.040	0.120	0.37	0.51	
9713.8	0.240	0.130	0.090	0.060	0.050	0.110	0.38	0.52	
9713.9	0.210	0.130	0.090	0.060	0.050	0.080	0.35	0.56	
9714.0	0.250	0.170	0.110	0.080	0.070	0.080	0.32	0.58	
9714.1	0.380	0.190	0.100	0.060	0.050	0.190	0.37	0.46	
9714.2	0.410	0.280	0.210	0.150	0.120	0.130	0.30	0.53	
9714.3	0.590	0.330	0.200	0.130	0.110	0.260	0.31	0.44	
9714.4	0.440	0.240	0.160	0.110	0.090	0.200	0.34	0.46	
9714.5	0.460	0.280	0.190	0.130	0.110	0.180	0.31	0.48	MP 45
9714.6	0.420	0.240	0.190	0.130	0.120	0.180	0.33	0.47	
9714.7	0.350	0.200	0.150	0.120	0.110	0.150	0.34	0.49	
9714.8	0.380	0.200	0.130	0.090	0.080	0.180	0.35	0.46	
9714.9	0.460	0.250	0.170	0.110	0.100	0.210	0.34	0.45	
9715.0	0.440	0.230	0.150	0.100	0.080	0.210	0.35	0.45	
9715.1	0.530	0.270	0.150	0.090	0.080	0.260	0.34	0.43	PATCH
9715.2	0.570	0.340	0.230	0.170	0.140	0.230	0.30	0.45	
9715.3	0.750	0.510	0.380	0.320	0.260	0.240	0.27	0.47	
9715.4	0.950	0.600	0.440	0.360	0.290	0.350	0.27	0.42	PATCH
9715.5	0.770	0.530	0.400	0.320	0.250	0.240	0.26	0.47	MP 44
9715.6	0.700	0.490	0.390	0.310	0.250	0.210	0.26	0.49	PATCH
9715.7	0.710	0.470	0.360	0.300	0.240	0.240	0.27	0.46	
9715.8	0.680	0.460	0.350	0.280	0.230	0.220	0.27	0.47	S= 59

Example 1c

DIST.	COUNTY	CONT.	SECT.	PPSN	HIGHWAY	DATE	DYNAFLECT
68	HARDROCK				IH 102	05-04-82	48

DYNAFLECT DATA

ODOMETER	W1	W2	W3	W4	W5	SCI	AS2	AP2	REMARKS		
9715.9	0.490	0.350	0.280	0.220	0.170	0.140	0.28	0.53			
9716.0	0.600	0.370	0.260	0.200	0.160	0.230	0.29	0.46			
9716.1	0.660	0.440	0.330	0.270	0.210	0.220	0.28	0.47			
9716.2	0.620	0.410	0.280	0.220	0.170	0.210	0.28	0.47			
9716.3	0.690	0.420	0.270	0.190	0.150	0.270	0.29	0.44			
9716.4	0.580	0.380	0.280	0.200	0.160	0.200	0.29	0.48			
9716.5	0.500	0.300	0.200	0.140	0.110	0.200	0.31	0.47	MP 43		
9716.6	0.460	0.270	0.180	0.120	0.100	0.190	0.32	0.47			
9716.7	0.560	0.340	0.230	0.170	0.130	0.220	0.30	0.46			
9716.8	0.470	0.270	0.180	0.120	0.110	0.200	0.32	0.46			
9716.9	0.720	0.400	0.210	0.160	0.130	0.320	0.30	0.42			
9717.0	0.550	0.330	0.220	0.180	0.120	0.220	0.30	0.46			
9717.1	0.440	0.270	0.200	0.130	0.100	0.170	0.31	0.48			
9717.2	0.470	0.230	0.110	0.060	0.050	0.240	0.36	0.43			
9717.3	0.680	0.450	0.290	0.180	0.130	0.230	0.28	0.47			
9717.4	0.550	0.290	0.160	0.090	0.080	0.260	0.33	0.43			
9717.5	0.570	0.250	0.120	0.070	0.060	0.320	0.38	0.40	MP 42		
9717.6	0.600	0.310	0.170	0.100	0.080	0.290	0.33	0.42			
9717.7	0.710	0.350	0.170	0.100	0.070	0.360	0.33	0.40			
9717.8	0.370	0.190	0.120	0.080	0.070	0.180	0.36	0.46			
9717.9	0.420	0.200	0.150	0.070	0.060	0.220	0.38	0.44			
9718.0	0.330	0.170	0.100	0.060	0.050	0.160	0.37	0.48	TRAP ROCK		
9718.1	0.630	0.340	0.190	0.100	0.080	0.290	0.32	0.42			
9718.2	0.460	0.280	0.190	0.120	0.090	0.180	0.31	0.48	TRAP ROCK		
9718.3	0.460	0.250	0.150	0.090	0.070	0.210	0.34	0.45			
9718.4	0.410	0.210	0.130	0.080	0.060	0.200	0.36	0.45			
9718.5	0.570	0.310	0.160	0.080	0.070	0.260	0.32	0.43	MP 41		
9718.6	0.410	0.210	0.120	0.080	0.070	0.200	0.36	0.45			
9718.7	0.360	0.210	0.140	0.100	0.070	0.150	0.33	0.49			
9718.8	0.420	0.230	0.140	0.080	0.070	0.190	0.34	0.46	MP 40.7		
9718.9	0.360	0.230	0.160	0.100	0.080	0.130	0.32	0.52	0 1/2	0 1/2	0
9719.0	0.460	0.260	0.150	0.090	0.070	0.200	0.33	0.46	0 3/4	0 1/2	0
9719.1	0.450	0.250	0.160	0.090	0.080	0.200	0.33	0.46	0 1/2	0 1/4	0
9719.2	0.550	0.280	0.150	0.100	0.080	0.270	0.34	0.42	0 3/4	0 5/8	0
9719.3	0.480	0.260	0.150	0.090	0.080	0.220	0.33	0.45	0 1/2	0 3/8	0
9719.4	0.440	0.230	0.140	0.090	0.070	0.210	0.35	0.45	0 3/4	0 3/4	0
9719.5	0.400	0.220	0.150	0.090	0.080	0.180	0.34	0.47	0 5/8	0 1/4	0
9719.6	0.410	0.230	0.160	0.090	0.070	0.180	0.34	0.47	MP 39.9		
9719.7	0.460	0.250	0.140	0.090	0.070	0.210	0.34	0.45			
9719.8	0.500	0.270	0.160	0.110	0.080	0.230	0.33	0.44			
9719.9	0.430	0.200	0.140	0.090	0.070	0.230	0.38	0.43	S= 43		
9729.5	0.400	0.210	0.120	0.070	0.050	0.190	0.35	0.46	STA 116+00		
9729.6	0.430	0.220	0.140	0.080	0.070	0.210	0.35	0.45			
9729.7	0.510	0.270	0.160	0.100	0.080	0.240	0.33	0.44			
9729.8	0.340	0.170	0.090	0.050	0.050	0.170	0.38	0.47			

Example 1d

DIST.	COUNTY	CONT.	SECT.	PPSN	HIGHWAY	DATE	DYNAFLECT
68	HARDROCK				IH 102	05-04-82	48

DYNAFLECT DATA

ODOMETER	W1	W2	W3	W4	W5	SCI	AS2	AP2	REMARKS
9729.9	0.510	0.260	0.160	0.100	0.080	0.250	0.34	0.43	
9730.0	0.510	0.300	0.210	0.140	0.110	0.210	0.31	0.46	MP 39
9730.1	0.360	0.210	0.130	0.080	0.070	0.150	0.33	0.49	
9730.2	0.410	0.260	0.190	0.130	0.100	0.150	0.31	0.50	
9730.3	0.490	0.320	0.230	0.160	0.120	0.170	0.29	0.49	
9730.4	0.460	0.320	0.230	0.150	0.110	0.140	0.29	0.52	
9730.5	0.710	0.510	0.370	0.270	0.180	0.200	0.26	0.50	CRACK IN PAVEMENT
9730.6	0.550	0.360	0.270	0.170	0.130	0.190	0.29	0.48	
9730.7	0.370	0.230	0.170	0.100	0.080	0.140	0.32	0.50	
9730.8	0.640	0.400	0.260	0.170	0.120	0.240	0.29	0.45	END = STA 50+00
9730.8	0.630	0.380	0.250	0.160	0.110	0.250	0.30	0.45	STA 50+00 EXIT37WBL
9730.9	0.580	0.380	0.260	0.160	0.100	0.200	0.29	0.48	
9731.0	0.420	0.250	0.150	0.080	0.060	0.170	0.32	0.48	MP 38
9731.1	0.970	0.650	0.480	0.350	0.240	0.320	0.26	0.44	
9731.2	0.610	0.590	0.490	0.360	0.250	0.020	0.18	1.13	
9731.3	0.680	0.370	0.220	0.140	0.100	0.310	0.31	0.42	
9731.4	0.730	0.430	0.270	0.180	0.130	0.300	0.29	0.43	
9731.5	0.660	0.350	0.200	0.120	0.100	0.310	0.32	0.42	
9731.6	0.740	0.370	0.190	0.120	0.090	0.370	0.32	0.40	END OF JOB INTERCHAN
AVERAGES	0.470	0.275	0.181	0.122	0.097	0.194	0.33	0.48	
STANDARD DEVIATION						0.066	0.04	0.07	

NUMBER OF POINTS IN AVERAGE = 109

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

shape and magnitude of the basin deflections can be further interpeted to indicate the load-carrying properties of the individual pavement-subgrade components. It is generally recognized that the deflections nearest the Dynaflect wheel load, W_1 and W_2, are a measure of the capacity of the pavement layers. The extreme end of the basin, deflection W_5, is accepted as an indicator of subgrade load-carrying ability.

The FPS performance equation is developed on the following premise:

> "The wheel load stress acting on 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."

This premise is represented in the performance equation in terms of the SCI which is the difference of $W_1 - W_2$. Thus, examining the deflection basins and/ or the printed output from the Stiffness Coefficient Program reveals the important role assigned to the SCI value.

In the internal workings of the Dynaflect Stiffness Coefficient Program, the pavement and subgrade stiffness coefficients, AP2 and AS2, are obtained by assuming values and computing the resulting deflection basin using the Dynaflect Deflection Equation. The calculated deflections at points W_1 and W_2 are compared with the measured deflection values at W_1 and W_2 and when they agree within a given allowable error, it is assumed that the AP2 and AS2 values for the measured basin have been determined. Frequently, the computed and measured deflection values in the W_5 area do not compare favorably. This condition can be monitored by requesting a computer plot of the measured and calculated deflection for each basin. This feature is available with the Dynaflect Stiffness Coefficient Program.

If the program is not doing a satisfactory job in calculating AS2 as evidenced by the comparison plots, the user may wish to make "hand" adjustments. The basin-fitting difficulty is due to the program using the two-point fit (W_1 and W_2) whereas the remainder of the basin is also of vital importance.

A study of deflection basin shapes is done by assuming a simple three-layer pavement; 5" Asphaltic Concrete, 12" Flexible Base, and Raw Subgrade.

Table 1, Stiffness Coefficient for Dynaflect Basin Shape Study, outlines a matrix of assumed coefficients. These coefficients and layer thicknesses were used in the Dynaflect Equation to compute deflection basins for each basin shown in Figures 6 through 10. A brief interpretation of the basins follows.

Figure 6, Basin Study-Variable Subgrade

1. Variation in subgrade coefficient affects vertical position more so than basin shape.
2. The coefficient ranges of 0.20 to 0.30 is apparently non-linear as witnessed by the non-centered location of the basin for coefficient 0.25.

Figure 7, Basin Study-Variable Surfacing

1. The ACP coefficient range of 0.60 - 1.40 represents the extremes of a statewide study.
2. Extreme changes in surfacing coefficient show up as a basin change predominately in the load area.
3. Changes in surfacing coefficient have almost no effect in the W_5 area.

Figure 8, Basin Study-Variable Base

1. Changes in base material coefficient produce a change in the load area.
2. Base material coefficient changes have very little effect in the W_5 area.

Figure 9, Basin Study-Combined Conditions

1. Effects of very poor surfacing and base are cumulative.
2. Changes in base or surfacing coefficients have very little effect in the W_5 area.

Figure 10, Basin Study - Extreme Conditions

1. The high magnitude deflections often noted are the apparent result of all pavement elements being "bad."

TABLE 1

STIFFNESS COEFFICIENTS FOR DYNAFLECT BASIN STUDY

Figure	Surfacing (5" ACP)	Base (12" Flex.Base)	Subgrade	Remarks
6	1.00	0.60	0.30	Very good subgrade
	1.00	0.60	0.25	Average subgrade
	1.00	0.60	0.20	Very poor subgrade
7	1.40	0.60	0.25	Very good surfacing
	1.00	0.60	0.25	Average surfacing
	0.60	0.60	0.25	Very poor surfacing
8	1.00	0.80	0.25	Very good base
	1.00	0.60	0.25	Average base
	1.00	0.40	0.25	Very poor base
9	1.00	0.60	0.25	All average
	0.60	0.60	0.25	Very poor surfacing
	1.00	0.40	0.25	Very poor base
	0.60	0.40	0.25	Very poor surfacing and base
10	1.40	0.80	0.30	All very good
	1.00	0.60	0.25	All average
	0.60	0.40	0.20	All very poor

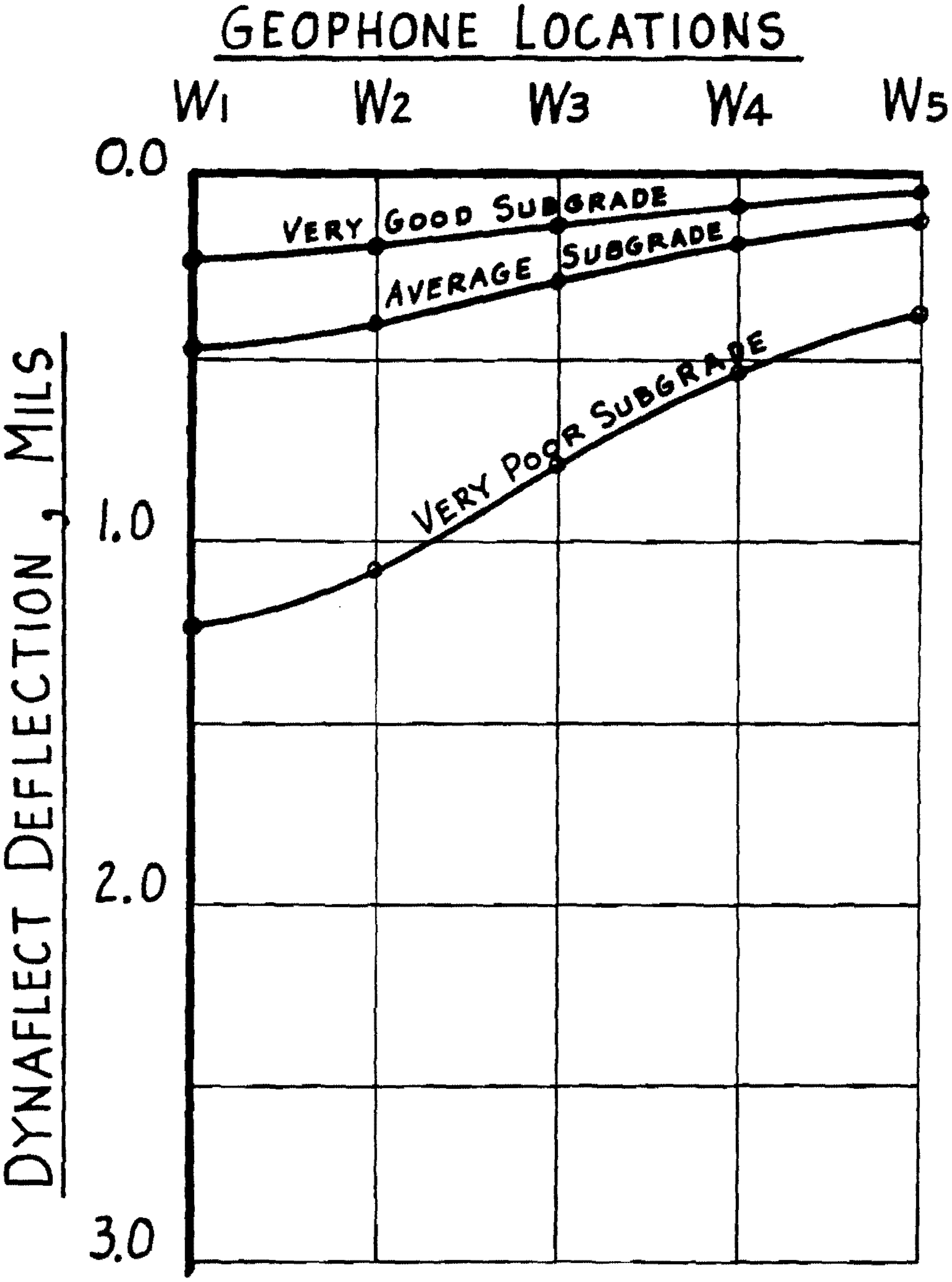


FIGURE 6

BASIN STUDY - VARIABLE SUBGRADE

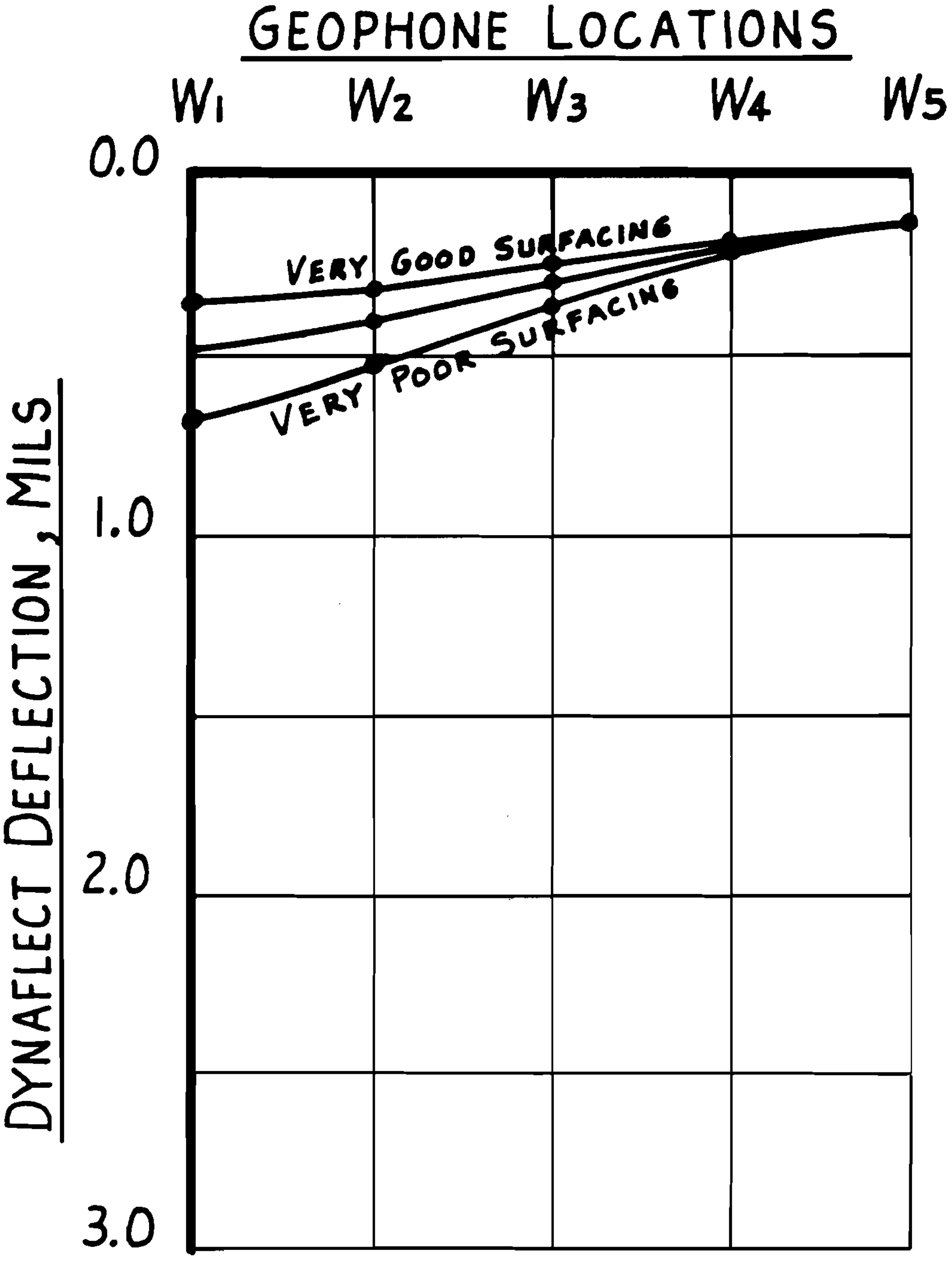


FIGURE 7

BASIN STUDY - VARIABLE SURFACING

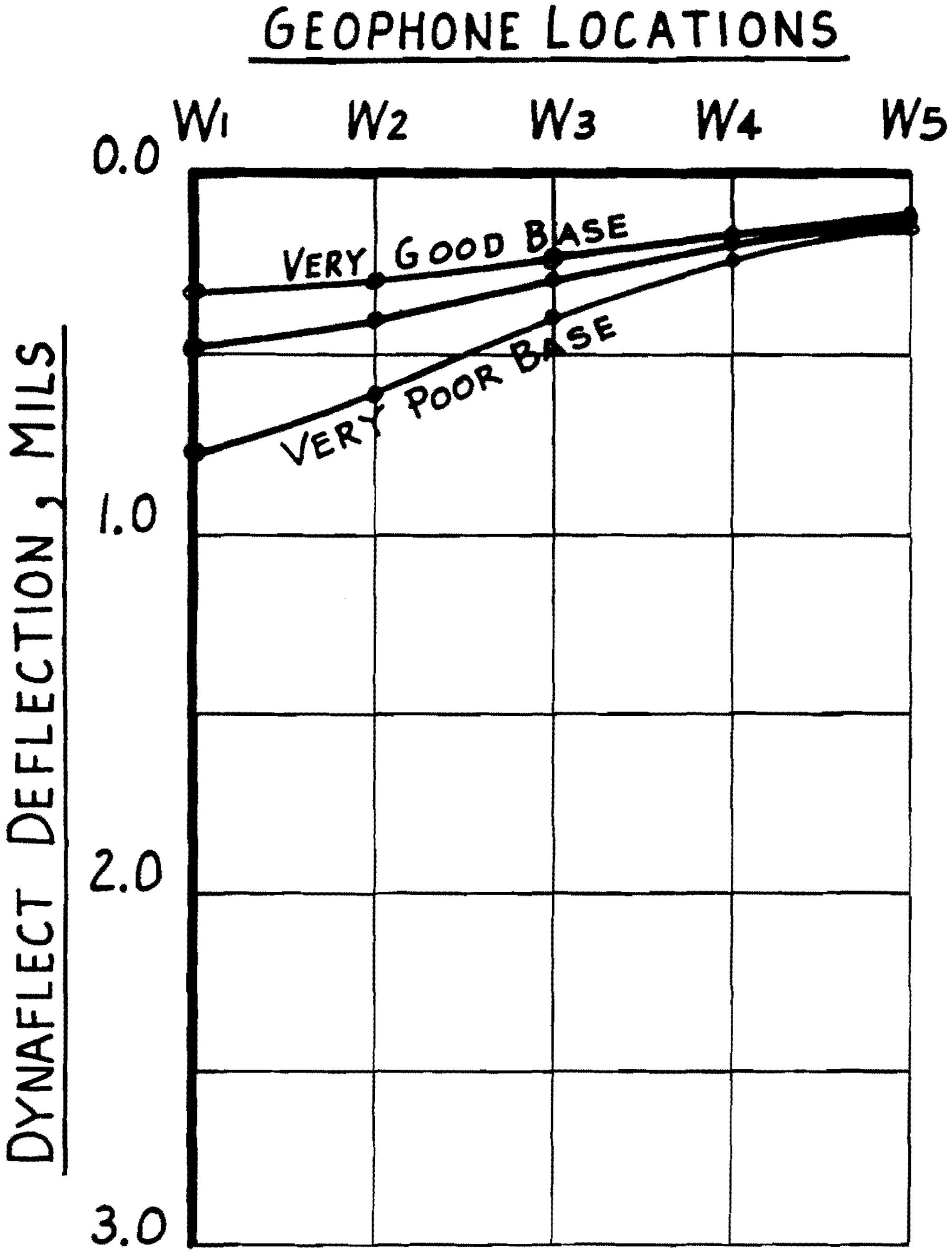


FIGURE 8

BASIN STUDY - VARIABLE BASE

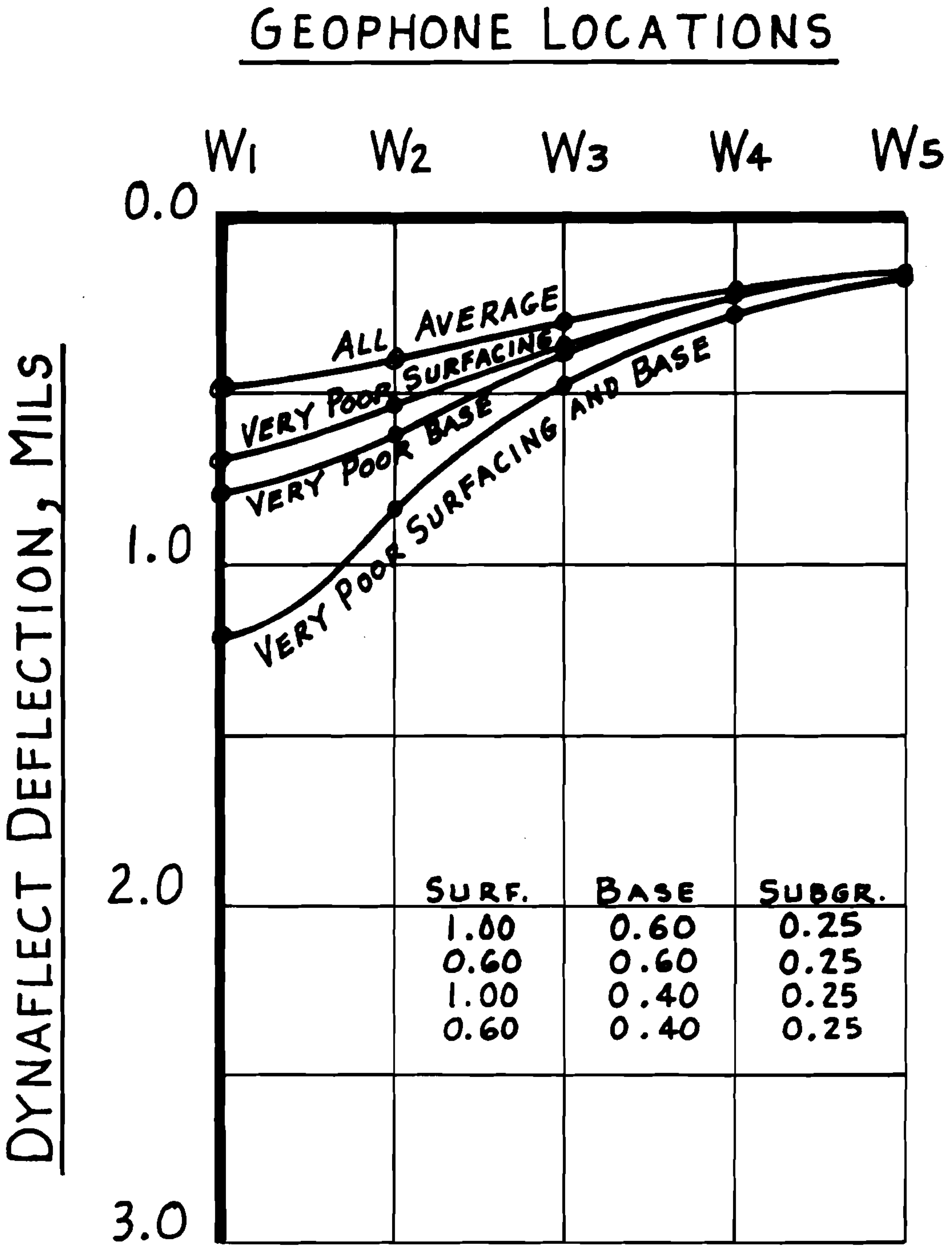


FIGURE 9

BASIN STUDY - COMBINED CONDITIONS

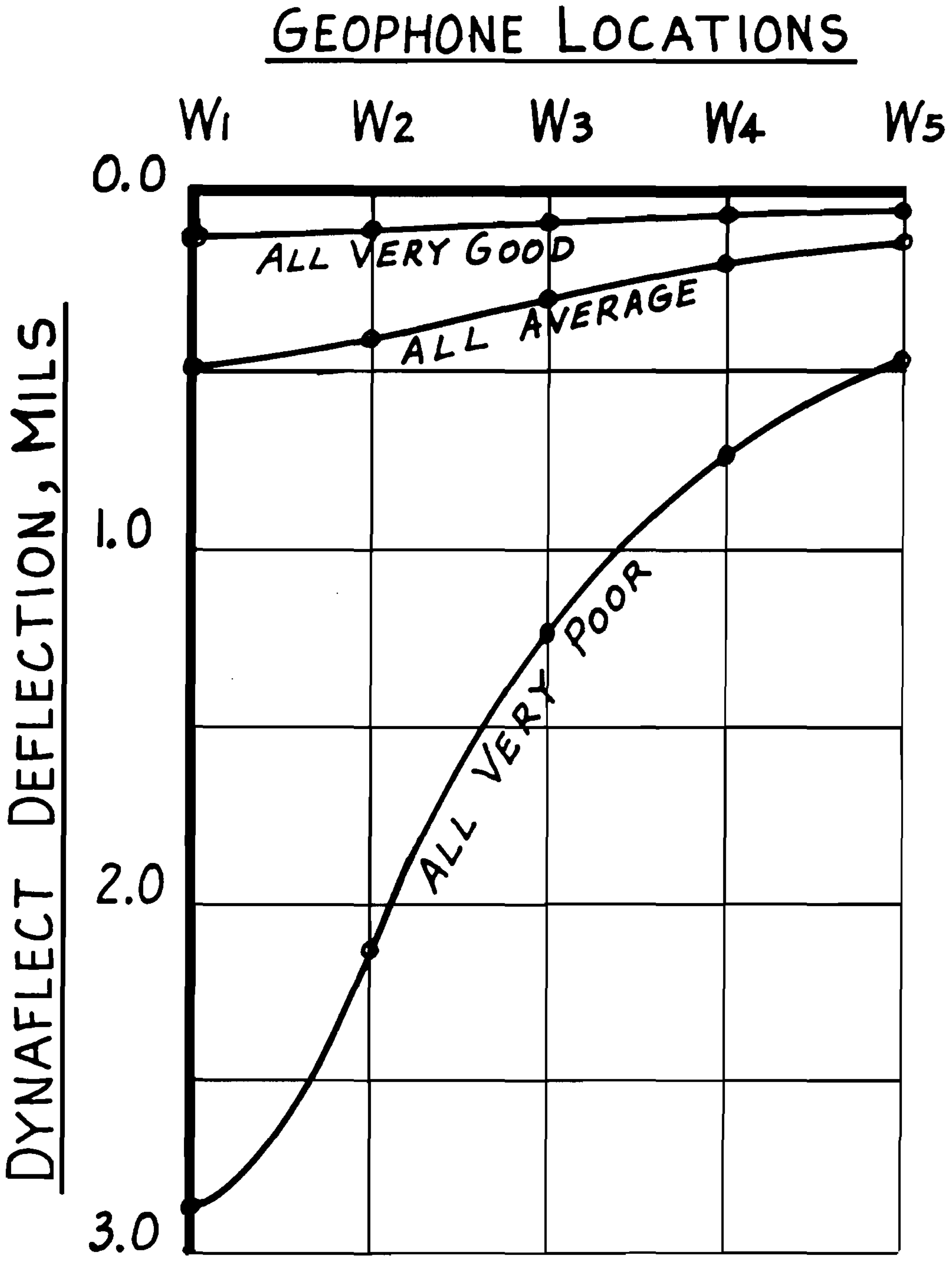


FIGURE 10

BASIN STUDY- EXTREME CONDITIONS

2. The extremely flat and low deflection basin of "all good" is the apparent result of all three elements being "good."
3. The "good" and "bad effects indicate that the W_1 area is pavement structure and the W_5 area is subgrade.

Figure 11, Pavement Layer Compressions, may give a better indication as to the "why" for some of the plot shapes in Figures 6 through 10. If it is assumed that the pavement and subgrade are elastic in nature, then pavement surface deflection must be a summation of the vertical compressions (displacements) in the various pavement layers. Figure 11 depicts the average pavement and subgrade coefficient values previously used. A brief examination reveals that the surfacing and base account for only 6.6 percent of the total deflection. From Figure 11, it is easy to conclude that "big" deflections are a function of subgrade condition; bad surfacing and/or base alone cannot produce the "big" deflections.

Thus far, the Dynaflect deflection data have been obtained, processed with the Dynaflect Stiffness Coefficient Program, and the program output examined as well as the meaning of the shape of the delfection basin. To complete the data analysis, design section selection must be made. Design section selection divides itself into three tasks.

1. Data variable versus location plots
    a. Deflection W_1 versus stations
    b. Subgrade or pavement coefficient (AS2 or AP2)
    c. Surface Curvature Index (SCI) versus stations
2. Design section selection
3. Statistical verification of design section selection (Profile Analysis Program)

Figure 12, Plot of SCI versus Odometer Station, is a simple hand plot of Surface Curvature Index (SCI) values versus Odometer Station. This data was taken from Example 1a through 1d which is the deflection data processed through the Dynaflect Stiffness Coefficient Program. Recall that the SCI is a measure of overall pavement structure and subgrade bending stiffness. In

	Layer Compression	Percent Compression
5" ACP (1.00)	0.0054	1.1
12" BASE (0.60)	0.0261	5.5
SUBGRADE (0.25)	0.4446	93.4
TOTAL DEFLECTION (Compression)	0.4761	100.0

Figure 11

Pavement Layer Compressions

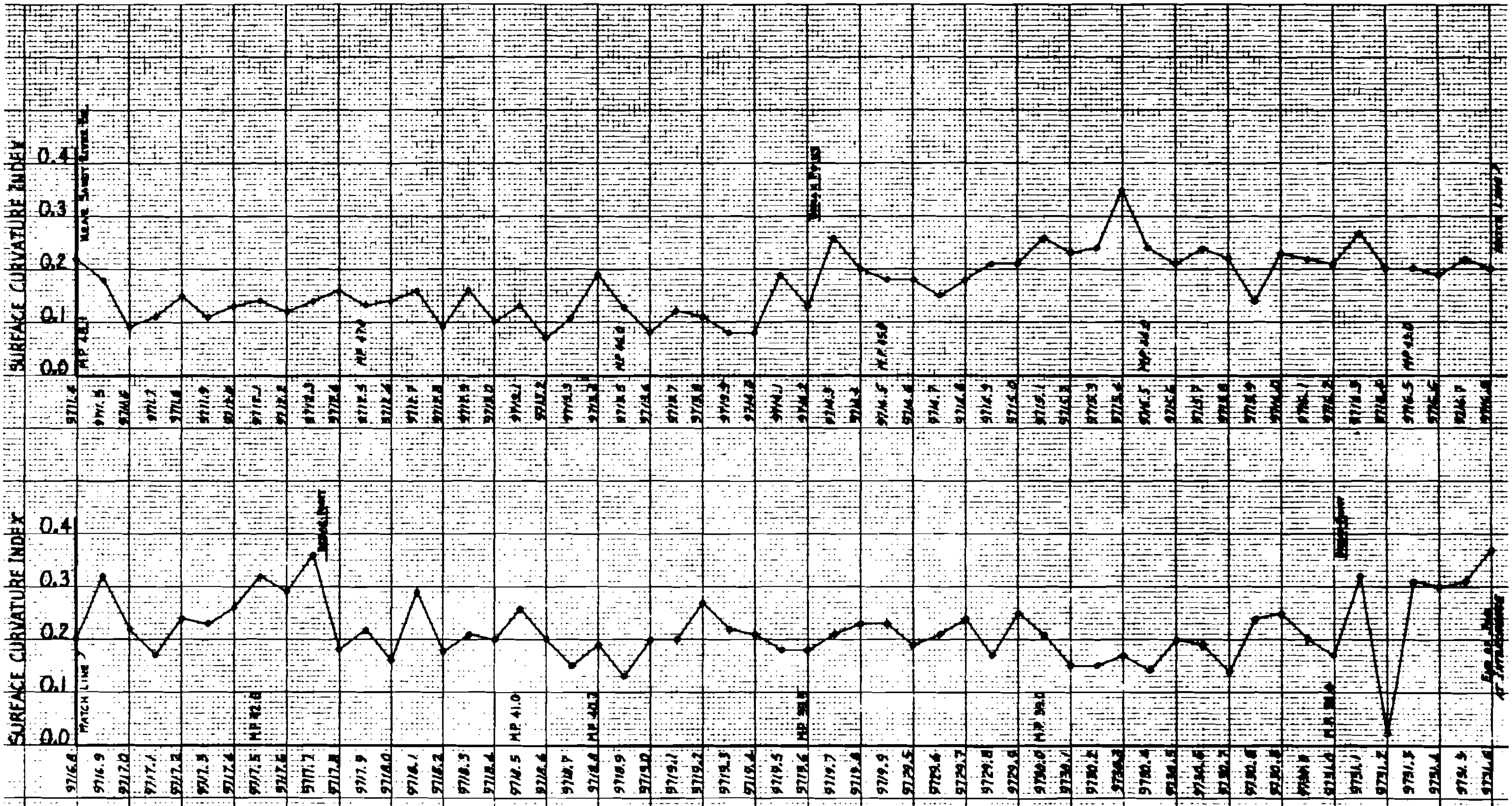


FIGURE 12
PLOT OF SCI vs. ODOMETER STATION

DISTRICT 6A
SH 10E : FROM NEAR SANDY RIVER BR.
TO INTERSECTION US 583
HARDROCK COUNTY

flexible pavement design the SCI data with its corresponding standard deviation is the prime input to the FPS-11 Program, Overlay Mode.

An examination of the plot shown in Figure 12 shows considerable "down the road" variation in the SCI values. The designer can assume that there is no reason to have subsections and, consequently, the project average of SCI and its overall standard deviation will control in design. Or, the alternate choice is the selection of subsections which will be tested for statistical difference. For this example, Figure 12 shows that the designer has selected four subsections for statistical testing. Example 2a through 2d shows the complete code sheets for the Profile Analysis Program. All that remains to be done at this stage is the review of the output from the Profile Analysis Program as shown in Example 3a through 3d. The first review of the Profile Analysis output should be a proofreading of the inputs to verify that analyzation has actually been made. The last page of the printout will give the results. In this instance, the program has verified that all four of the selected subsections are statistically different.

Finally, the program has produced for each subsection an average value of SCI as well as a corresponding value of standard deviation. At this point, enough data should be available to proceed with an overall design for the subsections. If the four subsections were used to produce asphaltic concrete overlay designs, the resultant overlay thickness would be examined for practical differences in thickness which would be the ultimate method of examining the data.

EXAMPLE 2a.

TEXAS HIGHWAY DEPARTMENT

FLEXIBLE PAVEMENT-DESIGN SYSTEM

PROFILE ANALYSIS

CARD NO. 1 - PROJECT IDENTIFICATION

DIST.

6	8
4	5

COUNTY

			H	A	R	D	R	O	C	K			
6	7	8	9	10	11	12	13	14	15	16	17	18	19

CONTROL

9	3	0	7
20	21	22	23

SECTION

0	8
24	25

JOB

26	27

HIGHWAY

	I	H		1	0	2
28	29	30	31	32	33	34

DATE

0	6	/	1	6	/	8	2
35	36	37	38	39	40	41	42

NO. OF SECTIONS

	4
43	44

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

	2	9		6	4	1	0	3	1	0	9																		
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

CARD NO. 3 - DATA CARDS

REF POINT	STATION							MEASURED OR CALCULATED VALUES				AVG VALUE				
	1	2	3	4	5	6	7					8	9	10	11	12
1	9	7	1	1	•	4						0	.	2	2	
2	9	7	1	1	•	5						0	.	1	8	
3	9	7	1	1	•	6						0	.	0	9	
4	9	7	1	1	•	7						0	.	1	1	
5	9	7	1	1	•	8						0	.	1	5	
6	9	7	1	1	•	9						0	.	1	1	
7	9	7	1	2	•	0						0	.	1	3	
8	9	7	1	2	•	1						0	.	1	4	
9	9	7	1	2	•	2						0	.	1	2	
10	9	7	1	2	•	3						0	.	1	4	
11	9	7	1	2	•	4						0	.	1	6	
12	9	7	1	2	•	5						0	.	1	3	

Form 1115-1

EXAMPLE 2b.

CARD NO. 3 - DATA CARDS

REF POINT	STATION	MEASURED OR CALCULATED VALUES				AVG VALUE
	1 2 3 4 5 6 7					8 9 10 .. 12
13	9712.6					0.14
14	9712.7					0.16
15	9712.8					0.09
16	9712.9					0.16
17	9713.0					0.10
18	9713.1					0.13
19	9713.2					0.07
20	9713.3					0.11
21	9713.4					0.19
22	9713.5					0.13
23	9713.6					0.08
24	9713.7					0.12
25	9713.8					0.11
26	9713.9					0.08
27	9714.0					0.08
28	9714.1					0.19
29	9714.2					0.13
30	9714.3					0.26
31	9714.4					0.20
32	9714.5					0.18
33	9714.6					0.18
34	9714.7					0.15
35	9714.8					0.18
36	9714.9					0.21
37	9715.0					0.21
38	9715.1					0.26
39	9715.2					0.23
40	9715.3					0.24
41	9715.4					0.35
42	9715.5					0.24
43	9715.6					0.21
44	9715.7					0.24
45	9715.8					0.22
46	9715.9					0.14
47	9716.0					0.23

Form 1115-2

EXAMPLE 2c.

CARD NO. 3 - DATA CARDS

REF POINT	STATION	MEASURED OR CALCULATED VALUES				AVG VALUE
	1 2 3 4 5 6 7					8 9 10 11 12
48	9716.1					0.22
49	9716.2					0.21
50	9716.3					0.27
51	9716.4					0.20
52	9716.5					0.20
53	9716.6					0.19
54	9716.7					0.22
55	9716.8					0.20
56	9716.9					0.32
57	9717.0					0.22
58	9717.1					0.17
59	9717.2					0.24
60	9717.3					0.23
61	9717.4					0.26
62	9717.5					0.32
63	9717.6					0.29
64	9717.7					0.36
65	9717.8					0.18
66	9717.9					0.22
67	9718.0					0.16
68	9718.1					0.29
69	9718.2					0.18
70	9718.3					0.21
71	9718.4					0.20
72	9718.5					0.26
73	9718.6					0.20
74	9718.7					0.15
75	9718.8					0.19
76	9718.9					0.13
77	9719.0					0.20
78	9719.1					0.20
79	9719.2					0.27
80	9719.3					0.22
81	9719.4					0.21
82	9719.5					0.18

EXAMPLE 2d.

CARD NO. 3 - DATA CARDS

REF POINT	STATION	MEASURED OR CALCULATED VALUES				AVG VALUE
	1 2 3 4 5 6 7					8 9 10 11 12
83	9719.6					0.18
84	9719.7					0.21
85	9719.8					0.23
86	9719.9					0.23
87	9729.5					0.19
88	9729.6					0.21
89	9729.7					0.24
90	9729.8					0.17
91	9729.9					0.25
92	9730.0					0.21
93	9730.1					0.15
94	9730.2					0.15
95	9730.3					0.17
96	9730.4					0.14
97	9730.5					0.20
98	9730.6					0.19
99	9730.7					0.14
100	* 9730.8					0.24
101	* 9730.8					0.25
102	9730.9					0.20
103	9731.0					0.17
104	9731.1					0.32
105	9731.2					0.02
106	9731.3					0.31
107	9731.4					0.30
108	9731.5					0.31
109	9731.6					0.37
	+					.
	+					.
	+					.
	+					.
	+					.
	+					.
	+					.
	+					.

* Duplicate Station Numbers.

Example 3a

```
                              TEXAS HIGHWAY DEPARTMENT

                            PROFILE ANALYSIS FOR    IH 102

                           THIS PROGRAM WAS RUN - 07-26-82

DIST.        COUNTY       CONT.  SECT.  JOB  HIGHWAY    DATE    NO. OF SECT.
 68         HARDROCK      9307    08         IH 102   06/16/82        4

                          REFERENCE       STA.       INPUT
                           POINTS                    DATA

                               1         9711.4       0.220
                               2         9711.5       0.180
                               3         9711.6       0.090
                               4         9711.7       0.110
                               5         9711.8       0.150
                               6         9711.9       0.110
                               7         9712.0       0.130
                               8         9712.1       0.140
                               9         9712.2       0.120
                              10         9712.3       0.140
                              11         9712.4       0.160
                              12         9712.5       0.130
                              13         9712.6       0.140
                              14         9712.7       0.160
                              15         9712.8       0.090
                              16         9712.9       0.160
                              17         9713.0       0.100
                              18         9713.1       0.130
                              19         9713.2       0.070
                              20         9713.3       0.110
                              21         9713.4       0.190
                              22         9713.5       0.130
                              23         9713.6       0.080
                              24         9713.7       0.120
                              25         9713.8       0.110
                              26         9713.9       0.080
                              27         9714.0       0.080
                              28         9714.1       0.190
                              29         9714.2       0.130
                              30         9714.3       0.260
                              31         9714.4       0.200
                              32         9714.5       0.180
                              33         9714.6       0.180
                              34         9714.7       0.150
                              35         9714.8       0.180
                              36         9714.9       0.210
                              37         9715.0       0.210
                              38         9715.1       0.260
                              39         9715.2       0.230
                              40         9715.3       0.240
```

Example 3b

```
DIST.      COUNTY      CONT.  SECT.  JOB  HIGHWAY    DATE    NO. OF SECT.
 68       HARDROCK     9307    08         IH 102   06/16/82        4

                       PROFILE ANALYSIS FOR    IH 102

                       REFERENCE      STA.      INPUT
                        POINTS                  DATA

                          41        9715.4      0.350
                          42        9715.5      0.240
                          43        9715.6      0.210
                          44        9715.7      0.240
                          45        9715.8      0.220
                          46        9715.9      0.140
                          47        9716.0      0.230
                          48        9716.1      0.220
                          49        9716.2      0.210
                          50        9716.3      0.270
                          51        9716.4      0.200
                          52        9716.5      0.200
                          53        9716.6      0.190
                          54        9716.7      0.220
                          55        9716.8      0.200
                          56        9716.9      0.320
                          57        9717.0      0.220
                          58        9717.1      0.170
                          59        9717.2      0.240
                          60        9717.3      0.230
                          61        9717.4      0.260
                          62        9717.5      0.320
                          63        9717.6      0.290
                          64        9717.7      0.360
                          65        9717.8      0.180
                          66        9717.9      0.220
                          67        9718.0      0.160
                          68        9718.1      0.290
                          69        9718.2      0.180
                          70        9718.3      0.210
                          71        9718.4      0.200
                          72        9718.5      0.260
                          73        9718.6      0.200
                          74        9718.7      0.150
                          75        9718.8      0.190
                          76        9718.9      0.130
                          77        9719.0      0.200
                          78        9719.1      0.200
                          79        9719.2      0.270
                          80        9719.3      0.220
```

Example 3c

```
DIST.       COUNTY      CONT.  SECT.  JOB  HIGHWAY     DATE    NO. OF SECT.
 68        HARDROCK     9307    08         IH 102   06/16/82        4

                        PROFILE ANALYSIS FOR    IH 102

                        REFERENCE      STA.       INPUT
                         POINTS                   DATA

                            81       9719.4       0.210
                            82       9719.5       0.180
                            83       9719.6       0.180
                            84       9719.7       0.210
                            85       9719.8       0.230
                            86       9719.9       0.230
                            87       9729.5       0.190
                            88       9729.6       0.210
                            89       9729.7       0.240
                            90       9729.8       0.170
                            91       9729.9       0.250
                            92       9730.0       0.210
                            93       9730.1       0.150
                            94       9730.2       0.150
                            95       9730.3       0.170
                            96       9730.4       0.140
                            97       9730.5       0.200
                            98       9730.6       0.190
                            99       9730.7       0.140
                           100       9730.8       0.240
                           101       9730.8       0.250
                           102       9730.9       0.200
                           103       9731.0       0.170
                           104       9731.1       0.320
                           105       9731.2       0.020
                           106       9731.3       0.310
                           107       9731.4       0.300
                           108       9731.5       0.310
                           109       9731.6       0.370

 INPUT BREAK PTS. AT   29  64 103 109
```

Example 3d

```
                          TEXAS HIGHWAY DEPARTMENT

                        PROFILE ANALYSIS FOR    IH 102

                       THIS PROGRAM WAS RUN - 07-26-82

DIST.       COUNTY      CONT.  SECT.  JOB  HIGHWAY    DATE   NO. OF SECT.
 68        HARDROCK     9307    08         IH 102   06/16/82       4


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


 BREAK POINTS AT   29  64 103 109
       REF. POINTS       AVERAGE        STANDARD          F             F
         LIMITS            OF           DEVIATION       CALC.        TABLE
       OF SECTIONS       SECTIONS       OF SECTIONS                  VALUE

         1  TO  29        0.129            0.037     78.627        3.997
        30  TO  64        0.230            0.051      8.838        3.984
        65  TO 103        0.199            0.038      8.837        4.068
       104  TO 109        0.272            0.126      0.0          0.0
```

Asphaltic Concrete Pavement Overlay Design Procedure

In the previous sections on Data Requirements and Data Analysis, overall data requirements for the FPS System were discussed and specific data for the FPS ACP Overlay design mode were developed. To this point, it has been assumed that an overlay of the existing pavement was an applicable rehabilitation strategy. Chapter 9 of the FPS User's Manual discusses the applicability of the overlay procedure to the pavement in question.

The overlay procedure, or an overlay, is intended as a strengthening of the existing pavement. FPS does not consider skid resistance, appearance, roughness, etc. These items must be addressed by the designer through separate means.

With the above qualifying remarks in mind, it is decided that an ACP overlay of the existing pavement is the correct rehabilitation technique. Using the previously developed design sections, which are defined by the average SCI and standard deviation, the development of an overlay design continues.

To code an FPS overlay design problem, Cards 1 through 9 must be completed. Detailed instructions for the coding are in the FPS User's Manual. In Example 4a through 4g, handwritten comments have been added to the code sheets to convey some suggested courses of action as well as answers to frequently asked questions.

The ACP Overlay Design generated as a result of processing the previously coded overlay design is designated as Example 5a through 5c. Upon receipt of the "computer printout" it is the designer's responsibility to proofread or verify that all inputs were entered as intended. Pages 1 and 2 of the FPS-11 design procedures is a literal "print back" or "echo" of the input data. The input data serves as a review of input correctness and documentation of the entire design except the output. Page 3 and the subsequent pages are a summary of the best overlay schemes in order of increasing total cost.

The selection of the best overlay strategy for the project is the final task for the designer. Since the "Ordering" of design strategies is by total cost, it may be necessary to select a design other than No. 1. Initial Cost is usually a decision-maker since the various future costs are "down the road," so to speak. In general, the design selection should meet all or most of the

EXAMPLE 4a.

TEXAS HIGHWAY DEPARTMENT
FLEXIBLE PAVEMENT DESIGN SYSTEM
FPS - 11

PROJECT IDENTIFICATION

1.0	Card type	01	1 2
1.1	Problem number	* 001	3 4 5
1.2	District		6 7
1.3	County	HARDROCK	8 9 10 11 12 13 14 15 16 17 18 19 20 21
1.4	Control	9307	22 23 24 25
1.5	Section	08	26 27
1.6	Highway	IH 102	28 29 30 31 32 33 34 35 36 37
1.7	Date	06-16-82	38 39 40 41 42 43 44 45
1.8	IPE		46 47 48 49

* A new problem number should be used when the problem (design) is to be re-run and one or more inputs are being changed.

EXAMPLE 4b.

Note : The where, what and who commen are very importan for future revie and review by others.

TEXAS HIGHWAY DEPARTMENT
FLEXIBLE PAVEMENT DESIGN SYSTEM
FPS - 11

PROJECT COMMENTS

Card Type

02 LIMITS : FRØM INTERSECTIØN ØF US 599 WE
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
ST ØF JØNES, EAST
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

02 TØ LAZY CØUNTY LINE(SANDY RIVE
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
R) EAST ØF JØNES
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

02 ACP ØVERLAY DESIGN FØR WESTBØUND LANE,
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
ØDØMETER STATIØN 9711.40 TØ 9714.25
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

02 EXISTING SECTIØN : 1.50" HMAC TY D, 2.5
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
0" HMAC TY C, 0.60" 2CR SURF TR,
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

02 10.00" FB CR LIMESTØNE, 6.00" FC SANDY
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
GRAVEL
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

02
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

02 · SUBMITTED BY: BØ
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
B MIKULIN , D-8PD , TEX-AN 823-8101
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

Form 1114-2

Example 4c.

TEXAS HIGHWAY DEPARTMENT
FLEXIBLE PAVEMENT DESIGN SYSTEM
FPS - 11

BASIC DESIGN CRITERIA

3.0 Card type	0 3	1 2
3.1 Length of analysis period (years)	2 0	4 5
3.2 Minimum time to first overlay (years) *		9 10
3.3 Minimum time between overlay (years)	6	14 15
3.4 Minimum serviceability index	3 • 0	19 20 21
3.5 Design confidence level	D	23
3.6 Interest rate (%)	7 • 0	25 26 27

PROGRAM CONTROLS AND CONSTRAINTS

4.0 Card type	0 4	1 2
4.1 Problem type: 1 = new pavt. const., 2 = ACP overlay	2	4
4.2 Number of summary output pages (8 designs/page)	3	6
4.3 Max. funds available per S.Y. for initial const. ($) **	1 8 • 0 0	7 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)	1 6 • 0	18 19 20 21

* Not required in ACP Overlay Mode

** Column 7 is "active" allowing a maximum Value of 99.99 to be input. This input can also be used to control maximum overlay thickness.

Form 1114-3

EXAMPLE 4d.

TEXAS HIGHWAY DEPARTMENT
FLEXIBLE PAVEMENT DESIGN SYSTEM
FPS - 11

* Note, traffic data must be for a 20 year projection.

TRAFFIC DATA

5.0 Card type ______ 05
1 2

5.1 ADT at the beginning of the analysis period (veh./day) ______ * 4100.
5 6 7 8 9 10 11

5.2 ADT at the end of 20 years (veh./day) ______ * 17300.
15 16 17 18 19 20 21

5.3 One-drctn. cumulative 18 KSA at the end of 20 years ______ * 21896000.
23 24 25 26 27 28 29 30 31

5.4 Avg. approach speed to the overlay zone (mph) ______ 60
34 35

5.5 Avg. speed through overlay zone (overlay direction) (mph) ______ 30
39 40

5.6 Avg. speed through overlay zone (non-overlay direction) (mph) ______ 50
44 45

5.7 Percent of ADT arriving ea. hr. of construction ______ 6.0
49 50 51

5.8 Percent trucks in ADT ______ 49
54 55

ENVIRONMENT AND SUBGRADE

6.0 Card type ______ 06
1 2

6.1 District temperature constant ______ 23
4 5

6.2 Swelling probability ______ 0.00
9 10 11 12

6.3 Potential vertical rise (inches) ______ 0.0
13 14 15 16

6.4 Swelling rate constant ______ 0.00
19 20 21 22

6.5 Subgrade stiffness coefficient Not required in ACP Overlay Mode ______ .
24 25 26 27

EXAMPLE 4e.

TEXAS HIGHWAY DEPARTMENT
FLEXIBLE PAVEMENT DESIGN SYSTEM
FPS - 11

CONSTRUCTION AND MAINTENANCE DATA

7.0	**Card type**	0 7	1 2
7.1	**Initial serviceability index** — Not required in ACP Overlay Mode	•	4 5 6
7.2	**Serviceability index after overlaying**	4 • 5	9 10 11
7.3	**Minimum overlay thickness (inches)**	1 • 5	14 15 16
7.4	**Overlay construction time (hrs/day)**	1 0	19 20
7.5	**Asph. conc. compacted density (tons/C.Y.)**	1 • 9 0	24 25 26 27
7.6	**Asph. conc. production rate (tons/hr)**	2 0 0	28 29 30
7.7	**Width of each lane (feet)**	1 2	34 35
7.8	**First year cost of routine maintenance (dollars/lane - mile)**	5 0 • 0 0	38 39 40 41 42 43
7.9	**Annual incremental increase in maintenance cost (dollars/lane - mile)**	3 0 • 0 0	44 45 46 47 48 49

EXAMPLE 4f.

TEXAS HIGHWAY DEPARTMENT
FLEXIBLE PAVEMENT DESIGN SYSTEM
FPS - 11

DETOUR DESIGN FOR OVERLAYS

8.0	Card type	0 8	1 2
8.1	Detour model used during overlaying	3	4
8.2	Total number of lanes of the facility	4	5 6
8.3	Number of lanes open in the overlay direction	1	8
8.4	Number of lanes open in the non-overlay direction	2	10
8.5	Distance traffic is slowed (overlay direction) (miles)	1 • 0	12 13 14
8.6	Distance traffic is slowed (non-overlay direction) (miles)	0 • 7	17 18 19
8.7	Detour distance around the overlay zone (miles)	* •	22 23 24

* Used with Detour Model 5 only.

EXAMPLE 4g.

TEXAS HIGHWAY DEPARTMENT
FLEXIBLE PAVEMENT DESIGN SYSTEM
FPS - 11

EXISTING PAVEMENT AND PROPOSED ACP

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

Example 5a

```
                              TEXAS HIGHWAY DEPARTMENT
                                      FPS - 11
                                 ACP OVERLAY DESIGN

PROB   DIST.      COUNTY      CONT.  SECT.    HIGHWAY     DATE      IPE   PAGE
001     68       HARDROCK     9307    08      IH 102    06-16-82            1
******************************************************************************
                            COMMENTS ABOUT THIS PROBLEM

LIMITS : FROM INTERSECTION OF US 599 WEST OF JONES, EAST
         TO LAZY COUNTY LINE(SANDY RIVER) EAST OF JONES
ACP OVERLAY DESIGN FOR WESTBOUND LANE, ODOMETER STATION  9711.40 TO 9714.25
EXISTING SECTION : 1.50" HMAC TY D, 2.50" HMAC TY C, 0.60" 2CR SURF TR,
10.00" FB CR LIMESTONE, 6.00" FC SANDY GRAVEL

                           SUBMITTED BY: BOB MIKULIN , D-8PD , TEX-AN 823-8101
******************************************************************************

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

  LENGTH OF THE ANALYSIS PERIOD (YEARS)                                   20.0
  MINIMUM TIME BETWEEN OVERLAYS (YEARS)                                    6.0
  MINIMUM SERVICEABILITY INDEX P2                                          3.0
  DESIGN CONFIDENCE LEVEL                                                  D
  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 FIRST OVERLAY (DOLLARS)              18.00
  ACCUMULATED MAX DEPTH OF ALL OVERLAYS (INCHES) (EXCLUDING LEVEL-UP)     16.0

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

  ADT AT BEGINNING OF ANALYSIS PERIOD (VEHICLES/DAY)                    4100.
  ADT AT END OF TWENTY YEARS (VEHICLES/DAY)                            17300.
  ONE-DIRECTION 20.-YEAR ACCUMULATED NO. OF EQUIVALENT 18-KSA       21896000.
  AVERAGE APPROACH SPEED TO THE OVERLAY ZONE(MPH)                         60.0
  AVERAGE SPEED THROUGH OVERLAY ZONE (OVERLAY DIRECTION) (MPH)            30.0
  AVERAGE SPEED THROUGH OVERLAY ZONE (NON-OVERLAY DIRECTION) (MPH)        50.0
  PROPORTION OF ADT ARRIVING EACH HOUR OF CONSTRUCTION (PERCENT)           6.0
  PERCENT TRUCKS IN ADT                                                   49.0

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

  DISTRICT TEMPERATURE CONSTANT                                           23.0
  SWELLING PROBABILITY                                                     0.0
  POTENTIAL VERTICAL RISE (INCHES)                                         0.0
  SWELLING RATE CONSTANT                                                   0.0
```

Example 5b

```
                                   TEXAS HIGHWAY DEPARTMENT
                                          FPS - 11
                                     ACP OVERLAY DESIGN

PROB   DIST.      COUNTY       CONT.  SECT.     HIGHWAY       DATE      IPE    PAGE
001     68       HARDROCK      9307    08       IH 102      06-16-82             2

                                   INPUT DATA CONTINUED


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

  SERVICEABILITY INDEX P1 AFTER AN OVERLAY                                   4.5
  MINIMUM OVERLAY THICKNESS (INCHES)                                         1.5
  OVERLAY CONSTRUCTION TIME (HOURS/DAY)                                     10.0
  ASPHALTIC CONCRETE COMPACTED DENSITY (TONS/C.Y.)                           1.90
  ASPHALTIC CONCRETE PRODUCTION RATE (TONS/HOUR)                           200.0
  WIDTH OF EACH LANE (FEET)                                                 12.0
  FIRST YEAR COST OF ROUTINE MAINTENANCE (DOLLARS/LANE-MILE)                50.00
  ANNUAL INCREMENTAL INCREASE IN MAINTENANCE COST (DOLLARS/LANE-MILE)       30.00

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

  TRAFFIC MODEL USED DURING OVERLAYING                                      3
  TOTAL NUMBER OF LANES OF THE FACILITY                                     4
  NUMBER OF OPEN LANES IN RESTRICTED ZONE (OVERLAY DIRECTION)               1
  NUMBER OF OPEN LANES  IN RESTRICTED ZONE (NON-OVERLAY DIRECTION)          2
  DISTANCE TRAFFIC IS SLOWED (OVERLAY DIRECTION) (MILES)                    1.00
  DISTANCE TRAFFIC IS SLOWED (NON-OVERLAY DIRECTION) (MILES)                0.70
  DETOUR DISTANCE AROUND THE OVERLAY ZONE (MILES)                           0.0

EXISTING PAVEMENT AND PROPOSED ACP
**********************************

  THE AVERAGE SCI OF THE EXISTING PAVEMENT                                  0.129
  THE STANDARD DEVIATION OF SCI                                             0.037
  THE COMPOSITE THICKNESS OF THE EXISTING PAVEMENT (INCHES)                20.1
  THE IN-PLACE COST/COMPACTED C.Y. OF PROPOSED ACP (DOLLARS)               80.00
  SALVAGE VALUE OF PROPOSED ACP AT END OF ANALYSIS PERIOD (PERCENT)        40.0
  IN-PLACE VALUE OF EXISTING PAVEMENT (DOLLARS/C.Y.)                        0.0
  SALVAGE VALUE OF EXISTING PAVT. AT END OF ANALYSIS PERIOD (PERCENT)       0.0
  LEVEL-UP REQUIRED FOR THE FIRST OVERLAY (INCHES)                          0.0
```

Example 5c

```
                          TEXAS HIGHWAY DEPARTMENT
                                  FPS - 11
                             ACP OVERLAY DESIGN

PROB   DIST.      COUNTY       CONT.  SECT.     HIGHWAY      DATE       IPE    PAGE
001     68       HARDROCK      9307    08       IH 102     06-16-82               3

       AVERAGE SCI = 0.129                    CONFIDENCE LEVEL = D

                      SUMMARY OF THE BEST OVERLAY SCHEMES
                       IN ORDER OF INCREASING TOTAL COST

                            1        2        3        4        5        6
*****************************************************************************
INITIAL OVERLAY
   CONSTRUCTION COST    10.00    10.00     7.78    12.22     7.78    14.44
   USER COST             0.03     0.03     0.02     0.04     0.02     0.04
FUTURE OVERLAY(S)
   CONSTRUCTION COST     3.17     3.34     5.76     1.41     6.92     0.0
   USER COST             0.03     0.03     0.04     0.02     0.04     0.0
ROUTINE MAINT. COST      0.28     0.27     0.21     0.37     0.27     0.43
SALVAGE VALUE           -1.61    -1.72    -1.72    -1.61    -1.84    -1.49
*****************************************************************************
*****************************************************************************
TOTAL COST              11.89    11.95    12.10    12.44    13.19    13.43
*****************************************************************************
*****************************************************************************
NO.OF PERF.PERIODS          2        3        3        2        2        1
*****************************************************************************
PERF. TIME (YEARS)
     T(1)                 11.      11.       7.      17.       7.      24.
     T(2)                 23.      19.      15.      28.      26.
     T(3)                          27.      23.
*****************************************************************************
1ST LEVEL-UP(INCHES)      0.0      0.0      0.0      0.0      0.0      0.0
FUTURE LEVEL-UP(S)        0.5      0.5      0.5      0.5      0.5      0.5
*****************************************************************************
OVERLAY POLICY(INCH)
(INCLUDING LEVEL-UP)
     O(1)                 4.5      4.5      3.5      5.5      3.5      6.5
     O(2)                 3.0      2.0      3.0      2.0      5.0
     O(3)                          2.0      2.0
*****************************************************************************
SWELLING CLAY LOSS
 (SERVICEABILITY)
    SC(1)                 0.0      0.0      0.0      0.0      0.0      0.0
    SC(2)                 0.0      0.0      0.0      0.0      0.0
    SC(3)                          0.0      0.0
*****************************************************************************


        THE TOTAL NUMBER OF FEASIBLE OVERLAY SCHEMES CONSIDERED WAS          6
```

following criteria:

1. It should be within present fiscal constraint.
2. The design has the potential to correct the existing deficiency and to serve satisfactorily for the indicated performance period.
3. It complies with the "FPS Limitations" on stresses in semi-rigid pavement layers (to be discussed in another portion of this report).

The final task of the designer is the documentation of the reasons for a particular design selection.

"New" Pavement Design Procedures

"New" Pavement Design Procedure as used in FPS terminology refers to the use of the "new" pavement mode. The new pavement may be a "new" or initial pavement structure; it may be the widening phase of an existing structure, or it may be the total or partial rehabilitation of an existing structure.

Regardless of the mode used, FPS is a three-part process: (1) obtaining inputs for the FPS program, (2) computing with the FPS program, and (3) selecting the best pavement design strategy. In previous discussion, the desirable and required data for FPS and the analysis of this data have been reviewed. The illustration of the "new" pavement design procedure will be in terms of hypothetical or assumed design inputs.

The "new" procedure is similar to the overlay procedure in some respects. Assuming that all input data have been gathered, properly analyzed, etc., the new pavement design procedure generally follows the outline below:

1. Code input data Items 1 through 8 and Item 10
2. Process design (Program FPS-11)
3. Review output
4. Select best design strategy.

The coding of input data is shown on Example 6a through 6k. Notes included on the code sheets explain certain areas of input which are often either troublesome areas or they are often overlooked. As the coding for this assumed problem is reviewed, it should be kept in mind that this is a preliminary design. At this point, the objective is to establish a pavement design and its initial construction cost per square yard which will be the basis for estimating pavement costs for the pending program. It should also be pointed out how important the unit materials costs will become to the eventual successful design and construction of this project.

On the assumption of a design example where a fixed sum of money per square yard was available, the coding for this problem would be considerably different. An overall thickness constraint would also affect the coding.

Steps 2 and 3 involve the design processed by the FPS-11 Program. The program output for Problem M-3 is designated as Example 7a through 7h. Pages

3, 4, and 5 were not included because of their redundancy.

First, it is desirable to review Example Sheets 7a and 7B (pages 1 and 2). These pages are an echo print of the input and should be reviewed to determine that the design has been processed according to intent. The second point of interest is Example Sheet 7e (page 7) which prints out the optimal five-layer design. At the bottom of this page is the statement "...at the optimal solution, the following boundary restrictions are active...". Layers 1 and 5 were restricted but this is as expected since these values were fixed for a given thickness. Since there are no boundary restriction messages with respect to layers 2, 3 or 4 (Materials B, C and D), the cost-thickness-strength optimization desired actually occurred.

The next step should be the selection of a design strategy and the summary shown on Example 7f through 7h (pages 8-10) can assist in this selection. It appears that a number of choices would be available but the initial costs and total costs have such a small range that selection is largely a matter of personal choice. Strategies 7 and 8 are good examples of the personal choice nature of this design.

When the selection of a final design has been completed it only remains for the designer to document the reasons for making the selection.

EXAMPLE 6a.

TEXAS HIGHWAY DEPARTMENT
FLEXIBLE PAVEMENT DESIGN SYSTEM
FPS - 11

PROJECT IDENTIFICATION

1.0 Card type ______ 01
1 2

1.1 Problem number ______ * M-3
3 4 5

1.2 District ______ 28
6 7

1.3 County ______ SLEEPY HOLLOW
8 9 10 11 12 13 14 15 16 17 18 19 20 21

1.4 Control ______ 1403
22 23 24 25

1.5 Section ______ 09
26 27

1.6 Highway ______ SPL 101
28 29 30 31 32 33 34 35 36 37

1.7 Date ______ 07-19-82
38 39 40 41 42 43 44 45

1.8 IPE ______ 9002
46 47 48 49

* A new problem number should be used when the problem (design) is to be re-run and one or more inputs are being changed.

Form 1114-1

EXAMPLE 6b.

Note:
The where, what, and who comments are very important in future review and review by others.

TEXAS HIGHWAY DEPARTMENT
FLEXIBLE PAVEMENT DESIGN SYSTEM
FPS - 11

PROJECT COMMENTS

Card Type

02 LIMITS : FROM SUNDOWN ROAD, SOUTH 7.6 M
ILES

02 TO COUNTRY CLUB ROAD

02 PRELIMINARY DESIGN FOR THE 1982 4X PROG
RAM

02
SUBMITTED BY : JOHN J. DOE

02

02

02

orm 1114-2

EXAMPLE 6c.

TEXAS HIGHWAY DEPARTMENT
FLEXIBLE PAVEMENT DESIGN SYSTEM
FPS - 11

BASIC DESIGN CRITERIA

3.0 Card type ________ 0 3
1 2

3.1 Length of analysis period (years) ________ 2 0
4 5

3.2 Minimum time to first overlay (years) ________ 1 0
9 10

3.3 Minimum time between overlay (years) ________ 8
14 15

3.4 Minimum serviceability index ________ 3 • 0
19 20 21

3.5 Design confidence level ________ D
23

3.6 Interest rate (%) ________ 9 • 0
25 26 27

PROGRAM CONTROLS AND CONSTRAINTS

4.0 Card type ________ 0 4
1 2

4.1 Problem type: 1 = new pavt. const., 2 = ACP overlay ________ 1
4

4.2 Number of summary output pages (8 designs/page) ________ 3
6

4.3 Max. funds available per S.Y. for initial const. ($) ________ * 4 4 • 0 0
7 8 9 10 11

4.4 Maximum total thickness of initial construction (inches) ________ 3 8 • 0
13 14 15 16

4.5 Maximum total thickness of all overlays (inches) ________ 8 • 0
18 19 20 21

* Column 7 is "active", allowing a maximum value of 99.99 to be input. For preliminary design compute this value on the cost of maximum layer thicknesses.

** Use sum of maximum layer thicknesses if an unrestricted design is desired.

EXAMPLE 6d.

*NOTE - Traffic data must be for a 20 year projection.

TEXAS HIGHWAY DEPARTMENT
FLEXIBLE PAVEMENT DESIGN SYSTEM
FPS - 11

TRAFFIC DATA

5.0 Card type ________ 05 (1 2)

5.1 ADT at the beginning of the analysis period (veh./day) ________ * 16800. (5 6 7 8 9 10 11)

5.2 ADT at the end of 20 years (veh./day) ________ * 43200. (15 16 17 18 19 20 21)

5.3 One-drctn. cumulative 18 KSA at the end of 20 years ________ * 16400000. (23 24 25 26 27 28 29 30 31)

5.4 Avg. approach speed to the overlay zone (mph) ________ 55 (34 35)

5.5 Avg. speed through overlay zone (overlay direction) (mph) ________ 25 (39 40)

5.6 Avg. speed through overlay zone (non-overlay direction) (mph) ________ 45 (44 45)

5.7 Percent of ADT arriving ea. hr. of construction ________ 6.0 (49 50 51)

5.8 Percent trucks in ADT ________ 17 (54 55)

ENVIRONMENT AND SUBGRADE

6.0 Card type ________ 06 (1 2)

6.1 District temperature constant ________ 26 (4 5)

6.2 Swelling probability ________ 0.80 (9 10 11 12)

6.3 Potential vertical rise (inches) ________ 5.0 (13 14 15 16)

6.4 Swelling rate constant ________ 0.10 (19 20 21 22)

6.5 Subgrade stiffness coefficient ________ 0.22 (24 25 26 27)

EXAMPLE 6e.

TEXAS HIGHWAY DEPARTMENT
FLEXIBLE PAVEMENT DESIGN SYSTEM
FPS - 11

CONSTRUCTION AND MAINTENANCE DATA

7.0	Card type	07	1 2
7.1	Initial serviceability index	4.4	4 5 6
7.2	Serviceability index after overlaying	4.2	9 10 11
7.3	Minimum overlay thickness (inches)	1.5	14 15 16
7.4	Overlay construction time (hrs/day)	8	19 20
7.5	Asph. conc. compacted density (tons/C.Y.)	1.80	24 25 26 27
7.6	Asph. conc. production rate (tons/hr)	150	28 29 30
7.7	Width of each lane (feet)	12	34 35
7.8	First year cost of routine maintenance (dollars/lane - mile)	300.00	38 39 40 41 42 43
7.9	Annual incremental increase in maintenance cost (dollars/lane - mile)	125.00	44 45 46 47 48 49

EXAMPLE 6f.

TEXAS HIGHWAY DEPARTMENT
FLEXIBLE PAVEMENT DESIGN SYSTEM
FPS - 11

DETOUR DESIGN FOR OVERLAYS

8.0 Card type ____ 0 8
1 2

8.1 Detour model used during overlaying ____ 3
4

8.2 Total number of lanes of the facility ____ 6
5 6

8.3 Number of lanes open in the overlay direction ____ 2
8

8.4 Number of lanes open in the non-overlay direction ____ 3
10

8.5 Distance traffic is slowed (overlay direction) (miles) ____ 0 • 8
12 13 14

8.6 Distance traffic is slowed (non-overlay direction) (miles) ____ 0 • 6
17 18 19

8.7 Detour distance around the overlay zone (miles) ____ * 0 • 0
22 23 24

* Required for Detour Model 5 only.

EXAMPLE 6g.

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	1	4
10.2	Letter code of material	A	8
10.3	Name of material	A C P T Y D	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. ($)	* 8 0 • 0 0	31 32 33 34 35
10.5	Stiffness coefficient	0 • 9 6	40 41 42 43
10.6	Min. allowable thickness of initial const. (inches)	** 1 • 5 0	47 48 49 50 51
10.7	Max. allowable thickness of initial const. (inches)	** 1 • 5 0	55 56 57 58 59
10.8	Material's salvage value as % of original cost	3 0	62 63 64 65
10.9	Check*	1	80

* This cost is carried forward for future overlays.

** This sets or fixes the layer depth. Minimum depth of materials A, B & C of this problem will equal 8" and comply with the minimum thickness recommendation for semi-rigid layers.

EXAMPLE 6h.

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

2
4

10.2 Letter code of material

B
8

10.3 Name of material

A	C	P		T	Y		C										
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. ($)

7	0	•	0	0
31	32	33	34	35

10.5 Stiffness coefficient

0	•	9	6
40	41	42	43

10.6 Min. allowable thickness of initial const. (inches) *

	2	•	5	0
47	48	49	50	51

10.7 Max. allowable thickness of initial const. (inches) **

	6	•	0	0
55	56	57	58	59

10.8 Material's salvage value as % of original cost

		3	0
62	63	64	65

10.9 Check*

1
80

* Minimum depths of materials A, B, & C of this problem will equal 8" and comply with the minimum thickness recommendation for semi-rigid layers.

** Opening this range allows materials B & C to optimize in a cost-thickness-strength relationship.

EXAMPLE 6i.

TEXAS HIGHWAY DEPARTMENT
FLEXIBLE PAVEMENT DESIGN SYSTEM
FPS - 11

PAVING MATERIAL INFORMATION

10.0 Card type ________ 10
1 2

10.1 Layer designation number ________ 3
4

10.2 Letter code of material ________ C
8

10.3 Name of material ________ ASPHALT STAB BASE
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. ($) ________ 65.00
31 32 33 34 35

10.5 Stiffness coefficient ________ 0.85
40 41 42 43

10.6 Min. allowable thickness of initial const. (inches) ________ * 4.00
47 48 49 50 51

10.7 Max. allowable thickness of initial const. (inches) ________ ** 10.00
55 56 57 58 59

10.8 Material's salvage value as % of original cost ________ 40
62 63 64 65

10.9 Check* ________ 1
80

* Minimum depths of materials A, B, & C of this problem will equal 8" and comply with the minimum thickness recommendation for semi-rigid layers.

** Opening the range for this material allows materials A, B, & C to optimize in a cost - thickness - strength relationship.

Form 1114-8

EXAMPLE 6j.

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
4

10.2 Letter code of material ______ D
8

10.3 Name of material ______ FLEXIBLE BASE
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. ($) ______ 21.00
31 32 33 34 35

10.5 Stiffness coefficient ______ 0.55
40 41 42 43

10.6 Min. allowable thickness of initial const. (inches) ______ 6.00
47 48 49 50 51

10.7 Max. allowable thickness of initial const. (inches) ______ 12.00
55 56 57 58 59

10.8 Material's salvage value as % of original cost ______ 75
62 63 64 65

10.9 Check* ______ 1
80

EXAMPLE 6k.

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		5	4
10.2	Letter code of material		E	8
10.3	Name of material		LIME TRTD SUBGRADE	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. ($)		14•00	31 32 33 34 35
10.5	Stiffness coefficient		0•35	40 41 42 43
10.6	Min. allowable thickness of initial const. (inches)	*	8•00	47 48 49 50 51
10.7	Max. allowable thickness of initial const. (inches)	*	8•00	55 56 57 58 59
10.8	Material's salvage value as % of original cost		100	62 63 64 65
10.9	Check*	**	0	80

* Fixed at a pre-selected value.

** Last materials card must be coded "zero" in column 80.

Example 7a

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

PROB   DIST.      COUNTY      CONT.  SECT.     HIGHWAY     DATE     IPE    PAGE
M-3     28    SLEEPY HOLLOW   1403    09       SPL 101   07-19-82  9002      1
********************************************************************************
                         COMMENTS ABOUT THIS PROBLEM


LIMITS : FROM SUNDOWN ROAD, SOUTH 7.6 MILES
         TO : COUNTRY CLUB ROAD
PRELIMINARY DESIGN FOR THE 1982 4X PROGRAM.

                                                   SUBMITTED BY : JOHN J. DOE

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

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

  LENGTH OF THE ANALYSIS PERIOD (YEARS)                                    20.0
  MINIMUM TIME TO FIRST OVERLAY (YEARS)                                    10.0
  MINIMUM TIME BETWEEN OVERLAYS (YEARS)                                     8.0
  MINIMUM SERVICEABILITY INDEX P2                                           3.0
  DESIGN CONFIDENCE LEVEL                                                   D
  INTEREST RATE OR TIME VALUE OF MONEY (PERCENT)                            9.0

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

  NUMBER OF SUMMARY OUTPUT PAGES DESIRED ( 8 DESIGNS/PAGE)                  3
  MAX FUNDS AVAILABLE PER SQ.YD. FOR INITIAL DESIGN (DOLLARS)              44.00
  MAXIMUM ALLOWED THICKNESS OF INITIAL CONSTRUCTION (INCHES)               38.0
  ACCUMULATED MAX DEPTH OF ALL OVERLAYS (INCHES) (EXCLUDING LEVEL-UP)       8.0

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

  ADT AT BEGINNING OF ANALYSIS PERIOD (VEHICLES/DAY)                    16800.
  ADT AT END OF TWENTY YEARS (VEHICLES/DAY)                             43200.
  ONE-DIRECTION 20.-YEAR ACCUMULATED NO. OF EQUIVALENT 18-KSA        16400000.
  AVERAGE APPROACH SPEED TO THE OVERLAY ZONE(MPH)                          55.0
  AVERAGE SPEED THROUGH OVERLAY ZONE (OVERLAY DIRECTION) (MPH)             25.0
  AVERAGE SPEED THROUGH OVERLAY ZONE (NON-OVERLAY DIRECTION) (MPH)         45.0
  PROPORTION OF ADT ARRIVING EACH HOUR OF CONSTRUCTION (PERCENT)            6.0
  PERCENT TRUCKS IN ADT                                                    17.0

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

  DISTRICT TEMPERATURE CONSTANT                                            26.0
  SWELLING PROBABILITY                                                      0.80
  POTENTIAL VERTICAL RISE (INCHES)                                          5.00
  SWELLING RATE CONSTANT                                                    0.10
  SUBGRADE STIFFNESS COEFFICIENT                                            0.22
```

Example 7b

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

PROB   DIST.      COUNTY       CONT.  SECT.    HIGHWAY      DATE     IPE    PAGE
M-3     28    SLEEPY HOLLOW    1403    09      SPL 101    07-19-82  900Z      2

                              INPUT DATA CONTINUED


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

  SERVICEABILITY INDEX OF THE INITIAL STRUCTURE                                 4.4
  SERVICEABILITY INDEX P1 AFTER AN OVERLAY                                      4.2
  MINIMUM OVERLAY THICKNESS (INCHES)                                            1.5
  OVERLAY CONSTRUCTION TIME (HOURS/DAY)                                         8.0
  ASPHALTIC CONCRETE COMPACTED DENSITY (TONS/C.Y.)                              1.80
  ASPHALTIC CONCRETE PRODUCTION RATE (TONS/HOUR)                              150.0
  WIDTH OF EACH LANE (FEET)                                                    12.0
  FIRST YEAR COST OF ROUTINE MAINTENANCE (DOLLARS/LANE-MILE)                  300.00
  ANNUAL INCREMENTAL INCREASE IN MAINTENANCE COST (DOLLARS/LANE-MILE)         125.00

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)                   2
  NUMBER OF OPEN LANES  IN RESTRICTED ZONE (NON-OVERLAY DIRECTION)              3
  DISTANCE TRAFFIC IS SLOWED (OVERLAY DIRECTION) (MILES)                        0.80
  DISTANCE TRAFFIC IS SLOWED (NON-OVERLAY DIRECTION) (MILES)                    0.60
  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   ACP TY D           80.00    0.96    1.50     1.50    30.00
     2    B   ACP TY C           70.00    0.96    2.50     6.00    30.00
     3    C   ASPHALT STAB BASE  65.00    0.85    4.00    10.00    40.00
     4    D   FLEXIBLE BASE      21.00    0.55    6.00    12.00    75.00
     5    E   LIME TRTD SUBGRADE 14.00    0.35    8.00     8.00   100.00
```

Example 7c

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

 PROB   DIST.      COUNTY       CONT.  SECT.     HIGHWAY      DATE      IPE    PAGE
 M-3     28    SLEEPY HOLLOW    1403    09       SPL 101    07-19-82   900Z      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  ACP TY D             80.00   0.96     1.50     1.50   30.00
  2     B  ACP TY C             70.00   0.96     2.50     6.00   30.00
  3     C  ASPHALT STAB BASE    65.00   0.85     4.00    10.00   40.00
           SUBGRADE                     0.22


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

Example 7d

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

  PROB    DIST.      COUNTY        CONT.   SECT.     HIGHWAY       DATE      IPE    PAGE
  M-3      28    SLEEPY HOLLOW     1403     09      SPL 101     07-19-82   9007      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  ACP TY D               80.00    0.96     1.50     1.50   30.00
   2     B  ACP TY C               70.00    0.96     2.50     6.00   30.00
   3     C  ASPHALT STAB BASE      65.00    0.85     4.00    10.00   40.00
   4     D  FLEXIBLE BASE          21.00    0.55     6.00    12.00   75.00
            SUBGRADE                        0.22

   4   THE OPTIMAL DESIGN FOR THE MATERIALS UNDER CONSIDERATION--
        FOR INITIAL CONSTRUCTION THE DEPTHS SHOULD BE
              ACP TY D                1.50 INCHES
              ACP TY C                4.50 INCHES
              ASPHALT STAB BASE       6.00 INCHES
              FLEXIBLE BASE          12.00 INCHES
        THE LIFE OF THE INITAL STRUCTURE = 11. YEARS
        THE OVERLAY SCHEDULE IS
               2.00 (INCH(ES) (INCLUDING 0.5 INCH LEVEL-UP) AFTER   11. YEARS.

        TOTAL LIFE = 21. YEARS
        SERVICEABILITY LOSS DUE TO SWELLING CLAY IN EACH PERFORMANCE PERIOD IS
              (1)  0.873
              (2)  0.297

        THE TOTAL COSTS PER SQ. YD. FOR THESE CONSIDERATIONS ARE
              INITIAL CONSTRUCTION COST          29.917
              TOTAL ROUTINE MAINTENANCE COST      1.125
              TOTAL OVERLAY CONSTRUCTION COST     1.722
              TOTAL USER COST DURING
                      OVERLAY CONSTRUCTION        0.045
              SALVAGE VALUE                      -2.535
              TOTAL OVERALL COST                 30.273

        NUMBER OF FEASIBLE DESIGNS EXAMINED FOR THIS SET --      327

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

Example 7e

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

 PROB   DIST.      COUNTY        CONT.  SECT.    HIGHWAY     DATE      IPE    PAGE
 M-3     28    SLEEPY HOLLOW     1403    09      SPL 101   07-19-82  900Z      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  ACP TY D              80.00    0.96     1.50     1.50    30.00
  2    B  ACP TY C              70.00    0.96     2.50     6.00    30.00
  3    C  ASPHALT STAB BASE     65.00    0.85     4.00    10.00    40.00
  4    D  FLEXIBLE BASE         21.00    0.55     6.00    12.00    75.00
  5    E  LIME TRTD SUBGRADE    14.00    0.35     8.00     8.00   100.00
          SUBGRADE                       0.22

  5   THE OPTIMAL DESIGN FOR THE MATERIALS UNDER CONSIDERATION--
       FOR INITIAL CONSTRUCTION THE DEPTHS SHOULD BE
              ACP TY D                  1.50 INCHES
              ACP TY C                  3.00 INCHES
              ASPHALT STAB BASE         5.50 INCHES
              FLEXIBLE BASE            12.00 INCHES
              LIME TRTD SUBGRADE        8.00 INCHES
       THE LIFE OF THE INITAL STRUCTURE = 11. YEARS
       THE OVERLAY SCHEDULE IS
               2.00 (INCH(ES) (INCLUDING 0.5 INCH LEVEL-UP) AFTER   11. YEARS.

       TOTAL LIFE = 21. YEARS
       SERVICEABILITY LOSS DUE TO SWELLING CLAY IN EACH PERFORMANCE PERIOD IS
              (1)  0.879
              (2)  0.296

       THE TOTAL COSTS PER SQ. YD. FOR THESE CONSIDERATIONS ARE
              INITIAL CONSTRUCTION COST           29.208
              TOTAL ROUTINE MAINTENANCE COST       1.125
              TOTAL OVERLAY CONSTRUCTION COST      1.722
              TOTAL USER COST DURING
                     OVERLAY CONSTRUCTION          0.045
              SALVAGE VALUE                       -2.870
              TOTAL OVERALL COST                  29.231


       NUMBER OF FEASIBLE DESIGNS EXAMINED FOR THIS SET --      508


         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  5
                    4. THE MAXIMUM DEPTH OF LAYER  5
```

Example 7f

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

PROB   DIST.       COUNTY       CONT.  SECT.     HIGHWAY      DATE      IPE     PAGE
M-3     28    SLEEPY HOLLOW     1403    09       SPL 101    07-19-82   900Z      8
                        SUMMARY OF THE BEST DESIGN STRATEGIES
                         IN ORDER OF INCREASING TOTAL COST

                              1       2       3       4       5       6       7       8
*******************************************************************************************
MATERIAL ARRANGEMENT        ABCDE   ABCDE   ABCDE   ABCDE   ABCDE   ABCDE   ABCDE   ABCDE
INIT. CONST. COST           29.21   28.37   29.14   29.28   28.44   29.35   29.42   29.22
OVERLAY CONST. COST          1.72    2.67    1.88    1.72    2.67    1.72    1.72    1.88
USER COST                    0.04    0.08    0.05    0.05    0.08    0.05    0.05    0.05
ROUTINE MAINT. COST          1.12    1.09    1.09    1.12    1.09    1.12    1.12    1.09
SALVAGE VALUE               -2.87   -2.97   -2.88   -2.86   -2.96   -2.85   -2.83   -2.73
*******************************************************************************************
TOTAL COST                  29.23   29.24   29.28   29.31   29.33   29.39   29.48   29.51
*******************************************************************************************
NUMBER OF LAYERS              5       5       5       5       5       5       5       5
*******************************************************************************************
LAYER DEPTH (INCHES)
     D(1)                    1.50    1.50    1.50    1.50    1.50    1.50    1.50    1.50
     D(2)                    3.00    3.50    2.50    3.50    4.00    4.00    4.50    5.00
     D(3)                    5.50    4.50    6.00    5.00    4.00    4.50    4.00    4.00
     D(4)                   12.00   12.00   12.00   12.00   12.00   12.00   12.00   10.00
     D(5)                    8.00    8.00    8.00    8.00    8.00    8.00    8.00    8.00
*******************************************************************************************
NO.OF PERF.PERIODS            2       3       2       2       3       2       2       2
*******************************************************************************************
PERF. TIME (YEARS)
     T(1)                    11.     10.     10.     11.     10.     11.     11.     10.
     T(2)                    21.     20.     20.     21.     20.     22.     22.     20.
     T(3)                            30.                     31.
*******************************************************************************************
OVERLAY POLICY(INCH)
(INCLUDING LEVEL-UP)
     O(1)                    2.0     2.0     2.0     2.0     2.0     2.0     2.0     2.0
     O(2)                            2.0                     2.0
*******************************************************************************************
SWELLING CLAY LOSS
 (SERVICEABILITY)
    SC(1)                    0.88    0.85    0.87    0.89    0.86    0.89    0.90    0.87
    SC(2)                    0.30    0.30    0.30    0.30    0.30    0.29    0.29    0.30
    SC(3)                            0.12                    0.12
*******************************************************************************************
```

Example 7g

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

PROB   DIST.       COUNTY       CONT.  SECT.    HIGHWAY     DATE      IPE    PAGE
M-3     28     SLEEPY HOLLOW    1403    09      SPL 101   07-19-82   9002     9
                        SUMMARY OF THE BEST DESIGN STRATEGIES
                         IN ORDER OF INCREASING TOTAL COST

                           9      10      11      12      13      14      15      16
*************************************************************************************
MATERIAL ARRANGEMENT     ABCDE   ABCDE   ABCDE   ABCDE   ABCDE   ABCDE   ABCDE   ABCDE
INIT. CONST. COST        29.85   29.78   29.01   29.92   29.08   29.99   29.15   30.06
OVERLAY CONST. COST       1.72    1.88    2.74    1.72    2.67    1.72    2.67    1.72
USER COST                 0.04    0.05    0.08    0.04    0.08    0.05    0.08    0.05
ROUTINE MAINT. COST       1.12    1.09    1.06    1.12    1.09    1.12    1.09    1.12
SALVAGE VALUE            -2.84   -2.85   -2.94   -2.83   -2.93   -2.82   -2.92   -2.81
*************************************************************************************
TOTAL COST               29.90   29.94   29.95   29.98   29.99   30.06   30.08   30.14
*************************************************************************************
NUMBER OF LAYERS           5       5       5       5       5       5       5       5
*************************************************************************************
LAYER DEPTH (INCHES)
     D(1)                 1.50    1.50    1.50    1.50    1.50    1.50    1.50    1.50
     D(2)                 3.00    2.50    3.50    3.50    4.00    4.00    4.50    4.50
     D(3)                 6.50    7.00    5.50    6.00    5.00    5.50    4.50    5.00
     D(4)                10.00   10.00   10.00   10.00   10.00   10.00   10.00   10.00
     D(5)                 8.00    8.00    8.00    8.00    8.00    8.00    8.00    8.00
*************************************************************************************
NO.OF PERF.PERIODS         2       2       3       2       3       2       3       2
*************************************************************************************
PERF. TIME (YEARS)
     T(1)                 11.     10.     10.     11.     10.     11.     10.     11.
     T(2)                 21.     20.     19.     21.     20.     21.     20.     22.
     T(3)                                 30.             30.             31.
*************************************************************************************
OVERLAY POLICY(INCH)
(INCLUDING LEVEL-UP)
     O(1)                 2.0     2.0     2.0     2.0     2.0     2.0     2.0     2.0
     O(2)                                 2.0             2.0             2.0
*************************************************************************************
SWELLING CLAY LOSS
 (SERVICEABILITY)
    SC(1)                 0.87    0.86    0.85    0.88    0.85    0.89    0.86    0.89
    SC(2)                 0.30    0.30    0.30    0.30    0.30    0.29    0.30    0.29
    SC(3)                                 0.13            0.12            0.12
*************************************************************************************
```

Example 7h

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

PROB   DIST.      COUNTY        CONT.  SECT.    HIGHWAY     DATE      IPE    PAGE
M-3     28    SLEEPY HOLLOW     1403    09      SPL 101   07-19-82   900Z     10
                    SUMMARY OF THE BEST DESIGN STRATFGIES
                     IN ORDER OF INCREASING TOTAL COST

                            17       18       19       20       21       22       23       24
**********************************************************************************************
MATERIAL ARRANGEMENT       ABCDE    ABCD     ABCD     ABCDE    ABCD     ABCD     ABCD     ABCD
INIT. CONST. COST          29.93    29.92    29.85    30.00    29.99    29.15    30.06    29.22
OVERLAY CONST. COST         1.88     1.72     1.88     1.88     1.72     2.74     1.72     2.67
USER COST                   0.05     0.04     0.05     0.05     0.04     0.08     0.05     0.08
ROUTINE MAINT. COST         1.09     1.12     1.09     1.09     1.12     1.06     1.12     1.09
SALVAGE VALUE              -2.69    -2.54    -2.55    -2.68    -2.52    -2.62    -2.51    -2.61
**********************************************************************************************
TOTAL COST                 30.26    30.27    30.32    30.34    30.36    30.41    30.44    30.45
**********************************************************************************************
NUMBER OF LAYERS            5        4        4        5        4        4        4        4
**********************************************************************************************
LAYER DEPTH (INCHES)
     D(1)                   1.50     1.50     1.50     1.50     1.50     1.50     1.50     1.50
     D(2)                   5.50     4.50     4.00     6.00     5.00     5.50     5.50     6.00
     D(3)                   4.50     6.00     6.50     4.00     5.50     4.50     5.00     4.00
     D(4)                   8.00    12.00    12.00     8.00    12.00    12.00    12.00    12.00
     D(5)                   8.00                       8.00
**********************************************************************************************
NO.OF PERF.PERIODS          2        2        2        2        2        3        2        3
**********************************************************************************************
PERF. TIME (YEARS)
     T(1)                   10.      11.      10.      10.      11.      10.      11.      10.
     T(2)                   20.      21.      20.      20.      21.      19.      21.      20.
     T(3)                                                                30.               31.
**********************************************************************************************
OVERLAY POLICY(INCH)
(INCLUDING LEVEL-UP)
     O(1)                   2.0      2.0      2.0      2.0      2.0      2.0      2.0      2.0
     O(2)                                                                2.0               2.0
**********************************************************************************************
SWELLING CLAY LOSS
 (SERVICEABILITY)
    SC(1)                   0.86     0.87     0.87     0.87     0.88     0.85     0.88     0.86
    SC(2)                   0.30     0.30     0.30     0.30     0.30     0.30     0.30     0.30
    SC(3)                                                                0.12              0.12
**********************************************************************************************

         THE TOTAL NUMBER OF FEASIBLE DESIGNS CONSIDERED WAS        835
```

Limitations of the FPS System

The performance equation of FPS-11 is empirical in nature. It is possible for FPS to produce answers outside the limits or experience range for which it was developed. It is the responsibility of well qualified pavement designers to examine all designs generated by FPS for reasonableness. Chapter 1A, "Limitations of the FPS System" of the Flexible Pavement Designer's Manual, outlines these areas of limitations which the designer must avoid when using the FPS system.

In discussing the limitations of FPS, attention is directed to Figure 13, Critical Wheel Load Induced Stresses in Pavements. The three very general failure areas in a typical flexible pavement are:

1. Tensile stress failure of semi-rigid pavement layers,
2. Shear failures of surface courses and base courses,
3. Compressive failures of the subgrade.

Tensile stresses at the bottom of semi-rigid surfacing (bound) layers on untreated flexible layers can become excessively high and induce premature fatigue cracking of the surfacing layers. Figure 14, Tensile Stresses in Semi-Rigid Pavement Layers, defines the elements involved in tensile stress failures of semi-rigid pavement layers. The "E" value is the modulus of elasticity of the respective pavement layers. When the ratio of E1/E2 becomes large and the thickness of the semi-rigid layer (D1) is relatively small, the resulting condition is referred to as "a plate of glass on a sponge."

Referring again to Figure 14, there is a need to study the effects of increasing the surfacing layer thickness (D1) while monitoring the stress condition at the bottom of the surfacing layer and directly under the wheel load. Figure 15, Stress-Layer Thickness Relationship, shows what happens as the D1 value is increased. With a very thin surfacing layer the stress is compressive and approaches the value of tire pressure under the wheel load. As the thickness D1 is increased the stress becomes less compressive and then at some degree of thickness D1 passes into tension. If the thickness D1 continues to increase, there is a peak in the tensile stress after which there is a decrease in tensile stress with an increased surface layer thickness. In repeating this for different modular ratios, the peak tensile value increases

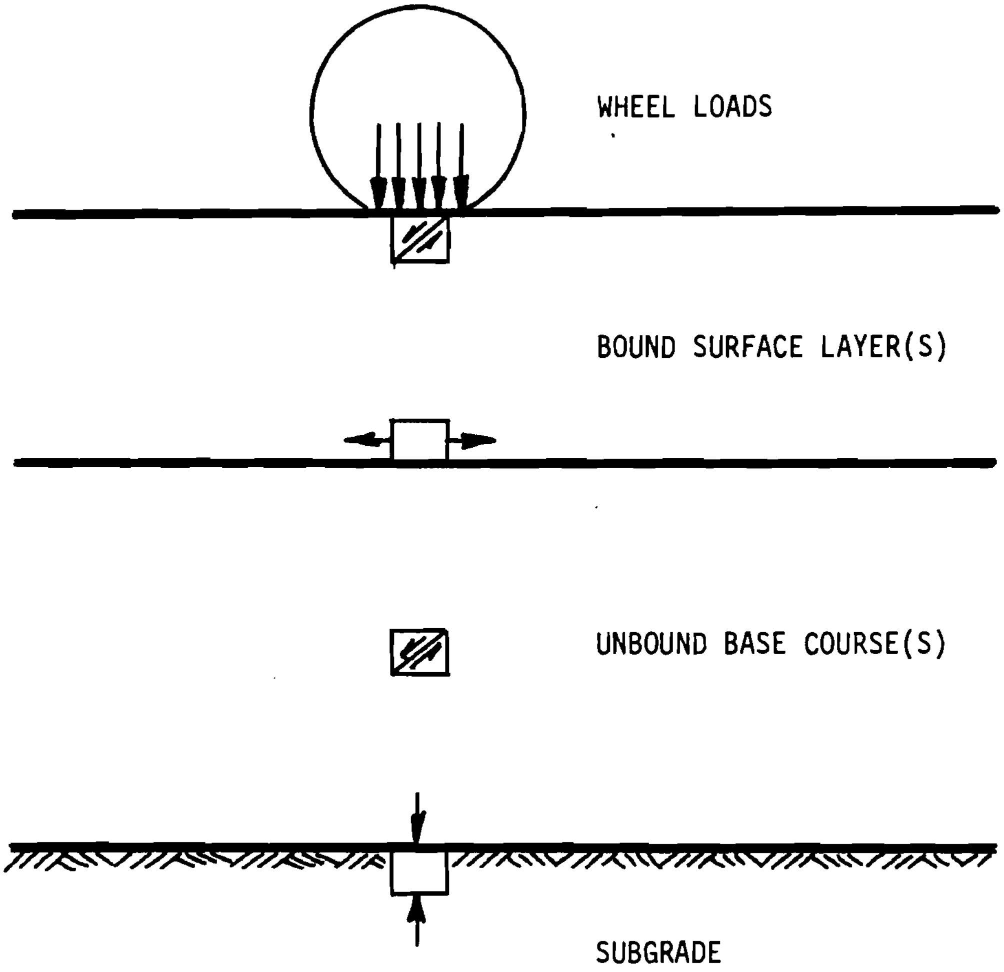


FIGURE 13

Critical Wheel Load Induced Stresses in Pavements

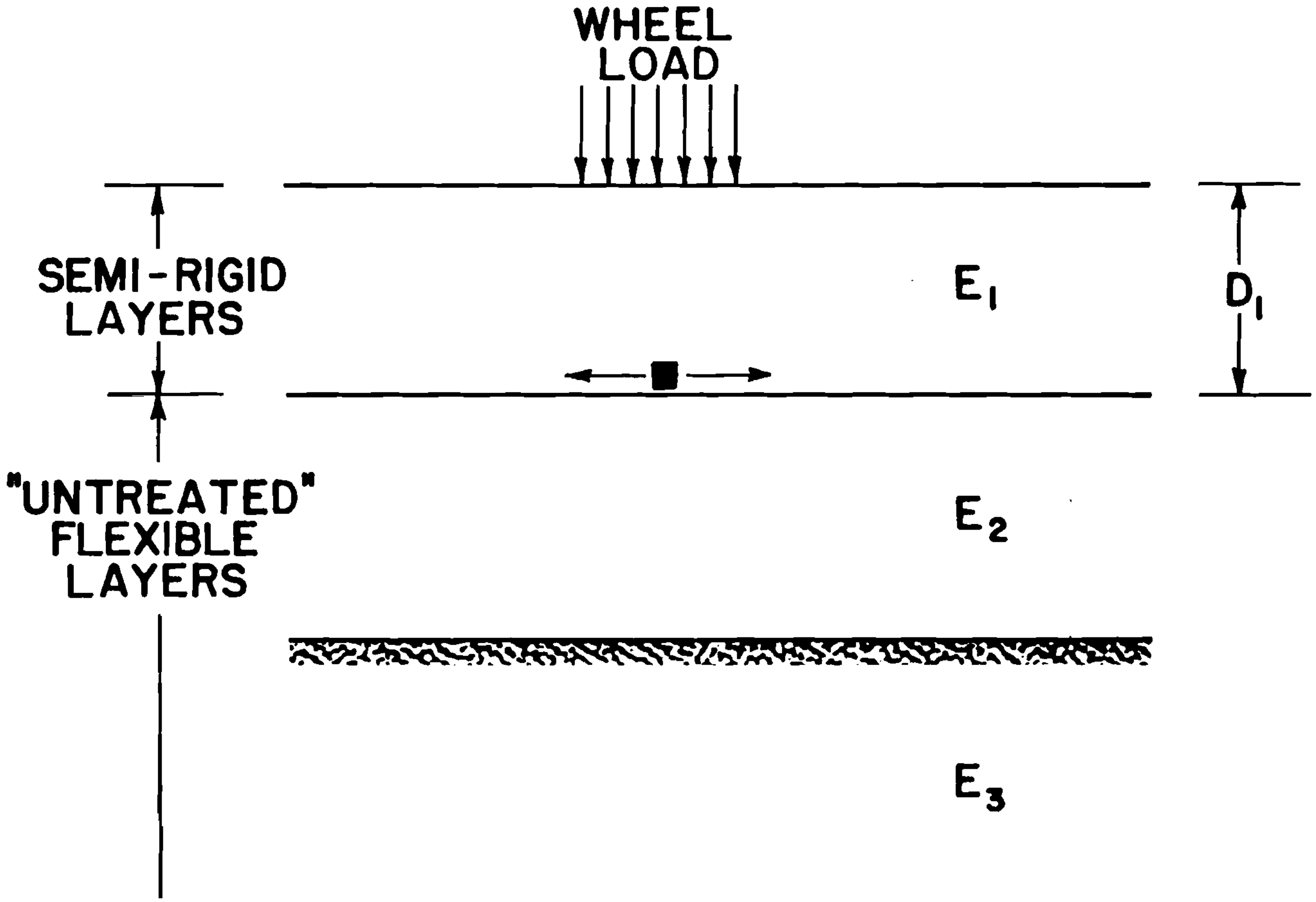


FIGURE 14

TENSILE STRESSES IN SEMI-RIGID PAVEMENT LAYERS

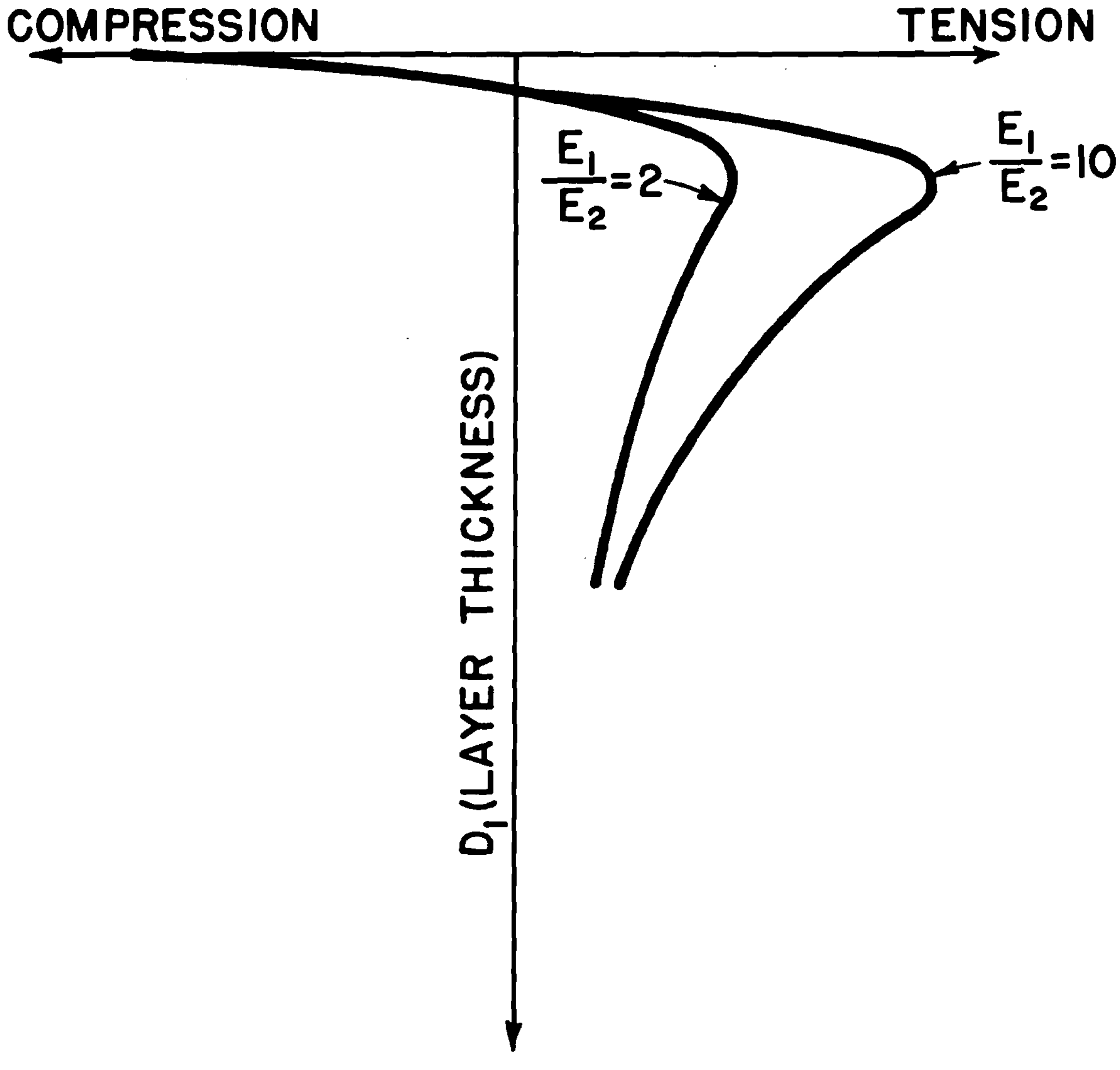


FIGURE 15

STRESS-LAYER THICKNESS RELATIONSHIP

as the modular ratio E1/E2 becomes larger.

The conclusion from the preceding is that there are three areas of surfacing layers thickness with respect to the limiting tensile stress condition. Figure 16, Surfacing Layer(s) Thickness Ranges, shows these ranges as thin, intermediate, and thick. Figure 16 shows that the thin and thick ranges are in the safe range with respect to tensile stresses at the bottom of the surfacing; whereas, the intermediate range depicts the danger area or the area of thickness which is more likely to produce premature fatigue cracking.

Table 2, Recommended Minimum Semi-Rigid Layer thicknesses, is from the Flexible Pavement Designer's Manual and gives guidelines or recommendations on minimum layer thickness as a function of design wheel load. It appears that for general highway pavement design the combined thickness of all semi-rigid surfacing layers should not be less than seven inches and, in most instances, the eight inches would be the more desirable value. On the practical side, experience has also indicated that pavements in a continually warm climate do not suffer from this condition and that thin surfacing has a reasonable survival rate.

The thin area or range is another consideration. As a general rule, these areas should not exceed two inches in thickness during their design period. In addition to being thin, it is also imperative that they be flexible. The multilayer surface treatments plus seal coats are best examples of thin and flexible and perform very well under the traffic conditions for which they were intended.

Again referring to Figure 13, the area of failure concern in a flexible pavement structure is shear stress in surface course and base layers. In general, this failure area has not been a limitation in FPS. The shear failure of a surface course is usually referred to as "rutting" and this is a subject better addressed in the mix design phase of flexible pavement design. Shear failures in base courses are rare. Specifications address this in terms of triaxial requirements for the specified base course which has been a satisfactory procedure. While it is acknowledged that current specifications do not specify Dynaflect stiffness coefficient requirements for a given base material, the development of this coefficient for design purposes is assumed to be from a base course which has met a given specification requirement. It is assumed

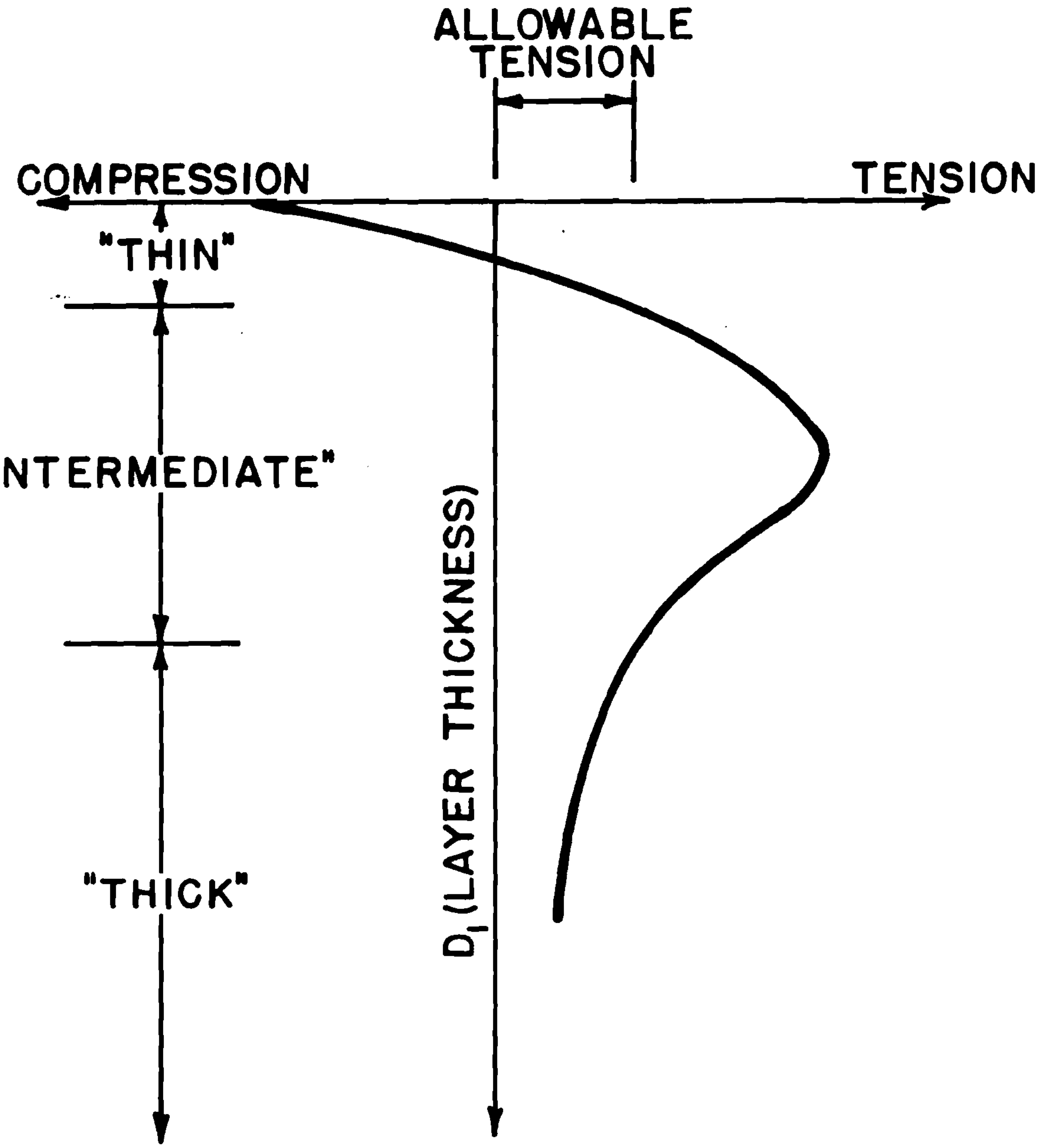


FIGURE 16

SURFACING LAYER(S) THICKNESS RANGES

TABLE 2

RECOMMENDED MINIMUM
SEMI-RIGID LAYER THICKNESSES

Design Wheel Load (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"

that the design coefficient can be repeated by specifying materials from the specification under which the coefficient was derived. In conclusion, shear stress failures in base courses are only minor problems.

Figure 14 indicates that compressive stress in the subgrade is one of the three critical stress areas. One of the significant limitations to FPS is its tendency to produce thin designs when the traffic (18-KSA applications) is low. The FPS system uses 18-KSA equivalents as a performance equation input. Low traffic roads such as city streets or farm-to-market roads may have low values of 18-KSA applications, but there may be a few very heavy wheel loads in this traffic and these loads produce the high compressive stress in the subgrade if the design is too thin. To cope with this limitation to FPS the Flexible Pavement Designer's Manual recommends that all designs determined by FPS be checked by a "quick" or "short" triaxial design procedure to assure adequate pavement cover over the subgrade. A section of this report deals with flexible pavement design by triaxial design procedures. The section on triaxial design presents a procedure known as the "Modified Triaxial Design Procedure for Use with Flexible Pavement Design System (FPS)," which is recommended as a check on all designs determined by FPS.

In summarizing the section on limitations of FPS, there are two basic considerations:

1. Semi-rigid pavement layers shall be thick and stiff enough to withstand the inherent tensile stresses.
2. All FPS designs shall be checked by triaxial procedures to insure adequate cover over the subgrade.

Pavement Design Assistance By D-8PD

The offer to assist with pavement-related matters is general in nature and applies to all pavement types.

Generally it will be the District's responsibility to do the data collection, data analysis, design or analysis procedures and selection of optimal strategies. Personnel from File D-8PD will assist and advise District personnel to the extent necessary.

On very special projects File D-8PD will do the data collection, data analysis, design or analysis procedures and recommend optimal strategies. The limited number of D-8PD personnel and other duties make it necessary that this service be used on a limited basis.

File D-8PD personnel will, as always, be glad to respond to specific problems by telephone or other means.

File D-8PD will also be glad to consider requests for pavement design training. It is anticipated that training sessions would be in Austin when sufficient requests are received, but other requests would be considered.

Any problems concerning the Flexible Pavement Design System (FPS) should be communicated to D-8PD personnel by telephone or other suitable means.

In addition to the references listed in this report, the reader may wish to consult the "Suggested Reading List" at the end of the report.

References

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

2. Hudson, W. R., Finn, F. N., McCullough, B. F. McCullough, Nair, K., and Vallerga, B. A., "Systems Approach to Pavement Design, Systems Formulation, Performance Definition and Materials Characterization," Final Report NCHRP Project 1-10, Materials Research and Development, Inc., March 1968.

3. Hudson, W. Ronald, McCullough, B. Frank, Scrivner, F. H., and Brown, James L., "A Systems Approach Applied to Pavement Design and Research," Report No. 123-1, March 1970. Describes a long-range comprehensive research program to develop a pavement systems analysis and presents a working systems model for the design of flexible pavements.

4. Buttler, Larry and Orellana, Hugo, "Implementation of a Complex Research Development of Flexible Pavement Design System Into Texas Highway Department Design Operations," Report No. 123-20, June 1973. Describes the step-by-step process used in incorporating the implementation research into the actual working condition.

5. Orellana, Hugo E., "FPS-11 Flexible Pavement System Computer Program Documentation," Report No. 123-15, October 1972. Gives the documentation of the computer program FPS-11.

6. Scrivner, F. H., and Moore, W. M., "An Empirical Equation for Predicting Pavement Deflections," Report No. 32-12, Texas Transportation Institute, Texas A&M University, 1968.

Suggested Reading List

1. Yoder, E. J. and M. W. Witczak, Principles of Pavement Design, Second Edition, John Wiley & Sons, Inc., New York, N. Y., 1975.
2. Haas, R. and Hudson, W. R., Pavement Management Systems, McGraw-Hill Book Company, New York, N. Y., 1978.
3. Hudson, W. Ronald, McCullough, B. Frank, Brown, James L., Peck, Gerald B., and Lytton, Robert L., "Overview of Pavement Management Systems Developments in the State Department of Highways and Public Transportation," Report No. 123-30F, January 1976. Summarizes the findings and output of a research project which lasted seven years giving the approach and program in several sections. In particular, special attention is given to implementation activities in the project and the benefits which have been and will be derived from the work.

TEXAS TRIAXIAL DESIGN PROCEDURES

TEXAS TRIAXIAL DESIGN PROCEDURES

The Texas Triaxial Design Procedure for flexible pavements is a development by the Texas State Department of Highways and Public Transportation. The exact date of the procedures' conception is difficult to establish. The development of the Texas Triaxial Design procedure is generally credited to Mr. Chester McDowell, former Soils Engineer, Texas Highway Department. In the early 1950's, Mr. McDowell published various papers which were forerunners of the formal procedure. Mr. Frank H. Scrivner, former Research Engineer, Texas Highway Department, apparently also deserves significant credit in the development of the Texas Triaxial Design Procedure. There is published evidence available that in the late 1940's, Mr. Scrivner was working on stress/strain solutions in two- and three-layer elastic systems using the Burmister theory. It appears almost certain that these computations form the numerical basis of the Texas Triaxial Design System.

As late as 1974 there were two official versions of the Texas Triaxial Design procedures for flexible pavement. The Materials and Tests Division and the Highway Design Division each sponsored a version of the procedure. The procedures were not identical and substantial difference in design could be noted by comparison of procedures. In 1974, the Highway Design Division adopted the Flexible Pavement Design System (FPS) as its primary flexible pavement design procedure and the triaxial procedure was deleted. In the Flexible Pavement Designer's Manual, reference is made to the need for checking all FPS-generated designs for adequate thickness to prevent compressive subgrade failures. The Designer's Manual made reference to a "quick" or "short" triaxial design procedure.

The Materials and Test Division, File D-9, maintain in their Manual of Testing Procedures, Test Method Tex-117-E, entitled "Triaxial Compressive Tests for Disturbed Soils and Base Materials". This procedure is frequently referred to as the "Texas Triaxial Design System" and is the Department's official triaxial design system. A copy of Test Method Tex-117-E will be placed in Appendix A of this report for ready reference.

A very brief discussion concerning each of these procedures will follow. The modified procedure will be presented in full in a following section of this report.

Test Method Tex-117E, Triaxial Compression Tests for Disturbed Soils and Base Materials

The triaxial design procedure designated as Test Method Tex-117-E may be divided into two very general areas a classification procedure for base materials and subgrade soils, and a base thickness design procedure. The remarks which follow are intended to address only the base thickness design procedure.

The basic purpose of the procedure is to insure that the pavement design is of adequate thickness to protect against a compressive failure of the subgrade material. This feature of the procedure has been the reason for the general acceptance and successful long term usage. The procedure is also used to determine adequate thickness above each base layer to insure that shear failures do not occur.

The inability of this procedure to adequately account for the very high level of repetitive loading may be one of the areas of concern at this point in time. The equivalency or trade-off of bound layers versus unbound layers is addressed through the cohesiometer reduction feature of the program and is also a concern area. It is necessary to justify the use of premium materials such as asphalt stabilized base if design cost optimization is to be achieved. The adequacy of the cohesiometer test to respond to the equivalency question makes it difficult to use the procedure when the need for thick-stiff asphalt layers is dictated by experience but the means of justification is not fully available.

The flexible pavement design procedure defined as Test Method Tex-117-E is recommended when load repetitions are not excessive and when it is anticipated that the surfacing design will be of the thin flexible variety. This procedure should also be used when the use of a full traixial design procedure is specifically desired.

Modified Triaxial Design Procedure for Use with the Flexible Pavement Design System (FPS)

The modified procedure is a modification of Test Method Tex-117-E. The procedure was developed as a rapid means of checking FPS-generated designs for triaxial adequacy to guard against compressive subgrade failures. The FPS Designer's Manual on page 1A.3, recommends that this check for triaxial adequacy be made.

It is not recommended that the modified procedure be used for any other purpose than the checking of FPS designs for overall triaxial adequacy to prevent subgrade failures.

If full triaxial design procedures are desired, the procedure outlined in Test Method Tex-117-E is recommended for usage.

Summary and Recommendation

The two triaxial design/analysis procedures available to Departmental personnel are:

1. Test Method Tex-117-E, Triaxial Compression Tests Disturbed Soils and Base Materials.
2. Modified Triaxial Design Procedure for Use with the Flexible Pavement Design System (FPS).

Recommendations concerning these triaxial procedures are as follow:

1. It is recommended that all designs generated by the Flexible Pavement Design System be checked for triaxial adequacy by use of the modified procedure.
2. The modified procdure is not to be used as the sole design procedure.
3. When triaxial design procedures are to be used exclusively, it is recommended that the procedure outlined in Test Method Tex-117-E, be used.

SWELLING CLAYS IN THE FPS SYSTEM

SWELLING CLAYS IN THE FPS SYSTEM

The objectives of this presentation is two-fold, first a brief condensed description of the equation modeling swelling clay serviceability losses in the FPS-11 computer program is presented and second there will be a suggested procedure for applying the swelling clay performance loss concept in the design of flexible pavements.

The current swelling clay model in computer program FPS-11 was developed by Dr. Robert L. Lytton, Texas Transportation Institute, Texas A&M University, College Station, Texas. The equation is as follows:

$$PSI(Loss) = 0.335*C1*C2*(1 - e^{-\theta t})$$

PSI(Loss) = Serviceabilty loss due to Swelling clay component.

C1 = The fraction of a roadway length that has expansive clay in locations that are likely to promote volume changes.

C2 = The maximum amount of differential heave in inches that is likely to be noted along a roadway.

θ = A constant which determines the rate of heaving of the expansive clay.

t = The time (years) since initial construction.

The second part of this report discusses a suggested procedure for applying the swelling clay performance loss concept to the design of flexible pavements. This procedure is based on the fact that increasing the pavement thickness alone will not appreciably decrease the losses in pavement serviceability with time. Basically it is proposed that a non-swelling condition should be designed for and constructed, but the proposed design should be re-run with FPS-11 using 100% swelling clay probability (C1=1.0) to estimate the projected effects on performance.

Figure 1, Project Layout, shows a proposed project which is seven (7) miles in length. Within the project limits there is a two (2) mile section which contains soils which are subject to swelling based on past experience and laboratory testing. In this example 29 percent of the project has soils which are subject to swelling. If the fractional approach is used as suggested in the FPS Manual it becomes obvious that the non-swelling portion of the project will be slightly overdesigned. The section with swelling clays will also have been increased in thickness in an effort to increase performance life. A slight increase in pavement thickness cannot produce enough "surcharge effect" to overcome the tendency to swell or swelling energy of swelling clay soils.

The procedure presented is intended to make the designer and planner aware of the future consequences of constructing a pavement on a soil which has swelling potential. It is proposed that flexible pavements be designed for the non-swelling condition and investigated at the 100 percent swelling condition to determine or anticipate the future maintenance and/or rehabilitation requirements in those areas where the swelling soils are present. Figure 2, Effects of Swelling Clays on Pavement Performance, diagrams the results of swelling clays on a given pavement design. The upper diagram indicates the performance expected on a design if swelling clays are not present. The pavement design in question is as follows:

1" Asphaltic Concrete Pavement
10" Flexible Base
12" Foundation Course
Natural Subgrade (Coefficient = 0.24)

As noted the initial performance period is 14 years at which time a 1.5 inch asphaltic concrete overlay is expected to extend the performance period out to 24 years. Looking at the lower part of Figure 2 the effects of swelling clays (100 percent) on the performance of the above noted design can be observed. The initial performance period has been reduced to 6 years when a 1.5 inch asphaltic concrete overlay is required the second performance period terminates at 14 years when another 1.5 inch asphaltic concrete overlay is required. The third and final performance period will extend out to 24 years. The consequences of the swelling clays on this design are the reduction of the initial performance period and the requirement of an additional overlay within the analysis period. The designer needs to make financial plans for the additional overlay which will be within the design period. The second point to consider is whether the short or reduced performance periods are acceptable.

There are procedures such as ponding, vertical moisture barriers and deep undercutting which have potential to eliminate or at least reduce the effects of swelling clays on performance, but these procedures are costly. This presents the need for a cost benefit study with respect to reducing future maintenance or rehabilitation and also the enhancement of the design by achieving longer performance periods.

To give the designer a feel for the reducton in serviceability due to swelling clays Figure 3, Plot of Swelling Clay Losses, has been prepared. As noted under C1, the plots in Figure 3 are on the basis of 100 percent swelling clays.

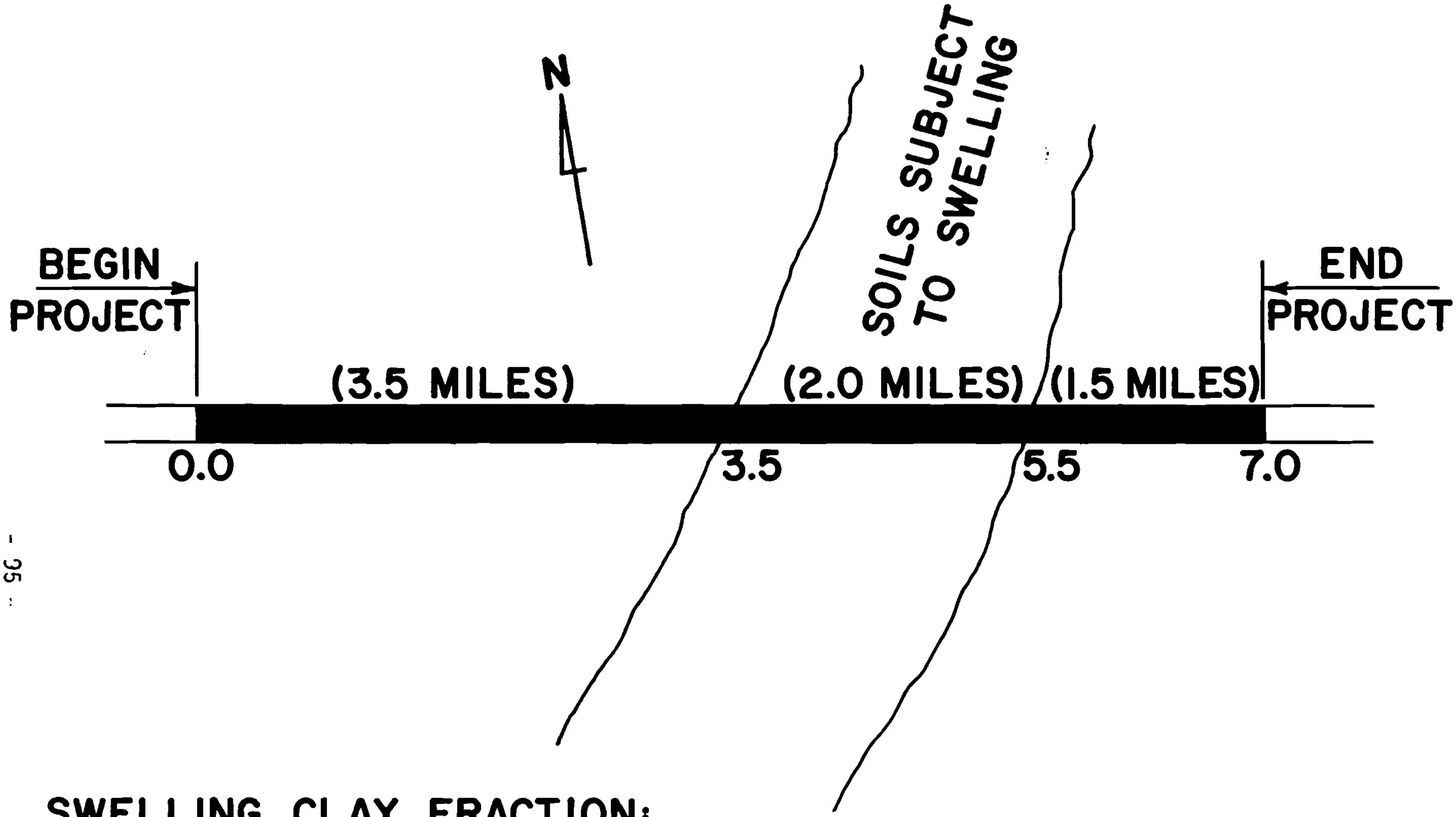
The FPS-11 program, on its output sheets, prints out the serviceability loss due to swelling clay in each performance period. These values indicate what part of the serviceability of a pavement is being used to satisfy the swelling clay requirement thus the remainder is available to traffic demands, etc.

To use the plots in Figure 3, it is necessary to know the potential vertical rise (heave), the swelling rate constant and the time period in question. In the Flexible Pavement Designers Manual (FPS User's Manual), Figure 6.3, Nomograph For Selecting Swelling Rate Constant, provides a means of estimating the swelling rate constant of a soil. From this figure it is seen that the swelling rate constant is a function of moisture supply and subgrade soil fabric. Example Problem No. 1, which is attached, outlines the use of Figure 3 by use of a simple example problem.

The maximum heave anticipated can be equated to the Potential Vertical Rise (PVR) of a soil as defined in Test Method Tex-124-E, "Method for Determining the Potential Vertical Rise, PVR". Another method of estimating the vertical heave would be to examine an older existing pavement with respect to the amount of level-up that has been necessary in areas where similar swelling clays exist. The method described in Tex-124-E could be a costly laboratory analysis procedure and the benefits from accurately knowing the amount of potential heave versus a rough estimate have to be considered.

In summary, it is the intention of this report to present a suggested procedure for applying the swelling clay performance loss concepts of computer program FPS-11 to the design of flexible pavements. Basically the pavement designer is urged to design for the non-swelling condition, but to check the proposed design by reapplying FPS-11 with the swelling clay component set at 100 percent. The resulting performance periods and overlay requirements should be reviewed with respect to acceptability and future funding requirements.

Questions concerning the concepts proposed in this report should be addressed to the Pavement Design Section (D-8PD) of the Highway Design Division.



SWELLING CLAY FRACTION:

$C1 = (2.0 / 7.0) * 100 = 29\%$

$C2 = 5''$

$\theta = 0.12$

FIGURE 1

PROJECT LAYOUT

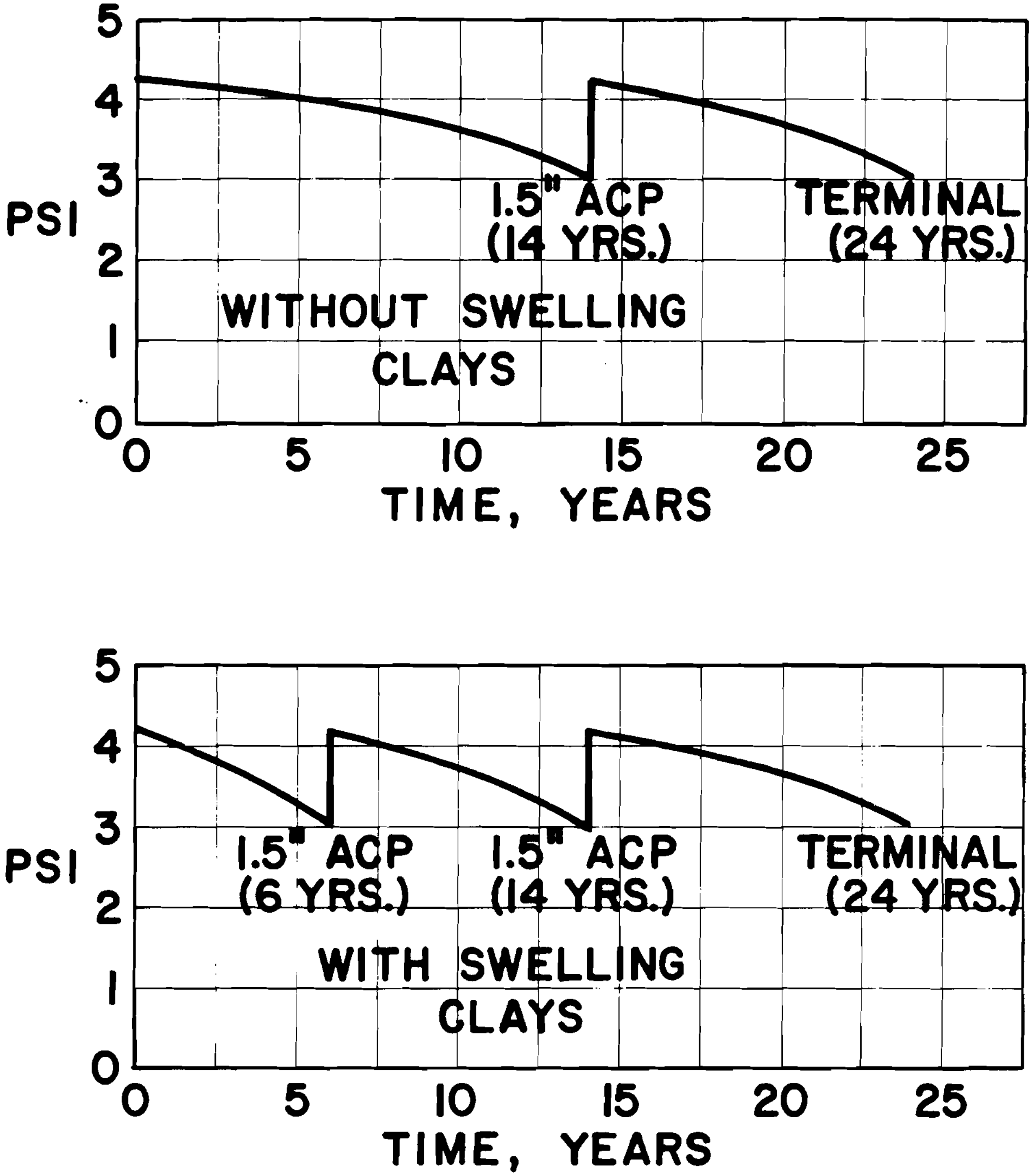
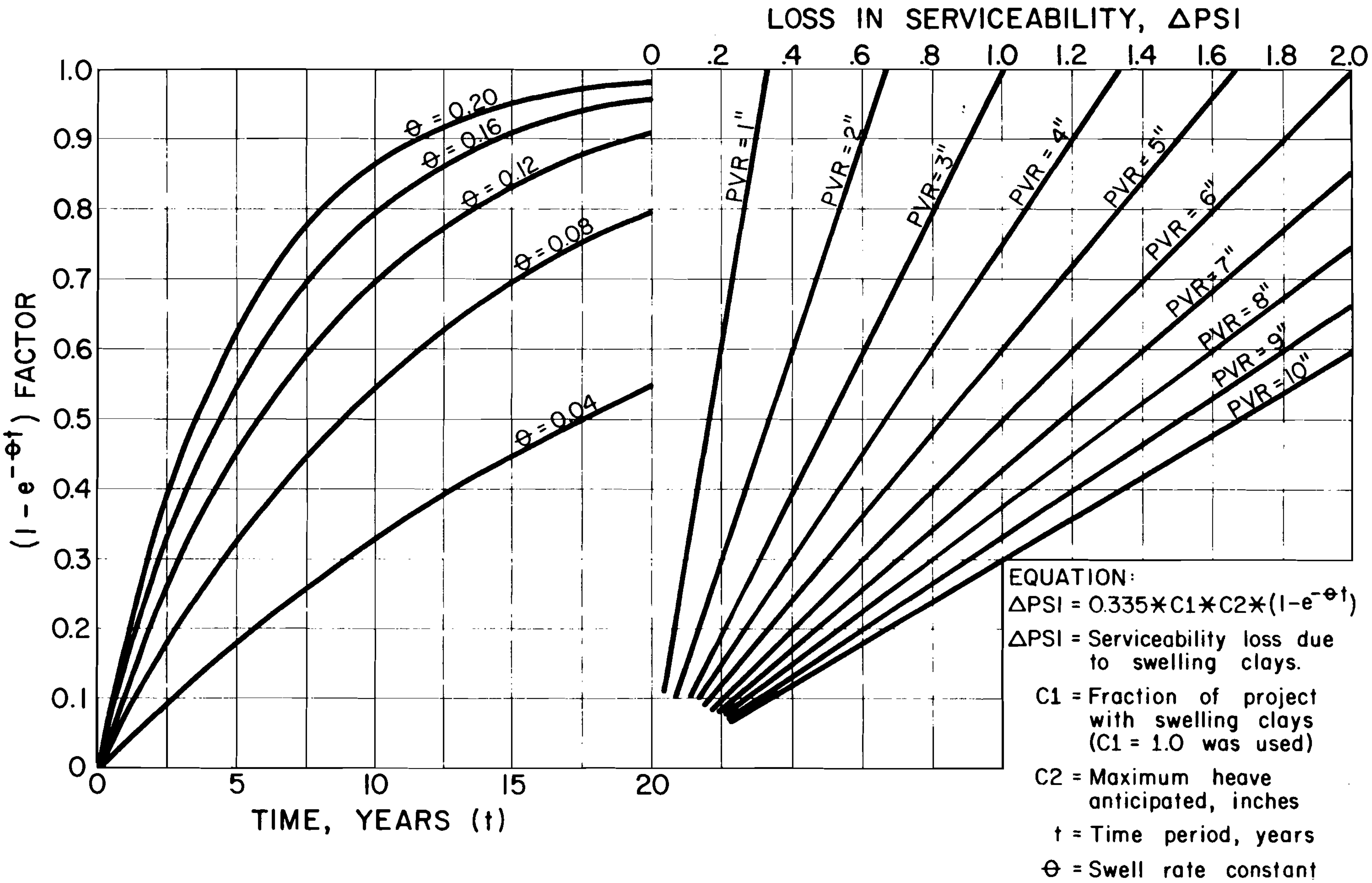


FIGURE 2

EFFECT OF SWELLING CLAYS ON PAVEMENT PERFORMANCE



EQUATION:

$\Delta PSI = 0.335 * C1 * C2 * (1-e^{-\theta t})$

ΔPSI = Serviceability loss due to swelling clays.

C1 = Fraction of project with swelling clays (C1 = 1.0 was used)

C2 = Maximum heave anticipated, inches

t = Time period, years

θ = Swell rate constant

Figure 3

PLOT OF SWELLING CLAY LOSSES

Example Problem No. 1:

The purpose of this example problem is to give the FPS user insight on the use of the FPS swelling clays equation. The attached Figure 3, Plot of Swelling Clay Losses, is being modified to show the working of the swelling clay losses chart and to diagram the solution of this example problem.

Given:
(1) 6 year performance period
(2) 100% of project subject to swelling
(3) Swell rate = 0.12
(4) Potential Vertical Rise = 5"

Find: The loss in pavement serviceability due to the action of swelling clays during a 6 year performance period.

Procedure:
(1) Enter time scale at 6 years.
(2) Proceed vertically to the 0.12 swell rate line.
(3) Proceed horizontally to the 5" PVR line.
(4) Proceed vertically to the loss in serviceability scale and read 0.83.

Answer: Loss in serviceability in 6 years is 0.83.

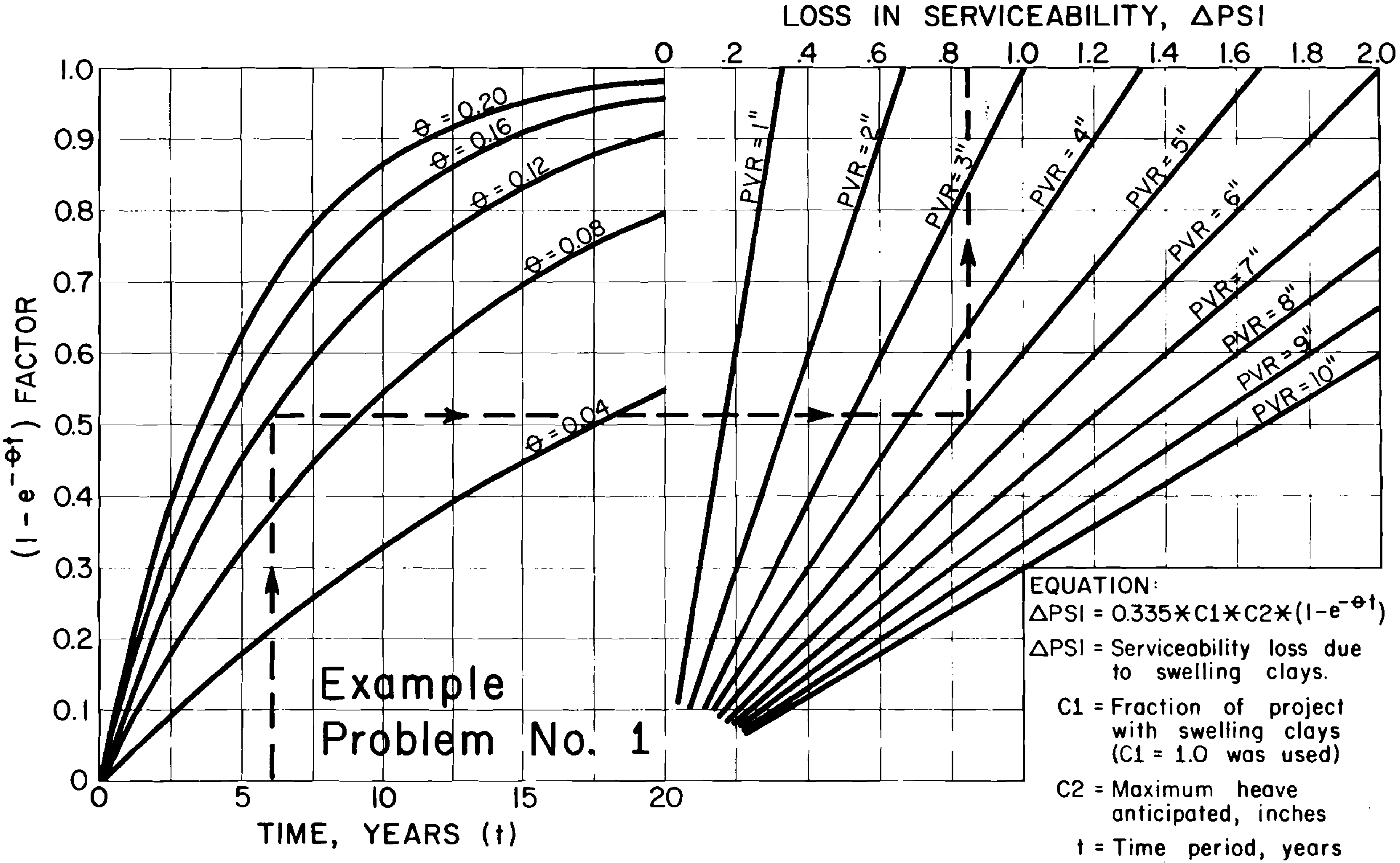


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Figure 3

PLOT OF SWELLING CLAY LOSSES

THE FPS TRAFFIC EQUATION

The FPS Traffic Equation

In general it is not necessary for the FPS user to become involved with the FPS traffic equation on a regular basis. It is desirable to have a knowledge of how the equation functions within the program and what could be expected under various traffic conditions. There are also special applications where the external usage of the FPS traffic equation may be useful to the pavement designer. The FPS traffic equation and one method of deriving the equation will be presented in this report on the FPS traffic equation.

There are five traffic related inputs to FPS and they are:

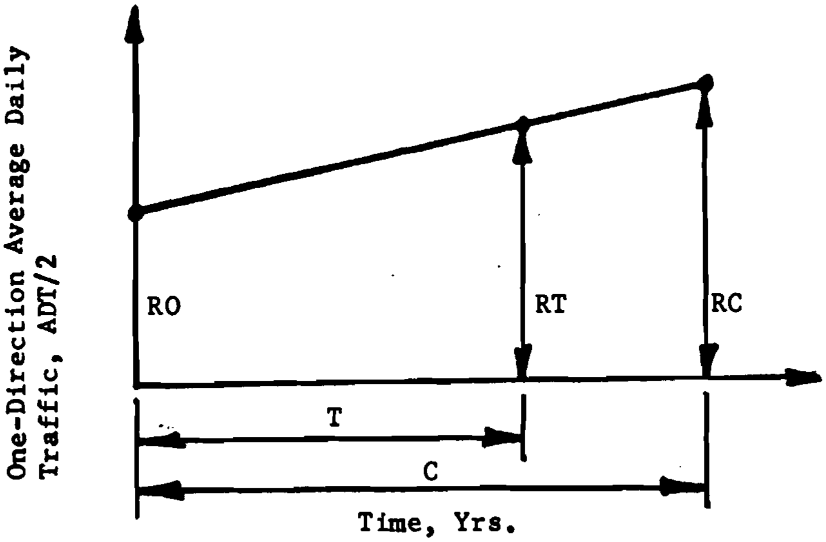
1. Beginning Average Daily Traffic
2. Ending Average Daily Traffic
3. 20 year Accumulated One Direction 18-Kip Single Axle applications
4. Percent trucks in the ADT
5. Percent ADT per hour of construction

The FPS traffic equation uses the first three inputs. The beginning and ending ADT represent the traffic growth rate. Assuming that the trucks in the ADT will grow in proportion to the ADT growth rate there are three basic shapes which the 18-KSA equivalents can assume with time, these shapes are:

1. The ADT is constant from beginning to ending of analysis period, the accumulated 18-KSA will be represented by a positive sloped straight line which begins at zero.
2. Second and most common case is when the ADT is linearly increasing, the accumulated 18-KSA curve would again start at zero but it would curve upward. This is the most usual or the expected shape for the accumulation of 18-KSA with time.
3. The third condition is a linearly decreasing ADT with time. The accumulated 18-KSA curve again begins at zero, but this time the curve turns downward. FPS will accept a decreasing ADT condition, but it will print out a warning message, "Note Decreasing ADT. It is suggested that the designer not input a decreasing ADT condition.

The FPS traffic equation is presented to give the FPS user a concept on the inner workings of the program with respect to the average daily traffic and the 18-KSA equivalents. Two example problems are being included to show possible usages for the FPS equation.

TRAFFIC EQUATIONS AND DEFINITIONS



C = Length of traffic data analysis period, Yrs.

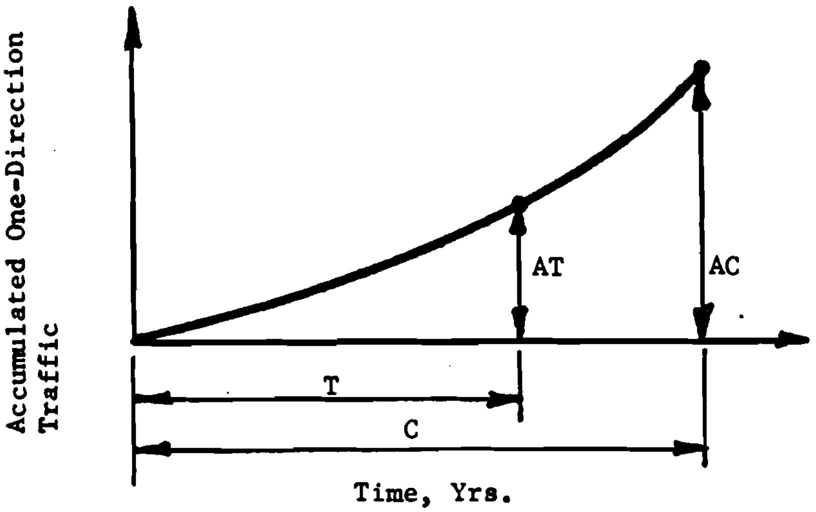
T = Time period between beginning of traffic analysis period and year of desired data, Yrs.

RO = One direction ADT at beginning o traffic data analysis period, VPD.

RC = One direction ADT at end of traffi data analysis period, VPD.

RT = One direction ADT at time = T, VPD

$$\boxed{RT = RO + \frac{T}{C}(RC-RO)}$$

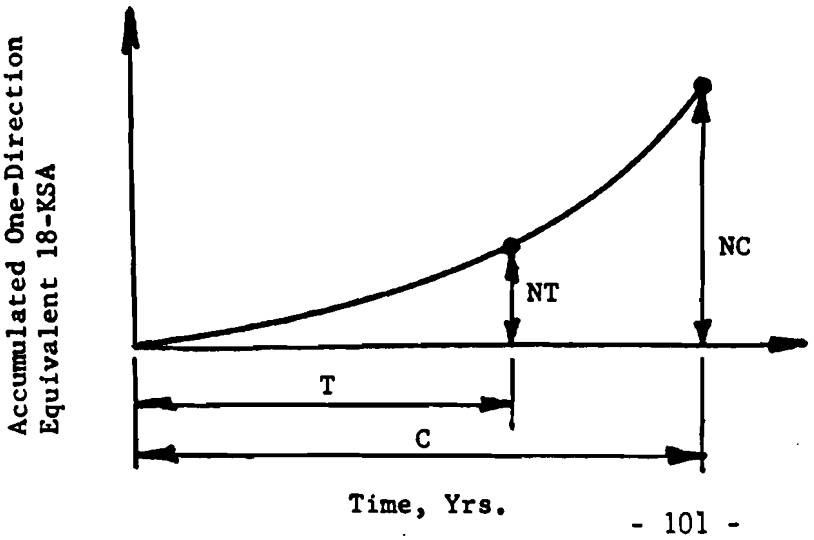


AC = Accumulated One-Direction Traffic for traffic data analysis period

AT = Accumulated One-Direction Traffic at time = T.

$$\boxed{AC = C\left(\frac{RO + RC}{2}\right)}$$

$$\boxed{AT = T\left(\frac{RO + RT}{2}\right)}$$



NC = Accumulated number of equivalent 18-KSA for traffic data analysis period.

NT = Accumulated number of equivalent 18-KSA at time = T.

$$\boxed{NT = \frac{NC}{C(RO+RC)}\left[2 \cdot RO \cdot T + \left(\frac{RC-RO}{C}\right) T^2\right]}$$

TRAFFIC EQUATION DERIVATION:

Step 1. Assume that the total traffic increases uniformly from beginning to end of analysis period.

General equation of a straight line is as follows:

$$y = mx+b$$

$$m = \text{traffic growth rate} = \frac{RC-RO}{C}$$

Substituting thus:

$$RT = RO + \frac{T}{C}(RC-RO)$$

Step 2. Accumulated One-Direction Traffic at time = T and C is the product of average rate and time interval:

$$AC = C\left(\frac{RO+RC}{2}\right)$$

$$AT = T\left(\frac{RO+RT}{2}\right)$$

Step 3. Assume that the Accumulated One-Direction Traffic and Accumulated One-Direction Equivalent 18-KSA are proportional:

$$\frac{NT}{AT} = \frac{NC}{AC}$$

Substitute for AT and AC

$$\frac{NT}{T\left(\frac{RO+RT}{2}\right)} = \frac{NC}{C\left(\frac{RO+RC}{2}\right)}$$

Substitute for RT

$$NT = \frac{NC}{C\left(\frac{RO+RC}{2}\right)}\left[2\cdot RO\cdot T + \left(\frac{RC-RO}{C}\right)T^2\right]$$

FPS TRAFFIC EQUATION - EXAMPLE 1

ADJUSTMENT OF ESTIMATED TRAFFIC DATA

Assume that 20 year traffic projection data for the 1980-2000 year time period was obtained from File D-10P but it is now 1985 and a "rush" pavement design must be made "immediately".

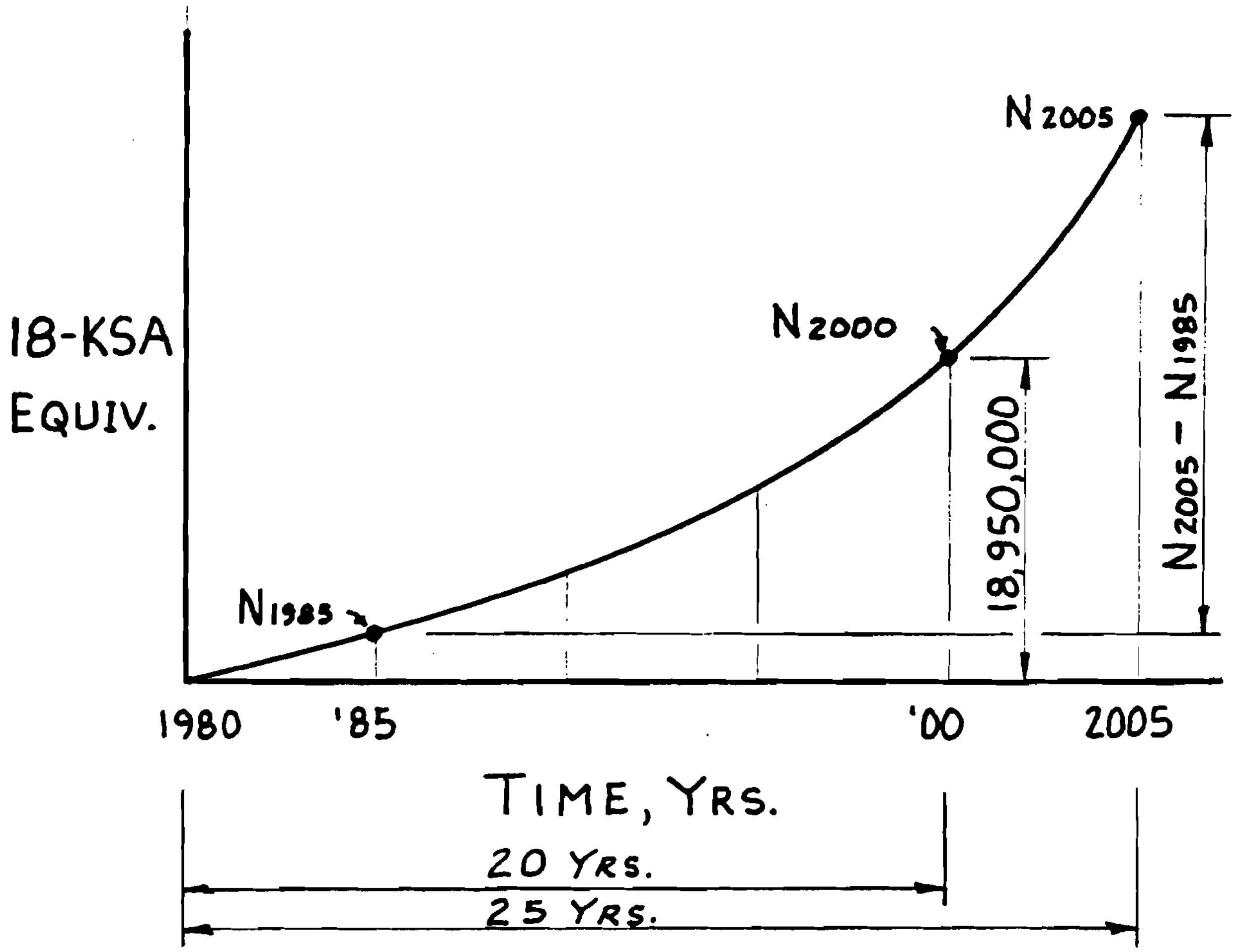
If traffic increases on beyond the year 2000 on the same growth pattern what value of 18-KSA equivalents should be expected for the 1985-2005 time period?

1980-2000 Traffic Data:

Beginning ADT = 13,750 VPD
Ending ADT = 31,650 VPD

18-KSA Equiv. = 18,958,000

FPS TRAFFIC EQUATION - EXAMPLE NO. 1 (CONT'D



$$N_{1985} = \frac{18,950,000}{20(6,875+15,825)}\left[(2*6,875*5)+\left(\frac{15,825-6,875}{20}\right)*(5)^2\right]$$

$$N_{1985} = 3,336,598 = 3,337,000$$

$$N_{2005} = \frac{18,950,000}{20(6,875+15,825}\left[(2*6,875*25)+\left(\frac{15,825-6,875}{20}\right)*(25)^2\right]$$

$$N_{2005} = 26,022,336 = 26,022,000$$

$$N_{(1985-2005)} = 26,022,336 - 3,336,598 = 22,685,738$$

$$\underline{\underline{N_{(1985-2005)} = 22,686,000}}$$

FPS TRAFFIC EQUATION - EXAMPLE NO. 2

INTERPOLATING AND EXTRAPOLATING TRAFFIC DATA

It is possible to use the FPS Traffic Equation to interpolate and extrapolate a given set of traffic data if the assumption is made that the traffic is linear within the initial period and out to the point of needed extropolation.

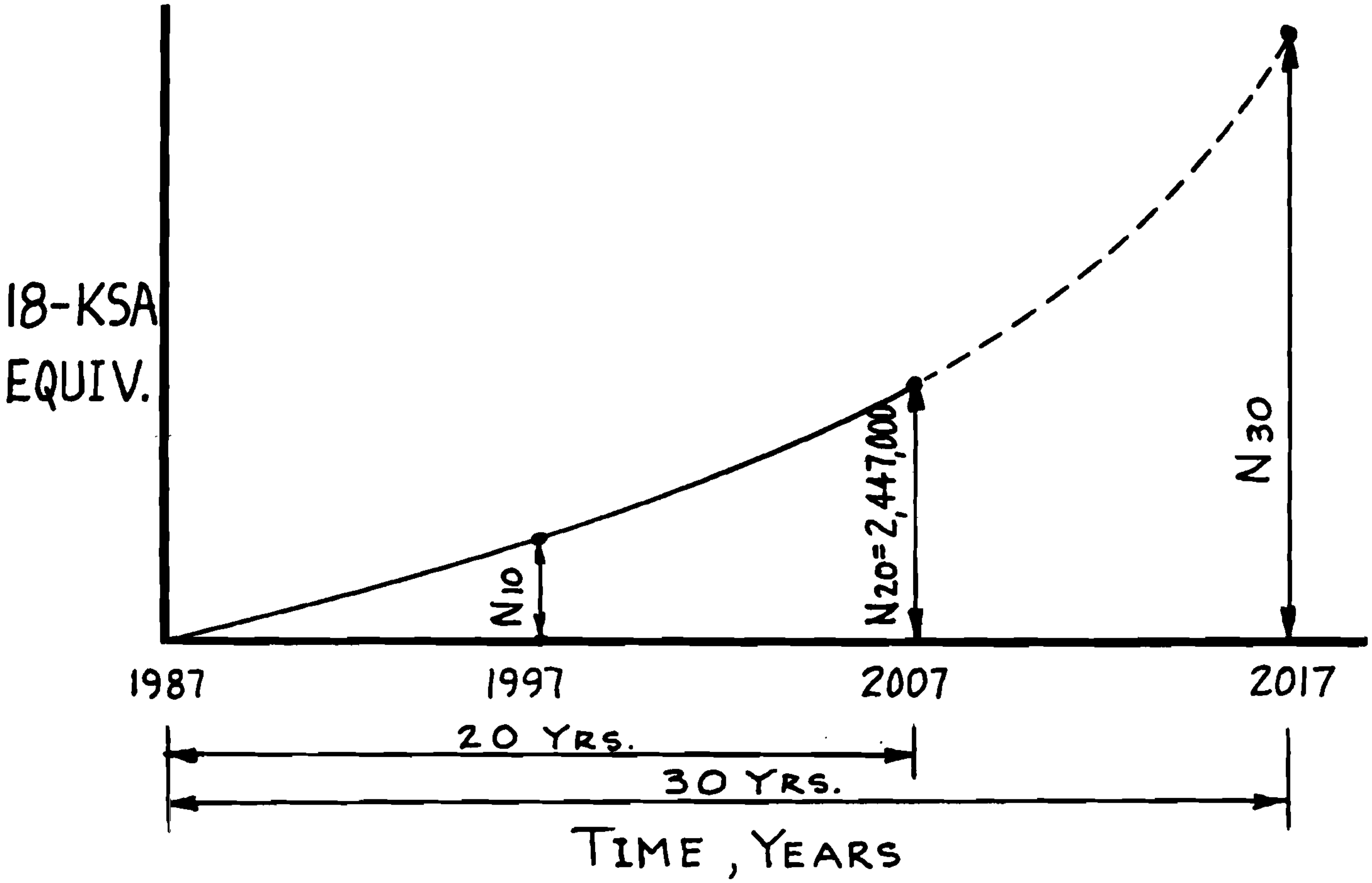
Assume that 20 year traffic projection for the 1987-2007 year time period was obtained from File D-10P. It is desired to compute accumulated 18-KSA for two additional time periods of 1987-1997 and 2017 this being 10 year and 30 year time periods respectively.

The 20 year traffic data is as follows:

Beginning ADT (1987) = 12,750 VPD
Ending ADT (2007) = 43,000 VPD

18-KSA Equivalents = 2,447,000

FPS TRAFFIC EQUATION - EXAMPLE NO. 2 (CONT'D)



$$N_{10} = \frac{2,447,000}{20(6,375+21,500)}\left[(2*6,375*10)+\left(\frac{21,500-6,375}{20}\right)(10)^2\right]$$

$$\underline{\underline{N_{10} = 892,000}}$$

$$N_{30} = \frac{2,447,000}{20(6,375+21,500)}\left[(2*6,375*30)+\left(\frac{21,500-6,375}{20}\right)(30)^2\right]$$

$$\underline{\underline{N_{30} = 4,666,000}}$$

TEST METHOD TEX-117-E
"TRIAXIAL COMPRESSION TEST FOR DISTURBED SOILS AND BASE MATERIALS"

State Department of Highways and Public Transportation

Materials and Tests Division

TRIAXIAL COMPRESSION TESTS FOR DISTURBED SOILS AND BASE MATERIALS

Scope

This method of procedure provides for the determination of the shearing resistance, water absorption and expansion of soils or soil aggregate mixtures. The test consists of applying an axial load to cylindrical specimens of definite dimensions, supported by various known lateral pressures until failure occurs. The test method is applied in Part I to laboratory compacted specimens of disturbed soil or material containing aggregate with the largest size particle passing the 1-3/4 inch sieve. Part II describes an accelerated procedure which has been carefully correlated with the standard method of Part I. It is intended to use the accelerated method to control the quality of material during construction.

Definitions

1. Triaxial Test: A test in which force is applied in three mutually perpendicular directions.

2. Axial Load: This force is the sum of the applied load and dead load which includes the weight of the top porous stone, metal block and bell housing and is applied along the vertical axis of the test specimen.

3. Lateral Pressure: The force supplied by air in the cell and is applied in a radial or horizontal direction.

4. Unit Stress: This term is defined as the axial load divided by the end area of the cylindrical specimen.

5. Strain: Strain is unit deformation and is equal to deformation of specimen divided by the original height often expressed as a percentage.

6. Mohr's Diagram: A graphical construction used in analyzing data from tests on bodies acted on by combined forces in static equilibrium which shows more information as to physical properties of the material than other methods in common use.

7. Mohr's circle of failure: A stress circle constructed from principal stresses acting on the specimen at failure.

8. Mohr's envelope of failure: The envelope of failure is the common tangent to a series of failure circles constructed from different pairs of principal stresses required to fail the material. The envelope is generally curved, its curvature depending on the factors related to the characteristics of the material.

Apparatus

1. Apparatus used in Test Methods Tex-101-E and Tex-113-E
2. Axial Cells, lightweight stainless steel cylinders; 6-3/4 inches inside diameter and 12 inches in height, fitted with standard air valve and tubular rubber membrane 6 inches in diameter (Figure 1).
3. Aspirator or other vacuum pump
4. Air Compressor
5. Damp room or moist cabinet equipped with shelves and regulated air pressure.
6. Screw jack press and assembly (Figure 3)
7. Pressure regulator, gauges and valves
8. Micrometer dial gauge, calibrated in 0.001 inch, with support to measure deflection of specimen.
9. Dial housing and loading block to transmit load to cylindrical specimen
10. Ring dynamometer which has been calibrated in accordance with Test Method Tex-902-K.
11. Circumference measuring device, special made metal tape measure (Figure 5).
12. Lead weights for surcharge loads
13. Rectangular stainless steel pans 9 x 16 x 2-1/4 inches deep equipped with porous plates

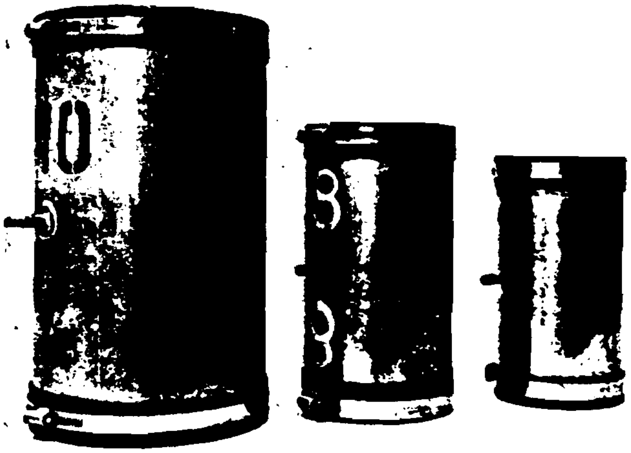


Figure 1
Axial Cells of Various Sizes

Figure 2
Capillary Wetting of Triaxial Specimens

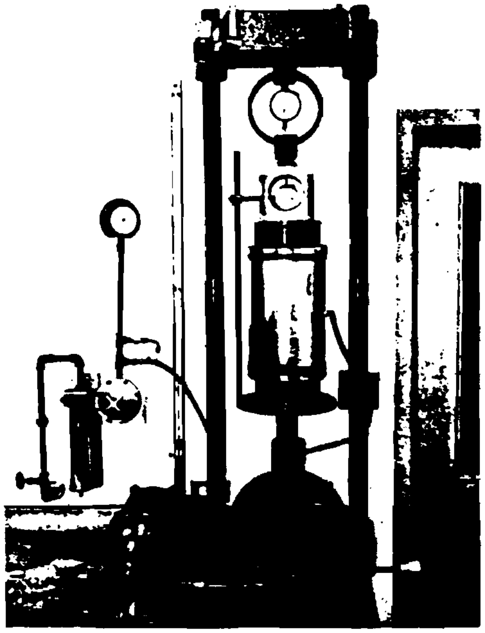


Figure 3
Press Assembly with Specimen in Place

Test Record Forms

Record test data on Form No. 1062, Figure 10, M/D and Triaxial Test Work Sheets, Figure 9, and Triaxial Compression Test Capillary Wetting Data, Figure 8. After test and calculations are completed, summarize results on Triaxial Test Summary Sheet, Figure 15.

Preparation of Sample

Prepare approximately 200 pounds of material according to the procedure given in Part II of Test Method Tex-101-E. See General Notes.

PART I

STANDARD TRIAXIAL COMPRESSION TEST

Procedure

A. Determining Moisture-Density Relations

Determine the optimum moisture and maximum density as outlined in Test Method Tex-113-E, using the compactive effort specified for the type of material being tested.

B. Compaction of Test Specimens

1. Follow Steps 1 through 12 under procedure of Test Method Tex-113-E and mold at optimum moisture a total seven specimens, including the specimen from the peak of the M-D Curve for all materials containing aggregates. (Base and subbase materials). For fine grain soils or those containing small amounts of aggregates mold a total of six specimens at optimum moisture and density conditions. These specimens should be six inches in diameter and 8 inches in height to the nearest 1/4 pound of dry material. These test specimens should be wet, mixed, molded and finished as nearly identical as possible. Identify each test specimen by laboratory number and specimen number.

2. Immediately after extruding the specimen from the mold, enclose the specimen in a triaxial cell, with top and bottom porous stones in place and allow all the specimens to remain undisturbed at room temperature until the entire set of test specimens has been molded. Record data on M-D and Triaxial Work Sheet shown in Figure 9.

Notes

When a different compactive effort is desired, a complete new M-D Curve and test specimens must be molded.

C. Curing Test Specimens

After the entire test set has been completed, remove the triaxial cells and dry cure the specimens according to the type of material. To avoid excessive cracking which will damage the specimen the dry curing is accomplished as follows:

1. For flexible base materials and select granular soils with little or no tendency to shrink, place specimens in the oven air dryer and remove 1/3 to 1/2 of the molding moisture content at a temperature of 140°F. (This will require 3 to 6 hours depending on the

material, the optimum moisture content and the load of other wet material in the oven.) Allow the specimens to return to room temperature before preparation for and subjection to capillarity.

2. Very plastic clay subgrade soils subject to large volume change crack badly while shrinking. Air dry these soils at room temperature inspecting the specimens frequently by looking at the sides of the specimens and raising the top porous stones to examine the extent of cracking at the top edges of the specimens. When these cracks have formed to a depth of approximately 1/4 inch, replace the triaxial cell and prepare the specimens for capillary wetting.

3. For moderately active soils that might crack badly if placed in an air dryer for full curing time, dry at 140°F and check frequently for the appearance of shrinkage cracks. If cracks appear, examine the extent of cracking as described under Step 2, and allow some air drying at room temperature during the cooling period before enclosing specimens in cells.

D. Subjecting Test Specimens to Capillary Absorption

1. The specimens are now ready to be prepared for capillary wetting. Do not change the porous stones or remove them until the specimens have been tested. Weigh each specimen and its accompanying stones and record weight. Cut a piece of filter paper 10 in. by 20 in. fold to 5 in. by 20 in. and make several cuts with scissors (Jack-o-lantern fashion). These cuts will prevent any restriction by the paper. Wrap the filter paper around the specimen and stones, allowing the bottom of the paper to be near the bottom of the bottom porous stone, and fasten with a piece of tape. Replace cell by applying a partial vacuum to the cell, deflating the rubber membrane, then place the cell over the specimen and release the vacuum.

2. Transfer the specimens to the damp room and place them into the rectangular pans provided for capillary wetting shown in picture of damp room, Figure 2. Adjust the water level on the lower porous stones to approximately 1/2 inch below the bottom of the specimens. Add water later to the pans, as necessary, to maintain this level. Note schematic arrangement, Figure 4.

3. Connect each cell to the air manifold and open valve to apply a constant lateral pressure of 1 psi. Maintain this constant pressure throughout the period of absorption.

4. Next, place a suitable vertical surcharge load (which will depend upon the proposed use or location of the material in the roadway) on the top porous stone. For flexible base use 1/2 pound per square inch and for subgrade soils use 1 pound per square inch of end area of the specimen. Consider the weight of the top porous stone as part of the surcharge weight, Figure 4.

5. Subject all flexible base materials and soils with plasticity index of 15 or less to capillary absorption for 10 days. Use a period of time in days equal to the plasticity index of the material for subgrade soils with PI above 15. Keep the specimens in the damp room, equipped with spray system, during the period of capillary absorption.

E. Preparing Specimens for Testing

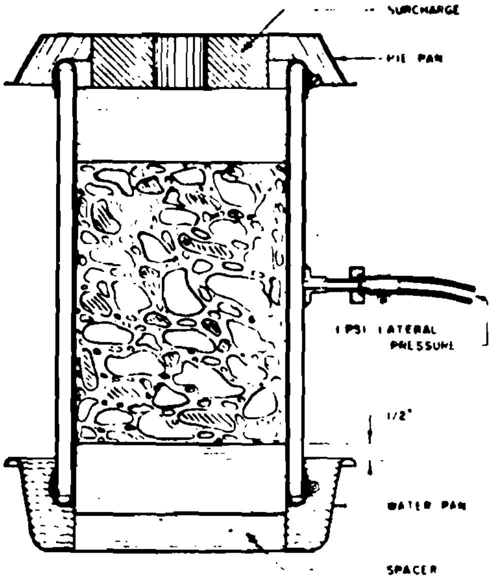


Figure 4
Schematic Arrangement for Capillary Wetting

1. Disconnect air hose from cell, remove surcharge weight and return specimens to laboratory for testing. Use a vacuum and deflate the rubber membrane to aid in removing the cell from specimens and discard filter paper. If any appreciable material clings to paper, carefully press it back into the available holes along the side of the specimen.

2. Weigh the specimens and record as total weight after capillary absorption. Note that the wet weight of stones is obtained after the specimens are tested. Record on Figure 8.

3. Measure the circumference of each specimen by means of the metal measuring tape. Measure the height of the specimen including the stones, and enter on data sheet as height over stones. Also record the height of each stone (Figures 5 and 6).

4. Replace the axial cell on the specimen, release the vacuum, and the specimen is ready to be tested. The cell need not be placed on the specimen to be tested at zero lateral pressure if tested immediately after preparation. It is important to keep the proper identification on the specimens at all times because weights, measurements, test values and calculations are determined for each individual specimen.

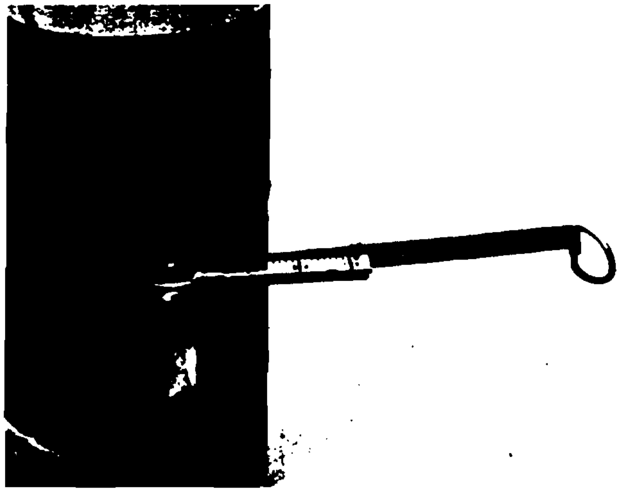


Figure 5
Circumference Measuring Device

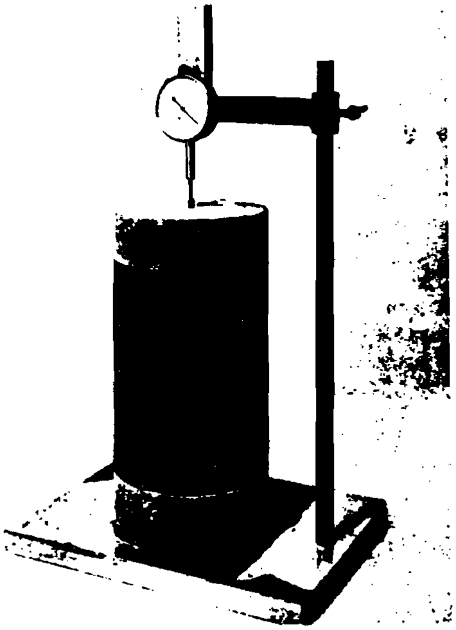


Figure 6
Measuring Overall Height of Specimen and Stones

F. Testing Specimens

In brief, the specimens are tested in compression while being subjected to their assigned constant lateral pressure. The motorized press is geared to travel at the rate of 0.135 inches per minute plus or minus 0.015 inches per minute. Simultaneous readings of load and deformation are taken at intervals of 0.01 inch deformation until specimen fails, Figure 7.

1. Disengage the worm gear drive and crank the press down far enough to have room to place specimen, metal loading blocks and the special bell dial housing in the press.

2. Center the specimen with upper and lower metal loading blocks in place in the press. Adjust the deformation gauge in such a manner that it will be down against the center of the top spacer block and also compressed for almost the length of travel of the stem. The gauge must be placed in this position since the specimen moves away from the gauge during the compression. Set the dial of the strain gauge to read zero.

3. Next, set the bell housing over the deformation gauge and adjust so that it does not touch the gauge or its mounting. At this point it should be noted that the compressive stress will necessarily be applied along a vertical line through the center of the ball that is mounted in the top of the bell housing. Since it is desirable to apply the compressive force along the vertical axis of the test specimen, shift the bell housing laterally to bring the ball directly over the axis of the specimen. Raise the press by means of the motor, align and seat the ball on the bell housing into the socket in the proving ring. Then apply just enough pressure to obtain a perceptible reading on the proving ring gauge. Read the deformation gauge and record as deformation under dead load.

4. Connect the air line to the axial cell and apply lateral pressure to the specimen. The usual lateral pressures used for a series of tests are 0, 3, 5, 10, 15, and 20 psi. In cases where the load or stress is high (175 - 180 psi) for the specimen tested at 15 psi lateral pressure, use 7 psi instead of 20 psi for the last specimen. The lateral pressure applied by the air will tend to change the initial reading of the gauge. As the air pressure is adjusted, start the motor momentarily to compress the specimen until the deformation gauge reads the same as recorded in Step 3. Read the proving ring gauge and enter in load column opposite the initial deformation reading (Figure 10).

5. The test is ready to be started. Turn on the motor and read the proving ring dial at each .01 inch deformation of the specimen. Continue readings until 60 readings have been taken unless failure occurs earlier. Failure is reached when the proving ring dial readings remain constant or decrease with further increments of deformation. In testing specimens with aggregates, the slipping and shearing of aggregates will cause tem-

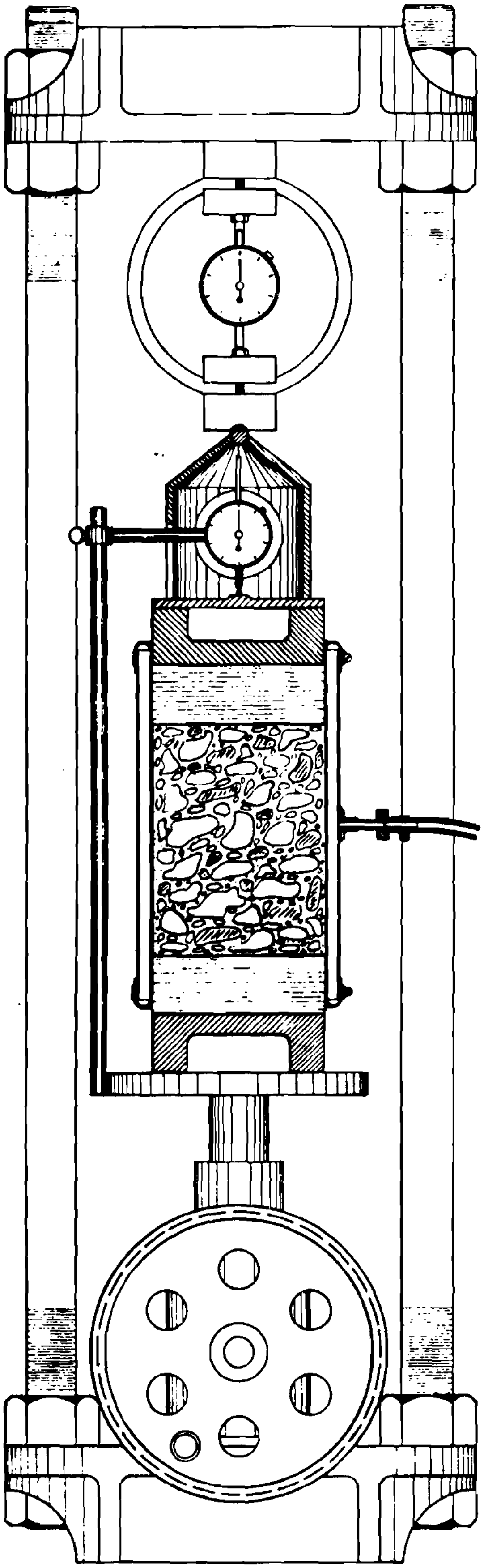


Figure 7a

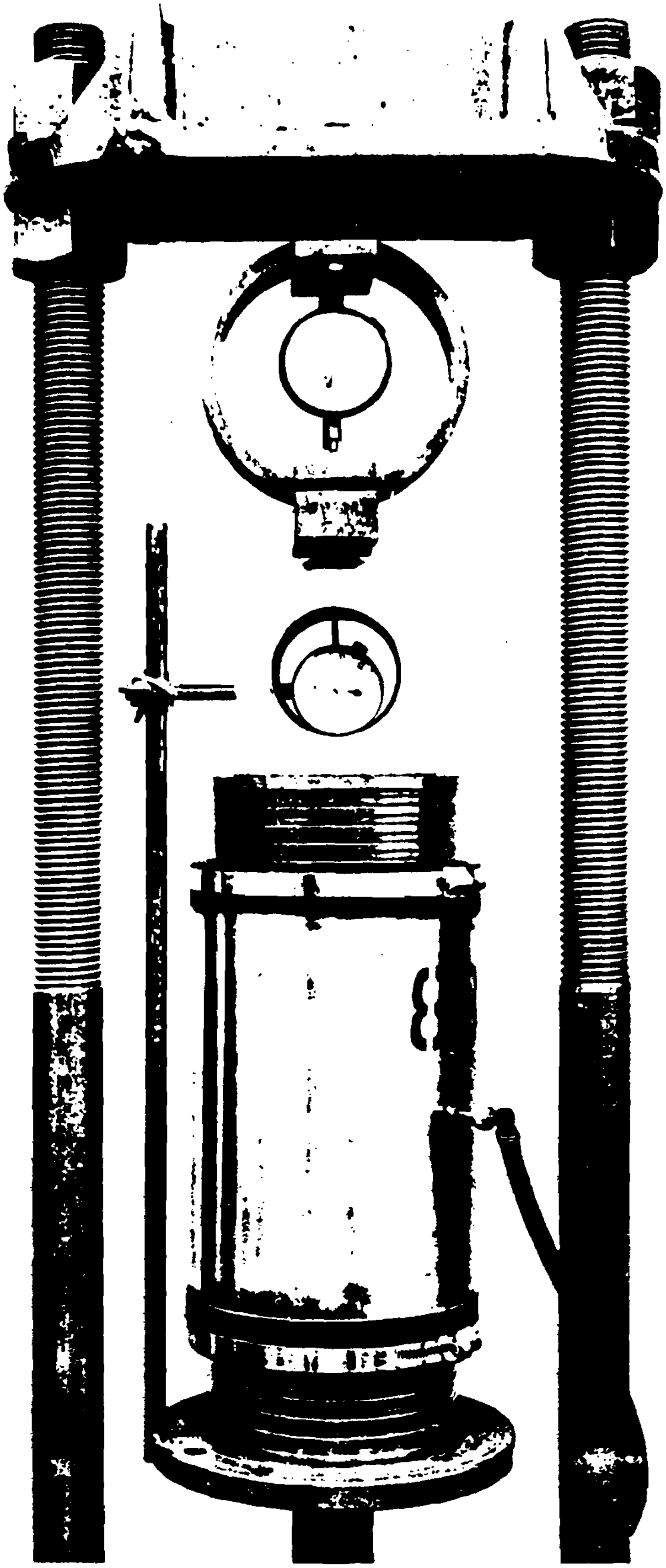


Figure 7b

Press Assembly for Triaxial Test

porary decreases in proving ring readings. The test should be continued until true failure is reached. After 60 readings the cross sectional area of the specimen has increased so that the subsequent small increase in load readings is little more than the increase in tension of the membrane acting as lateral pressure.

6. All of the above procedure applies to the unconfined specimen except that no air or axial cell is used. For materials which contain a large amount of aggregate, compact and test two specimens at zero lateral pressure. Use average of test results unless large rocks appear to have created point bearing; in this case use highest value.

G. Obtaining Dry Weight of Specimens and Stones

1. The specimen and stones are removed from the cell over a flat tared drying pan. Use a spatula to clean the material from the inside of cell and stones. Break up the specimen taking care to lose none of the material and place the identification tag in the tray.

2. Dry the material to constant weight at a temperature of 230°F and determine the dry weight.

3. The damp stones are weighed, dried at 140°F and the dry weight obtained. This weight completes the test procedure.

Calculations

1. Volume of compacted specimen = volume per inch of mold x height of specimen.

2. Calculate dry density of specimen as follows:

$$\text{Dry density} = \frac{\text{Dry weight of specimen in pounds}}{\text{Volume of specimen in cu. ft.}}$$

3. Molding moisture =

$$\frac{\text{Weight of specimen wet - weight of specimen dry}}{\text{Weight of specimen dry}} \times 100$$

4. Calculate the percentage of volumetric swell by the expression:

$$V_S = \frac{V_A - V_M}{V_M} \times 100$$

Where: V_S = Percentage volumetric swell

V_A = Volume of specimen after capillary absorption

V_M = Volume of specimen as molded

5. Calculate the moisture before and after capillarity as follows:

Where:

M_C = Percent moisture in specimen after capillarity
M_B = Percent moisture in specimen before capillarity

$$M_C = \frac{W_A - W_B - W_D}{W_D} \times 100$$

$$M_B = \frac{W_C - W_S - W_D}{W_D} \times 100$$

W_A = Wet weight of specimen and stones after absorption
W_B = Wet weight of stones
W_C = Weight of specimen and stones before capillarity
W_D = Correct oven-dry weight of specimen
W_S = Dry weight of stones

6. Calculate the values of stress and strain for each individual specimen from the following relations:

$$S = \frac{d}{h} \times 100$$

Where:

S = Percent strain
d = Total vertical deformation at the given instant, measured in inches by deformation gauge.
h = The height of the specimen in inches, measured after specimen is removed from capillarity.

$$p = \frac{P}{A}\left(1 - \frac{S}{100}\right)$$

Where:

p = The corrected vertical unit stress in pounds per square inch

A correction is necessary because the area of the cross-section increases as the specimen is reduced in height. The assumption is made that the specimen deforms at constant volume.

P = The total vertical load on the specimen at any given deformation expressed in pounds. It is the sum of the applied load measured by the proving ring plus the dead weight of the upper stone, loading block and dial housing.

A = The end area of cylindrical specimen expressed in square inches at the beginning of test.

TRIAXIAL COMPRESSION TEST CAPILLARY WETTING DATA

LAB. NO. ______________

Sample No.												
Cell No.												
Lbs. of Added Surcharge												
Date Molded												
Date in Air Dryer												
Date in Capillarity												
Date out Capillarity												
Heighth in Capillarity												
Heighth out Capillarity												
Weight after Air Dry												
Dry Weight Stones												
Dry Weight Sample												
Weight Moisture in Sample												
% Moisture to Capillarity												
Weight after Capillarity												
Wet Weight Stones												
Wet Weight Sample												
Dry Weight Sample												
Weight Moisture in Sample												
% Moisture after Capillarity												
Remarks:												

Figure 8

M/D & TRIAXIAL WORK SHEET

LAB NO.__________

____% HYGRO ALLOWED

Date Molded												
Sample No.												
Compactive Effort												
Total % Water												
Pounds Material												
Pounds Water Desired												
Pounds Hygroscopic Water												
Pounds Water Added												
Tare Weight of Jar												
Weight Jar and Water												
Mold No.												
Wet Wt. Specimen & Mold												
Tare Weight Mold												
Wet Weight Specimen												
Height of Mold												
Dial Reference												
Dial Reading												
Height Specimen												
Vol. per Linear Inch												
Vol. of Specimen												
Wet Density Specimen												
Dry Weight Pan & Specimen												
Tare Weight Pan												
Dry Weight Material												
Weight Water												
Percent Water on Total												
Dry Density												
Guestimated Dry Density												

Figure 9

FORM 1062

TRIAXIAL TEST DATA SHEET

Lab. No.____________
Specimen No.________
Lat. Pressure________
Date Molded________
Date Tested________
No. Days in Cap.______
Ring Factor______
Dead Load_______Lbs.
DL/A___________Psi

Area______________
1/A______________
_______/A_______
_________ft. lbs./cu. in. Compaction
Initial Vol.__________

Circumference________
Avg. Dia.__________
Strain Rate = .15"/min.
Final Vol.__________

Ht. / Stones_________
Stones______&______
New Height_________
% Vol. Swell________

$$\text{Strain} = \frac{.01}{\text{New Ht.}} = \frac{.01}{\_\_\_\_} = \_\_\_\_\_\_$$

Deformation	Load	Uncorr'd. Stress	1-Strain	% Strain	Corrected Stress	Deformation	Load	Uncorr'd. Stress	1-Strain	% Strain	Corrected Stress
.01						.31					
.02						.32					
.03						.33					
.04						.34					
.05						.35					
.06						.36					
.07						.37					
.08						.38					
.09						.39					
.10						.40					
.11						.41					
.12						.42					
.13						.43					
.14						.44					
.15						.45					
.16						.46					
.17						.47					
.18						.48					
.19						.49					
.20						.50					
.21						.51					
.22						.52					
.23						.53					
.24						.54					
.25						.55					
.26						.56					
.27						.57					
.28						.58					
.29						.59					
.30						.60					

Figure 10

Graphs and Diagrams

1. Plot the moisture-density curve shown in Figure 8 of Test Method Tex-113-E.

2. Plot the stress-strain diagram as shown in Figure 12 when requested.

3. The Mohr's diagram of stress (Figure 13) is constructed upon coordinate axes in which ordinates represent shear stress and abscissas represent normal stress, both expressed as pounds per square inch to the same scale.

L = Minor principal stress which is the constant lateral pressure applied to the specimen during an individual test.

V = The major principal stress which is the ultimate compressive strength or the highest value of p determined at the given lateral pressure.

Each individual test will be shown by one stress circle drawn as follows:

Plot L and V on the base line of normal stress. Locate the center of each circle a distance of $(V + L)/2$ from the origin and construct a semi-circle with its radius equal to $(V - L)/2$ intersecting the base line at V and L. Repeat these steps for each specimen tested at different lateral pressures to provide enough stress circles to define the failure envelope on the Mohr's diagram.

Draw the failure envelope tangent to all of the stress circles. Since it is practically impossible to avoid compacting an occasional specimen that is not identical with the other specimens in the same set, disregard any stress circle that is obviously out of line when drawing the tangent line.

Classification of Material

Transfer the envelope of failure on to the chart for classification of subgrade and flexible base materials (Figure 14) and classify the material to the nearest one-tenth of a class. When the envelope of failure falls between class limits, select the critical point or weakest condition on the failure envelope. Measure the vertical distance down from a boundary line to the point to obtain the exact classification (3.7) as shown in Figure 14.

Reporting Test Results

Report the soil constants, grading and Wet Ball Mill Value for the aggregate on Form 476-A. Summarize test results on Triaxial Test Summary Sheet, Figure 15, and strength classification plotted as given in Figure 14.

PART II

ACCELERATED METHOD FOR TRIAXIAL COMPRESSION OF SOILS

This accelerated procedure is based on a correlation with the standard method for Triaxial Compression Test, Part I., performed on a large number of different types of soils. Generally it is intended to use the accelerated test to control the quality of base materials of group (d) during stockpiling and in such cases roadway samples will not necessarily be considered to be representative.

Procedure

1. Prepare all materials in accordance with Test Method Tex-101-E, Part II.

2. Determine the optimum moisture and maximum density as outlined in Test Method Tex-113-E with the following addition that materials having a PI of 20 or above and containing aggregate; wet the portion passing the No. 10 sieve and retained on the No. 20 sieve with the aggregate.

3. Group the soils into five general types of materials and treat as follows:

a. Fine granular materials with plasticity index less than 5.
b. Very low swelling soils with plasticity index of 5 through 11.
c. Swelling subgrade soils, plasticity index of 12 or more.
d. Flexible base and subbase materials with considerable amounts of aggregate.
e. Combination soil types.

Group (a)

Fine Granular Materials with Plasticity Index Less Than 5

1. Mold 6 specimens 6 inches in diameter and 8 inches in height at the optimum moisture and density, using the same compactive effort that was specified in Test Method Tex-113-E.

2. Cover the specimen (with stones in place) with a triaxial cell immediately after removing from mold and allow to set overnight undisturbed at room temperature. Do not dry cure or subject specimens to capillary absorption.

3. Test the specimens at the usual lateral pressures.

4. Calculate unit stress, plot diagrams and classify material.

Group (b)

Very Low Swelling Soils with Plasticity Index of 5 thru 11

1. Compact a set of 6 identical specimens at the optimum moisture and density condition.

2. Use filter paper, lead surcharge weights and air pressure for lateral support and subject the specimens to capillary absorption overnight as described in Section D of Part I.

3. The next morning, remove filter paper and test the specimens at the usual lateral pressure shown above. Calculate unit stress, plot diagrams and classify material.

Group (c)

Swelling Subgrade Soils, Plasticity Index of 12 or More.

1. Obtain the plasticity index and hygroscopic moisture of these soils in advance of molding specimens.

2. Determine the optimum moisture and dry density of the materials as outlined in Test Method Tex-113-E, using the compactive effort specified in Test Method Tex-113-E under Compactive Effort.

3. Calculate the molding moisture to use as follows: Percent Molding Moisture = (1.4 x optimum moisture) - 2.2.

4. Obtain the desired molding density from the following expression:

$$\text{Molded Dry Density} = \frac{\text{Optimum dry density (Step 2)}}{1 + \frac{\text{percent volumetric swell}}{100}}$$

To determine the percent volumetric swell to be expected, use average condition in chart shown in Figure 11 or soil pressure Slide Rule. If Slide Rule is available, use A_2 Scale, an infinite thickness of layer and the plasticity index of the soil. It is important to modify the percent volumetric swell by multiplying by percent soil binder divided by 100 to obtain the percent volumetric swell to be expected.

5. Use the moisture content (Step 3), vary the compactive effort (usually 25 blows per layer will suffice on most materials) until the desired density (Step 4) is obtained and mold a set of six specimens. Where this moisture content is too great to permit the desired density, reduce the molding water slightly (usually about 1%) and continue molding. The specimens, being in capillarity overnight, will pick up this moisture that was left out.

6. When the six specimens have been molded, they are put to capillary absorption (as in Part I) overnight. Test at the usual lateral pressures and classify.

Group (d)

Flexible Base and Subbase Materials With Aggregate

1. When classification is required, weigh out enough material to mold 6 or more specimens, in individual pans, keeping the portion passing the No. 10 sieve separate. Sprinkle all the soaking water on the + No. 10 aggregate portion in the mixing pan and allow to soak for four or more hours. The soaking water is the optimum moisture as determined in Tex-113-E except, where the flat top curve exists, then the soaking water should be the amount of the left side or dry side of the flat portion.

2. When desired in testing base and subbase materials with aggregates, the following procedure may be used where strengths are required. Begin the M-D curve as outlined in Test Method Tex-113-E and mold at least 2 specimens on the dry side of optimum moisture with the second specimen being slightly below optimum moisture. Weigh out the plus No. 10 portion of 9 specimens in individual pans and sprinkle the water as determined to be just below optimum moisture on each specimen then stir so as to wet the aggregates thoroughly. As each pan is wet, weigh the contents to obtain the weight of pan + soil + water and record. Cover with a lid or suitable cover and stir contents every hour (or 3 times). Continue molding the M-D curve until optimum moisture and density are determined. The difference between optimum moisture and the water the specimens were sprinkled with must be added to the + 10 material in the pans. If in the event the specimens have been wet with only slightly more than optimum, they may be dried back at room temperature, by stirring, to the desired weight.

3. Replace any evaporated water, add in the material passing No. 10 sieve, mix and compact. Materials which can be compacted to the desired density without the addition of more water, should be molded at optimum moistures ± 0. 1%. Many materials require the addition of small amounts of moisture to obtain the desired density. If needed, add in the required amounts of additional water (by trial and error method) until the desired density is obtained and compact a set of eight specimens using 13.26 ft. lbs. per cu. in. effort. The intent of this technique is to use the minimum amount of moisture equal to or above optimum moisture that will produce a set of accelerated test specimens whose average density is within 1/2 lb per cu. ft. of the maximum cubic foot density of the original moisture density curve. It should be noted that excessive densities can sometimes be obtained in the accelerated set but these are almost always very wet specimens and their resultant strengths can be misleading.

4. Subject specimens to overnight capillarity.

5. Test and if required classify in accordance with Part I. If strengths at zero and 15 lb lateral pressures are specified, test five specimens at zero

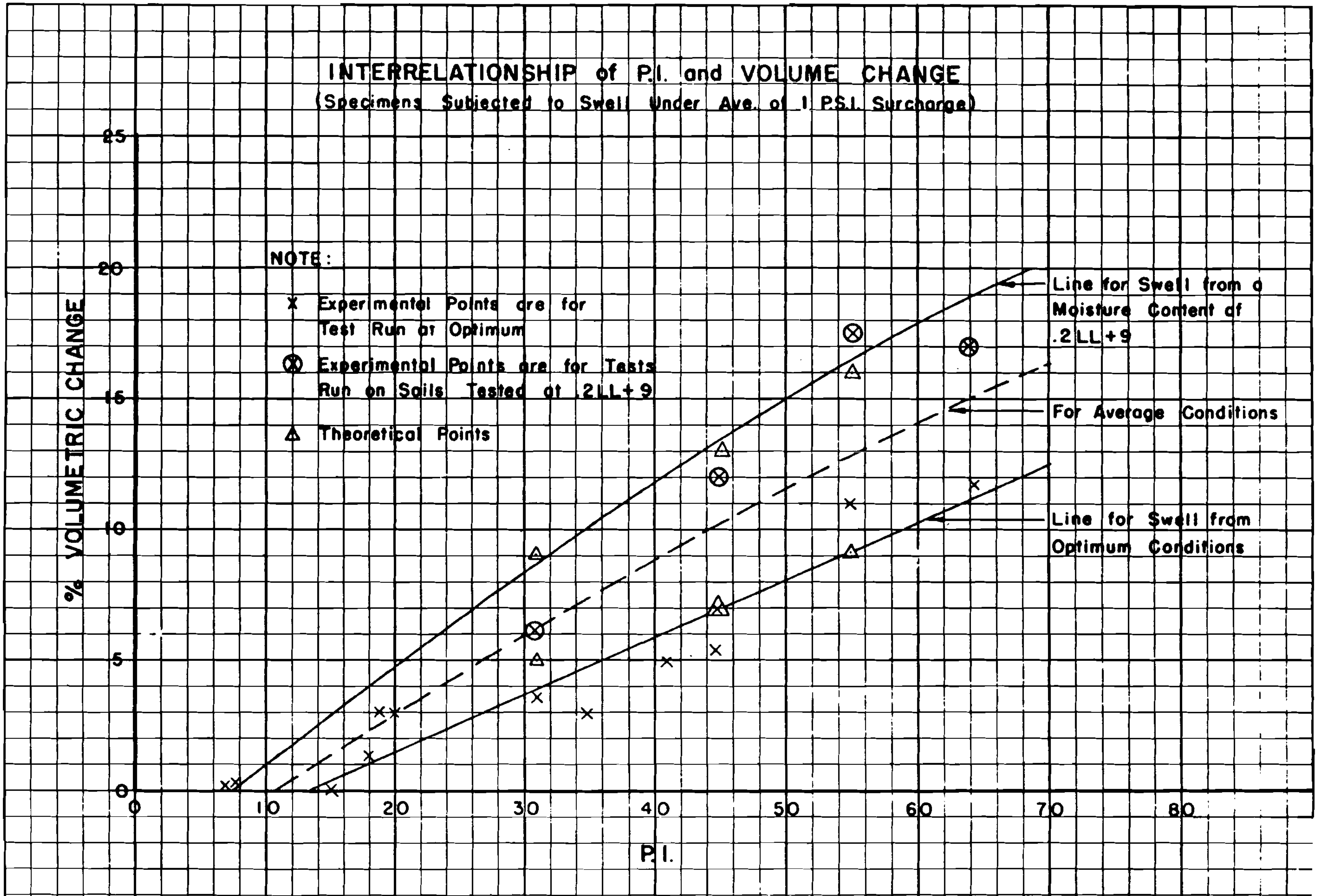

INTERRELATIONSHIP of P.I. and VOLUME CHANGE
(Specimens Subjected to Swell Under Ave. of 1 P.S.I. Surcharge)
% VOLUMETRIC CHANGE
0
5
10
15
20
25
P.I.
0
10
20
30
40
50
60
70
80
NOTE:
X Experimental Points are for Test Run at Optimum
⊗ Experimental Points are for Tests Run on Soils Tested at .2LL+9
△ Theoretical Points
Line for Swell from a Moisture Content of .2LL+9
For Average Conditions
Line for Swell from Optimum Conditions

Figure 11

lateral confinement and three at 15 lb lateral confinement and average the three highest values for each state of confinement for the control values.

Note: When strengths at zero and 15 psi lateral pressures are specified, it is permitted to run correlation tests on a given source of material.

The correlation shall be as follows: As soon as three satisfactory accelerated test specimens have been molded in accordance with Paragraph 2 above, two of them will be tested at zero lateral pressure and the results averaged as one test. The third specimen will be tested at 15 psi lateral pressure. If these specimens pass it is safe to assume the set to be tested the next day will pass.

Group (e)

Combination Soil Types

This group includes all materials with enough soil binder to separate the aggregate particles or overfill the voids of the compacted specimen. For example, if the material is a clay gravel with high plasticity index, treat the material as a swelling soil, and allow the + No. 20 material to soak a minimum of 4 hours as do aggregate materials. It should be noted that the total swelling is figured only for that part passing the No. 40 sieve. Other combinations must be recognized and tested in the proper group. Subject all specimens to overnight capillarity, test and classify.

Notes:

When testing aggregate materials under Part II where classification is required, test two specimens at 0 psi and the others at 3, 5, 10 and 15 psi. Average the result of the zero lateral pressure tests as one value. Fine grain soils are classified using lateral pressures of 0, 3, 5, 10, 15 and 20 psi.

Reporting Test Results

The reports and forms are the same as given in Part I of this procedure.

Pavement Design Notes:

After materials have been classified in accordance with Part I or Part II and cohesiometer values for stabilized layers and surfacing have been determined, the following steps should be followed for the thickness design:

1. Obtain from the Transportation Planning Division, D-10, the current and projected traffic data.

2. Select a design wheel load from D-10, traffic data, and known local conditions. Consideration should be given to increasing the design wheel load by 30 percent if traffic is anticipated to have over 50 percent tandem axles. Use Figure 16 to calculate total depth of pavement to protect the subgrade.

3. Reduce total depth of pavement by using Figure 17 whenever stabilized layers are used in the pavement structure. Enter above depth on ordinate of Figure 17 and follow across page until intersection of cohesiometer value selected (see below) for use is reached, then project to abscissa to read reduction in depth due to bridging effects.

Standard cohesiometer values (corrected to represent values from 3-inch height specimens) are used with Figure 17 regardless of thickness of stabilized layer except where asphaltic mixtures are used. The modification of cohesiometer values for 3 inch high specimens for application to other thicknesses of asphaltic mixtures is obtained by the following formula:

$$C_m = \frac{C \times t^2}{9}$$

Where:

C_m = Modified cohesiometer value

C = Standard cohesiometer value for a 3-inch height specimen

t = Proposed thickness of Bituminous Mixtures in inches

4. The load frequency design factor can be obtained from the tabulation in Figure 18. The depth obtained in Step 3 is then multiplied by this factor and used with the Flexible Base Design Chart in Figure 16 to design each course of the pavement structure.

5. Figure 19 presents data which was interpreted from good engineering practice supplemented by utilizing the AASHTO Road Test data and is a suggested method for determining the thickness of surface courses.

Limitations:

1. For a 6 inch or greater layer thickness, use a value of 6 in. in the formula for t.

2. When adjacent layers of stabilization and asphaltic concrete are used, the cohesiometer value to be used with Figure 17 should be equal to the sum of the standard cohesiometer value for the stabilized layer and the modified cohesiometer value of the asphaltic concrete. When two adjacent layers of stabilization are used, or if a layer of untreated flexible base material exists between asphaltic concrete and a stabilized layer only the greater of the two cohesiometer values should be used in Figure 17. Considerable caution and good

engineering judgement should be used in selecting cohesiometer values for use in reduction of base depths. This is especially true in cases where hot mix-cold laid asphaltic concrete is bid as an alternate to hot mix asphaltic concrete laid hot. In the case of stabilized bases, subbases and subgrades, average values rather than highest values should be selected for use in Figure 17.

General Notes:

1. Wetted stabilized materials taken from the roadway during construction should be screened over a No. 4 sieve at the field moisture content without drying. Each of these two sizes is mixed for uniformity and weighed. Specimens are then weighed and recombined with like amounts of plus No. 4 material. Moisture can be adjusted in each specimen by adding to the plus No. 4 material or removing from the minus No. 4 material by a fan, as needed.

2. See appropriate test method listed below for testing wetted stabilized materials taken from the roadway during construction.

a. Cement Stabilization: Test Method Tex-120-E

b. Lime Stabilization: Test Method Tex-121-E

In any event, the stabilized material should not be completely air dried as outlined in Test Method Tex-101-E.

3. When molding a set of IPE specimens for testing lime stabilized subgrades and base materials, refer to Figure 3 in Test Method Tex-121-E for the recommended amounts of lime to be used.

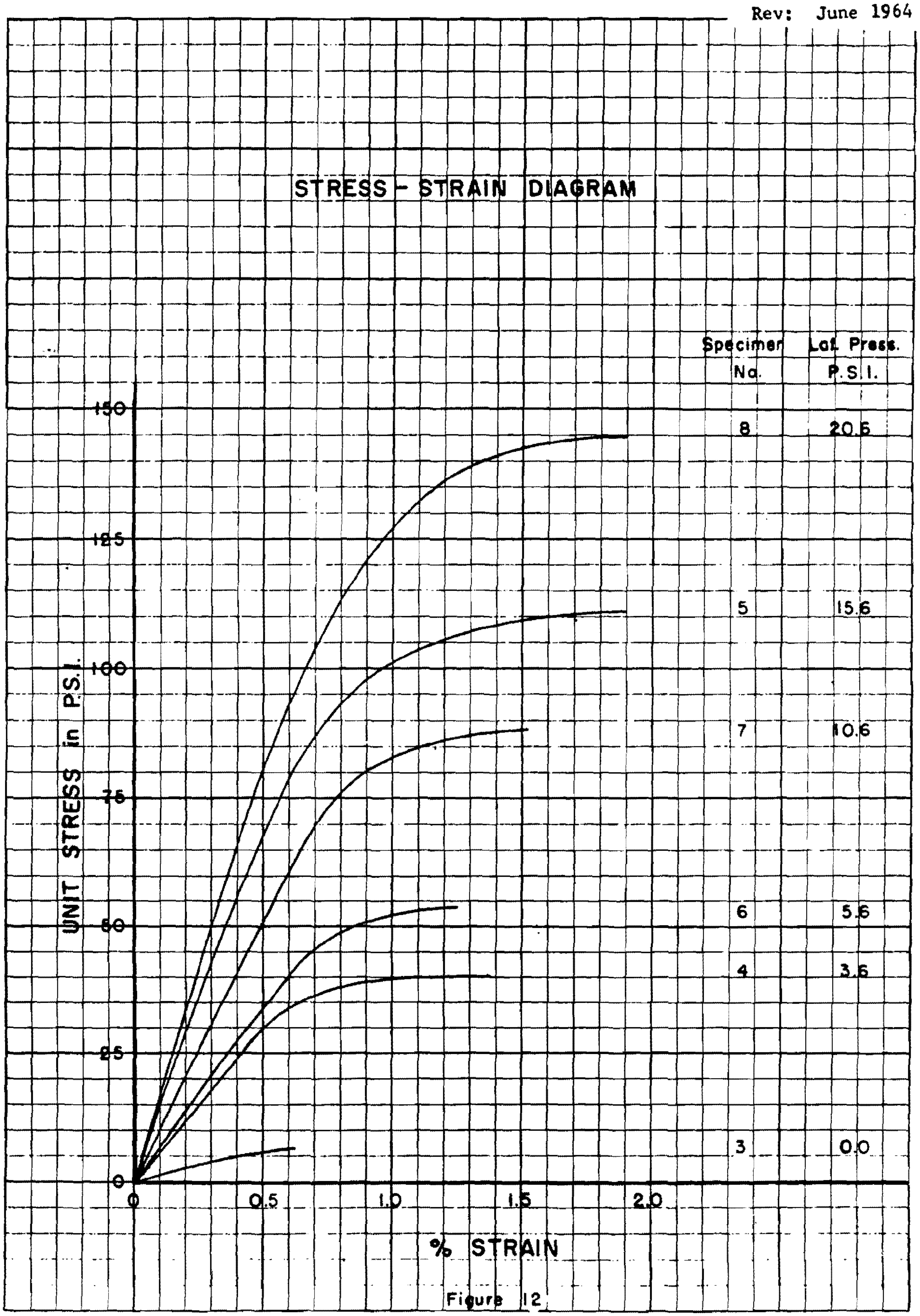

STRESS - STRAIN DIAGRAM
Specimen No.
Lat. Press. P.S.I.
8
20.6
5
15.6
7
10.6
6
5.6
4
3.6
3
0.0
UNIT STRESS in P.S.I.
150
125
100
75
50
25
0
% STRAIN
0
0.5
1.0
1.5
2.0

Figure 12

MOHR'S DIAGRAM

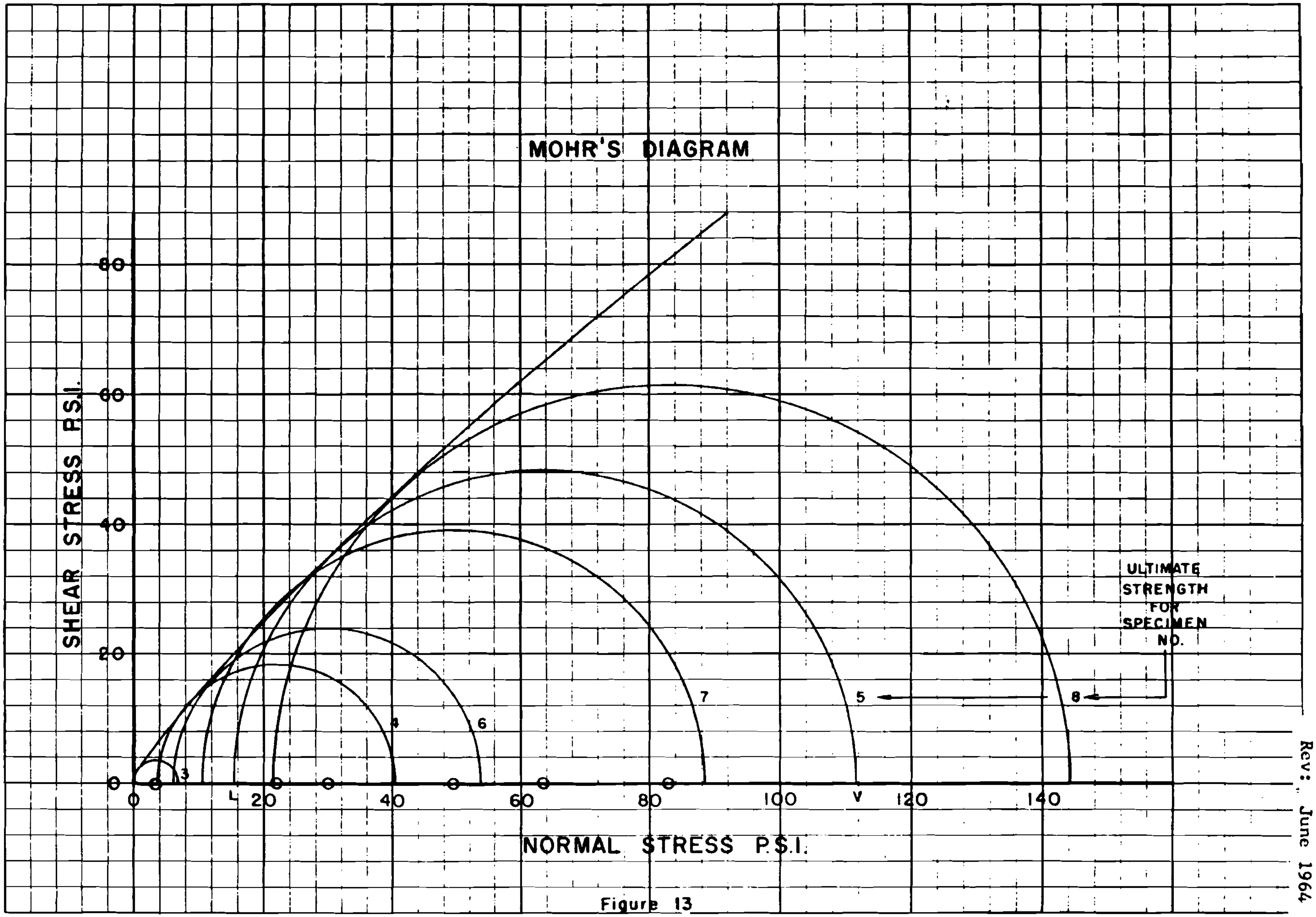


Figure 13

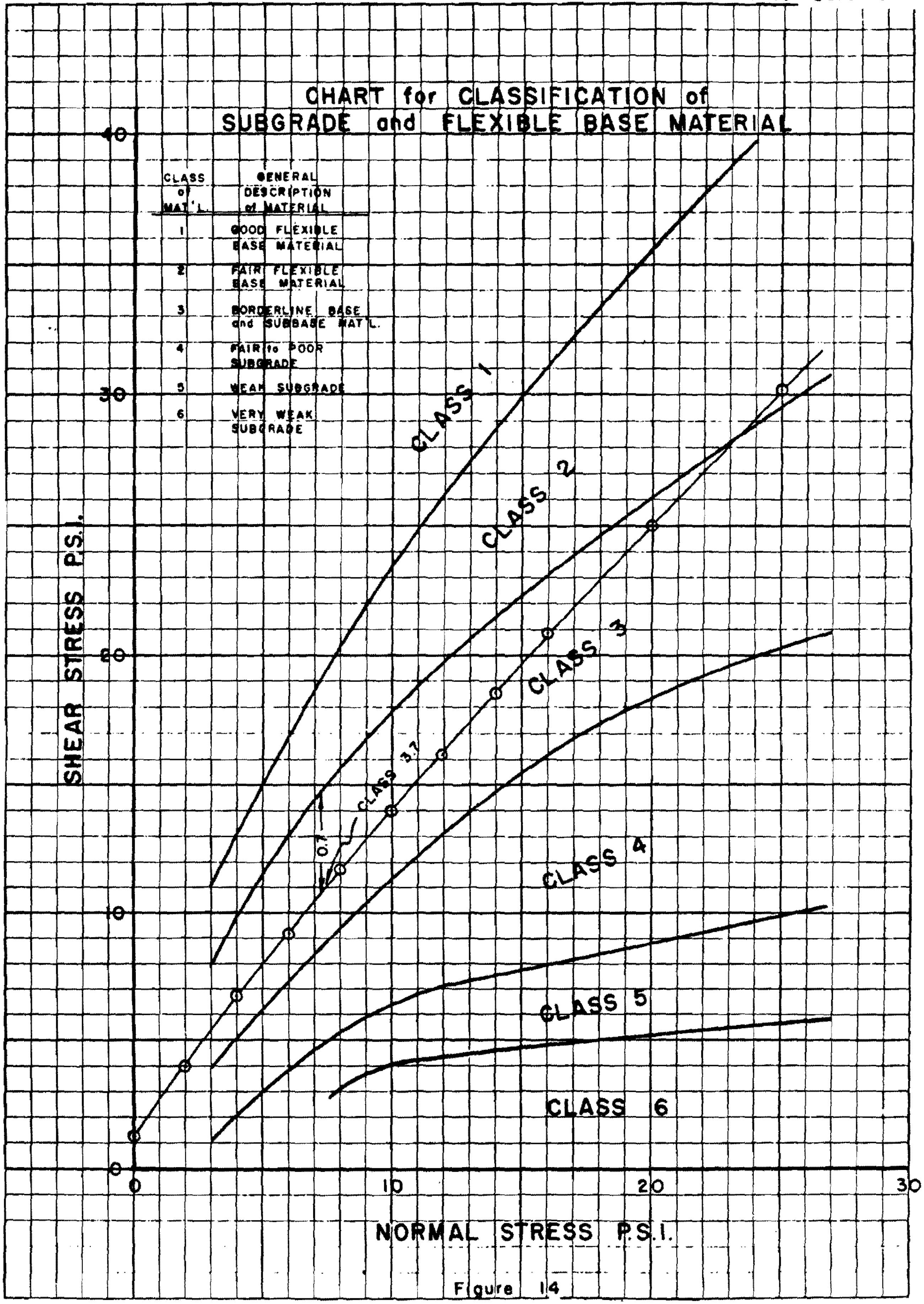


CHART for CLASSIFICATION of
SUBGRADE and FLEXIBLE BASE MATERIAL
CLASS of MAT'L.
GENERAL DESCRIPTION of MATERIAL
1 GOOD FLEXIBLE BASE MATERIAL
2 FAIR FLEXIBLE BASE MATERIAL
3 BORDERLINE BASE and SUBBASE MAT'L.
4 FAIR to POOR SUBGRADE
5 WEAK SUBGRADE
6 VERY WEAK SUBGRADE
CLASS 1
CLASS 2
CLASS 3
CLASS 3.7
0.7
CLASS 4
CLASS 5
CLASS 6
SHEAR STRESS P.S.I.
NORMAL STRESS P.S.I.
0
10
20
30
40

Figure 14

TRIAXIAL TEST SUMMARY SHEET

TABLE NO. ____

Lab No.____________County____________Highway________Project__________

Material________________________Identification__________________

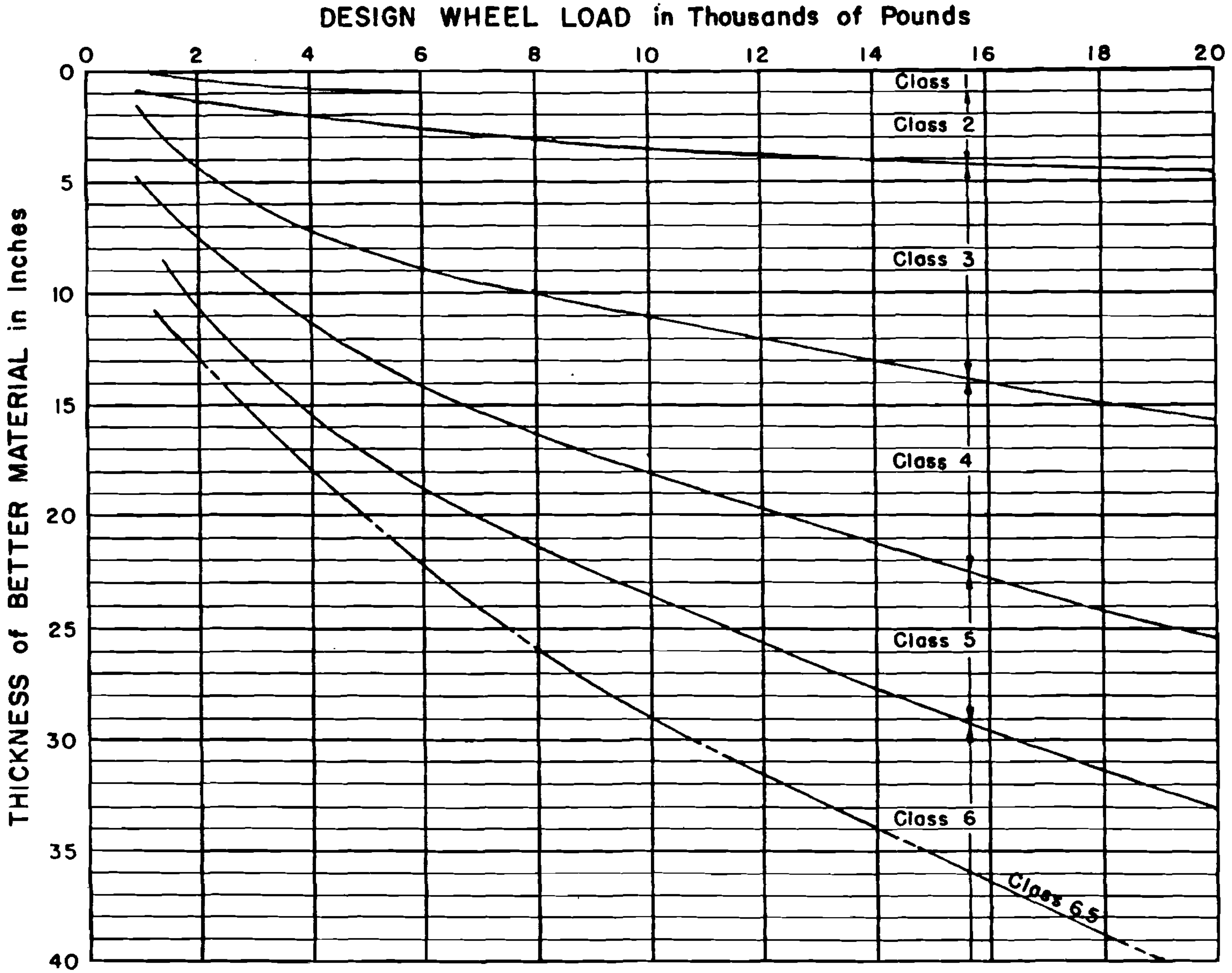
Description____

____

Opt. Moist.________Opt. Dry Density________at Comp. Effort________ft.-lbs./cu. in.

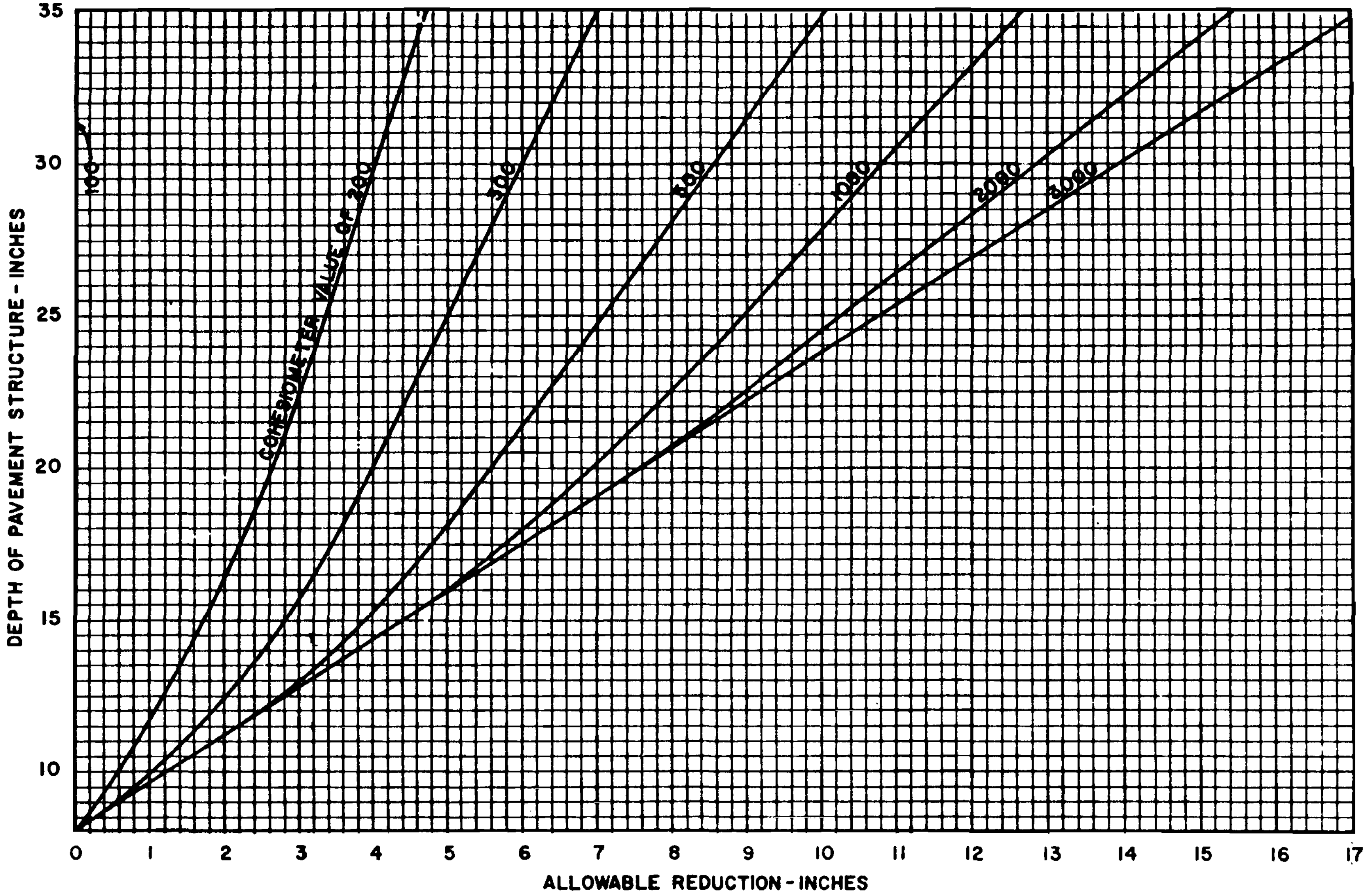
Molding Data			Curing Data			Testing Data			
				Water Content					
Specimen No.	Water Percent Dry Weight	Dry Density Lbs./Cu.Ft.	Capillary Moisture Time Days	After Drying Percent Dry Weight	After Capillary Absorption % Dry Wt.	Applied Lateral Pressure PSI	Ultimate Compressive Strength PSI	Percent Strain at Ultimate	Percent Volumetric Swell

Figure 15



FLEXIBLE BASE DESIGN CHART

Figure 16



THICKNESS REDUCTION CHART FOR STABILIZED LAYERS

Figure 17

CRITERIA FOR OBTAINING THE LOAD-FREQUENCY DESIGN FACTOR

Total Equivalent 18,000 Pound Single Axle Load Applications	Design Wheel Load in Pounds (ADTHWL)	*Load Frequency Design Factor
14,00	6,000	0.65
25,000	6,200	0.70
38,000	6,300	0.75
61,000	6,500	0.80
100,000	6,800	0.85
150,000	7,200	0.90
250,000	7,900	0.95
400,000	8,700	1.00
600,000	9,500	1.05
1,000,000	10,900	1.10
1,500,000	12,000	1.15
2,500,000	13,500	1.20
4,000,000	14,900	1.25
10,000,000	17,300	1.35

*A load-frequency design factor less than 1.0 is not recommended for the design of the main lanes of a controlled access highway.

Figure 18

SUGGESTED MINIMUM THICKNESSES OF SURFACE COURSES
INCHES

Item 248

Total Equivalent 18 Kip Single Axle Load Applications	When Tests Show Materials to be Specifications Grades* of Base Materials		
	Grade 1	Grade 2	Grade 3**
14,000	ST	ST	ST
25,000	ST	ST	ST
38,000	ST	ST	ST
61,000	ST	ST	1 1/2
100,000	ST	1 1/2	2
150,000	ST	1 3/4	2 1/2
250,000	1 1/4	2	3
400,000	1 1/2	2 1/4	3 1/2
600,000	1 3/4	2 1/2	4
1,000,000	2	3	4 1/2
1,500,000	2 1/2	3 1/2	5
2,500,000	3	4	5 1/2
4,000,000	3 1/2	4 1/2	6
10,000,000	4 1/2	5 1/2	7

Not recommended for use except where availability of better base materials is very expensive

*It is assumed that the material in question is no better than the grade shown.

**Exclusive of Cohesionless Materials.

Notes: ST denotes surface treatments.
Stage construction of surfacing permitted if traffic studies indicate slow development of axle load equivalencies.

Figure 19

"MODIFIED TRIAXIAL DESIGN PROCEDURE FOR USE WITH THE FLEXIBLE PAVEMENT DESIGN SYSTEM (FPS)"

MODIFIED TRIAXIAL DESIGN PROCEDURE FOR USE WITH THE FLEXIBLE PAVEMENT DESIGN SYSTEM (FPS)

The modified triaxial procedure presented herein is intended to supplement the Department's computerized Flexible Pavement Design System (FPS) . FPS is outlined in *Texas State Department of Highways and Public Transportation, Pavement Design System, Part I, Flexible Pavement Designer's Manual*, Highway Design Division, 1972 (Revised through May 1983). The modified triaxial procedure is briefly described on page 1A.3 of the FPS manual. It is recommended that all flexible pavement designs generated by the use of FPS be checked by this procedure.

The specific purpose of the modified triaxial procedure is to insured that all pavement design strategies proposed for construction have enough overall thickness to protect the subgrade against a compressive failure.

FPS uses the number of repetitions of an 18-KSA equivalent wheel load as its primary traffic input. On low truck-traffic highways such as state highways, farm-to-market roads and urban system projects, it is frequently found that the number of repetitions of the 18-KSA equivalents is quite low while the wheel loads may be normal or greater than normal. From this it is apparent that FPS has the potential to generate pavement design strategies with an overall or equivalent pavement thickness which would not satisfy triaxial requirements.

Figure 1, Typical Three Layer Pavement Structure, depicts a pavement structure and the critical subgrade element which must be protected against compressive failure. The several ways of reducing the compressive stress on the subgrade are to increase

(1) base course thickness,

(2) surfacing course thickness, or

(3) the rigidity of the upper layers (E_1 and E_2 .

This, in effect, is saying that the overall thickness must be increased or the layerd materials must be made more rigid.

The modified triaxial procedure proposed here is a modification of Test Method Tex-117-E as outlined in the Department's Manual of Testing Procedures. In addition to the modifications, a step-by-step procedure and example problem are presented.

Traffic: Traffic data for pavement design should be obtained from File D-10P of the Transportation Planning Division. For this procedure, the traffic elements needed are Average of Ten Heaviest Wheel Loads Daily (ATHWLD), and the percentage of the trandem axles in the ATHWLD, Figure 2, Tandem Axle Loads, shows an elementary diagram of stress distribution for tandem wheel loads. The diagram indicates a zone of combined stresses or an area where the combined effect on the subgrade is greater when the wheel loads are in a tandem arrangement. It is generally accepted that wheel loads in a tandem arrangement deflect or compress the subgrade layer about 30 perent more than a single wheel load, thus a factor of 1.3 is used to modify ATHWLD values where there is 50 percent or more tandem axles in the ATHWLD.

Subgrade Triaxial Class: An estimate of subgrade triaxial class by someone knowledgeable is all that is expected in this modified procedure. This is one of the major modifications to the procedure.

Cohesiometer Value: Credit in terms of overall thickness reduction must be allowed for stabilized and bound materials such as asphaltic concrete pavement, asphalt stabilized base, cement stabilized base, lime stabilized subgrade, etc., if these premium-priced materials are to compete with the unbound materials such as flexible base, foundation course, etc. The stabilized materials are generally acknowledged to be "stronger" than their counterparts and this cohesiometer credit must be used to justify their increased cost. Cohesiometer values can be taken from previous testing, from Table 1 of this paper, or from an estimation by knowledgeable persons, or a combination thereof. It should be noted that the values of Table 1 are modified values to be used directly with Figure 17 of the Test procedure. Values obtained otherwise may need to be modified according to the formula on page 13 of the Test procedure.

Load Frequency Design Factor: The Load Frequency Design Factor (LFDF) for this procedure is to be used as 1.0. The FPS solutions consider the effects of traffic repetitions (18-KSA); therefore, this aspect of the triaxial design procedure can be modified. The step considering the Load Frequency Design Factor can be bypassed since this factor is assigned the value of unity.

A Step-by-Step Modified Design - Analysis Procedure:

1. Obtain the ATHWLD and percent tandem axles in the D-10P traffic analysis. If the percentage of tandem axles in the ATHWLD is equal to or greater than 50 percent, then

   Design Wheel Load = 1.3 X ATHWLD.

   If the percentage of tandem axles in the ATHWLD is less than 50 percent, then

   Design Wheel Load = ATHWLD.

2. Determine a Subgrade Triaxial Class for the subgrade material under consideration.

3. Obtain the pavement structure design as determined by the Flexible Pavement Design System (FPS) and determine the total thickness of pavement structure material proposed by FPS. Designate this thickness as T_{FPS}. Examine the proposed FPS design for stabilized layers which would be eligible for cohesiometer credit. If more than one layer is stabilized, select only the layer that will allow the largest amount of cohesiometer credit and note this value. If there are no stabilized layers in the FPS design, skip Step 5.

4. With the Subgrade Triaxial Class and the Design Wheel Load enter Figure 16, Flexible Base Design Chart from the Test procedure and determine the required thickness of better material or required subgrade cover. Designate this as T_R.

5. Using the previously required thickness of better material, T_R, determined in Step 4 and the modified cohesiometer value for the cohesive layer selected in Step 3 proceed to Figure 17 Thickness Reduction Chart For Stabilized Layers, from the Test procedure and determine the allowable reduction in pavement structure thickness due to the cohesive layer. Designate this value as AR. Subtract AR from T_R and designate this value as T_M.

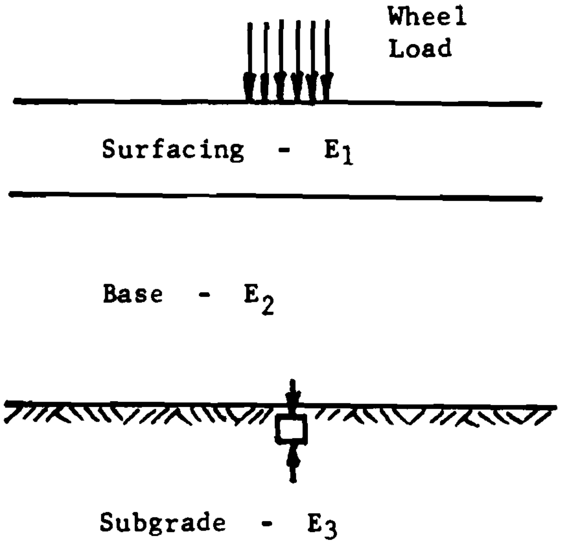
6. For the designs without stabilized layers, compare the total thickness of pavement structure material determined by this triaxial procedure ($T_{FPS}:T_R$). If the FPS thickness is less than that determined by the triaxial procedure, it is recommended that the thickness be adjusted to comply with the value obtained by triaxial procedures.

   For those FPS designs with stabilized layers for which cohesiometer credit was given, compare the total thickness T_{FPS} with the modified triaxial thickness ($T_{FPS}:T_M$). If the modified triaxial thickness is greater than the total thickness of the FPS design, it is recommended that the thickness be adjusted to comply with the value obtained by triaxial procedures.

Recommendations: It is recommended that all designs generated by the Flexible Pavement Design System be checked against this modified triaxial procedure to assure that adequate cover is provided over the subgrade to protect against compressive failures of the subgrade resulting from the Design Wheel Load.

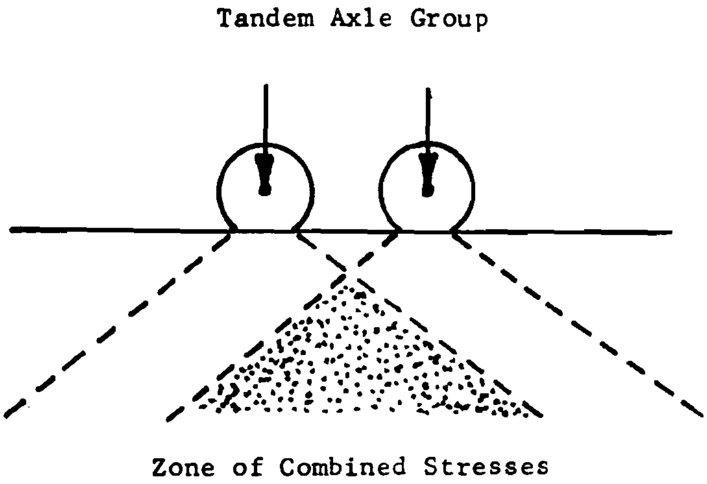
It is expressly recommended that this modified procedure not be used as the sole design procedure.

If triaxial procedures are to be used exclusively, it is specifically recommended that the procedure designated as Test Method Tex 117-E, outlined in the Manual of Testing Procedures, be used.



Typical Three Layer Pavement Structure

Figure 1



Tandem Axle Loads

Figure 2

Table 1

Material Type	Modified Cohesiometer Value (C_m)
Lime Treated Base greater than 3" thick	300
Lime Treated Subgrade greater than 3" thick	250
Cement Treated Base greater than 3" thick	1000
Cold Mixed Bituminous Materials greater than 3" thick	300
Hot Mixed Bituminous Materials greater than 6" thick	800
Hot Mixed Bituminous Materials 4" to 6" thick	550
Hot Mixed Bituminous Materials 2" to 4" thick	300

Note: Use cohesiometer values from Table 1 if other information is not available.

EXAMPLE PROBLEM

STEP 1 - TRAFFIC DATA

ATHWLD = 10,000 lbs.

% Tandems in ATHWLD = 60%

Design Wheel Load = 1.3 X 10,000 = 13,000 lbs.

STEP 2 - SUBGRADE

Subgrade Triaxial Class = 5.0

Determined by Consultation With Laboratory Engineer

STEP 3 - FPS DESIGN

3" Asph. Conc. Pav. (ACP)

6" Cement Treated Base (CTB)

8" Flexible Base

T_{FPS} = 17"

C_M = 1000 (From Table 1 - CTB)

STEP 4 - REQUIRED THICKNESS

Design Wheel Load = 13,000 lbs.

Subgrade Triaxial Class = 5.0

T_R = 20.5" (From Figure 16)

STEP 5 - MODIFIED THICKNESS

T_R = 20.5" (From Step 4)

C_M = 1000 (From Step 3)

AR = 7.2" (From Figure 17)

$T_M = T_R - AR$

T_M = 20.5" - 7.2"

T_M = 13.3"

STEP 6 - DESIGN SELECTION

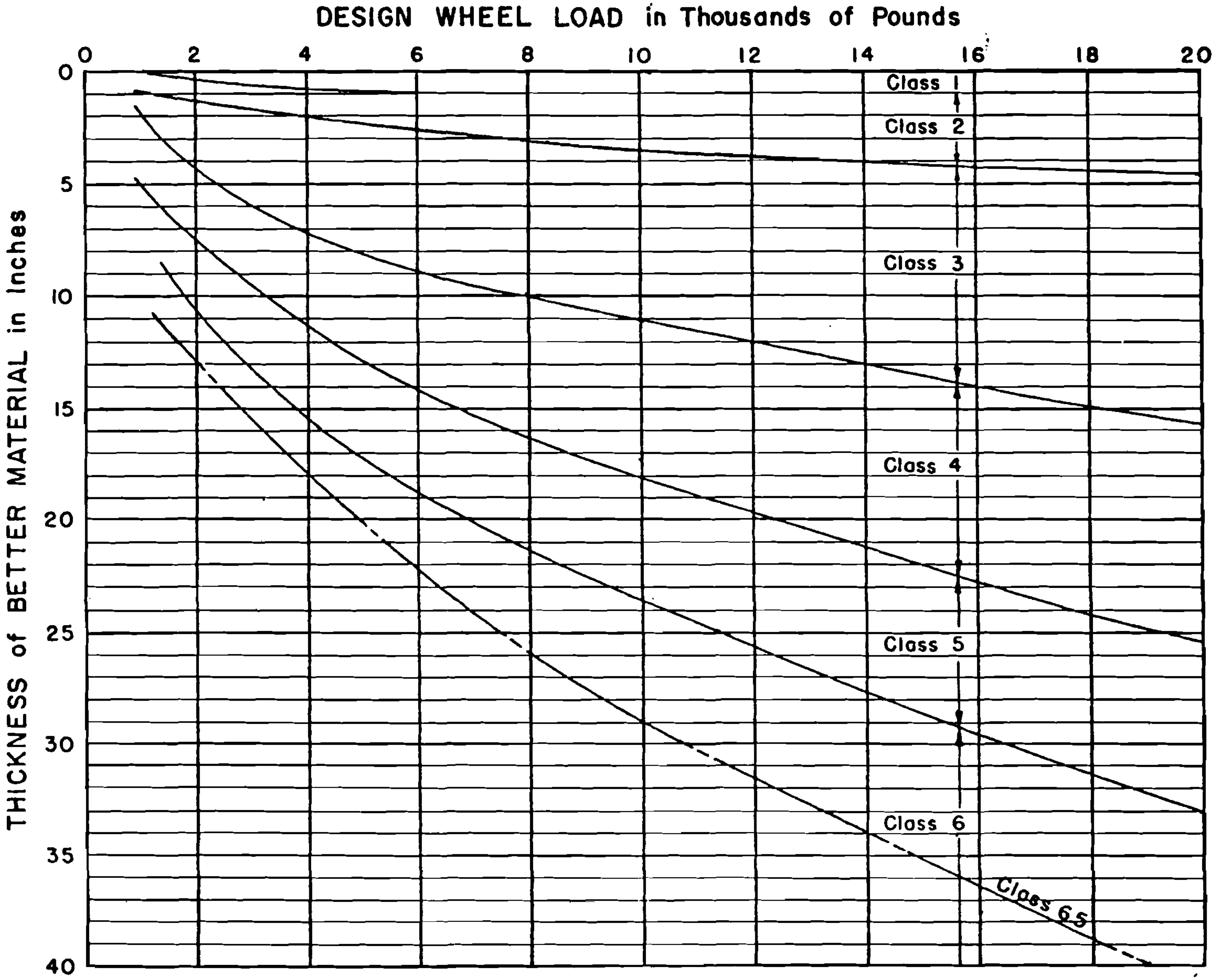
Compare T_{FPS} : T_M

T_{FPS} = 17" (Step 3)

T_M = 13.3" (Step 5)

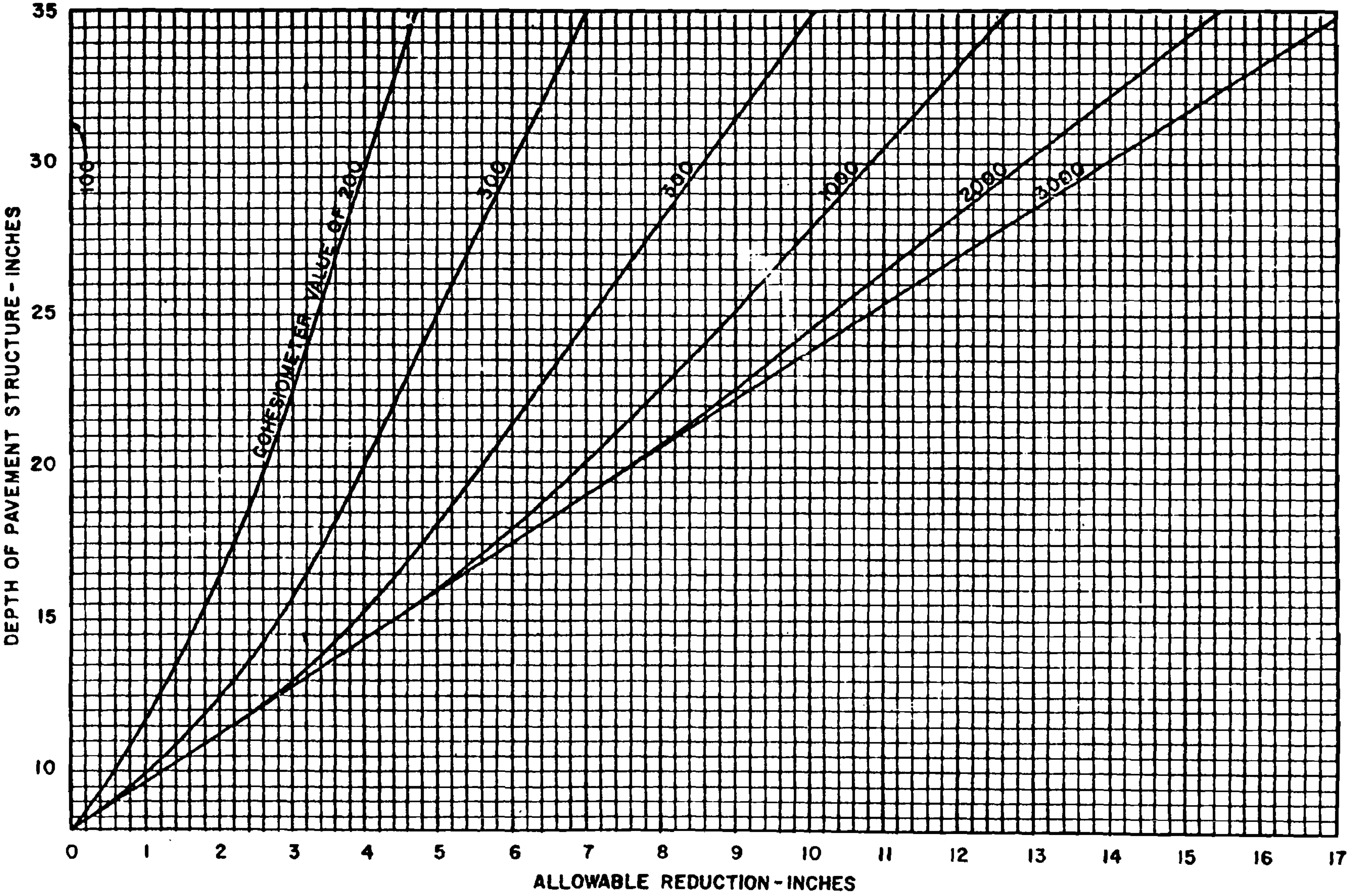
T_{FPS} Greater than T_m

FPS Design is Okay.



FLEXIBLE BASE DESIGN CHART

Figure 16



THICKNESS REDUCTION CHART FOR STABILIZED LAYERS

Figure 17