Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FHWA-RD-77-133		PB 80 192693

4. Title and Subtitle	5. Report Date
Flexible and Rigid Pavement Overlay Design Procedure	October 1977
	6. Performing Organization Code
7. Author(s) Harvey J. Treybig, B. Frank McCullough, Phil Smith, Harold VonQuintus, and Peter Jordahl	8. Performing Organization Report No.
9. Performing Organization Name and Address Austin Research Engineers Inc 2600 Dellana Lane Austin, Texas 78746	10. Work Unit No. (TRAIS) FCP 35D2-202
	11. Contract or Grant No. DOT-FH-11-8544
12. Sponsoring Agency Name and Address Offices of Research and Development Federal Highway Administration U. S. Department of Transportation Washington, D.C. 20590	13. Type of Report and Period Covered Final Report
	14. Sponsoring Agency Code S0975

15. Supplementary Notes

FHWA Contract Manager: R. A. McComb (HRS-14)

16. Abstract

This manual presents design procedures for overlays of both flexible and rigid pavements. The design procedure includes an evaluation of the existing pavement based on nondestructive deflection testing, condition surveys, and materials sampling and testing. Based on this information the pavement is divided into separate design sections and each section is classified according to its condition of cracking.

An analysis to determine the required overlay thickness is then made based on the category to which the existing pavement is assigned. The overlay analysis makes extensive use of elastic layered theory and selects the overlay thickness based on the concept of failure by fatigue cracking or rutting.

The design procedure uses three computer programs for the pavement evaluation and overlay thickness design. Input guides and illustrative problems for the use of these programs are presented in this report.

17. Key Words	18. Distribution Statement
Overlay design, pavement design, overlays, rigid overlays, rutting, fatigue cracking, flexible overlays, deflection analysis, pavement evaluation.	No restrictions. This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161.

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified		

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

NOTICE

PREFACE

This manual is the fifth report in a series concerning the design of overlays for flexible and rigid pavements. The four previous reports which led to the development of this manual are as follows:

FHWA Report No. FHWA-RD-75-75, "Asphalt Concrete Overlays of Flexible Pavements, Volume I - Development of New Design Criteria"

FHWA Report No. FHWA-RD-75-76, "Asphalt Concrete Overlays of Flexible Pavements, Volume II - Design Procedures"

FHWA Report No. FHWA-RD-77-66, "Overlay Design and Reflection Cracking Analysis for Rigid Pavements, Volume I - Development of New Design Criteria"

FHWA Report No. FHWA-RD-77-67, "Overlay Design and Reflection Cracking Analysis for Rigid Pavements, Volume II - Design Procedures".

The work presented in these five reports was accomplished by a team including Harvey J. Treybig, B. F. McCullough, Phil Smith, Harold Von Quintus, Frank Carmichael, Peter Jordahl, Stephen Seeds, and Jack O'Quin. W. R. Hudson also provided technical assistance in certain phases of the project.

Support for the project was provided by the Federal Highway Administration, Office of Research and Development, under Contract No. DOT-FH-11-8544. We are grateful for the technical coordination provided by Mr. Richard McComb, Contract Manager during this phase of the contract.

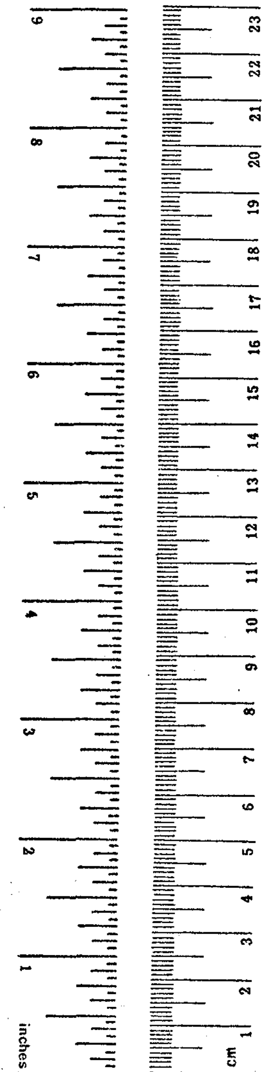
Austin Research Engineers Inc

METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

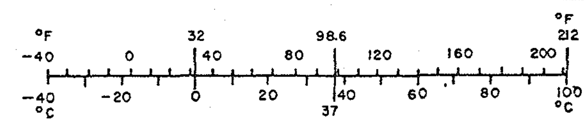
Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
	AREA			
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
	MASS (weight)			
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
	VOLUME			
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
	TEMPERATURE (exact)			
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
	AREA			
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
	MASS (weight)			
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
	VOLUME			
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
	TEMPERATURE (exact)			
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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SECTION 1

INTRODUCTION

This design manual describes the use of a universal pavement overlay design procedure developed for the Federal Highway Administration's FCP Project 5D, Structural Rehabilitation of Pavement Systems. The development of the criteria for the procedure is discussed in two reports written previously for this project (Ref. 1, 2).

1.1 Objective

This manual outlines a procedure for the thickness design of overlays for both flexible and rigid existing pavements. It combines and updates the two previously written manuals for this project-one for overlays of flexible pavements (Ref. 3) and one for overlays of rigid pavements (Ref. 4).

1.2 Scope of Procedure

The procedure covers flexible overlays of flexible pavements and both flexible and rigid overlays of rigid pavements. Both jointed and continuous rigid pavements are included as well as bonded and unbonded overlays. It covers existing pavements that have remaining life, those that are substantially cracked, and those that are in such deteriorated condition that they will be mechanically broken up into small pieces. The procedure infers that overlay materials and construction specifications will not differ from those now in use in highway design and construction. However, it does include some non-conventional materials testing methods.

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[1] Austin Research Engineers Inc, "Asphalt Concrete Overlays of Flexible Pavements, Volume 1 - Development of New Design Criteria," FHWA Report No. FHWA-RD-75-75, August 1975.

[2] Austin Research Engineers Inc, "Overlay Design and Reflection Cracking Analysis for Rigid Pavements, Volume I - Development of New Design Criteria," FHWA Report No. FHWA-RD-77-66, August 1977.

[3] Austin Research Engineers Inc, "Asphalt Concrete Overlays of Flexible Pavements, Volume 2--Design Procedures," Report FHWA-RD-75-76, August 1975.

[4] Austin Research Engineers Inc, "Overlay Design and Reflection Cracking Analysis for Rigid Pavements, Volume 2 - Design Procedures," Report FHWA-RD-77-67, August 1977.

1.3 Design Concepts

The design concepts account for rehabilitation of existing portland cement concrete and asphaltic concrete pavements by overlaying with either portland cement concrete or asphaltic concrete. There are three basic steps: (1) evaluation of the existing pavement, (2) determination of design inputs, and (3) overlay thickness analysis. The procedures are illustrated in flow chart form in Figure 1.1. Evaluation of the existing pavement is accomplished by a condition survey and deflection measurements. This information enables the designer to distinguish between different segments of the existing pavement based on their condition. Each segment becomes a "design section" and is analyzed separately. Thus, the most economical rehabilitation is accomplished by varying overlay thickness along the roadway according to the existing pavement condition.

Determination of the design inputs includes both past and projected future traffic, environmental considerations, and materials testing and analysis. Results of the deflection measurements also serve as an aid in establishing properties of the subgrade material.

The overlay thickness analysis is based on the concepts of failure by excessive rutting and fatigue cracking for flexible pavements and excessive fatigue cracking for rigid pavements. Stresses and strains in the pavement are computed using linear elastic layered theory (Ref. 5)[1]. The overlay life is determined by entering these stresses into a fatigue or rutting equation that relates stress or strain magnitude and repetitions to failure. The overlay thickness that satisfies the fatigue and rutting criteria is selected as the design thickness.

The design procedure is automated in the form of three separate computer programs which are as follows:

1. PLOT2 for plotting deflection profiles (Ref. 4)
2. TVAL2 for determining design sections (Ref. 4)
3. POD1 for determining overlay thickness to prevent fatigue cracking and rutting

[1] Warren, H. and W. S. Dieckman, "Numerical Computation of Stresses and Strains in a Multiple-Layered Asphalt Pavement System," California Research Company, September 1963.

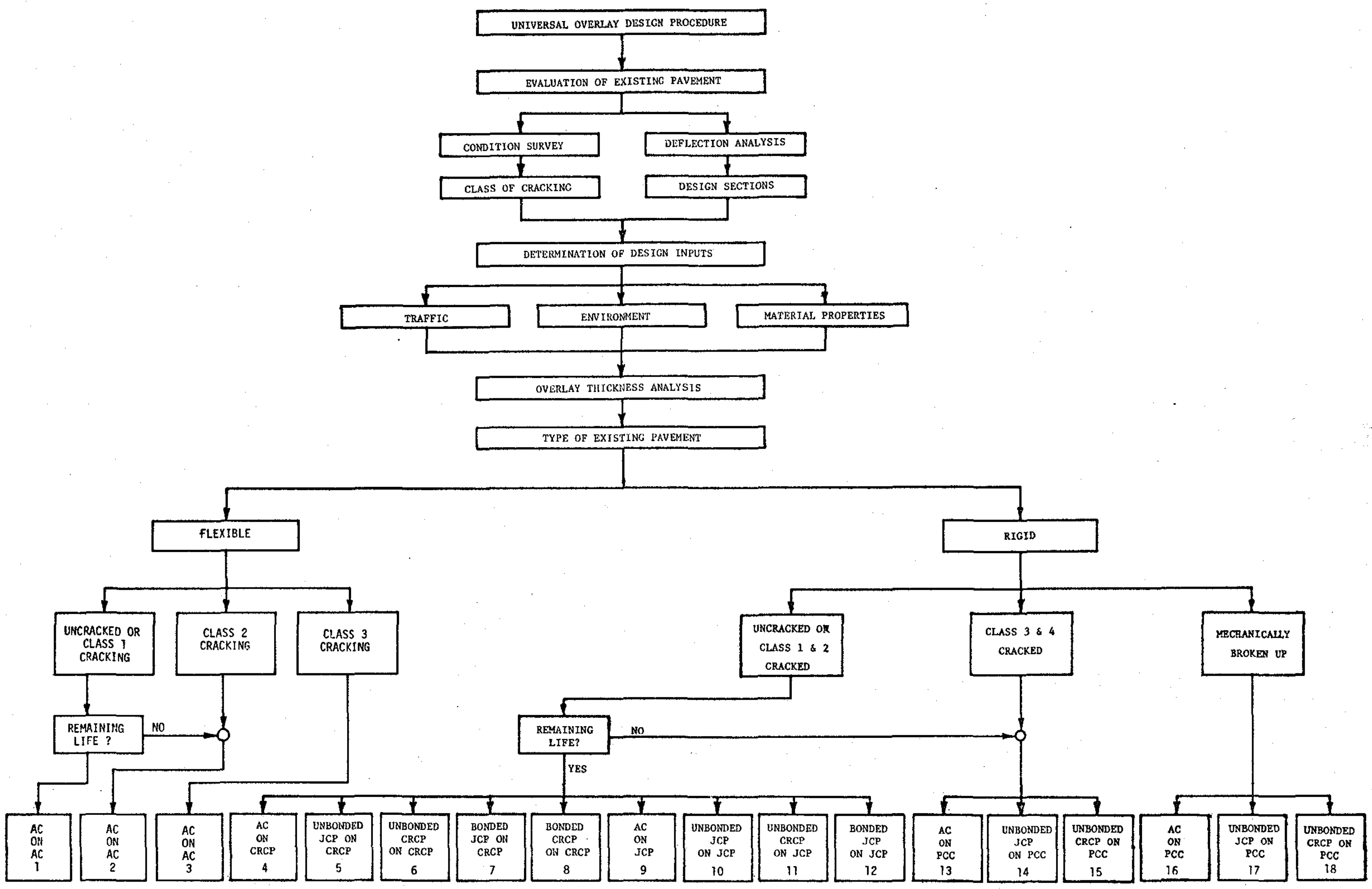

Figure 1.1 Flow chart of pavement overlay design procedure

Thus, the designer is required to make only minor hand computations, these being aids in determining computer program input data. However, if the user desires, he can make hand plots in lieu of using the program PLOT2 and hand statistical computations in lieu of using the program TVAL2.

1.4 Equipment Requirements

The hardware requirements for using this procedure include deflection testing equipment such as Dynaflect, Road Rater, Benkleman Beam or deflectograph, and laboratory testing equipment for resilient modulus of soils and other unbound base or subbase materials. Test equipment to measure the dynamic modulus of elasticity for asphalt concrete and portland cement concrete is also desirable.

The computer software which is part of the procedure is a series of programs which require a computer system such as the CDC 6600, IBM S/360, or the Univac 1108.

1.5 Contents of Design Manual

Section 2 of this manual discusses the requirements for deflection testing, condition surveys, and traffic computations. Section 3 discusses the selection of design sections based on the deflection and condition survey data which includes use of the computer programs PLOT2 and TVAL2. A hand method for statistical analysis is given which can be used in lieu of TVAL2. Section 4 describes the necessary materials sampling and testing. Section 5 discusses the designation of the proper overlay design analysis to be used. Section 6 describes the use of the fatigue analysis program POD1. Section 7 presents overlay design example problems. The appendices include a condition survey procedure, computer program input guides, and materials testing procedures.

SECTION 2

GENERATION OF DESIGN PROCEDURE INPUTS

The design procedure requires input from the following areas:

1. Deflection testing
2. Condition surveys
3. Traffic data

2.1 Deflection Testing

Deflection testing is used to measure the response of the in-service pavement to loads. From this behavior pattern, areas of equal performance and material properties can be derived.

2.1.1 Equipment Type - Deflection measuring equipment such as the Dynaflect (Ref. 6)[1], the Road Rater (Ref. 7)[2], or any other equipment which will give satisfactory deflection results may be used. Both Dynaflect and Road Rater are available on a rental basis or for purchase. The equipment lends itself to rapid testing, thus making it possible to thoroughly investigate a pavement economically and rapidly. Deflections measured with a Benkleman Beam and an 18,000 pound single axle load may also be used.

2.1.2 Recommended Testing Conditions - The design procedure is based on measurements that were made during the season of the year yielding the maximum deflection. It is recommended that the user also measure deflections at the time of year yielding the maximum values. For other seasons, the user should develop corrections to relate the measurements to the worst or maximum condition. This manual offers no seasonal adjustment factors for translating deflection measurements made in any season other than the maximum period.

2.1.3 Sampling Frequency and Procedure - The testing recommended includes at least one deflection profile along the outer wheelpath of the existing roadway. The spacing between the measurements should be

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[1] Swift, Gilbert, "Dynaflect - A New Highway Deflection Measuring Instrument," Proceedings, 48th Annual Tennessee Highway Conference, University of Teneessee, 1966.

[2] Scrivner, F. H. and W. M. Moore, "An Electro-Mechanical System for Measuring the Dynamic Deflection of a Road Surface Caused by an Oscillating Load," Research Report 32-4, Texas Highway Department, Texas Transportation Institute, 1964.

a minimum of 100 feet. For two directional roadways, it is desirable to obtain two lines of deflection profiles, one on either side of the center line in the outside wheel path. Each line should have the measurements spaced 100 feet apart, but staggered 50 feet between the lines, thus providing profile data with 50-foot spacing between measurements. For divided highways, deflection profiles are required in outside lanes of both roadways on a staggered basis.

For undivided highways the two deflection profiles should be combined into one that represents the entire width of roadway. However, for divided highways, the pavements on either side of the median should be considered to have separate deflection profiles. Two profiles will give adequate coverage of most highways. These measurements, however, need to be located between cracks or joints in a good portion of the pavement, spaced at regular intervals and so documented. The following is a suggested guideline of spacings for deflection tests for various conditions.

TABLE 2.1 GUIDELINE FOR DEFLECTION MEASUREMENTS

Condition of Location	Spacing of Measurements
Rolling terrain	100 feet
Numerous cut to fill transitions	100 feet
Level with uniform soil	250 feet

In addition to the above described measurements for the determination of a deflection profile, it is necessary to make measurements of deflection at the slab corners if the existing pavement is a jointed concrete pavement. This data will be needed later in determining the degree of load transfer. These measurements should be kept separate and not included in the deflection profile, but should be made at the same time as the interior measurements, to conserve time and money.

2.2 Condition Surveys

As part of the site investigation, the condition of the existing pavement should be carefully documented. Condition survey information should be obtained which includes such items as an accurate inventory of the different types and amount of cracking, rutting, spalling, joint condition, faulting, pumping, blowups, and some inventory of roughness. It is suggested that the condition surveys be done at the same time as the deflection testing. This enables the technicians to note and document locations of cracking, repairs, etc., relating to the location of deflection measurements. Appendix A includes some condition survey techniques that may be used.

2.2.1 Cracking in Rigid Pavements - Cracking shall be defined and recorded according to the AASHO definitions, i.e., Class 1, Class 2, Class 3, and Class 4 (Ref. 8)[1].

Class 1 includes fine cracks not visible under dry surface conditions to a man with good vision standing at a distance of 15 feet. Class 2 cracks are those that can be seen at a distance of 15 feet, but which exhibit only minor spalling such that the opening at the surface is less than 1/4 inch. A Class 3 crack is defined as a crack opened or spalled at the surface to a width of 1/4 inch or more over a distance equal to at least one-half the crack length, except that any portion of the crack opened less than 1/4 inch at the surface for a distance of 3 feet or more is classified separately. A Class 4 crack is defined as any crack which has been sealed.

2.2.2 Cracking in Flexible Pavements - As for rigid pavements, cracking shall be defined and recorded according to the AASHO definitions, i.e., Class 2, Class 3, etc. (Ref. 8). Class 2 cracking is defined as that which has progressed to the stage where cracks have connected together to form a grid type pattern. Class 2 cracking is commonly referred to as alligator cracking. Class 3 cracking is the progression from Class 2 in which the Class 2 cracks spall more severely at the edges, lose integrity between blocks, and the segments of pavement surface loosen and move or rock under traffic.

Condition surveys of the existing pavement can conveniently be made on reasonably large-scaled maps, thus making it possible to record the distressed areas directly. The condition surveys provide important data for explaining variations observed in the deflection profiles and also differences in materials properties determined from laboratory investigations. A comparison of the deflection profile and the observed distress should be considered in formulating the materials sampling plan, Section 4.1. Furthermore, the observed cracking type present on the existing surface becomes a decision criterion relative to the method of characterization of the existing pavement and the kind of analysis performed.

2.2.3 Rutting - The rutting measurements in wheelpaths on existing asphalt concrete surfaces are included in the condition survey to give: 1) insight into the selection of an allowable rut depth, and 2) an estimate of the level up required on the existing surface prior to overlay. It is recommended that the rut depth be measured every

[1]"The AASHO Road Test, Report 5, Pavement Research," Special Report 61E, Highway Research Board, 1962.

500 feet in both wheel paths and that the averages for the two wheel paths be determined for the same pavement lengths as the sections established from the deflection profiles, Section 3.1. These measurements may be made by simple mechanical devices similar to those used at the AASHO Road Test. An alternative method is the stringline or other long straight edge laid across the wheelpath and the net depth measured with a scale.

2.2.4 General Observations - The condition survey shall include some recording of other general information relevant to the pavement such as drainage areas, soil changes, and cut/fill transition areas. Construction plans for the existing roadway if available, offer information relative to changes in cross section which will be unknown until any borings are made. Some measurement of profile or roughness is desirable in a condition survey. In this design procedure the roughness profile is only considered in a qualitative way in the selection of design sections. The drainage data serves as input to the consideration of tradeoffs between overlay thickness and drainage improvements. In some design situations, it may be possible to improve drainage which will in turn improve material properties and result in less overlay thickness. Economic comparisons should be made between these two approaches.

2.2.5 Environmental Data - If the existing pavement is an asphaltic concrete, it is necessary to obtain temperature information. The number of days per year that the average daily temperature exceeds 64°F must be determined for use in the rutting analysis. This can usually be obtained fairly easily from past weather records.

2.3 Traffic Information

Traffic information is required for the design procedure in terms of 18-kip equivalent single axle load applications determined in accordance with AASHO Interim Guide for the Design of Pavement Structures-1972 (Ref. 9)[1]. The total number of load applications experienced on the existing surface shall be estimated. The number of load applications shall also be projected for the anticipated life of the overlay.

2.3.1 Design Lane Traffic - If the traffic projection represents the total of all lanes for both directions of travel, the traffic must be distributed by direction and lanes for design purposes as follows:

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[1]"AASHO Interim Guide for Design of Pavement Structures," American Association of State Highway and Transportation Officials, 1972.

$$18KSAD = (18KSA) \cdot DDF \cdot LDF \quad (2.1)$$

where:

18KSA = Total 18-kip single axle loads expected in both directions,

DDF = Directional distribution factor, the ratio of traffic in a given direction to the total traffic,

LDF = Lane distribution factor, the ratio between the traffic in the lane of interest and the one-directional traffic, and

18KSAD = The 18-kip single axle loads experienced or expected in the design lane.

Directional distribution is normally made by assigning 50 percent to each direction unless special conditions warrant some other distribution. In regard to lane distribution, the controlling lane is generally the outside lane. If an agency has developed lane distribution factors for facilities with two or more lanes in each direction these should be used. Table 2.2 may be used as a guideline for selecting the lane distribution factor. If there is doubt as to which factor to apply, it is suggested that the most conservative range be used. The equation must be solved for both of the conditions of traffic described in paragraph 2.3.

TABLE 2.2 LANE DISTRIBUTION FACTORS FOR MULTILANE ROADWAYS (After Ref. 9)

Total Number of Lanes, One Direction	Lane Distribution Factor
2	1.0
3	0.8-1.0
3+	0.4-0.6

SECTION 3

SELECTION OF DESIGN SECTIONS

Using the nondestructive deflection test data, a highway can be divided into various design sections, which are areas where the pavement responds or deflects differently under the load.

3.1 Deflection Profiles

The deflection data obtained in the site investigations, excluding joint deflections, are plotted in the form of profiles throughout the length of the roadway as shown in Figure 3.1. Profiles from separate lanes shall be combined according to location or station number. These plots may be made manually or by using the computer program PLOT2. Instructions for using PLOT2 are in Appendix B.

3.2 Preliminary Design Sections

The deflection profiles from Section 3.1 shall be divided into areas of similar deflection. The limits of each design section should be recorded in terms of station number or mile points. A pavement may exhibit as few as one or two different levels of deflection, but variations may be so great in the subgrade support or surface condition that there may be as many as 7-10 different areas on a two mile length of roadway. Information from the condition survey (Section 2.2) shall be used as additional guidelines for dividing the profiles into sections. The deflection profile sections should also be compared with the cracking surveys to show any differences in the deflection and the performance of the pavement. Areas of different cross sections should be assigned different sections of deflection profile. Normally, this will be obvious in the deflection measurements. The reason for this is related to the structural analysis of the existing pavement.

3.3 Statistical Hypothesis Testing

Adjacent design sections of the same cross section should be checked to see if they are significantly different or whether they are from the same population of data. Standard statistical methods for testing of significance of the difference between two samples such as the hypothesis tests for equal means should be used for making this check (Ref. 10)[1]. The following steps and formulas are used to make this test:

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[1]Alder, Henry L. and Edward B. Roessler, Introduction to Probability and Statistics, Third Edition, W. H. Freeman and Company, San Francisco, California, 1965.

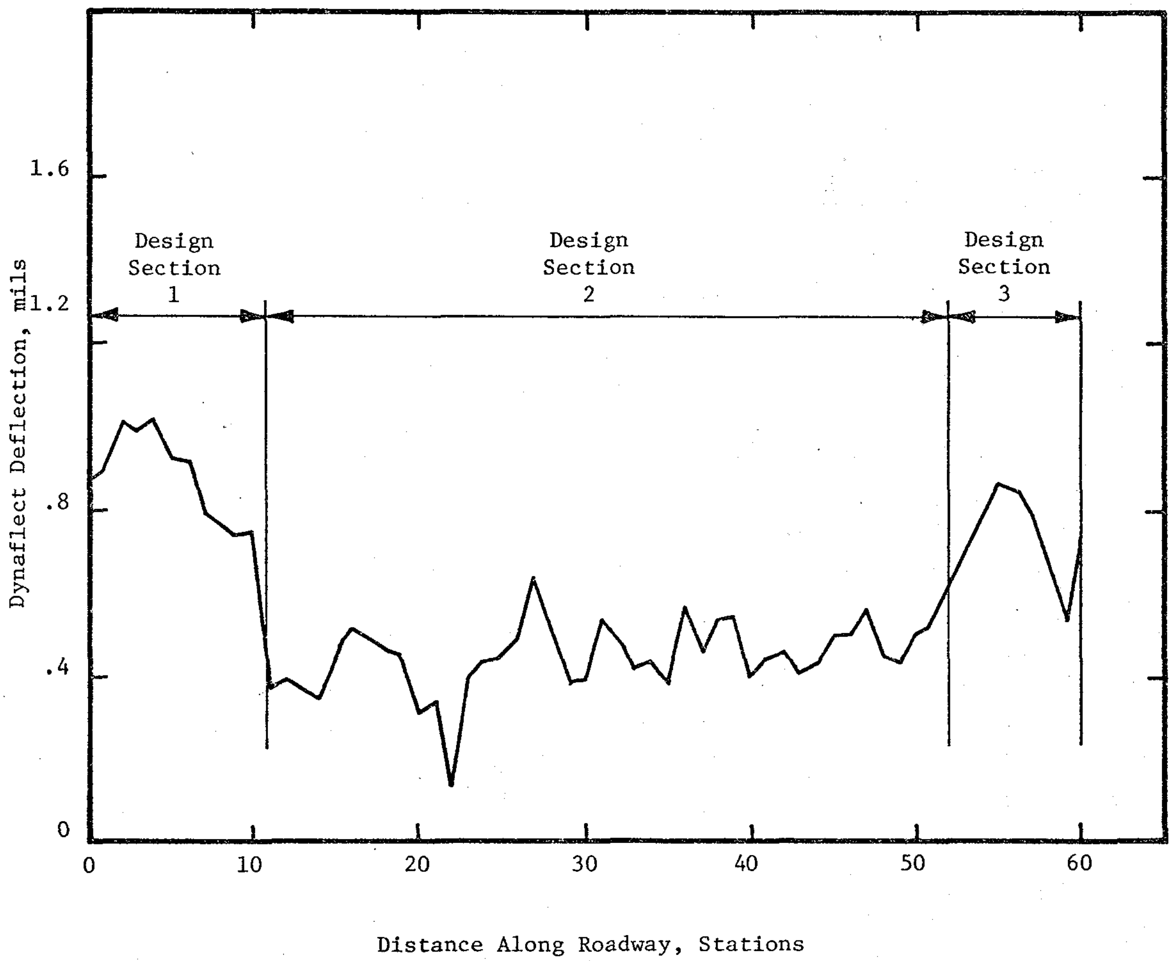

Figure 3.1. Sample deflection profile.

a_i, b_i = individual measurements or variates in sections designated 1 or 2 respectively

$\bar{a}$, $\bar{b}$ = mean value of measurements of variates in Sections 1, 2

n_a, n_b = number of variates in Sections 1, 2

d_f = the number of degrees of freedom

Step 1 - Calculate the mean ($\bar{a}$) from the section 1 data:

$$\bar{a} = \frac{\Sigma a_i}{n_a} \quad \ldots \quad (3.1)$$

Step 2 - Calculate the mean ($\bar{b}$) from the section 2 data:

$$\bar{b} = \frac{\Sigma b_i}{n_b} \quad \ldots \quad (3.2)$$

Step 3 - Calculate the "pooled estimate of the standard deviation" (S) from the two sections. This way the standard deviation determined is not affected by any difference which may exist between the means of each section.

$$S = \left[\frac{\sum_{i=1}^{n_a} (a_i - \bar{a})^2 + \sum_{i=1}^{n_b} (b_i - \bar{b})^2}{n_a + n_b - 2}\right]^{1/2} \quad \ldots \quad (3.3)$$

Step 4 - Determine the best estimate of the standard deviation of the mean of n_a sample variates for section 1, $S_{\bar{a}}$

$$S_{\bar{a}} = \frac{S}{(n_a - 1)^{1/2}} \quad \ldots \quad (3.4)$$

Step 5 - Do Step 4 for Section 2,

$$S_{\bar{b}} = \frac{S}{(n_b - 1)^{1/2}} \quad \ldots \quad (3.5)$$

Step 6 - Calculation from Step 4 and Step 5.

$$S_{(\bar{a} - \bar{b})} = (S_{\bar{a}}^{\,2} + S_{\bar{b}}^{\,2})^{1/2} \quad \ldots \quad (3.6)$$

Step 7 - The hypothesis to be tested is that the difference in mean values of the two parent populations from which the a_i and b_i were sampled differ by a value $^M(\bar{a}-\bar{b})$, here = 0. This hypothesis implies that if a very large number of samples were taken for a_i and b_i, their means would differ by $^M(\bar{a}-\bar{b})$. Calculate Student's t.

$$t = \frac{(\bar{a}-\bar{b}) - {}^M(\bar{a}-\bar{b})}{{}^S(\bar{a}-\bar{b})} \qquad \text{. . . . . 3.7}$$

Step 8 - Assume an appropriate significance level for the test. This is the probability that the hypothesis (equal means) will be rejected even though true. Obtain from a table of the Student's t distribution the t value corresponding to the number of degrees of freedom (n_a+n_b-2) and the chosen significance level (usually designated by γ and α, respectively).

Step 9 - Compare the two values of t. If the computed t is larger than the tabular value, the hypothesis is false at the assumed level of significance, and the two sets of deflections come from parent populations with different means; stated another way, the two sets of deflections come from sections which have significantly different mean deflections, and which therefore should be analyzed separately.

If two adjacent sections are not significantly different, they should be combined into one and that one checked against the next section. This procedure will establish the design sections, each of which then becomes a separate design problem.

The designer selects the significance level at which the deflection differences are tested; a level of 5 percent is recommended for general use. The statistical check may be made either by hand or by use of computer program TVAL2. A description of the program and its input guide are presented in Appendix C.

3.4 Determination of Design Deflection

The deflection data for each design section has previously been analyzed to obtain its mean value and standard deviation. The standard deviations give an indication of the variations which exist within the design sections. The design deflection for any given design section is a function of the mean deflection, the variation, and the reliability level selected for design. The reliability level, R for design is the percentage of deflections that would exceed the chosen design deflection

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*t-value table not reproduced here because of copyright laws.

on the assumption of a normal distribution for the deflections. Similarly the confidence level, C, is the percentage of deflections that would fall below the selected design deflection value on the same assumption. Hence confidence level C = 1-R. The design deflection shall be computed using the following relation:

$$W_d = \bar{w} + z\ S_{dw} \quad \ldots\ldots\ldots\ldots\ldots \quad 3.8$$

where:

w_α = design deflection based on Dynaflect measurements on Benkleman beam with 18-kip load, in.

$\bar{w}$ = mean deflection, in.

S_{dw} = standard deviation of mean deflection, in.

z = distance from mean to selected significance level on a normal distribution curve. The selected significance level is equal to R/2.

Table 3.1 is a list of z values corresponding to various design confidence or reliability levels.

TABLE 3.1 Z VALUES FOR VARIOUS CONFIDENCE LEVELS

Design Confidence Level	Reliability (R)	z Value
50	50	0
75	25	0.674
90	10	1.282
95	5	1.645
97.5	2.5	1.960
99	1	2.330

The design deflections calculated for a specific design confidence level, 95% for example, means that on the assumption of a normal distribution for the deflections, 95% of the deflections measured fall below the design deflection.

The computer program TVAL2 computes the design deflection for each design section also. Thus, Equation 3.8 and Table 3.1 do not have to be utilized if TVAL2 is run.

SECTION 4

MATERIALS SAMPLING AND TESTING

This section describes the materials sampling and testing requirements of the procedure. The testing methods noted are for determining the quasi-elastic properties for use in the design procedure.

4.1 Sampling Plan

At this point, the design sections are all established and the plan for materials sampling must be formulated. It is recommended that at least one boring be made in each design section, and for extremely long sections more than one boring may be desirable. If it is impossible to obtain this many borings, the absolute minimum sampling should be for the extreme conditions, i.e., materials sampling should include core borings at selected locations throughout the length of the pavement being investigated.

4.1.1 Type of Sampling - These borings should include as a minimum cores of any paving layers which are intact, such as (1) existing asphalt or concrete, (2) cement stabilized, (3) asphalt stabilized, or (4) other chemically treated materials. Any granular or gravel layers which are encountered should be sampled by collection of augered materials from the drill hole. Unbound materials should be sampled in sufficient quantity for remolding of specimens. For this remolding, the inplace moisture and density are required and are easily obtainable if nuclear equipment is available. In materials where it is possible to push such samples, Shelby tubes should be used to obtain undisturbed samples. The drill hole should be very carefully logged so as to accurately document the layer thicknesses in the existing pavement structure. Normally a total depth of 10 feet is sufficient for pavement borings.

4.2 Asphalt Concrete and Portland Cement Concrete Testing

Materials properties required for asphaltic concrete and portland cement concrete are Poisson's ratio, modulus of elasticity, and flexural strength (PCC only). Other properties pertinent to mix design and construction will be necessary, but for thickness design purposes only these three properties are required.

4.2.1 Modulus of Elasticity - The asphalt concrete material shall be tested for its dynamic modulus of elasticity. At this time there is no ASTM standard for this test, but there are established procedures. The designer should determine the modulus over a range of temperatures and then select the modulus based on his selected temperature(s). A temperature of 70°F is suggested for design. In the absence of an ASTM standard for the test procedure, recommended procedures are furnished in Appendix D. The modulus of elasticity for portland cement concrete may be determined according to ASTM C469. The flexural strength may be determined according to ASTM C78.

4.2.2 Poisson's Ratio - Normally tests will not be performed for Poisson's ratio, as it does not vary significantly. It is recommended that a value of 0.3 be used for asphalt and .15 for concrete in the design analyses. The overlay design computer program has default values of 0.3 and .15 built in for Poisson's ratio of asphalt and concrete, respectively.

4.3 Base Materials Testing

All base and subbase materials must be tested for their modulus of elasticity. Poisson's ratio tests are not necessary. Default values in the computer program are 0.20 for stabilized bases and .40 for granular bases.

4.3.1 Bound Materials - Bound base or subbase materials will in most cases be either asphalt or cement treated materials. When cement treated base layers are present in existing flexible pavements these layers must be characterized for a modulus of elasticity. Undisturbed samples should be tested in compression to determine the modulus of elasticity using ASTM C469 or its equivalent. The value selected for design analyses should be the mean value of the tests conducted.

Asphalt treated base or subbase materials should be tested by the dynamic modulus test as described for asphalt concrete in Appendix D.

4.3.2 Unbound Materials - Usually the base and subbase materials will be disturbed samples thus requiring recompaction. The inplace density and moisture content should be determined if possible and the materials remolded at these values. Otherwise samples should be recompacted at optimum moisture content with not less than 95% of the density corresponding to that moisture content used for construction control. Base and subbase materials should be tested with confining pressures equal to the overburden pressure and if that is less than one psi, the tests should be unconfined. The tests should be performed with a deviator stress of 20 psi if the total concrete thickness is six inches or less and 10 psi if it is greater than six inches. Recommended test procedures are included in Appendix E.

4.4 Subgrade Materials Testing

Usually subgrade samples will be undisturbed samples, and if that is not the case they should be treated similar to the base materials.

Undisturbed subgrade samples should be tested with confining pressures equal to the overburden and over a range of repeated deviator stresses such as 2 to 12 psi. The laboratory tests should be performed with a minimum of four levels of deviator stress; 2, 5, 8 and 12 psi are offered as recommended levels. The modulus values and corresponding deviator stresses serve as inputs to the computer program. Recommended test procedures are included in Appendix E. Characteristically, clay type soils will show a decrease in resilient modulus with increased applied stress while granular materials will be the opposite. A default value of 0.45 is used for Poisson's ratio of the subgrade.

4.5 Summary of Materials Properties

The properties that are needed in the analysis of the existing pavement and overlay design are summarized as follows:

- Portland Cement Concrete - modulus of elasticity and Poisson's ratio
- Asphaltic Concrete - dynamic modulus of elasticity and Poisson's ratio
- Base and Subbase - resilient modulus of elasticity and Poisson's ratio
- Subgrade - resilient modulus of elasticity and the corresponding deviator stresses; Poisson's ratio

In lieu of testing to determine Poisson's ratio for the materials the following values are recommended and also fixed as default values should no values be input to the computer program:

Portland cement concrete	0.15
Asphaltic concrete	0.30
Stabilized bases	0.20
Granular bases	0.40
Subgrade	0.45

SECTION 5

DESIGNATION OF OVERLAY DESIGN CATEGORY

5.1 Existing Pavement Classification

Use of the design procedure requires that each design section of the existing pavement be classified into one of the following categories:

1. Remaining life PCC - a PCC pavement which is uncracked or which has Class 1 or 2 cracking as defined in Section 2.2.1.

2. Cracked PCC - a PCC pavement which exhibits Class 3 or 4 cracking as defined in Section 2.2.1. The program can switch a design section originally in category 1 to this category if the calculated remaining life of the existing pavement is less than a pre-established minimum.

3. Mechanically broken PCC - a PCC pavement in such poor condition that the designer feels it should be broken up to serve as a base material before overlay. Repair and/or removal and replacement of the damaged portions may instead be used to upgrade the section to category 2.

4. Remaining life AC - an AC pavement which is uncracked or which shows less than five percent Class 2 cracking as defined in Section 2.2.2.

5. Mildly cracked AC - an AC pavement which exhibits more than five percent Class 2 cracking but less than five percent Class 3 cracking, as defined in Section 2.2.2. If those areas exhibiting cracking are removed and replaced to meet the conditions specified for category 4, then the analysis for category 4 (remaining life) may be used.

6. Severely cracked AC - an AC pavement which shows more than five percent Class 3 cracking, as defined in Section 2.2.2. Pavements in this category may be upgraded to category 5 or category 4 by appropriate repair and/or removal and replacement of the damaged portions.

5.2 Types of Overlay Analyses

The category assigned to the existing pavement (Section 5.1) and the materials types for the existing pavement and the overlay, all of which are required program inputs, determine the type of overlay analysis. In addition, for pavement sections designated as remaining life pavements, the number of loads to date (18kip ESAWL) effects the internal selection of the analysis in the calculation of the fraction of remaining life; if this fraction is less than a preassigned minimum, the section is no longer considered as a remaining life case.

A total of eighteen overlay analysis types are considered; nine for PCC remaining life pavements, three for PCC with Class 3 or 4 cracking, three for PCC which will be mechanically broken up, one for AC remaining life pavement, one for mildly cracked AC, and one for severely cracked AC.

When the existing pavement is a CRCP with remaining life, asphaltic concrete, bonded and unbonded JCP, and bonded and unbonded CRCP are acceptable overlays. When the existing pavement is a JCP with remaining life, asphaltic concrete, bonded and unbonded JCP, and unbonded CRCP are acceptable overlays. Bonded CRCP is not allowed for this case. When the existing pavement has Class 3 or 4 cracking or will be mechanically broken up, asphaltic concrete, unbonded JCP, and unbonded CRCP are acceptable overlays. Bonded JCP and bonded CRCP are not allowed for this case. Only AC overlays are permitted on AC existing pavements.

SECTION 6

USE OF OVERLAY DESIGN COMPUTER PROGRAM POD1

Program POD1 is used to determine the overlay thickness needed to satisfy the relevant design criteria for a given design section. In the case of PCC existing pavements, only a fatigue cracking criterion is applied, while for AC existing pavements both fatigue and rutting criteria are applied; in the latter case the larger of the thicknesses required by the two criteria is used.

Information necessary to develop the required input for the program has been discussed previously; it will be summarized here. Input guides are provided in Appendices F and G showing the format required for the program inputs.

6.1 Outline of Program Operation

POD1 performs the following operations:

1. Determines the subgrade modulus under the design load from the design deflection, the measured characteristics of the subgrade soil, and the characteristics of the deflection and design loads.
2. Computes the fraction of remaining life in the existing pavement from stresses in the pavement before overlay, when appropriate.
3. Calculates the stress (strain for AC pavements) in the pavement system for the design load (an 18-kip single axle wheel load) for overlay thicknesses from 3 to 12 inches.
4. Obtains the fatigue life from the stress or strain for each overlay thickness; obtains the rutting life (life to specified rut depth) for AC pavements in categories 5 and 6 as defined in Section 5. The rutting model is not applicable to category 4.
5. Plots lifetimes vs. overlay thickness; interpolates for thicknesses corresponding to the design lifetimes input.

6.2 Summary of Input Information

The information needed to determine input values for POD1 is summarized below:

1. The design deflection as determined using PLOT2, TVAL2, and Equation 3.8 for the design deflection.
2. The load magnitude, tire pressure, and wheel configuration of the deflection measuring device.

3. The condition of the existing pavement surface, i.e., whether it is uncracked, the type of cracking if present, and whether it will be mechanically broken before overlay.
4. The ratio of the corner deflection to the interior deflection, if the existing pavement is JCP.
5. The presence or absence of voids beneath the existing pavement.
6. The number of equivalent 18-kip single-axle loads the pavement has experienced to date, and the number (or numbers) it is being designed to accept before failure - as determined in Section 2.3.
7. For AC existing pavement only, the allowable rut depth before rutting failure is assumed, and the number of days per year with a mean temperature greater than 64°F.
8. The material type, thickness, Poisson's ratio, and modulus for each layer in the existing system.
9. The deviator stresses and corresponding modulus values determined for the subgrade material by laboratory tests.
10. The flexural strengths for the existing pavement, if PCC.
11. The type of overlay and its modulus, Poisson's ratio, and flexural strength.
12. The type of bond breaker, if used, and its thickness, modulus, and Poisson's ratio.

The program contains default values for the Poisson's ratio values based on material types; default values are also provided for bond breaker thickness and modulus. If the condition survey has shown the existing pavement to be a class 3 or 4 cracked PCC or one that will be mechanically broken up or a class 2 or 3 cracked AC, the modulus value that is input for the surface layer will be automatically defaulted to predetermined values.

6.3 Input Guides

Program POD1 was written so that the required data could be input in a simple yet logical manner; problems dealing with nearly similar situations can be stacked by inputting for each problem after the first only the directives (data input cards) containing the item which is changed. For any one problem the directives can appear in any order, except that a PROBLEM directive must begin the data for each problem, and an END directive must follow the data for the last problem.

An input guide describing and making full use of this flexibility appears in Appendix F. For the new user, or one who is more familiar with an input guide rigidly prescribing card order and content, the guide in Appendix G is presented. It is highly recommended that a prospective user read both input guides, beginning with Appendix F, before preparing data; Appendix F has more general information about the structure of the data input, while Appendix G has more specifics as to the source of the required data. Either will serve after some familiarity is gained with the program.

6.4 Program Execution Information

POD1 requires approximately 50000_8 words of memory on a CDC CYBER 74 or a CDC 6600 computer, and requires approximately 8 to 10 seconds of CPU time for a complete problem. If the subgrade modulus for the first problem of several stacked together is applicable for the remaining problems, those remaining will execute in approximately 4 seconds each.

No peripheral equipment is required except a card reader and a line printer. If the program is on a permanent file, it can be executed from a remote teletype; the output is relatively compact and can be printed easily except for the printer plot of lifetime vs. thickness. If use of these plots is anticipated beyond a "quick glance", it is recommended that a copy of the output be obtained on a line printer.

SECTION 7

ILLUSTRATIVE OVERLAY DESIGN PROBLEMS

This section of the manual presents design problems that illustrate overlays of both rigid and flexible pavements. It includes example input and resulting output for each of the three computer programs - PLOT2, TVAL2, and POD1. The problems are presented in the following format according to Figure 1.1:

1. Basic design information
2. Condition survey
3. Deflection survey
4. Division of pavement into design sections
5. Classification of existing pavement
6. Determination of material properties
7. Traffic computations
8. Environmental considerations
9. Fatigue cracking or rutting analysis and overlay thickness selection

Section 7.1 presents a complete rigid pavement example problem and Section 7.2 presents an abbreviated flexible pavement problem.

7.1 Rigid Pavement Overlay Design Problem

A 6100 foot long section of plain jointed concrete pavement on a two lane highway is expected to have a substantial traffic increase in the near future. To handle the anticipated traffic, the decision was made to overlay the pavement with either a bonded jointed concrete overlay or an asphaltic concrete overlay. Designs must be made for each type of overlay in order to make a comparison between the two.

7.1.1 Condition Survey - The condition survey based on the procedure described in Section 2.2, indicated the pavement is generally in good condition. Spalling, faulting and pumping are minimal and the pavement is fairly smooth. No voids are present beneath the surface. The pavement is built on a uniform fill and has adequate drainage characteristics. The cracking present is class 1 and 2. A review of the construction plans showed the pavement cross section to be as shown in Figure 7.1. Stations 0 to 10 have an 8 inch JCP on a 7 inch crushed stone base, stations 10 to 52 have an 8 inch JCP on 6 inches of gravel base and 6 inches of granular subbase, and stations 52 to 61 have an 8 inch JCP on a 7 inch crushed stone base.

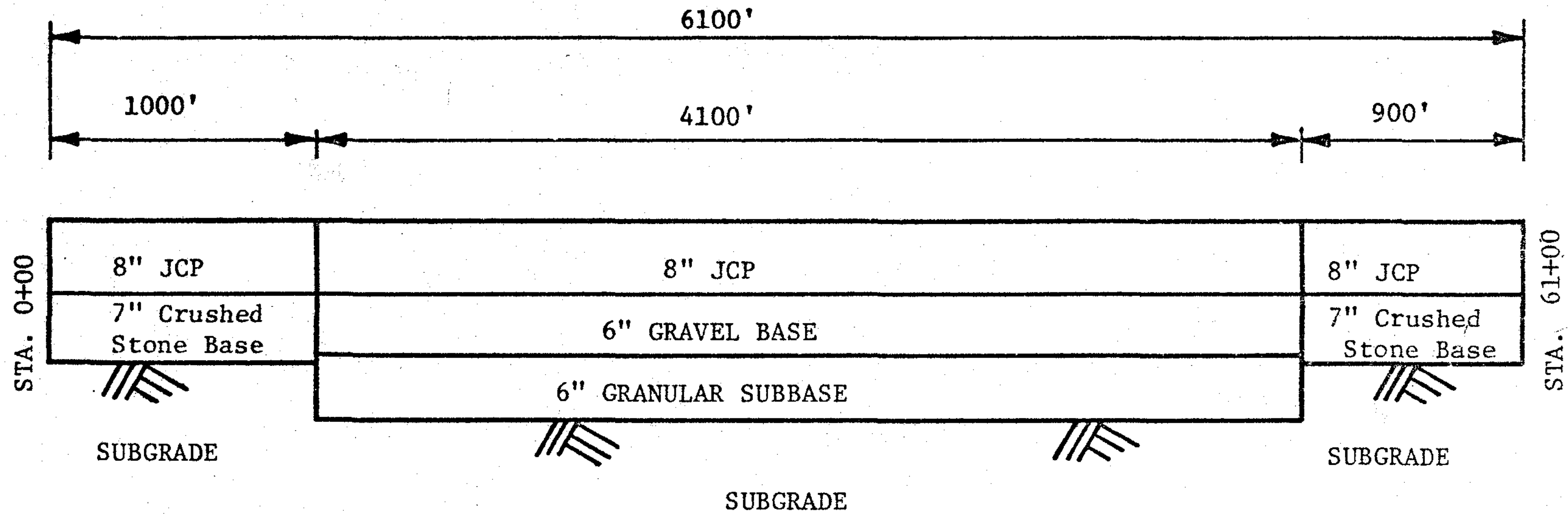


Figure 7.1 Cross Section of Pavement to be overlaid

7.1.2 Deflection Survey - The deflection survey, based on the procedure described in Section 2.1, was made with the Dynaflect. The Dynaflect load consists of 500 lbs. at 167 psi on each of two wheels spaced 20 inches apart. Measurements were made in the outside wheel path of each lane at 200 foot intervals. They were staggered by 100 feet between the two lanes, so that by combining the data a deflection profile could be obtained with measurements each 100 feet. These measurements were made in the interior portion of the slabs.

In addition to the interior measurements, deflections were also measured on slab corners at 500 foot intervals. These were made so that the joint condition can be evaluated by computing a ratio of corner deflection to interior deflection. The mean ratio was found to be 1.40, which is indicative of fairly jood joint performance.

7.1.3 Division of Pavement into Design Sections - Both the condition survey and deflection survey are used to divide the pavement into design sections, based on the procedure described in Section 3. Review of the pavement cross section shown in Figure 7.1 indicates that the pavement can be obviously divided into the following three design sections.

Design section 1	Stations 0 to 10
Design section 2	Stations 10 to 52
Design section 3	Stations 52 to 61

However, to illustrate the use of the programs PLOT2 and TVAL2, the deflection survey data is also analyzed here before final selection of design sections. A plot of the interior deflections measured each 100 feet was made using the computer program PLOT2. The data input for running the program is shown on the input guide in Table 7.1. The resulting deflection profile plot is shown in Figure 7.2 The station number of each measurement location and the actual deflection value plotted are shown on the axes of the plot. The plotted points were connected by hand and the plot was divided by visual inspection into three design sections shown in the figure. These sections correspond to the sections resulting from the review of the cross section in Figure 7.1.

The three sections must be statistically tested using program TVAL2 to see if they are significantly different. The data input to the program is shown in Table 7.2. The resulting output is shown in Table 7.3. The deflections evaluated for each section are listed in order across the page and down. The mean and standard deviation are then printed out. Each section is then compared to each of the other

TABLE 7.1

INPUT DATA FOR PROGRAM PLOT2

CARD TYPE	1–10	11–20	21–30	31–40	41–50	51–60	61–70	71–80
1		ILLUSTRATIVE OVERLAY DESIGN PROBLEM						
2	DYNAFLECT READING - SENSOR 1			STATIONING	(FEET)	DEFLECTION	(MILS)	
3	(2A4,A2,F10.0,F5.0)							
4*	0+10	.86	1.					
5	FINISH							

* A total of 61 cards of this type were included, one for each deflection measurement.

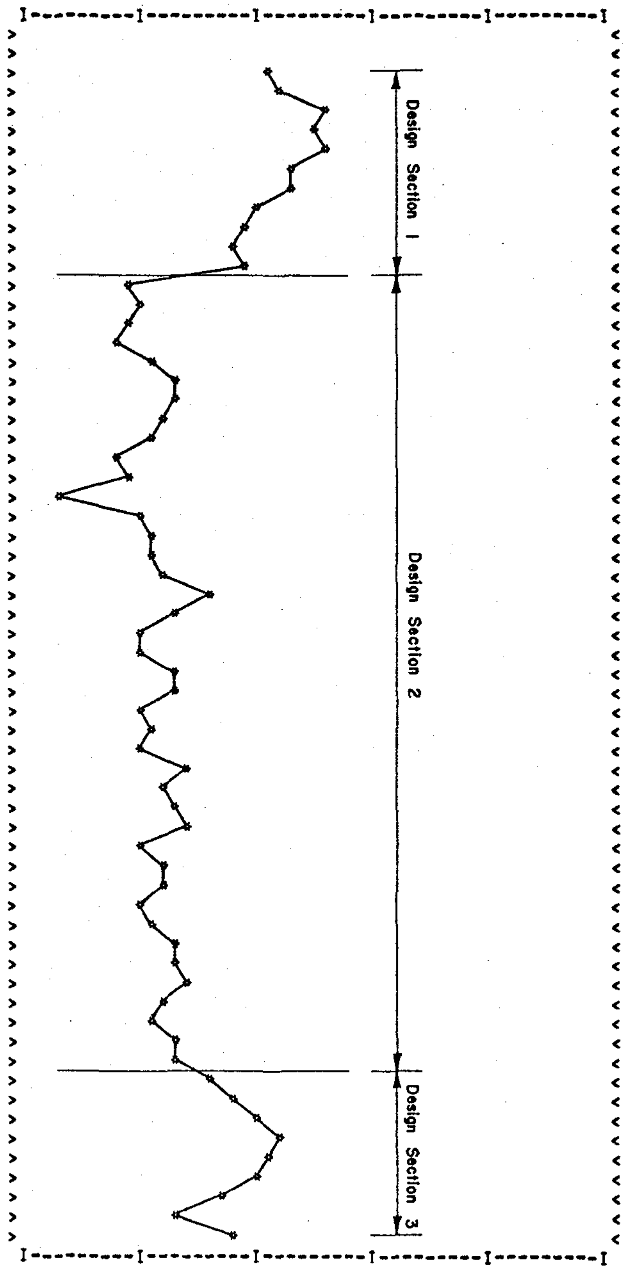
PLOT2 - DEFLECTION PLOT PROGRAM, VERSION 2.0

ILLUSTRATIVE OVERLAY DESIGN PROBLEM

DYNAFLECT READING - SENSOR 1

DEFLECTION (MILS)

0.000 .400 .800 1.200 1.600 2.000



0.000 .400 .800 1.200 1.600 2.000

STATIONING (FEET)	DEFLECTION (MILS)
0+10	.860
1+10	.900
2+10	1.020
3+10	.990
4+10	1.020
5+10	.930
6+10	.920
7+10	.800
8+10	.760
9+10	.740
10+10	.750
11+10	.370
12+10	.400
13+10	.370
14+10	.340
15+10	.450
16+10	.520
17+10	.500
18+10	.460
19+10	.450
20+10	.310
21+10	.350
22+10	.132
23+10	.400
24+10	.440
25+10	.440
26+10	.490
27+10	.640
28+10	.510
29+10	.390
30+10	.400
31+10	.540
32+10	.500
33+10	.420
34+10	.440
35+10	.380
36+10	.580
37+10	.460
38+10	.540
39+10	.560
40+10	.400
41+10	.460
42+10	.470
43+10	.420
44+10	.440
45+10	.510
46+10	.510
47+10	.580
48+10	.460
49+10	.440
50+10	.510
51+10	.530
52+10	.640
53+10	.720
54+10	.790
55+10	.880
56+10	.860
57+10	.800
58+10	.680
59+10	.540
60+10	.720

TOTAL NUMBER OF POINTS PLOTTED = 61

FIGURE 7.2. DEFLECTION PROFILE PLOT OF PAVEMENT TO BE OVERLAID

TABLE 7.2

INPUT DATA FOR PROGRAM TVAL2

CARD TYPE	1–5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80
1	61	3	ILLUSTRATIVE OVERLAY DESIGN PROBLEM													
2	11	41	9													
3	95	95	(10X,F10.0,F5.0)													
4*			.86		1.											

*A total of 61 cards of this type were included, one for each deflection measurement.

TABLE 7.3

OUTPUT FROM PROGRAM TVAL2

TVAL2 - DEFLECTION SECTION COMPARISON PROGRAM, VERSION 2.0

ILLUSTRATIVE OVERLAY DESIGN PROBLEM

DEFLECTIONS FOR EACH SECTION

SECTION 1	.860	.900	1.020	.990
	1.020	.930	.920	.800
	.760	.740	.750	
SECTION 2	.370	.400	.370	.340
	.450	.520	.500	.460
	.450	.310	.350	.132
	.400	.440	.440	.490
	.640	.510	.390	.400
	.540	.500	.420	.440
	.380	.580	.460	.540
	.560	.400	.460	.470
	.420	.440	.510	.510
	.580	.460	.440	.510
	.530			
SECTION 3	.640	.720	.790	.880
	.860	.800	.680	.540
	.720			

	MEAN	STANDARD DEVIATION
SECTION 1	.881	.107
SECTION 2	.452	.088
SECTION 3	.737	.109

SECTION VS. SECTION		DF	CALCULATED T	95 P/C CONF. LEVEL TABLE T	PASS/FAIL
1	2	50	13.779	2.011	FAIL
1	3	18	2.986	2.101	FAIL
2	3	48	8.464	2.013	FAIL

DESIGN DEFLECTION CONFIDENCE LEVEL 95.0

SECTION	INTERIOR DESIGN DEFLECTION
1	1.056
2	.596
3	.915

sections to see if they are significantly different. The results show that each comparison failed to pass the "Student's t" test, which means they are significantly different and should be considered as separate design sections.

The last set of output in Table 7.3 is the design deflection for each design section based on a 95 percent confidence level. These same results could be obtained by using equation 3.8 and Table 3.1.

The final design sections selected, based on both the condition survey and deflection analysis, are given in Table 7.4.

TABLE 7.4 FINAL DESIGN SECTIONS

Design Section Number	Station Limits	Design Deflection (mils)
1	0 to 10	1.056
2	10 to 52	.596
3	52 to 61	.915

7.1.4 <u>Classification of Existing Pavement</u> - Each design section must be assigned to one of the overlay design categories described in Section 5. From the condition survey all three sections were found to have class 1 and 2 cracking as defined in Section 2.2.1. Thus, each design section is assigned to category 1 - pavement with remaining life. The overlay design program POD1 will analyze each section as remaining life pavements and compute the amount of remaining life. If it finds that the remaining life is less than the established minimum of 25 percent, it will automatically change the classification from category 1 to category 2.

The type of existing pavement is specified as a JCP and the types of overlays are specified as bonded JCP and AC. This will key the program to perform analyses 9 and 12 from Figure 1.1.

7.1.5 <u>Determination of Material Properties</u> - Properties for each material in each design section must be determined according to Section 4. After selection of design sections, a boring plan was established which consisted of the following:

One boring in design section 1
Three borings in design section 2
One boring in design section 3

Cores were obtained from the existing concrete and bulk samples were obtained from the base and subbase materials. Undisturbed tube samples were obtained from the subgrade. Materials for the proposed concrete and AC overlays were obtained from the proper materials sources.

The concrete cores were tested for modulus of elasticity according to Section 4.2.1. The base and subbase samples were recompacted to the estimated in-place moisture and density and tested for modulus of elasticity according to Section 4.3.2. The subgrade samples were tested for resilient modulus of elasticity according to Section 4.4.

Specimens were prepared from the proposed concrete and AC overlay material and tested for modulus of elasticity in accordance with Section 4.2.1. Poisson's ratio tests were not performed for any of the materials. Values were estimated from those recommended in Section 4.5. Flexural strength of the concrete was determined according to Section 4.2.1.

The resulting material properties are given in Table 7.5 for design section 1. Properties for sections 2 and 3 were similarly listed. The PCC flexural strength, which is not included in the tables, was found to be 690 psi.

The layer thicknesses of each material determined from the boring logs were in agreement with the construction plan thicknesses determined in the condition survey and shown in Figure 7.1.

7.1.6 Traffic Computations The traffic information necessary for the overlay design is determined according to Section 2.3. The number of equivalent 18-kip single axle load applications was determined by using equation 2.1 with a directional distribution factor of 0.50 and a lane distribution factor of 1.0 (taken from Table 2.2 for a two lane roadway). The number of actual traffic applications to date were determined as well as three values of projected traffic for different design lives. Results of the traffic computations are given in Table 7.6.

TABLE 7.6 TRAFFIC COMPUTATIONS FOR OVERLAY DESIGN

Equivalent 18-kip single axle load applications to date		300,000
Projected equivalent 18-kip single axle load applications:		
	Design life A	2,000,000
	Design life B	4,000,000
	Design life C	6,000,000

The same traffic information is used in all three design sections.

TABLE 7.5 MATERIAL PROPERTIES FOR DESIGN SECTION 1

Material Type	Modulus of Elasticity (psi)	Poisson's Ratio
Proposed AC overlay	450,000 @ 70°F	.30
Proposed JCP overlay	4×10^6	.15
Existing JCP	4×10^6	.15
Crushed Stone base	33,000	.35
Subgrade	123,500 @ σ_d * = 3 psi	.45
	91,500 @ σ_d = 5 psi	
	86,400 @ σ_d = 7 psi	
	69,500 @ σ_d = 9 psi	
	67,900 @ σ_d =11 psi	

*σ_d = deviator stress

7.1.7 Environmental Considerations - The pavement is located in a climate that has no severe temperature or moisture effects that should be given special consideration. The environment was considered in the deflection survey by using the recommended procedure of measuring deflections during the most critical season of the year. In this case the pavement was expected to have the highest deflection in Spring, so this is when the deflections were measured.

7.1.8 Fatigue Cracking Analysis and Overlay Thickness Selection - The fatigue cracking analysis and resulting overlay thicknesses are determined according to Section 6, through use of the overlay design computer program POD1. All of the data necessary to run the program have now been determined. The data input for the AC overlay on design section 1 is shown in Table 7.7. Data were input for the other design sections using the same format.

The output resulting from the computer runs for design section 1 is in Appendix H. Output is included for both the JCP and AC overlay for design sections 1. The printout contains two major categories - input variables which consist of (1) existing pavement, (2) deflection data, (3) laboratory tests of subgrade samples, (4) overlay characteristics, and (5) design traffic; and system results which consists of (1) overlay life predictions, (2) a plot of overlay thickness versus fatigue life, and (3) a table of interpolated overlay thicknesses for the requested design fatigue lives.

A summary of the overlay thicknesses for the three design lives is given in Table 7.8.

TABLE 7.8 SUMMARY OF OVERLAY THICKNESSES

Design Section	JCP Overlay (in) Design Life ($x10^6$)			AC Overlay (in) Design Life ($x10^6$)		
	2	4	6	2	4	6
1	3.2	4.8	5.9	7.5	10.3	12
2	3.0	4.7	5.7	7.2	10.0	11.7
3	2.3	4.0	5.0	6.0	8.7	10.4

A comparison can now be made between the JCP and AC overlays and the desired one can be chosen for construction. Since there is a considerable difference in the JCP and AC thicknesses, material availability and costs as well as construction costs would be key decision factors in choosing the overlay type. Assuming the JCP materials

TABLE 7.7

INPUT DATA FOR JCP OVERLAY ON DESIGN SECTION 1

CARD TYPE	1–8	10	11–20	21–25	26–30	31–34	35–38	41–50	51–60	61–70	71–80
1	PROBLEM	1	1								
2	ILLUSTRATIVE OVERLAY DESIGN PROBLEM, SECTION 1.										
3	PAVEMENT	3	300000.	690.	X	TYPE	1,2				
4	LAYER	1	4000000.	8.	.15	JCP					
4	LAYER	2	33000.	7.	.35	GRAN					
4	LAYER	3	50000.	0.	.45	SUBG					
5	LOADS	2	500.	167.							
6	0.		0.	20.		0.					
7	DEFLECT	X	.001056	10.	0.						
8	LAB DATA	5									
9	123500.		3.	91500.		5.		86400.	7.	69500.	9.
9	67900.		11.								
10	OVERLAY	X	4000000.	.15	X	JCP	BOND				
12	CORNER	X	1.4								
14	TRAFFIC	3									
15	2000000.		4000000.	6000000.							
16	END										

cost only slightly more than AC materials for the area where this overlay is to be constructed, the JCP overlay is preferable to the AC overlay. It may be most desirable, from a construction feasibility viewpoint, to construct a 6 inch JCP overlay. This would provide a design life of slightly greater than 6 x 10^6 18-kip SAWL, as shown by the overlay design solutions. Thus, the final overlay design is selected to be a 6 inch bonded JCP.

7.2 Flexible Pavement Overlay Design Problem

A section of asphaltic concrete pavement is to be overlaid with asphaltic concrete as part of a rehabilitation and widening project. Determination of the overlay thickness necessary to satisfy both the fatigue cracking and rutting criteria is presented. However, the solution is in an abbraviated form. The determination of design sections using programs PLOT2 and TVAL2 is not presented since the use of these programs was adequately illustrated in the rigid pavement sample problem. Thus, assumptions are made concerning the deflection survey.

7.2.1 Condition and Deflection Survey Summary - The condition survey showed the pavement to be in a deteriorated condition due to numerous heavy loads over an extended period of time. The surface is severely cracked with class 3 cracking as determined according to Section 2.2.2. The cross-section was determined to be as shown in Figure 7.3. The pavement is rutted with the average rut depth being approximately 0.5 inches as determined according to Section 2.2.3.

The deflection survey was accomplished by making measurements at 100 foot intervals using the Dynaflect as was done for the rigid pavement example problem. Use of the programs PLOT2 and TVAL2 resulted in only one design section. It has a design deflection of 1.75 mils.

7.2.2 Classification of Existing Pavement - Since the condition survey showed the pavement to have class 3 cracking it will fall into category 6 as prescribed in Section 5.1. The existing pavement and the overlay will be specified as AC. This will key the program POD1 to perform analysis 3 from Figure 1.1.

7.2.3 Determination of Material Properties - The materials sampling and testing was accomplished according to the procedures discussed in Section 4. The results are given in Table 7.9. The program uses the existing pavement modulus of 450,000 psi only in the determination of the subgrade modulus. For all the other computations it uses a predetermined reduced modulus value or the modulus of the base, whichever is larger, since the existing pavement has class 3 cracking.

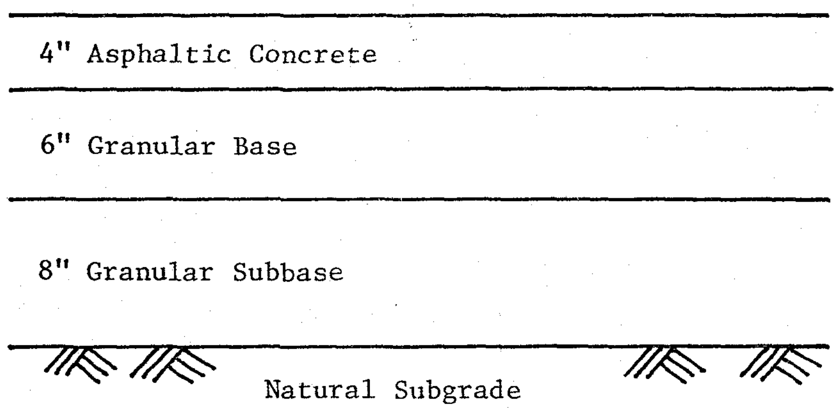


Figure 7.3. Cross section of asphaltic concrete pavement to be overlaid

TABLE 7.9 MATERIAL PROPERTIES FOR ASPHALTIC CONCRETE PAVEMENT

Material Type	Modulus of Elasticity (psi)	Poisson's Ratio
Proposed AC overlay	500,000 at 70°F	.30
Existing AC	450,000 at 70°F	.30
Granular Base	20,000	.35
Select Material Subbase	10,000	.35
Subgrade	30,000 at σ_d* = 2 psi	.45
	20,000 at σ_d = 4 psi	
	10,000 at σ_d = 8 psi	

*σ_d = deviator stress

7.2.4 Traffic Computations - The traffic information is determined according to Section 2.3. Since the existing AC pavement has class 3 cracking, it has no remaining life. Thus, it is not necessary to determine the traffic prior to overlay. The future traffic is determined using equation 2.1 with an assumed directional distribution factor of 0.50 and a lane distribution factor of 1.0. The projected traffic for the desired design life of the overlay was found to be 3 million 18-kip ESAWL. Traffic values of 1 and 10 million 18-kip ESAWL were also input for purposes of comparison.

7.2.5 Environmental Considerations - As in the rigid pavement example, deflections were measured at the time of year when they are expected to be greatest. For this flexible problem it is also necessary to obtain temperature information. It was found that the average daily temperature exceeds 64°F for 200 days out of the year. This is a required input for the rutting model in POD1.

7.2.6. Fatigue Cracking Analysis, Rutting Analysis, and Overlay Thickness Selection - Final overlay thickness selection is accomplished through the use of POD1 as described in Section 6. For this problem the program will determine a thickness necessary to satisfy both the rutting criterion and the fatigue cracking criterion. A maximum acceptable rut depth of 0.5 inches was selected for this problem. All other necessary data to run POD1 has now been determined. The data input is shown in Table 7.10.

The output resulting from the computer run is in Appendix H following the rigid pavement problem output. The overlay thickness necessary to satisfy the fatigue cracking and rutting criteria for a design life of 3 million 18-kip ESAWL applications were determined to be 8.0 inches and 5.7 inches, respectively as shown in the output. Since the fatigue cracking criterion thickness is the larger of the two it is selected as the overlay design thickness.

TABLE 7.10 DATA INPUT FOR POD1 FOR THE FLEXIBLE PAVEMENT OVERLAY DESIGN PROBLEM

CARD TYPE	1–8	9–10	11–20	21–25	26–30	31–34	35–38	39–40	41–50	51–60	61–70	71–80
1	PROBLEM	1	1									
2	EXAMPLE DESIGN PROBLEM FOR AC OVERLAY ON EXISTING FLEXIBLE PAVEMENT											
3	PAVEMENT	4			X	TYPE 3						
4	LAYER	1	450000.	4.	0.30	AC						
4	LAYER	2	20000.	6.	0.35	GRAN						
4	LAYER	3	10000.	8.	0.35	GRAN						
4	LAYER	4	10000.		0.45	SUBG						
5	LOADS	2	500.	167.								
6	0.		0.	20.		0.						
7	DEFLECT	X	.00175	10.	0.							
8	LAB DATA	4										
9	30000.		2.	20000.		4.			10000.	6.	5000.	8.
10	OVERLAY	X	500000.	.30		AC						
13	RUT	X	200.	0.5								
14	TRAFFIC	1										
15	1000000.		3000000.	10000000.								
16	END											

APPENDIX A

CONDITION SURVEY TECHNIQUES

The condition survey techniques outlined in the following paragraphs should be used in conjunction with the overlay design procedure outlined in the text of this design manual. The following paragraphs will relate specifically to the time of condition surveys, the essential data required in the design analysis, a format for recording data, and a procedure for reduction of the data for the design analysis.

TIMING OF CONDITION SURVEYS

Normally, condition surveys should be done when convenient to the project engineer and still provide current information. Condition surveys made at the time of nondestructive testing accomplishes two purposes. Distress observed in the field can be recorded directly with deflection measurements, and if detours or lane closure is required the survey crews are protected. Thus, less closure time results which is important relative to freeway operations.

ESSENTIAL DATA

The essential condition survey data for the overlay design analysis is an inventory of the class of cracking present on the existing pavement as well as the rut depth if it is a flexible pavement. A general assessment of the drainage, joint condition, faulting, spalling, pumping, and other factors might help to explain variation in a deflection profile. These elements of data will all be useful in the overlay design analysis. Specifically, the classification of cracking and the rut depth are the only decision factors necessary in the overlay design procedure. The drainage, grade, and other data are simply additional information which will enable an engineer to quantitatively evaluate variation he observes in deflection profiles and subsequent material tests from laboratory work. The drainage data also serve as input to the consideration of tradeoffs between overlay thickness and drainage improvements. In some design situations it may be possible to improve drainage which will in turn improve material properties and result in less overlay thickness. Economic comparisons should be made between the two.

FORMAT FOR RECORDING DATA

There are several ways to conveniently record condition survey data and an agency may want to use its experience to develop forms. If condition surveys are made at the time of deflection measurements, these data may be recorded on the same data sheet using the same identification as the deflection measurement, for example, station numbers. A suggested format for recording data is shown in Table A.1 for rigid pavements and A.2 for flexible pavements. The station limits are selected as base elements, normally one hundred feet. The various columns in the table should be either checked for the presence of the conditions or actual measurements such as faulting, spalling, pumping, etc., should be filled in.

Data may also be recorded on other types of records such as plan profiles with some information relative to the existing pavements, on soil profiles or any other existing information sheets for the pavement. Every opportunity should be taken to include existing data for the pavements where possible.

DATA REDUCTION FOR RIGID PAVEMENTS

The pavement condition should be classified according to its general type of cracking and should fit into one of the following classes:

1. Uncracked or class 1 and 2 cracking
2. Class 3 and 4 cracking
3. Severely enough cracked that the pavement should be mechanically broken up into small pieces.

The classification chosen determines the overlay analysis procedure that will be used. If voids exist beneath the pavement this must be recorded also.

DATA REDUCTION FOR FLEXIBLE PAVEMENTS

The pavement condition should be classified according to its general type of cracking and should fit into one of the following classes:

1. Uncracked or less than 5 percent class 2 cracking
2. Class 2 cracking
3. Class 3 cracking

The average rut depth should be computed for each design section which is selected along the roadway length. This average rut depth should be a guideline as to the allowable rut depth specified in the overlay design analysis. As for rigid pavements, the classification chosen determines the overlay analysis procedure that will be used.

TABLE A.1

SAMPLE CONDITION SURVEY DATA FORM
FOR RIGID PAVEMENTS

County ______________

Highway ______________

Date ______________

Stations		Cracking					Faulting	Spalling	Pumping	Drainage		Grade			OTHER COMMENTS
From	To	Uncr.	Cl. 1	Cl. 2	Cl. 3	Cl. 4				Good	Poor	Cut	Fill	Natural	

TABLE A.2
SAMPLE CONDITION SURVEY DATA FORM
FOR FLEXIBLE PAVEMENTS

County____________

Highway ____________

Date____________

Stations		Cracking		Rut Depth	Drainage		Grade			Other Comments
From	To	Class 2	Class 3		Good	Poor	Cut	Fill	Natural	

APPENDIX B

PLOT2 DESCRIPTION AND INPUT GUIDE

BACKGROUND

Program PLOT2 was written so that a computer could be used to generate a line printer plot of deflections vs. distance along the roadway; deflection being represented by the Y-value of the graph and distance being represented by the X-value. The program will, however, allow any two-dimensional graph to be plotted when given the X value and corresponding Y value of the function.

DATA INPUT

The input for PLOT2 consists primarily of a title heading, a coded format for reading the deflection data, X and Y axis labels, and a data card for each X - Y value pair (maximum of 300 X - Y value cards). Each X - Y value card also contains a multiplication factor for the Y value. The multiplication factors allows the user to input direct Dynaflect measurements, which contain a reading and a multiplier.

A more detailed explanation of PLOT2 input can be found in the input guide in Table B.1.

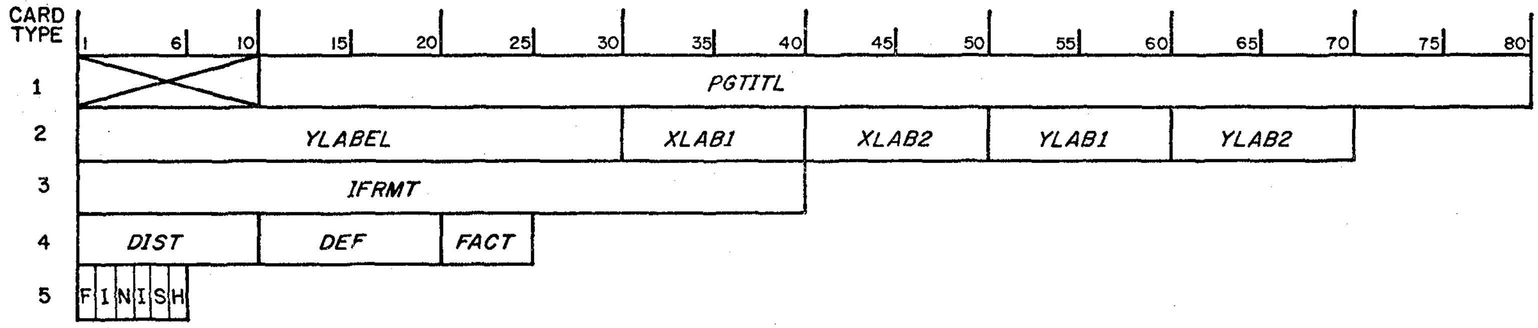
OUTPUT

Program PLOT2 generates a line printer plot in which only the Y or horizontal axis is scaled. The X-axis is not scaled so that regardless of deflection location, they are plotted on consecutive lines down the page with the coordinates of each point printed on either side of the plot.

The program will also count and print the number of X - Y value cards submitted. This number can then be used when submitting the same data with program TVAL2 whose input data must include the number of deflections.

TABLE B.1

INPUT GUIDE FOR PLOT2



<u>Card Type 1</u>: Problem Title Card
PGTITL = Title for this problem. (Col. 11-80, alphanumeric)

<u>Card Type 2</u>: Plot Label Card
YLABEL = General label for deflection axis of the plot. Default value is "DYNAFLECT READING, SENSOR 1". (Col. 1-30, alphanumeric)
XLAB1 = First row label for list of deflection locations. Default is "STATIONING ". (Col. 31-40, alphanumeric)
XLAB2 = Second row label for list of deflection locations. Default is "(FEET)". (Col. 41-50, alphanumeric)
YLAB1 = First row label for list of deflection values. Default is "DEFLECTION". (Col. 51-60, alphanumeric)
YLAB2 = Second row label for list of deflection values. Default is "(MILS)".

Note that it is useful to center each label in its field and that the second row labels are useful for specifying units. It is important that this format include the open and close parentheses.

<u>Card Type 3</u>: Deflection Format Card
IFRMT = Format for reading in the deflection data. Default is "(2A4,A2,F10.0,F5.0)" where the first 10 columns (2A4,A2) are for reading the deflection location or station, the next 10 columns (F10.0) are for reading the actual deflection and the last 5 columns, (F5.0) are for reading the deflection multiplier.

<u>Card Type 4</u>: Deflection Data Card
This card type is used to read the deflection data. A maximum of 300 deflections can be read and plotted.
Through the use of IFRMT in Card Type 3, it is possible for the user to specify the format in which he wishes to read this data. The user cannot, however, change the order in which the deflection and its multiplier are read. The deflection value (DEF) must be read first and the multiplier (FACT) last.
If the user does not specify an input format, the data will be read as follows:

DIST = Location where deflection measurement was taken. (Col. 1-10, alphanumeric)
DEF = Deflection value. (Col. 11-20, real)
FACT = Deflection multiplication factor. Default value is 1. (Col. 21-25, real)

<u>Card Type 5</u>: Termination Card
To designate the end of the data, the user must have "FINISH" in the first seven columns of the field in which the deflection location is read. If the default format for reading the deflection data was used, this would mean in Columns 1-7.

APPENDIX C

TVAL2 DESCRIPTION AND INPUT GUIDE

BACKGROUND

The purpose of program TVAL2 is to determine whether the mean deflection measurements for the different user specified roadway sections differ significantly using a Student's t analysis. The program will also compute the interior design deflection for each section if the user specifies some minimum confidence level. The procedure and tables used for the Student's t analysis in this program were taken from Introduction to Probability and Statistics, 3rd Edition, Alder and Roessler, W. H. Freeman and Co.

DATA INPUT

Inputs to the program include an alphanumeric title for each run, the total number of deflection measurements taken along the roadway, the number of sections into which these deflections have been separated, the number of deflections in each section, the individual deflection values themselves*, and the confidence levels for both the Student's t analysis and the design deflection determination.

A more detailed description of the data input can be found in the TVAL2 Input Guide in Table C.1.

DESCRIPTION OF STUDENT'S T ANALYSIS

In order to determine whether the means of two sections differ significantly using the Student's t analysis, it is necessary to assume that the standard deviations for each section do not differ significantly. The hypothesis is made that the means of the two sections being compared are the same. The ensuing calculations then determine whether this hypothesis is true or false. Before describing the equations used to make these calculations and those to determine the design deflection, it is useful to define the parameters, variables and subscripts that are used in them.

---

*Note that the default format for the deflection value cards for TVAL2 is the same as that for PLOT2.

TABLE C.1

INPUT GUIDE FOR TVAL2

CARD TYPE	1–5	6–10	11–15	16–20	21–25	26–30	31–35	36–40	41–45	46–50	51–55	56–60	61–65	66–70	71–75	76–80
1	NDEF	NSEC	TITLE													
2	NX1	NX2	NX3	NX4	NX5	NX6	NX7	NX8	NX9	NX10	NX11	NX12	NX13	NX14	NX15	NX16
3	ICL	CL	IFRMT													
4	X		DEF		FACT											

Card Type 1: Problem Description Card

NDEF = Total number of deflections to be read. (Col. 1-5, integer, right justify)

NSEC = Number of sections into which deflections are divided. (Col. 6-10, integer, right justify)

TITLE = Problem title; it is useful to specify the deflection units here also. (Col. 11-80, alphanumeric)

Card Type 2: Section Specification Card

NX1 = Number of deflections in section 1. (Col. 1-5, integer, right justify)

NX2 = Number of deflections in section 2. (Col. 1-6, integer, right justify)

NX_i = Number of deflections in section i, etc. (Maximum of 16 sections)

Card Type 3: Confidence Level and Deflection Format Card

ICL = Confidence level for Student's t analysis. Permitted values are: 90, 95, and 99 percent, default value (if left blank) is 95 percent. (Col. 1-5, integer, right justify)

CL = Confidence level for computing interior design deflection. Permitted values are: 99, 97.5, 95, 90, 75, and 50 percent. Leave blank if this option is not desired. (Col. 6-10, real)

IFRMT = Format for reading in the deflection data. (Col. 1-40, alphanumeric. Note that this format must include open and close parentheses. Default is (10X,F10.0,F5.0), where the 10X field designates that the first 10 columns of the card are skipped, the F10.0 field is for reading in the deflection and the F5.0 field is for reading in its multiplier)

Card Type 4: Deflection Data Card

This card type is used to read in the deflection data. A maximum of 1440 deflection values (16 sections at 90 per section) is allowed.

Through the use of IFRMT in Card Type 3, it is possible for the user to specify the format in which he wishes to read this data. The user cannot, however, change the order in which the deflection and its multiplier are read. The deflection value (DEF) must be read first and the multiplier (FACT) last.

If the user does not specify an input format, the data will be read as follows:

DEF = Deflection value. (Col. 11-20, real. Note that columns 1-10 are skipped as they may contain data such as the location of the deflection which is not required for the Student's t analysis).

FACT = Deflection multiplication factor. Default value is 1. (Col. 21-25, real)

j = subscript referring to the j^{th} section
k = subscript referring to the section being tested against the j^{th} section
M = total number of sections
x_i = i^{th} deflection (in j^{th} section)
N_j = total number of deflections in j^{th} section
$\bar{x}_j$ = mean deflection for j^{th} section
σ_j = standard deviation for j^{th} section
D_j = sum of the differences squared between the mean and the i^{th} deflection for each section
υ = number of degrees of freedom for the j^{th} versus k^{th} section combination
s_{jk} = pooled estimate of the standard deviation for the j^{th} versus k^{th} section combination
t = Student's t value calculated
T = minimum Student's t value required for hypothesis to be true (from table of degrees of freedom versus specified minimum confidence level)
α = specified minimum confidence level for determining design deflection
z = number of standard deviations beyond the section mean required to achieve the specified minimum confidence level
$x_{\alpha j}$ = design deflection for j^{th} section

The following equations are used to determine if the hypothesis of equal means is true:

$$\bar{x}_j = \frac{\sum_{i=1}^{N_j} x_i}{N_j} \quad \text{(C.1)}$$

$$D_j = \sum_{i=1}^{N_j} (x_i - \bar{x}_j)^2 \quad \text{(C.2)}$$

$$\upsilon = N_j + N_k - 2 \quad \text{(C.3)}$$

$$s_{jk} = \sqrt{\frac{D_j + D_k}{N_j + N_k - 2}} \quad \text{(C.4)}$$

$$t = \frac{\bar{x}_j - \bar{x}_k}{s_{jk} \sqrt{\frac{1}{N_j} + \frac{1}{N_k}}} \quad \ldots\ldots\ldots\ldots \quad (C.5)$$

If it is determined that this calculated t value is less than T, the table t value, then the hypothesis that the two section means do not differ significantly is true* or they "PASS" the test. Conversely, if the calculated t is greater than the table t, then the hypothesis is false and the two section means do differ significantly or they "FAIL" the test.

Equations C.1, C.2, and the following are used to determine the design deflection for each section.

$$\sigma_j = \sqrt{\frac{D_j}{N_j - 1}} \quad \ldots\ldots\ldots\ldots \quad (C.6)$$

$$x_{\alpha j} = \bar{x}_j + (z \cdot \sigma_j) \quad \ldots\ldots\ldots\ldots \quad (C.7)$$

OUTPUT

Program TVAL2 output consists of the deflections as they were grouped in each section, the mean and standard deviation for each section, a table of the results of the Student's t analysis for all possible combinations of sections taken two at a time, and finally the computed design deflection for each section.

*Note: Since the purpose of the overall procedure is to select sections with significantly different mean deflections, so as to produce significantly different overlay designs for each section, the user should consider combining any sections whose means do not differ significantly and then re-running TVAL2.

APPENDIX D

TEST PROCEDURE FOR DYNAMIC MODULUS OF ASPHALT CONCRETE

APPARATUS

1. Testing machine - the two types of equipment capable of producing one or more of the load pulses required are electro-hydraulic testing machines with function generators and pneumatic machines with fluidic timers. The former is readily available from well known sources and much more expensive, but has flexibility in shapes of pulses that may be generated. The latter is limited to square pulses, but is much less expensive, simple to operate and almost maintenance free. The pneumatic machine is basically of the type developed by Seed and others (Ref. 15)[1] for resilient modulus testing of soils, but a larger loading piston is used to produce the load required for asphaltic concrete specimens. A photograph of the testing machine is shown in Figure D.1.

2. Strain measurement system - both LVDT's (Linear Variable differential Transformers) and stain gauges have been used successfully.

The LVDT's are usually used in pairs on the opposite sides of the sample measuring vertical movement between two horizontal clamps firmly attached to the sample (See Figure D.1). The LVDT transducers are attached to one clamp, and rods that can be screwed in or out for zeroing to the other with the LVDT cores on the opposite end fitting into the transducers. Change in sample length between the clamps will result in an increase in voltage output through the transducer and a calibrated trace on a strip recorder's chart paper.

Wire strain gauges are also used in pairs bonded at mid-height on opposite sides of the specimen. The gauges are wired in a Wheatstone Bridge circuit with two active gauges on the test specimen and two temperature compensating gauges similarly bonded on an unstressed specimen exposed to the same environment as the test specimen.

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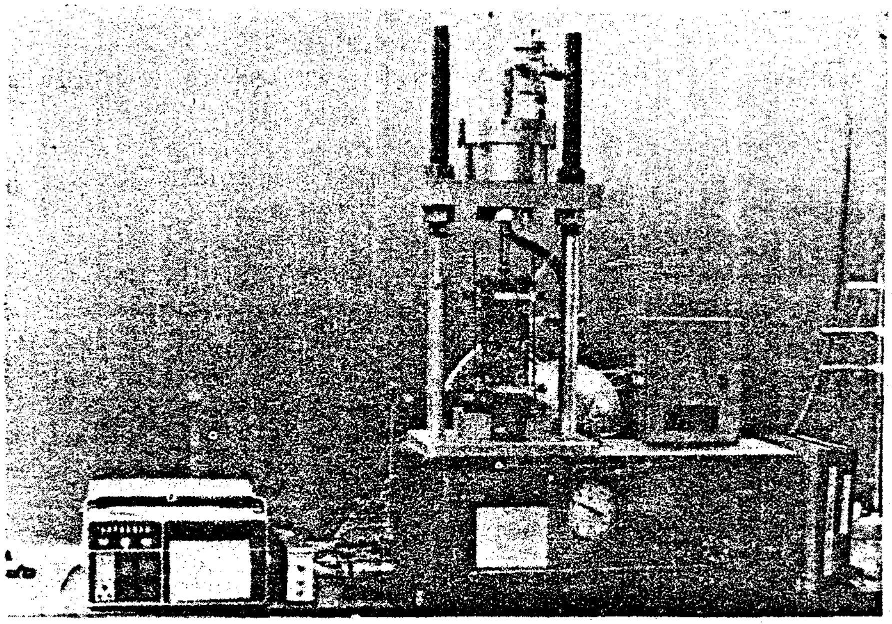
[1] Seeds, H. B., F. G. Mitry, C. L. Monismith, and C. K. Chan, Prediction of Flexible Pavement Deflection from Laboratory Repeated Load Test, NCHRP Report No. 35, 1967.



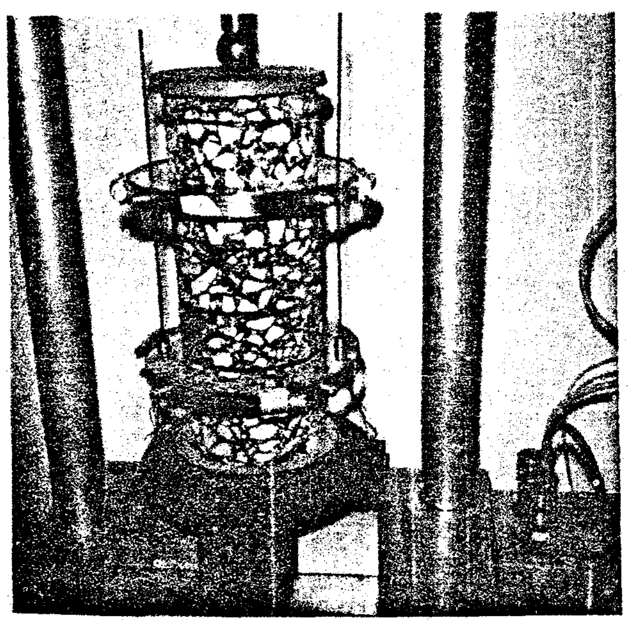


Figure D.1. Photographs of Dynamic Modulus Testing Equipment

The LVDT's or strain gauges should have the capability for operating across the range of strains occurring in the specimen and should, in combination with signal conditioning equipment and the recorder, produce traces on the chart paper that may be easily and accurately measured for the smallest strains (those at a specimen temperature of 40°F that will be measured). The system should at its highest sensitivity setting display 4 micro strain units or less per mm on the recorded chart for strain gauges. As the LVDT's measure total strain across a gauge length (usually around 4 inches or more), and a calculation is made to obtain unit strain, sensitivity must be measured in total strain.

As an example, 56 micro inches of movement will occur over a 4-inch gauge length in a material having a very high dynamic modulus of 2,500,000 psi and subjected to 35 psi of vertical stress. Assuming .05 inches (12.7mm) is the smallest trace that may be accurately measured, a sensitivity allowing measurement of 4.4 micro inches per mm of chart width should be required. A sensitivity of 3 micro inches per mm should be sufficient for all practical conditions.

The recorder should have sufficiently rapid response to swing almost full scale in .01 second. Recording oscillographs of good quality using light sensitive paper have proven satisfactorily responsive.

While both LVDT's and bonded strain gauges may be used successfully, more of the material is directly active in the test when measurements are made over a longer gauge length for LVDT's compared to the nominal length for strain gauges. In either case, special attention is warranted to assure firm attachment to the sample. The LVDT clamps should each have four pointed set screws that insure against clamp movement.

3. Load measurement system - load measurements for the varying load used for a haversine pulse produced by the electrohydraulic machine are usually made with a load cell generating a second trace on the chart paper. This may also be used for the two-phase (on-off) load for the square pulse from the pneumatic machine, but is not necessary in this case as it is sufficient to precisely control the air pressure to the air piston. The air pressure is precisely calibrated in terms of load delivered to the sample. Sensitivity in either case must be sufficient to allow accurate calculation of vertical load and thus stress.

4. Temperature control system - One or more temperature chambers having a capacity for 6 specimens may be used to produce temperatures

of 40°F, 70°F, and 100°F (5°, 21° and 38°C) controlled to ± 1°F (.5°C).

5. Loading plate - a hardened, steel plate no less than 1/4 inches thick and with a diameter equal to that of the specimen is required to transfer the load from the testing machine to the specimen.

PREPARATION OF SPECIMENS

1. Laboratory-prepared specimens: Most testing agencies have their own means of preparation and compaction to produce density and stability specimens that serve as the basis for material specifications. Compaction of specimens for dynamic modulus testing should be accomplished by the procedures in use by the agency involved. A specimen suitable for vertical compression testing requires modifications to produce a cylindrical specimen twice as long as its diameter.

One optional procedure is to prepare the bituminous mixture as specified by ASTM Method D 1560 , "Test for Resistance to Deformation and Cohesion of Bituminous Mixtures by Means of the Hveem Apparatus." Compaction is then accomplished with a California Kneeding Compactor using steel molding cylinders with 1/4 inch wall thickness, inside diameters of 4 inches and a height of 10 inches (twice as high as that recommended by ASTM D1561). A pre-heated insulated feeder trough and a paddle are used as in ASTM D 1561 to introduce the mixture into the mold, but in a different manner. One half of the approximately 4000 grams of bituminous mixture is weighed out and introduced into the trough. A paddle is then used to push 30 approximately equal portions into the mold continuously and uniformly while 30 tamping blows at a pressure of 250 psi are applied. The second half of the mixture is compacted in the mold in the same manner. This is followed immediately by application of a static load to the specimen while still in the mold. The load is applied with a compression machine by the double plunger method in which metal followers are employed as free-fitting plungers on top and bottom of the specimen. This load is applied at a rate of 0.05 inches per minute until an applied pressure of 1000 psi is reached. The load is then removed immediately. After the specimen is sufficiently cooled so that it will not deform in the mold, it is removed from the mold and placed on a smooth flat surface to cool to room temperature. The resulting bulk specific gravity is reported to approximate very closely that of specimens prepared as specified by ASTM D 1559, "Test for Resistance to Plastic Flow of Bituminous Mixtures Using Marshall Apparatus," and by ASTM D 1561, "Preparation of Specimens by means of California Kneeding Compactor."

Whatever the procedure used, the diameter of the specimens should be four or more times the maximum nominal size of aggregate specified. A diameter of 4 inches is normally used with a length of approximately 8 inches. A minimum of three specimens should normally be tested to suitably account for variability in the materials.

2. Pavement cores - During field sampling obtain cores having a minimum height to diameter ratio of 2 and with diameters not less than two times the maximum nominal size of an aggregate particle. Because of the high variability in dynamic modulus found for pavements in the field, six specimens should normally be tested to characterize a pavement section. The cores should be taken from locations selected to provide a representative sample of the pavement section.

As most highway pavement layers are less than 8 inches thick, it may be necessary to test cores with a two-inch diameter or else it may not be possible to use these procedures. For thin pavements, it is possible to obtain a dynamic modulus through dynamic indirect tensile tests on specimens of 4 to 6 inches in diameter.

TEST PROCEDURES

Capping of Specimens - All specimens should be capped with a sulphur mortar as specified by ASTMC617. The procedures for capping may be the same as those used for Portland cement concrete compression specimens except that a special capping fixture for four-inch diameter specimens must be used.

Place test specimens in a control temperature cabinet and bring them to the specified test temperature. A dummy specimen with a thermo couple in the center can be used to determine when the desired test temperature is reached or the specimens may remain in the controlled temperature environment overnight to insure even distribution of temperature.

Place specimen with strain gauges for strain measurement directly into the loading apparatus (strain gauges are bonded on the specimen prior to placement in the temperature cabinet). Then connect the strain gauge wires to the measurement system, place the hardened steel disk on top of the specimen and center both under the loading apparatus. Adjust and balance the electronic measuring system as necessary.

For specimens using LDVT's for strain measurement, the clamps and LDVT's are to be placed on the specimen as rapidly as possible before the specimen with the hardened steel disk on top is placed under the loading apparatus. The LDVT's must be zeroed prior to continuing.

Apply the selected pulse as previously described without impact, turning on the recorder about every 50 cycles to obtain a few traces of the strains caused by the load pulse. The resilient strain may be measured on the trace as the distance transverse to the edge of the chart paper between the maximum of the trace and the minimum of the trace just before the next load is applied. This measures the strain recovered. Comparisons of the amounts of strain after each 50 cycles should reveal that the amount of strain has stabilized around 200 cycles of loading. The resilient strain after the magnitudes have stabilized may be used in calculating the dynamic modulus.

The specimen may now be removed from the testing machine and disconnected from the strain measurement equipment, and stored until returned to the temperature cabinet in preparation for testing at a new temperature.

It is important to test in order of increasing temperatures of 40°F, 70°F, and 100°F, as the stiffness will decrease almost an order of magnitude between 40°F and 100°F. Testing in this order will allow the least possible amount of permanent strain prior to subsequent testing.

All portions of the procedure should be completed as quickly as possible to minimize the variation in temperature in the sample prior to completion of the test. The testing should be completed on a specimen within two minutes after it is removed from the temperature control cabinet. While this may not be possible when LDVT's are used because it takes that long to place the clamps and LDVT's in position and measure the gauge length and another two minutes to zero them, the test may be conducted rapidly enough to avoid important change in temperature. The clamps and LDVT's can also be placed on the specimen prior to removal from the temperature cabinet. If testing is conducted in a room or a temperature control cabinet meeting the specified temperature control tolerance limits, the requirement for expedited testing may be waived.

In the unlikely event that excessive deformation (greater than 2500 micro units of strain) occurs, the maximum loading stress level may be reduced and testing contained as described above.

Calculations

The measured quantity from dynamic modulus testing is the resilient strain taken after sufficient cycles of loading for it to stabilize. If the square load pulse is used, the resilient strain is modified by multiplication by 0.8 to better represent strains from a wheel load. The vertical stress is generally controlled at 35 psi (or 17.5 psi if exceptionally high strains occur as previously discussed).

The general equation for calculation is:

$$E^*(T) = \frac{\sigma_o}{\varepsilon_o(T)} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (D.1)$$

where:

$E^*(T)$ = Dynamic Modulus for the Asphaltic Mixture at temperature T

$\varepsilon_o(T)$ = Resilient unit strain from dynamic modulus test with the specimen at temperature T.

σ_o = Vertical test stress recommended at 35 psi.

Plot the results as indicated in Figure D.2 from the replicate tests. From these plots, a suitable curve may be selected for design or analysis. A mean curve with a rough approximation (dependent on number of replicate tests) of the variation around the mean may be appropriate for most uses.

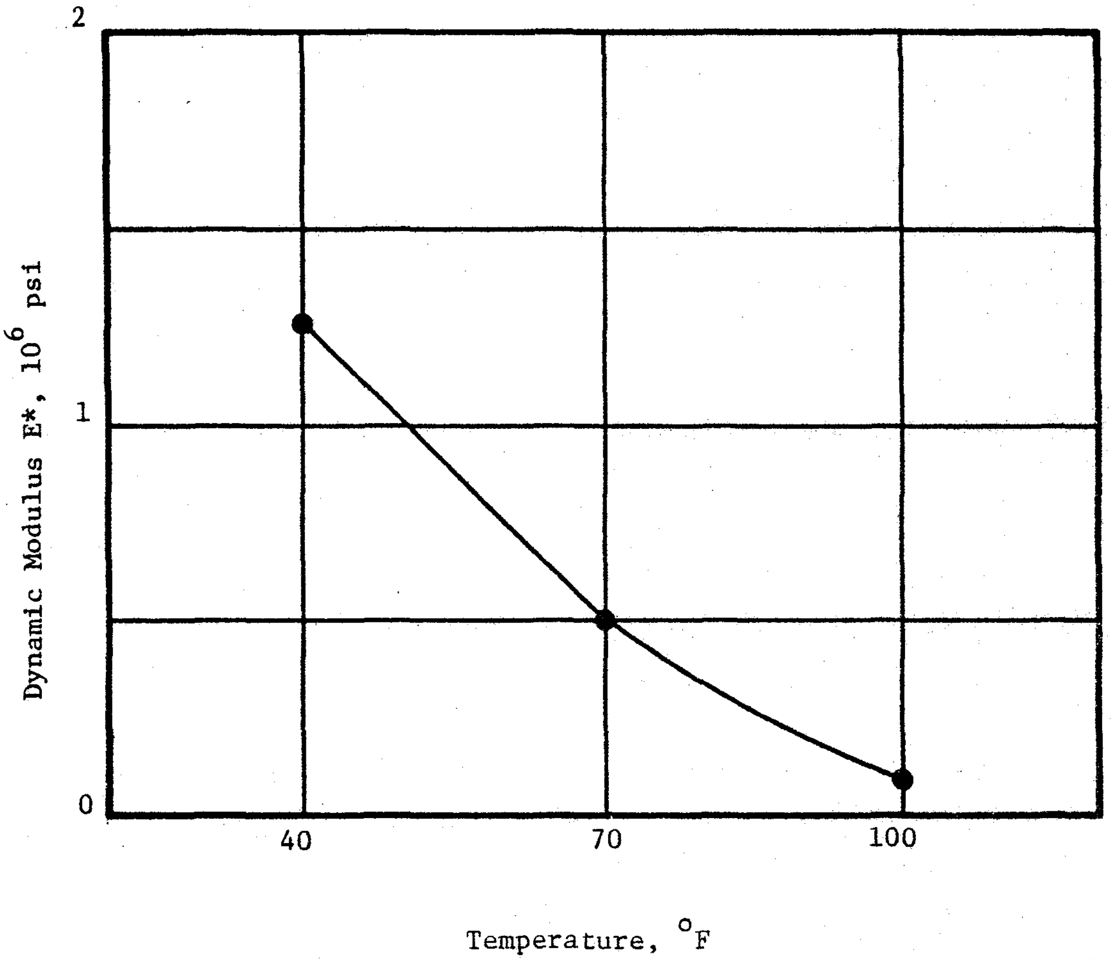


Figure D.2 Typical Dynamic Test Results for an Asphaltic Concrete Specimen Tested at Three Temperatures.

APPENDIX E

RECOMMENDED TEST PROCEDURES -- RESILIENT MODULUS OF ELASTICITY FOR BASE, SUBBASE, AND SUBGRADE MATERIALS

General

The use of elastic layer theory in the prediction of stresses and deflections in pavement systems gives added importance to accurate determination of the modulus of elasticity of base, subbase and subgrgrade materials. Overwhelming evidence indicates that the modulus of elasticity for most soils is stress sensitive and varies with repeated loading. An adequate laboratory simulation of soil in a base or subgrade then requires application of loads repetitiously to model the intensities and durations of wheel loads.

The triaxial load cell was developed years ago to allow better simulation of a sample of soil in place in the field. The lateral pressure in the cell simulates the resistance of surrounding soil to lateral displacement of the soil sample under vertical load. Equipment capable of applying closely controlled vertical load pulses to represent the intensity and duration of the stresses induced by a passing vehicle was recently introduced. Linear variable differential transformers (LVDTs) are used to produce electronic signals proportional to the amount of movement in the sample. These signals are conditioned for input to a strip recorder, which plots the deformation versus time. The resilient modulus, M_R, is the ratio of stress to resilient strain taken after an appropriate number of cycles of loading and at an appropriate level of vertical stress.

The resilient modulus derived under conditions closely simulating those the sample will experience in the field is used in lieu of a static modulus of elasticity (derived from long-term one-cycle tests) to characterize the material for the particular analytical procedure.

Failure to recognize the effects of repetitive loading on soils will involve overestimation of the modulus of elasticity for clay soils and underestimation for granular soils.

Sample Requirements for Resilient Modulus Testing

Resilient modulus testing may be conducted on undisturbed samples representing natural state in the field, samples compacted to optimum density or samples compacted to some intermediate density. Samples may be delivered to the laboratory as undisturbed samples wrapped to avoid moisture change and packed to protect the structural integrity of the sample or as disturbed samples to be compacted to some density.

As most of the resilient modulus testing done is conducted on samples with a diameter of 2.8 inches, a 3-inch thin-wall tube should be used for collection of undisturbed samples whenever possible. For cohesive soils, larger tubes may be used and the samples trimmed in the laboratory. Samples with a diameter of 1.4 inches may be tested but require considerable more effort and the results are not considered to be quite as accurate. If the material to be tested is to be used in a new subbase or subgrade for a pavement system, the density must be furnished or determined. This density should be consistent with the density control planned in the field; i.e., if 95% of modified AASHO compaction is to be specified, the optimum density can be established using modified AASHO compactive energy and compacting the sample to 95% of that amount. If some natural density is desired, it may be specified and the samples can be compacted to that amount. The latter requires trial and error. Moisture contents to simulate the field must also be specified or determined. Samples to be compacted in the laboratory may be sent in disturbed state in bags. Four pounds is sufficient for a single triaxial specimen.

Test Design

The repetitive loading triaxial machine allows considerable flexibility in simulation of anticipated field conditions. Those parameters that may be varied include intensity of deviator stress, lateral pressure, load period from 1/10th of a second upward, rest period between cyclic loads on the specimen, sequence of loading and cycles of loading prior to reading test values.

Deviator stresses as low as 1 psi and as high as 64 psi may be applied. Lateral pressures as low as 1/2 psi are not generally applicable as lateral pressure near the surface of the layer should be based on an estimate of the horizontal stresses induced by the load plus the deadload of the overlaying material.

It has been found that 1000 cycles at a specific loading is sufficient to stabilize the resilient modulus for a material and a particular set of loading conditions. 200 cycles will generally be sufficient for granular materials and is frequently adequate for cohesive soils as well.

Standard Test Procedure

The specimen is placed on the triaxial cell base, a membrane applied, the LVDT's clamped in place so that they measure vertical deformation of the middle third of the specimen and a vacuum is applied within the sample and a vacuum chamber to insure that there is no leakage through the membrane. The triaxial cell is then assembled and placed in the triaxial machine. The sample is conditioned by 1,000 cycles of loading at the lowest deviator stress to be applied and at the lateral pressure specified. Measuring equipment is then zeroed after another 200 cycles of loading at the lowest deviator stress. The cyclic load is applied and increased subsequent to test readings at the specified number of cycles for each load level.

The output of the LVDT's is combined for averaging and fed through a signal conditioner to a strip recorder with very rapid response. The recorded cyclic deformation plus the established deviator stress and sample dimensions provide all the information necessary to calculate the resilient modulus at any load level. A resilient modulus is calculated as follows:

$$M_R = \frac{\sigma_d}{\varepsilon_r} \quad \text{(E.1)}$$

where:

M_R = Resilient Modulus

σ_d = Deviator Stress, psi

ε_r = Resilient Strain, in./in.

The resilient moduli at the various load levels is then plotted on log-log paper to give clear insight as to the variation in resilient modulus with stress intensity.

Test Results

Test results are summarized in the form of a curve relating resilient modulus to deviator stress level at the specified lateral pressure and loading conditions (See Fig. E.1). Additional information and recommendations may also be provided from insight into soil behavior gained during test observations.

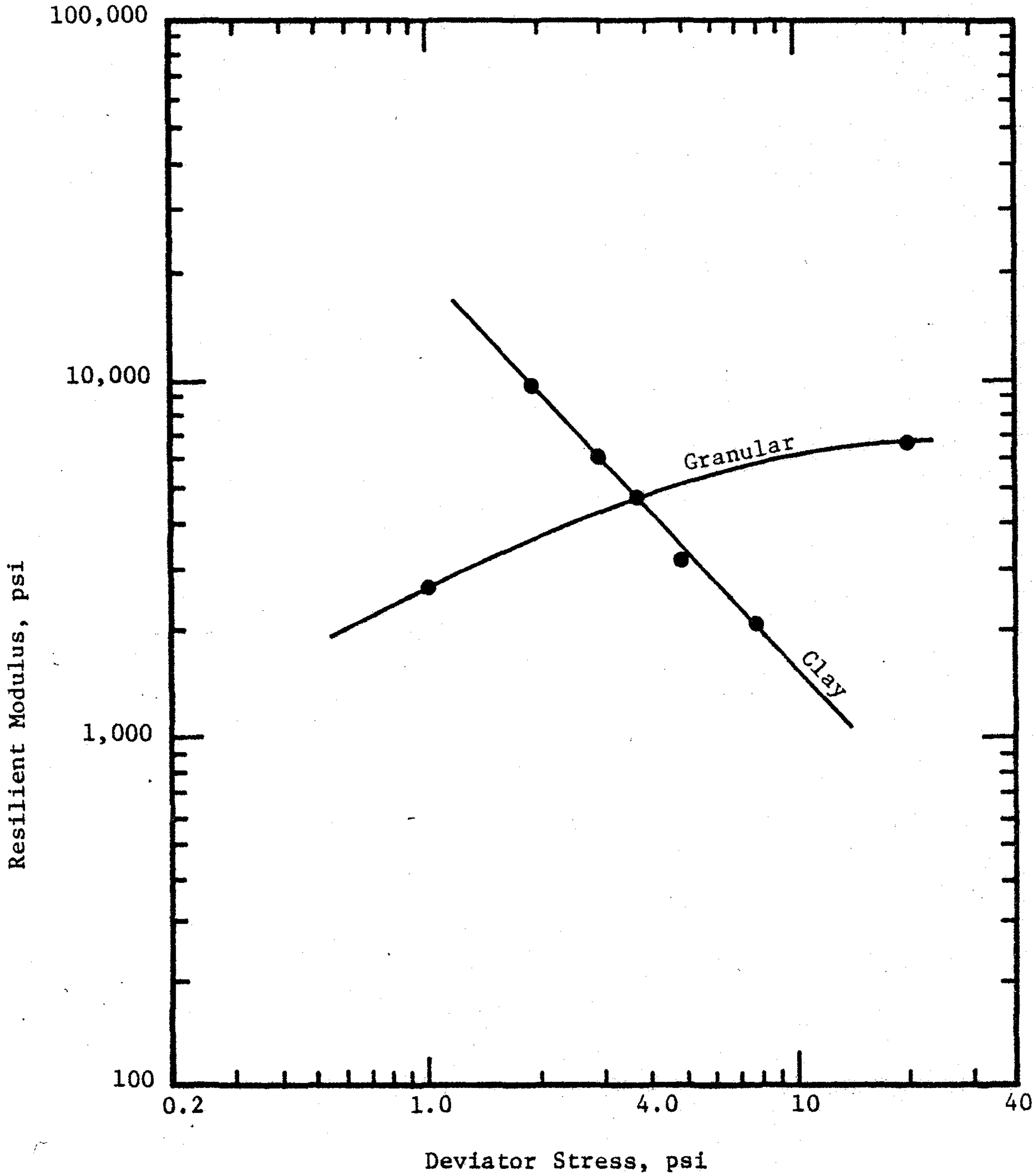


Figure E.1 Relation Between Resilient Modulus And Stress for Typical Clay and Granular Soils

APPENDIX F

RANDOM ORDER INPUT GUIDE FOR POD1

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      PROGRAM POD1 (INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT)
C
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POD1 - PAVEMENT OVERLAY DESIGN PROGRAM, VERSION 1.0

THIS PAVEMENT OVERLAY DESIGN COMPUTER PROGRAM WAS DEVELOPED BY AUSTIN RESEARCH ENGINEERS INC (2600 DELLANA LANE, AUSTIN, TEXAS 78746, PHONE (512) 327-3520, TWX 910-874-1324 ARE INC AUS) UNDER FEDERAL HIGHWAY ADMINISTRATION CONTRACT NO. DOT-FH-11-8544 IN AUGUST 1977. DEVELOPMENT OF THE DESIGN PROCEDURES IS PRESENTED IN FEDERAL HIGHWAY ADMINISTRATION REPORTS NO. FHWA-RD-75-75 AND NO. FHWA-RD-77-66. USE OF THE PROGRAM IS DESCRIBED IN REPORT NO. FHWA-RD-77- .

THIS PROGRAM REFLECTS THE VIEWS OF AUSTIN RESEARCH ENGINEERS INC AND NOT NECESSARILY THOSE OF THE DEPARTMENT OF TRANSPORTATION. HOWEVER, ANY USER OF THE PROGRAM MUST ASSUME ULTIMATE RESPONSIBILITY FOR ITS RESULTS.

I N P U T   G U I D E

INSTRUCTIONS TO THE PROGRAM ARE SUPPLIED IN THE FORM OF DIRECTIVES. A DIRECTIVE OCCUPIES EITHER THE FIRST OR SECOND HALF OF A CARD (COLUMNS 1-40 OR 41-80). THE FIRST EIGHT CHARACTERS OF EACH DIRECTIVE CONTAIN A KEYWORD IDENTIFYING THE TYPE OF INFORMATION BEING ENTERED. ALL KEYWORDS MAY BE ABBREVIATED TO THEIR FIRST FOUR CHARACTERS, THE REST OF THE IDENTIFIER IS IGNORED. IF THE FIRST FOUR CHARACTERS OF A DIRECTIVE ARE BLANK, THEN THE WHOLE DIRECTIVE IS SKIPPED, AND READING CONTINUES WITH THE NEXT DIRECTIVE. THIS MEANS THAT ALL DIRECTIVES MAY BEGIN IN COLUMN ONE AT THE OPTION OF THE USER.

MORE THAN ONE PROBLEM MAY BE SOLVED IN A SINGLE EXECUTION OF THE PROGRAM. EACH PROBLEM IS PREFACED WITH A 'PROBLEM' DIRECTIVE AND THE LAST PROBLEM OF A RUN IS TERMINATED BY AN 'END' DIRECTIVE. ALL RELEVANT INFORMATION MUST BE SUPPLIED FOR THE FIRST PROBLEM OF A RUN VIA THE VARIOUS DIRECTIVES WHICH ARE EXPLAINED BELOW. SUBSEQUENT PROBLEMS IN THE SAME RUN NEED ONLY SPECIFY DIRECTIVES WHICH ARE TO BE CHANGED, ALL OTHER VALUES WILL BE RETAINED FROM THE PRECEDING PROBLEM, WITH THE EXCEPTION OF THE CORNER DIRECTIVE, WHICH APPLIES ONLY TO THE CURRENT PROBLEM. ALL DATA ON A SINGLE DIRECTIVE MUST BE SUPPLIED, HOWEVER, EVEN IF ONLY ONE NUMBER IS BEING CHANGED.

ALL DIRECTIVES SHARE A COMMON FORMAT, BUT THE MEANINGS OF THE FIELDS DIFFER DEPENDING ON THE KEYWORD IDENTIFIER. THESE SPECIFIC MEANINGS ARE DESCRIBED BELOW UNDER THE HEADINGS OF THE APPROPRIATE KEYWORDS. THE GENERAL FORMAT IS AS FOLLOWS:

FIELD NAME	COLUMN NUMBERS	TYPE OF VALUE	FORMAT USED
KEYWORD	1-8	CHARACTER	2A4
IVL	9-10	INTEGER	I2
VAL(1)	11-20	REAL	F10.0
VAL(2)	21-25	REAL	F5.0
VAL(3)	26-30	REAL	F5.0
ITYPE(1)	31-34	CHARACTER	A4
ITYPE(2)	35-38	CHARACTER	A4

ADDING 40 TO THE COLUMNS LISTED ABOVE GIVES THE CORRESPONDING COLUMN NUMBER FOR A DIRECTIVE WHICH IS PUNCHED IN THE SECOND HALF OF THE CARD.

SOME DIRECTIVES REQUIRE FURTHER VALUES FROM CARDS WHICH ARE PLACED IMMEDIATELY AFTER THE CARD ON WHICH THE DIRECTIVE APPEARS. THESE CARDS WILL BE READ IN 8F10.0 FORMAT. AS MANY CARDS AS ARE NEEDED TO HOLD THE NUMBER OF VALUES TO BE INPUT SHOULD BE SUPPLIED. IF TWO SUCH DIRECTIVES ARE PUNCHED ON A SINGLE CARD, THE EXTRA CARDS FOR THE DIRECTIVE IN COLUMNS 1 THROUGH 40 SHOULD PRECEDE THOSE REQUIRED FOR THE ONE IN COLUMNS 41 THROUGH 80.

K E Y W O R D   D I C T I O N A R Y

BOND BKR

THIS DIRECTIVE IS NEVER REQUIRED. IF IT DOES NOT APPEAR, THEN THE DEFAULT VALUES FOR THE BOND BREAKER LAYER WILL BE USED. DEFAULT VALUES WILL ALSO BE SUPPLIED FOR ANY FIELD ON THE DIRECTIVE WHICH IS LEFT BLANK.

NOTE THAT A BOND BREAKER LAYER IS ONLY USED IF THE 'UNBD' OPTION IS SELECTED ON THE OVERLAY DIRECTIVE, INDICATING THAT AN UNBONDED OVERLAY IS TO BE BUILT (SEE COMMENTS FOR OVERLAY DIRECTIVE BELOW). IF THIS OPTION IS NOT SPECIFIED, THEN THE BOND BREAKER DESCRIPTION WILL BE IGNORED, ALTHOUGH THE VALUES SUPPLIED WILL STILL BE AVAILABLE TO SUBSEQUENT PROBLEMS.

FIELD DEFINITIONS:

VAL(1) = MODULUS OF BOND BREAKER LAYER IN PSI.
(DEFAULT IS 100000.0)
VAL(2) = THICKNESS OF BOND BREAKER LAYER IN INCHES.
(DEFAULT IS 1.0)
VAL(3) = POISSON/S RATIO FOR BOND BREAKER LAYER
(DEFAULT IS 0.3)

CORNER

THIS DIRECTIVE IS NEVER REQUIRED. IT IS USED ONLY WITH JCP EXISTING PAVEMENT, AND PROVIDES A MEASURED RATIO OF CORNER DEFLECTION TO INTERIOR DEFLECTION FOR A GIVEN PAVEMENT SECTION. THIS RATIO IS USED TO OBTAIN THE LOAD LOCATION (STRESS ADJUSTMENT) FACTOR FOR THE DETERMINATION OF REMAINING LIFE AND, FOR JCP OVERLAYS, OF ESTIMATED OVERLAY LIFE. THE LOAD LOCATION FACTOR IS DETERMINED USING INTERPOLATION IN A CURVE OF STRESS RATIO VS. DEFLECTION RATIO. THIS DIRECTIVE APPLIES ONLY TO THE PROBLEM WITH WHICH IT WAS READ. DEFAULT VALUE OF THE LOAD LOCATION FACTOR FOR JCP EXISTING PAVEMENT AND JCP/JCP OVERLAYS IS 1.5.

FIELD DEFINITIONS:

VAL(1) = RATIO OF DEFLECTION MEASURED AT A CORNER (JCP) TO THAT MEASURED AT AN INTERIOR POINT.

DEFLECT

THIS DIRECTIVE IS REQUIRED FOR THE FIRST PROBLEM OF EVERY RUN. DEFAULT VALUES WILL NOT BE SUPPLIED BY THE PROGRAM. NOTE THAT THE COORDINATE SYSTEM USED HERE IS THE SAME AS THAT USED FOR THE LOADS DIRECTIVE. IT WILL GENERALLY SAVE KEY-PUNCHING ON MULTI-PROBLEM RUNS IF THE DEFLECTION MEASUREMENTS ARE TAKEN AT THE ORIGIN.

IF THE DESIGN DEFLECTION ON THIS DIRECTIVE AND DEFLECTION LOAD AND THE DEFLECTION PRESSURE ON THE LOADS DIRECTIVE ARE ALL ZERO, THE VALUE OF MODULUS READ ON THE SUBGRADE LAYER DIRECTIVE WILL BE USED FOR REMAINING LIFE AND OVERLAY CALCULATIONS.

FIELD DEFINITIONS:

VAL(1) = DESIGN DEFLECTION IN INCHES. THIS DEFLECTION SHOULD BE REPRESENTATIVE OF THE MORE DISTRESSED PORTIONS OF THE PAVEMENT, HENCE A MINIMUM CONFIDENCE LEVEL OF 90 PERCENT IS RECOMMENDED.
(NO DEFAULT VALUE)

VAL(2) = X-COORDINATE OF DEFLECTION MEASUREMENT IN INCHES.
(NO DEFAULT VALUE)

VAL(3) = Y-COORDINATE OF DEFLECTION MEASUREMENT IN INCHES.
(NO DEFAULT VALUE)

END

THIS DIRECTIVE INFORMS THE PROGRAM THAT NO MORE PROBLEMS ARE TO BE EXECUTED IN THIS RUN. EVERY INPUT DECK MUST CONTAIN AN END DIRECTIVE, EVEN IF ONLY ONE PROBLEM IS TO BE ANALYZED. THIS DIRECTIVE HAS NO PARAMETERS.

LAB DATA

THIS DIRECTIVE IS REQUIRED IF THE LOAD UNDER WHICH THE DEFLECTION MEASUREMENTS WERE TAKEN DIFFERS SIGNIFICANTLY FROM 18 KIPS (THE DESIGN LOAD). LAB TESTS MUST BE MADE TO DETERMINE ELASTIC MODULUS AS A FUNCTION OF DEVIATOR STRESS FOR THE SUB-GRADE MATERIALS. THESE DATA ARE ENTERED ON CARDS WHICH ARE PLACED IMMEDIATELY AFTER THE DIRECTIVE IN 8F10.0 FORMAT. CORRESPONDING VALUES OF MODULUS AND DEVIATOR STRESS ARE ENTERED IN PAIRS, WITH THE MODULUS VALUE FIRST. A MINIMUM OF TWO POINTS AND A MAXIMUM OF 10 MAY BE SUPPLIED. FOUR POINTS CAN BE PUNCHED ON A SINGLE CARD. NO FIELDS CAN BE SKIPPED, AS MANY CARDS AS ARE NECESSARY TO HOLD THE DATA MUST BE PROVIDED.

FIELD DEFINITIONS:

IVL = NUMBER OF PAIRS OF POINTS TO BE READ. $(1 < IVL < 100)$
(NO DEFAULT VALUE)

LAYER

THIS DIRECTIVE DEFINES THE PROPERTIES OF A SINGLE LAYER OF THE EXISTING PAVEMENT. A LAYER DIRECTIVE IS REQUIRED FOR EACH LAYER DOWN TO AND INCLUDING THE SUBGRADE. AFTER THE FIRST PROBLEM IT IS POSSIBLE TO CHANGE THE VALUES FOR A SINGLE LAYER WITHOUT ALTERING THE OTHERS BY INCLUDING A LAYER DIRECTIVE FOR THAT LAYER ONLY. A MAXIMUM OF FOUR LAYERS ARE PERMITTED, UNLESS A BOND BREAKER LAYER IS TO BE USED (SEE OVERLAY DIRECTIVE) IN WHICH CASE ONLY THREE EXISTING LAYERS ARE ALLOWED. IF THE THICKNESS OF THE SUBGRADE LAYER IS INPUT AS ZERO, THEN IT IS ASSUMED TO BE SEMI-INFINITE. OTHERWISE THE PROGRAM WILL SIMULATE THE PRESENCE OF BEDROCK AT THE INDICATED DEPTH BELOW THE TOP OF THE SUBGRADE WHEN PERFORMING DEFLECTION CALCULATIONS.

FIELD DEFINITIONS:

```
IVL = LAYER NUMBER.  LAYERS ARE NUMBERED FROM THE TOP DOWN.
      0 < IVL < 5
      (NO DEFAULT VALUE)
VAL(1) = MODULUS OF ELASTICITY FOR LAYER MATERIAL IN PSI.
         (NO DEFAULT VALUE)
VAL(2) = LAYER THICKNESS IN INCHES (ZERO IF INFINITE).
         (NO DEFAULT VALUE UNLESS SUBGRADE)
VAL(3) = POISSON/S RATIO FOR LAYER MATERIAL.
         (DEFAULT VALUE BASED ON MATERIAL TYPE)
ITYPE(1) = MATERIAL TYPE AS FOLLOWS:
           'AC  ' - ASPHALTIC CONCRETE,
           'CRCP' - CONTINUOUSLY REINFORCED CONCRETE PAVEMENT,
           'GRAN' - GRANULAR BASE MATERIAL,
           'JCP ' - JOINTED CONCRETE PAVEMENT,
           'STAB' - STABILIZED BASE MATERIAL,
           'SUBG' - SUBGRADE LAYER.
           (MUST BE AC, JCP, OR CRCP IF TOP LAYER)
ITYPE(2) = RIGID BASE INTERFACE TYPE (REQUIRED IF RIGID BASE
           REQUESTED):
           'FF  ' - FULL FRICTION INTERFACE,
           'NF  ' - NO FRICTION INTERFACE.
           (NO DEFAULT VALUE)
```

THIS DIRECTIVE DESCRIBES THE LOAD GEOMETRY OF THE DEFLECTION MEASURING DEVICE. IT IS REQUIRED FOR THE FIRST PROBLEM OF A RUN, BUT ORDINARILY NEED NOT BE INPUT AGAIN UNLESS MORE THAN ONE SUCH DEVICE IS EMPLOYED. FROM ONE TO FOUR UNIFORM CIRCULAR LOADS MAY BE MODELLED WITH THIS DIRECTIVE. A SINGLE LOAD FORCE AND PRESSURE ARE INPUT FOR ALL OF THESE LOADS. AN EXTRA CARD MUST BE PROVIDED IMMEDIATELY AFTER THIS DIRECTIVE, SPECIFYING THE POSITIONS OF THE LOADS AS PAIRS OF X AND Y COORDINATES IN 8F10.0 FORMAT. THESE ARE THE HORIZONTAL CARTESIAN COORDINATES IT WILL USUALLY BE FOUND CONVENIENT TO SELECT A COORDINATE SYSTEM WHICH PLACES THE POINT AT WHICH DEFLECTIONS ARE MEASURED AT THE ORIGIN (SEE DEFLECT DIRECTIVE ABOVE).

FIELD DEFINITIONS:

```
IVL = NUMBER OF LOADS (0 < IVL < 5).
       (NO DEFAULT VALUE)
VAL(1) = DEFLECTION LOAD FORCE IN POUNDS.
          (NO DEFAULT VALUE)
VAL(2) = DEFLECTION LOAD PRESSURE IN PSI.
          (NO DEFAULT VALUE)
```

OVERLAY

THIS DIRECTIVE DEFINES THE TYPE OF OVERLAY TO BE BUILT. WITH IT THE DESIGNER SPECIFIES THE MATERIAL TO BE USED, ITS PROPERTIES, AND THE PRESENCE OR ABSENCE OF A BOND BREAKER LAYER. IT IS IMPORTANT TO NOTE THAT THE INCLUSION OF A BOND BREAKER LAYER (VIA THE 'UNBD' OPTION) REDUCES THE MAXIMUM NUMBER OF EXISTING PAVEMENT LAYERS FROM FOUR TO THREE. AN OVERLAY DIRECTIVE IS REQUIRED FOR THE FIRST PROBLEM OF EVERY RUN.

FIELD DEFINITIONS:

```
VAL(1) = MODULUS OF OVERLAY MATERIAL IN PSI.
         (NO DEFAULT VALUE)
VAL(2) = POISSON/S RATIO FOR OVERLAY MATERIAL.
         (DEFAULT VALUE BASED ON MATERIAL TYPE)
VAL(3) = CONCRETE FLEXURAL STRENGTH FOR PCC OVERLAY, IN PSI.
         (DEFAULT IS 690.)
ITYPE(1) = MATERIAL TYPE AS FOLLOWS:
           'AC  ' - ASPHALTIC CONCRETE OVERLAY,
           'CRCP' - CONTINUOUSLY REINFORCED CONCRETE OVERLAY,
           'JCP ' - JOINTED CONCRETE OVERLAY.
ITYPE(2) = BOND BREAKER CONDITION AS FOLLOWS:
         = BLANK IF AC OVERLAY,
         = 'BOND' IF BONDED PORTLAND CEMENT OVERLAY,
         = 'UNBD' IF UNBONDED PCC OVERLAY.
           (BOND BREAKER LAYER WILL BE USED)
```

PAVEMENT

THIS DIRECTIVE DESCRIBES THE CONDITION OF THE EXISTING PAVEMENT. IT IS REQUIRED FOR THE FIRST PROBLEM OF EVERY RUN. NOTE THAT LAYER DIRECTIVES ARE ALSO REQUIRED FOR EACH LAYER INCLUDING THE TOP ONE.

FIELD DEFINITIONS:

IVL = NUMBER OF LAYERS IN EXISTING PAVEMENT DOWN TO AND INCLUDING THE SUBGRADE. AT LEAST ONE AND NOT MORE THAN FOUR LAYERS MAY BE SPECIFIED (THREE IF BOND BREAKER LAYER SPECIFIED ON OVERLAY DIRECTIVE). (NO DEFAULT VALUE)

VAL(1) = NUMBER OF 18 KIP EQUIVALENT SINGLE AXLE WHEEL LOADS APPLIED TO DATE (PUNCHED WITH DECIMAL POINT). (DEFAULT IS 1.)

VAL(2) = CONCRETE FLEXURAL STRENGTH FOR EXISTING PCC PAVEMENT, IN PSI. (DEFAULT IS 690.0)

ITYPE = 8-CHARACTER FIELD SPECIFYING PAVEMENT CONDITION:

FOR PCC EXISTING PAVEMENT

BLANK	- NO CRACKING OR VOIDS PRESENT.
'VOID '	- VOIDS PRESENT BUT NO CRACKING.
'TYPE 1,2'	- TYPE 1 OR 2 CRACKING PRESENT.
'VOID 1,2'	- TYPE 1 OR 2 CRACKING WITH VOIDS PRESENT.
'TYPE 3,4'	- TYPE 3 OR 4 CRACKING PRESENT.
'MECH BKN'	- PAVEMENT WILL BE MECHANICALLY BROKEN PRIOR TO OVERLAY.

FOR AC EXISTING PAVEMENT

BLANK	- NO CRACKING OR TYPE 1 CRACKING PRESENT.
'TYPE 2 '	- TYPE 2 CRACKING PRESENT (>5 PER CENT).
'TYPE 3 '	- TYPE 3 CRACKING PRESENT (>5 PER CENT).

PROBLEM

THIS DIRECTIVE SIGNALS THE BEGINNING OF A GROUP OF DIRECTIVES THAT DESCRIBE A SINGLE PROBLEM FOR WHICH SOLUTIONS OF ALLOWABLE TRAFFIC AS A FUNCTION OF OVERLAY THICKNESS ARE DESIRED. IT PERMITS THE USER TO SPECIFY A TITLE AND A PROBLEM NUMBER WHICH WILL APPEAR IN THE PRINTED OUTPUT AND CAN BE USED TO IDENTIFY THE RESULTS. IF A NON-ZERO DIGIT APPEARS ANYWHERE BETWEEN COLUMNS 11 AND 20 OF THIS DIRECTIVE, THEN AN 80-CHARACTER TITLE IS READ FROM AN EXTRA CARD WHICH IMMEDIATELY FOLLOWS THE PROBLEM DIRECTIVE. THIS TITLE WILL REMAIN IN EFFECT UNTIL ANOTHER IS PROVIDED.

FIELD DEFINITIONS:

IVL = PROBLEM NUMBER (IVL < 100).
(DEFAULT IS 1 IF FIRST PROBLEM, PREVIOUS PROBLEM NUMBER PLUS ONE OTHERWISE)
VAL(1) = 0 IF NO TITLE CARD,
> 0 IF TITLE CARD FOLLOWS.

RUT

THIS DIRECTIVE DEFINES THE DESIGN PARAMETERS FOR RUTTING, WHERE RUTTING AS WELL AS FATIGUE IS TO BE CONSIDERED AS A FAILURE MODE. THIS DIRECTIVE IS NEVER REQUIRED, AND IS APPLICABLE ONLY TO AC EXISTING PAVEMENTS WITH NO REMAINING LIFE. THE EXISTING PAVEMENT SYSTEM MUST INCLUDE AT LEAST THREE (3) LAYERS IF THIS DIRECTIVE IS USED.

FIELD DEFINITIONS:

VAL(1) = NUMBER OF DAYS PER YEAR ON WHICH THE AVERAGE TEMPERATURE EXCEEDS 64 DEGREES F.
VAL(2) = ALLOWABLE RUT DEPTH.

TRAFFIC

THIS DIRECTIVE IS NEVER REQUIRED. IT PROVIDES UP TO 5 DESIGN TRAFFIC VALUES, FOR WHICH OVERLAY THICKNESSES ARE OBTAINED BY INTERPOLATION IN THICKNESS AS A FUNCTION OF LOG(PREDICTED APPLICATIONS TO FAILURE). CONSERVATIVE OVERLAY THICKNESSES ARE CALCULATED IF THE SPECIFIED FATIGUE LIFE IS LESS THAN THAT FOR THE RECOMMENDED MINIMUM OVERLAY THICKNESS.

AN EXTRA CARD MUST BE PROVIDED IMMEDIATELY AFTER THIS DIRECTIVE, SPECIFYING THE DESIGN TRAFFIC VALUES IN 5F10.0 FORMAT.

FIELD DEFINITIONS:

IVL = NUMBER OF DESIGN TRAFFIC VALUES (LESS THAN OR EQUAL TO 5)
(DEFAULT: 0)
END 'ABSENT'

'ETAILS DIAGNOSIS OF PROBLEM

NO END CARD, END LINE ASSUMED.

```
      PROGRAM POD1 (INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT)
C
C     POD1 - PAVEMENT OVERLAY DESIGN PROGRAM, VERSION 1.0
C
C        THIS PAVEMENT OVERLAY DESIGN COMPUTER PROGRAM WAS DEVELOPED
C     BY AUSTIN RESEARCH ENGINEERS INC (2600 DELLANA LANE, AUSTIN,
C     TEXAS 78746, PHONE (512) 327-3520, TWX 910-874-1324 ARE INC AUS)
C     UNDER FEDERAL HIGHWAY ADMINISTRATION CONTRACT NO. DOT-FH-11-8544
C     IN AUGUST 1977.  DEVELOPMENT OF THE DESIGN PROCEDURES IS PRESENTED
C     IN FEDERAL HIGHWAY ADMINISTRATION REPORTS NO. FHWA-RD-75-75 AND
C     NO. FHWA-RD-77-66.  USE OF THE PROGRAM IS DESCRIBED IN REPORT NO.
C     FHWA-RD-77-    .
C
C         THIS PROGRAM REFLECTS THE VIEWS OF AUSTIN RESEARCH ENGINEERS
C     INC AND NOT NECESSARILY THOSE OF THE DEPARTMENT OF TRANSPORTATION.
C     HOWEVER, ANY USER OF THE PROGRAM MUST ASSUME ULTIMATE RESPONS-
C     IBILITY FOR ITS RESULTS.
```

INSTRUCTIONS TO THE PROGRAM ARE SUPPLIED IN THE FORM OF DIRECTIVES. A DIRECTIVE OCCUPIES EITHER THE FIRST OR SECOND HALF OF A CARD (COLUMNS 1-40 OR 41-80). THE FIRST EIGHT CHARACTERS OF EACH DIRECTIVE CONTAIN A KEYWORD IDENTIFYING THE TYPE OF INFORMATION BEING ENTERED. ALL KEYWORDS MAY BE ABBREVIATED TO THEIR FIRST FOUR CHARACTERS, THE REST OF THE IDENTIFIER IS IGNORED. IF THE FIRST FOUR CHARACTERS OF A DIRECTIVE ARE BLANK, THEN THE WHOLE DIRECTIVE IS SKIPPED, AND READING CONTINUES WITH THE NEXT DIRECTIVE. THIS MEANS THAT ALL DIRECTIVES MAY BEGIN IN COLUMN ONE AT THE OPTION OF THE USER.

MORE THAN ONE PROBLEM MAY BE SOLVED IN A SINGLE EXECUTION OF THE PROGRAM. EACH PROBLEM IS PREFACED WITH A 'PROBLEM' DIRECTIVE AND THE LAST PROBLEM OF A RUN IS TERMINATED BY AN 'END' DIRECTIVE. ALL RELEVANT INFORMATION MUST BE SUPPLIED FOR THE FIRST PROBLEM OF A RUN VIA THE VARIOUS DIRECTIVES WHICH ARE EXPLAINED BELOW. SUBSEQUENT PROBLEMS IN THE SAME RUN NEED ONLY SPECIFY DIRECTIVES WHICH ARE TO BE CHANGED, ALL OTHER VALUES WILL BE RETAINED FROM THE PRECEDING PROBLEM, WITH THE EXCEPTION OF THE CORNER DIRECTIVE, WHICH APPLIES ONLY TO THE CURRENT PROBLEM. ALL DATA ON A SINGLE DIRECTIVE MUST BE SUPPLIED, HOWEVER, EVEN IF ONLY ONE NUMBER IS BEING CHANGED.

ALL DIRECTIVES SHARE A COMMON FORMAT, BUT THE MEANINGS OF THE FIELDS DIFFER DEPENDING ON THE KEYWORD IDENTIFIER. THESE SPECIFIC MEANINGS ARE DESCRIBED BELOW UNDER THE HEADINGS OF THE APPROPRIATE KEYWORDS. THE GENERAL FORMAT IS AS FOLLOWS:

FIELD NAME	COLUMN NUMBERS	TYPE OF VALUE	FORMAT USED
KEYWORD	1-8	CHARACTER	2A4
IVL	9-10	INTEGER	I2
VAL(1)	11-20	REAL	F10.0
VAL(2)	21-25	REAL	F5.0
VAL(3)	26-30	REAL	F5.0
ITYPE(1)	31-34	CHARACTER	A4
ITYPE(2)	35-38	CHARACTER	A4

ADDING 40 TO THE COLUMNS LISTED ABOVE GIVES THE CORRESPONDING COLUMN NUMBER FOR A DIRECTIVE WHICH IS PUNCHED IN THE SECOND HALF OF THE CARD.

SOME DIRECTIVES REQUIRE FURTHER VALUES FROM CARDS WHICH ARE PLACED IMMEDIATELY AFTER THE CARD ON WHICH THE DIRECTIVE APPEARS. THESE CARDS WILL BE READ IN 8F10.0 FORMAT. AS MANY CARDS AS ARE NEEDED TO HOLD THE NUMBER OF VALUES TO BE INPUT SHOULD BE SUPPLIED. IF TWO SUCH DIRECTIVES ARE PUNCHED ON A SINGLE CARD, THE EXTRA CARDS FOR THE DIRECTIVE IN COLUMNS 1 THROUGH 40 SHOULD PRECEDE THOSE REQUIRED FOR THE ONE IN COLUMNS 41 THROUGH 80.

K E Y W O R D   D I C T I O N A R Y

BOND BKR

THIS DIRECTIVE IS NEVER REQUIRED. IF IT DOES NOT APPEAR, THEN THE DEFAULT VALUES FOR THE BOND BREAKER LAYER WILL BE USED. DEFAULT VALUES WILL ALSO BE SUPPLIED FOR ANY FIELD ON THE DIRECTIVE WHICH IS LEFT BLANK.

NOTE THAT A BOND BREAKER LAYER IS ONLY USED IF THE 'UNBD' OPTION IS SELECTED ON THE OVERLAY DIRECTIVE, INDICATING THAT AN UNBONDED OVERLAY IS TO BE BUILT (SEE COMMENTS FOR OVERLAY DIRECTIVE BELOW). IF THIS OPTION IS NOT SPECIFIED, THEN THE BOND BREAKER DESCRIPTION WILL BE IGNORED, ALTHOUGH THE VALUES SUPPLIED WILL STILL BE AVAILABLE TO SUBSEQUENT PROBLEMS.

FIELD DEFINITIONS:

VAL(1) = MODULUS OF BOND BREAKER LAYER IN PSI.
(DEFAULT IS 100000.0)
VAL(2) = THICKNESS OF BOND BREAKER LAYER IN INCHES.
(DEFAULT IS 1.0)
VAL(3) = POISSON/S RATIO FOR BOND BREAKER LAYER
(DEFAULT IS 0.3)

CORNER

THIS DIRECTIVE IS NEVER REQUIRED. IT IS USED ONLY WITH JCP EXISTING PAVEMENT, AND PROVIDES A MEASURED RATIO OF CORNER DEFLECTION TO INTERIOR DEFLECTION FOR A GIVEN PAVEMENT SECTION. THIS RATIO IS USED TO OBTAIN THE LOAD LOCATION (STRESS ADJUSTMENT) FACTOR FOR THE DETERMINATION OF REMAINING LIFE AND, FOR JCP OVERLAYS, OF ESTIMATED OVERLAY LIFE. THE LOAD LOCATION FACTOR IS DETERMINED USING INTERPOLATION IN A CURVE OF STRESS RATIO VS. DEFLECTION RATIO. THIS DIRECTIVE APPLIES ONLY TO THE PROBLEM WITH WHICH IT WAS READ. DEFAULT VALUE OF THE LOAD LOCATION FACTOR FOR JCP EXISTING PAVEMENT AND JCP/JCP OVERLAYS IS 1.5.

FIELD DEFINITIONS:

VAL(1) = RATIO OF DEFLECTION MEASURED AT A CORNER (JCP)
TO THAT MEASURED AT AN INTERIOR POINT.

THIS DIRECTIVE IS REQUIRED FOR THE FIRST PROBLEM OF EVERY RUN. DEFAULT VALUES WILL NOT BE SUPPLIED BY THE PROGRAM. NOTE THAT THE COORDINATE SYSTEM USED HERE IS THE SAME AS THAT USED FOR THE LOADS DIRECTIVE. IT WILL GENERALLY SAVE KEY-PUNCHING ON MULTI-PROBLEM RUNS IF THE DEFLECTION MEASUREMENTS ARE TAKEN AT THE ORIGIN.

IF THE DESIGN DEFLECTION ON THIS DIRECTIVE AND DEFLECTION LOAD AND THE DEFLECTION PRESSURE ON THE LOADS DIRECTIVE ARE ALL ZERO, THE VALUE OF MODULUS READ ON THE SUBGRADE LAYER DIRECTIVE WILL BE USED FOR REMAINING LIFE AND OVERLAY CALCULATIONS.

FIELD DEFINITIONS:

VAL(1) = DESIGN DEFLECTION IN INCHES. THIS DEFLECTION SHOULD BE REPRESENTATIVE OF THE MORE DISTRESSED PORTIONS OF THE PAVEMENT, HENCE A MINIMUM CONFIDENCE LEVEL OF 90 PERCENT IS RECOMMENDED.
(NO DEFAULT VALUE)

VAL(2) = X-COORDINATE OF DEFLECTION MEASUREMENT IN INCHES.
(NO DEFAULT VALUE)

VAL(3) = Y-COORDINATE OF DEFLECTION MEASUREMENT IN INCHES.
(NO DEFAULT VALUE)

END

THIS DIRECTIVE INFORMS THE PROGRAM THAT NO MORE PROBLEMS ARE TO BE EXECUTED IN THIS RUN. EVERY INPUT DECK MUST CONTAIN AN END DIRECTIVE, EVEN IF ONLY ONE PROBLEM IS TO BE ANALYZED. THIS DIRECTIVE HAS NO PARAMETERS.

LAB DATA

THIS DIRECTIVE IS REQUIRED IF THE LOAD UNDER WHICH THE DEFLECTION MEASUREMENTS WERE TAKEN DIFFERS SIGNIFICANTLY FROM 18 KIPS (THE DESIGN LOAD). LAB TESTS MUST BE MADE TO DETERMINE ELASTIC MODULUS AS A FUNCTION OF DEVIATOR STRESS FOR THE SUB-GRADE MATERIALS. THESE DATA ARE ENTERED ON CARDS WHICH ARE PLACED IMMEDIATELY AFTER THE DIRECTIVE IN 8F10.0 FORMAT. CORRESPONDING VALUES OF MODULUS AND DEVIATOR STRESS ARE ENTERED IN PAIRS, WITH THE MODULUS VALUE FIRST. A MINIMUM OF TWO POINTS AND A MAXIMUM OF 10 MAY BE SUPPLIED. FOUR POINTS CAN BE PUNCHED ON A SINGLE CARD. NO FIELDS CAN BE SKIPPED, AS MANY CARDS AS ARE NECESSARY TO HOLD THE DATA MUST BE PROVIDED.

FIELD DEFINITIONS:

IVL = NUMBER OF PAIRS OF POINTS TO BE READ. (1 < IVL < 100)
(NO DEFAULT VALUE)

LAYER

THIS DIRECTIVE DEFINES THE PROPERTIES OF A SINGLE LAYER OF THE EXISTING PAVEMENT. A LAYER DIRECTIVE IS REQUIRED FOR EACH LAYER DOWN TO AND INCLUDING THE SUBGRADE. AFTER THE FIRST PROBLEM IT IS POSSIBLE TO CHANGE THE VALUES FOR A SINGLE LAYER WITHOUT ALTERING THE OTHERS BY INCLUDING A LAYER DIRECTIVE FOR THAT LAYER ONLY. A MAXIMUM OF FOUR LAYERS ARE PERMITTED, UNLESS A BOND BREAKER LAYER IS TO BE USED (SEE OVERLAY DIRECTIVE) IN WHICH CASE ONLY THREE EXISTING LAYERS ARE ALLOWED. IF THE THICKNESS OF THE SUBGRADE LAYER IS INPUT AS ZERO, THEN IT IS ASSUMED TO BE SEMI-INFINITE. OTHERWISE THE PROGRAM WILL SIMULATE THE PRESENCE OF BEDROCK AT THE INDICATED DEPTH BELOW THE TOP OF THE SUBGRADE WHEN PERFORMING DEFLECTION CALCULATIONS.

FIELD DEFINITIONS:

```
IVL = LAYER NUMBER.  LAYERS ARE NUMBERED FROM THE TOP DOWN.
      0 < IVL < 5
      (NO DEFAULT VALUE)
VAL(1) = MODULUS OF ELASTICITY FOR LAYER MATERIAL IN PSI.
         (NO DEFAULT VALUE)
VAL(2) = LAYER THICKNESS IN INCHES (ZERO IF INFINITE).
         (NO DEFAULT VALUE UNLESS SUBGRADE)
VAL(3) = POISSON/S RATIO FOR LAYER MATERIAL.
         (DEFAULT VALUE BASED ON MATERIAL TYPE)
ITYPE(1) = MATERIAL TYPE AS FOLLOWS:
           'AC  ' - ASPHALTIC CONCRETE,
           'CRCP' - CONTINUOUSLY REINFORCED CONCRETE PAVEMENT,
           'GRAN' - GRANULAR BASE MATERIAL,
           'JCP ' - JOINTED CONCRETE PAVEMENT,
           'STAB' - STABILIZED BASE MATERIAL,
           'SUBG' - SUBGRADE LAYER.
           (MUST BE AC, JCP, OR CRCP IF TOP LAYER)
ITYPE(2) = RIGID BASE INTERFACE TYPE (REQUIRED IF RIGID BASE
           REQUESTED):
           'FF  ' - FULL FRICTION INTERFACE,
           'NF  ' - NO FRICTION INTERFACE.
           (NO DEFAULT VALUE)
```

LOADS

THIS DIRECTIVE DESCRIBES THE LOAD GEOMETRY OF THE DEFLECTION MEASURING DEVICE. IT IS REQUIRED FOR THE FIRST PROBLEM OF A RUN, BUT ORDINARILY NEED NOT BE INPUT AGAIN UNLESS MORE THAN ONE SUCH DEVICE IS EMPLOYED. FROM ONE TO FOUR UNIFORM CIRCULAR LOADS MAY BE MODELLED WITH THIS DIRECTIVE. A SINGLE LOAD FORCE AND PRESSURE ARE INPUT FOR ALL OF THESE LOADS. AN EXTRA CARD MUST BE PROVIDED IMMEDIATELY AFTER THIS DIRECTIVE, SPECIFYING THE POSITIONS OF THE LOADS AS PAIRS OF X AND Y COORDINATES IN 8F10.0 FORMAT. THESE ARE THE HORIZONTAL CARTESIAN COORDINATES IT WILL USUALLY BE FOUND CONVENIENT TO SELECT A COORDINATE SYSTEM WHICH PLACES THE POINT AT WHICH DEFLECTIONS ARE MEASURED AT THE ORIGIN (SEE DEFLECT DIRECTIVE ABOVE).

FIELD DEFINITIONS:

IVL = NUMBER OF LOADS (0 < IVL < 5).
(NO DEFAULT VALUE)
VAL(1) = DEFLECTION LOAD FORCE IN POUNDS.
(NO DEFAULT VALUE)
VAL(2) = DEFLECTION LOAD PRESSURE IN PSI.
(NO DEFAULT VALUE)

OVERLAY

THIS DIRECTIVE DEFINES THE TYPE OF OVERLAY TO BE BUILT. WITH IT THE DESIGNER SPECIFIES THE MATERIAL TO BE USED, ITS PROPERTIES, AND THE PRESENCE OR ABSENCE OF A BOND BREAKER LAYER. IT IS IMPORTANT TO NOTE THAT THE INCLUSION OF A BOND BREAKER LAYER (VIA THE 'UNBD' OPTION) REDUCES THE MAXIMUM NUMBER OF EXISTING PAVEMENT LAYERS FROM FOUR TO THREE. AN OVERLAY DIRECTIVE IS REQUIRED FOR THE FIRST PROBLEM OF EVERY RUN.

FIELD DEFINITIONS:

VAL(1) = MODULUS OF OVERLAY MATERIAL IN PSI.
(NO DEFAULT VALUE)
VAL(2) = POISSON/S RATIO FOR OVERLAY MATERIAL.
(DEFAULT VALUE BASED ON MATERIAL TYPE)
VAL(3) = CONCRETE FLEXURAL STRENGTH FOR PCC OVERLAY, IN PSI.
(DEFAULT IS 690.)
ITYPE(1) = MATERIAL TYPE AS FOLLOWS:
'AC ' - ASPHALTIC CONCRETE OVERLAY,
'CRCP' - CONTINUOUSLY REINFORCED CONCRETE OVERLAY,
'JCP ' - JOINTED CONCRETE OVERLAY.
ITYPE(2) = BOND BREAKER CONDITION AS FOLLOWS:
= BLANK IF AC OVERLAY,
= 'BOND' IF BONDED PORTLAND CEMENT OVERLAY,
= 'UNBD' IF UNBONDED PCC OVERLAY.
(BOND BREAKER LAYER WILL BE USED)

PAVEMENT

THIS DIRECTIVE DESCRIBES THE CONDITION OF THE EXISTING PAVEMENT. IT IS REQUIRED FOR THE FIRST PROBLEM OF EVERY RUN. NOTE THAT LAYER DIRECTIVES ARE ALSO REQUIRED FOR EACH LAYER INCLUDING THE TOP ONE.

FIELD DEFINITIONS:

IVL = NUMBER OF LAYERS IN EXISTING PAVEMENT DOWN TO AND INCLUDING THE SUBGRADE. AT LEAST ONE AND NOT MORE THAN FOUR LAYERS MAY BE SPECIFIED (THREE IF BOND BREAKER LAYER SPECIFIED ON OVERLAY DIRECTIVE). (NO DEFAULT VALUE)

VAL(1) = NUMBER OF 18 KIP EQUIVALENT SINGLE AXLE WHEEL LOADS APPLIED TO DATE (PUNCHED WITH DECIMAL POINT). (DEFAULT IS 1.)

VAL(2) = CONCRETE FLEXURAL STRENGTH FOR EXISTING PCC PAVEMENT, IN PSI. (DEFAULT IS 690.0)

ITYPE = 8-CHARACTER FIELD SPECIFYING PAVEMENT CONDITION:

FOR PCC EXISTING PAVEMENT

```
BLANK        - NO CRACKING OR VOIDS PRESENT.
'VOID     '  - VOIDS PRESENT BUT NO CRACKING.
'TYPE 1,2'   - TYPE 1 OR 2 CRACKING PRESENT.
'VOID 1,2'   - TYPE 1 OR 2 CRACKING WITH VOIDS PRESENT.
'TYPE 3,4'   - TYPE 3 OR 4 CRACKING PRESENT.
'MECH BKN'   - PAVEMENT WILL BE MECHANICALLY BROKEN
               PRIOR TO OVERLAY.
```

FOR AC EXISTING PAVEMENT

```
BLANK        - NO CRACKING OR TYPE 1 CRACKING PRESENT.
'TYPE 2   '  - TYPE 2 CRACKING PRESENT (>5 PER CENT).
'TYPE 3   '  - TYPE 3 CRACKING PRESENT (>5 PER CENT).
```

PROBLEM

THIS DIRECTIVE SIGNALS THE BEGINNING OF A GROUP OF DIRECTIVES THAT DESCRIBE A SINGLE PROBLEM FOR WHICH SOLUTIONS OF ALLOWABLE TRAFFIC AS A FUNCTION OF OVERLAY THICKNESS ARE DESIRED. IT PERMITS THE USER TO SPECIFY A TITLE AND A PROBLEM NUMBER WHICH WILL APPEAR IN THE PRINTED OUTPUT AND CAN BE USED TO IDENTIFY THE RESULTS. IF A NON-ZERO DIGIT APPEARS ANYWHERE BETWEEN COLUMNS 11 AND 20 OF THIS DIRECTIVE, THEN AN 80-CHARACTER TITLE IS READ FROM AN EXTRA CARD WHICH IMMEDIATELY FOLLOWS THE PROBLEM DIRECTIVE. THIS TITLE WILL REMAIN IN EFFECT UNTIL ANOTHER IS PROVIDED.

FIELD DEFINITIONS:

IVL = PROBLEM NUMBER (IVL < 100).
(DEFAULT IS 1 IF FIRST PROBLEM, PREVIOUS PROBLEM NUMBER PLUS ONE OTHERWISE)
VAL(1) = 0 IF NO TITLE CARD,
> 0 IF TITLE CARD FOLLOWS.

RUT

THIS DIRECTIVE DEFINES THE DESIGN PARAMETERS FOR RUTTING, WHERE RUTTING AS WELL AS FATIGUE IS TO BE CONSIDERED AS A FAILURE MODE. THIS DIRECTIVE IS NEVER REQUIRED, AND IS APPLICABLE ONLY TO AC EXISTING PAVEMENTS WITH NO REMAINING LIFE. THE EXISTING PAVEMENT SYSTEM MUST INCLUDE AT LEAST THREE (3) LAYERS IF THIS DIRECTIVE IS USED.

FIELD DEFINITIONS:

VAL(1) = NUMBER OF DAYS PER YEAR ON WHICH THE AVERAGE TEMPERATURE EXCEEDS 64 DEGREES F.
VAL(2) = ALLOWABLE RUT DEPTH.

TRAFFIC

THIS DIRECTIVE IS NEVER REQUIRED. IT PROVIDES UP TO 5 DESIGN TRAFFIC VALUES, FOR WHICH OVERLAY THICKNESSES ARE OBTAINED BY INTERPOLATION IN THICKNESS AS A FUNCTION OF LOG(PRE- DICTED APPLICATIONS TO FAILURE). CONSERVATIVE OVERLAY THICK- NESSES ARE CALCULATED IF THE SPECIFIED FATIGUE LIFE IS LESS THAN THAT FOR THE RECOMMENDED MINIMUM OVERLAY THICKNESS.

AN EXTRA CARD MUST BE PROVIDED IMMEDIATELY AFTER THIS DIRECTIVE, SPECIFYING THE DESIGN TRAFFIC VALUES IN 5F10.0 FORMAT.

FIELD DEFINITIONS:

IVL = NUMBER OF DESIGN TRAFFIC VALUES (LESS THAN OR EQUAL TO 5)
(DEFAULT: 0)
END 'ABSENT'

APPENDIX G

FIXED-ORDER INPUT GUIDE FOR POD1

The fixed-order input guide is provided for beginning users of POD1 who may find the flexibility provided by the previous input guide (Appendix F) somewhat confusing at first. It consists of a pictorial representation of the input cards and the fields on each, with a number for each card type; each type is then listed by number and explained. The figure also provides a quick check against a listing of the data to be run. Not all of the card types will normally be present for one problem. It should be noted that the names on the fields shown on the figure are for reference in the descriptive text following and are not in general the variable names used in the program.

It is recommended that a beginning user read through Appendix F for general information on the structure of the data input and on stacking decks for multiple problem runs, even if he intends to use this fixed-order input guide.

APPENDIX G

FIXED-ORDER INPUT GUIDE FOR POD1

CARD TYPE	1–8	9–10	11–20	21–25	26–30	31–34	35–38	39–40	41–50	51–60	61–70	71–80
1	PROBLEM	PN	TCSW									
2	TITLE CARD (REQUIRED ONLY IF TCSW > 0.)											
3	PAVEMENT	NL	NESAWL	FCP	X	EPCON						
4	LAYER	N	EN	THN	VN	MTN						
5	LOADS	L	FORS	PRES								
6	XL1		YL1	XL2		YL2			XL3	YL3	XL4	YL4
7	DEFLECT	X	DESDEF	XDEF	YDEF							
8	LAB DATA	ND										
9	E1		DS1	E2		DS2			E3	DS3	E4	DS4
10	OVERLAY	X	EOV	VOV	FCV	OVTYP	BCON					
11	BOND BKR	X	EBB	THBB	VBB							
12	CORNER	X	CTIRAT									
13	RUT	X	DT64	ARD								
14	TRAFFIC	NT										
15	TRAF1		TRAF2	TRAF3		TRAF4			TRAF5			
16	END											

Card Type 1: New Problem Card

This card is used to designate the start of a new problem where:

PN = Problem number (Col. 9-10, integer).

TCSW = Title card switch (Col. 11-20, real). If this value is greater than zero, the entire 80 columns of the following card will be read as a title card.

Card Type 2: Title Card

This card is required only if the value of TCSW on the "New Problem Card" is greater than zero. (Col. 1-80, alphanumeric). This card must not be present if TCSW is equal to zero.

Card Type 3: Existing Pavement Card

This card describes the condition of the existing pavement where:

NL = Number of layers in existing pavement structure, down to and including the subgrade (Col. 9-10, integer). At least one and not more than four layers may be specified (only three if the new pavement structure is to include a bond breaker). This value also designates the number of Card Type 4 (layer cards) to be expected.

NESAWL = Number of 18-kip equivalent single axle wheel loads applied to date (Col. 11-20, real, must be non-zero, therefore default value = 1).

FCP = Concrete flexural strength, psi (Col. 21-25, real, default value = 690.0 psi).

EPCON = Existing pavement condition (Col. 31-38, alphanumeric).

Blank - No cracking or voids present.
"VOID " - Voids present, but no cracking.
"TYPE 1,2" - Type 1 or 2 cracking present.
"VOID 1,2" - Type 1 or 2 cracking with voids present.
"TYPE 3,4" - Type 3 or 4 cracking present.
"MECH BKN" - Pavement will be mechanically broken prior to overlay.

Card Type 4: Layer Card

This card type defines the properties of a single layer of the existing pavement and is required for each layer, down to and including the subgrade. The layers are numbered from the top down and a maximum of 4 layers is permitted unless a bond breaker is specified for the overlay, in which case only 3 layers are permitted. The modulus input for the subgrade layer is only an estimate to initiate calculation of a final value. If the thickness of the subgrade is input as zero, the program will assume it to be infinite. If the input subgrade thickness is non-zero, the program will assume the presence of bedrock beneath the subgrade layer in all following calculations. The variable definitions are:

N = Layer number (Col. 9-10, integer, right justify).
EN = Elastic modulus of layer N, psi (Col. 11-20, real).
THN = Thickness of layer N, inches (Col. 21-25, real).
VN = Poisson's ratio for layer N (Col. 26-30, real).
MTN = Material type of layer N (Col. 31-34, alphanumeric)
"AC " - Asphaltic concrete,
"CRCP" - Continuously reinforced concrete pavement,
"GRAN" - Granular base material,
"JCP " - Jointed concrete pavement,
"STAB" - Stabilized base material,
"SUBG" - Subgrade layer.
(Top layer must be either JCP or CRCP)

Card Types 5 and 6: Load Cards

These cards describe the load magnitude (Card Type 5) and geometry (Card Type 6) of the deflection measuring device. From one to four uniform circular loads (of equal magnitude) may be specified (Card Type 5) where:

L = Number of loads (Col. 9-10, integer, right justify).
FORS = Load magnitude, pounds (Col. 11-20, real).
PRES = Load pressure, psi (Col. 21-25, real).

Now, in order to describe the load geometry (Card Type 6), it is necessary to select a cartesian coordinate system with the XL_i and YL_i values on the card representing the x and y coordinates of each load (each value in consecutive 10 column fields, real).

Card Type 7: Design Deflection Card

This card designates the magnitude of the design deflection and also its location in the selected cartesian coordinate system.

DESDEF = Design deflection, inches (Col. 11-20, real). This value should be representative of the more distressed portions of the pavement, hence a minimum confidence level of 90 percent is recommended.

XDEF = x - coordinate of the design deflection location (Col. 21-25, real).

YDEF = y - coordinate of the design deflection location (Col. 26-30, real).

Note: Should the values of the design deflection deflection load and deflection pressure all be zero, the value of the subgrade modulus (read from a Type 4 Card) will be used for the remaining life overlay calculations.

Card Types 8 and 9: Lab Data Cards

These cards are required if the load under which the deflection measurements are taken differs significantly from the 18-kip single axle design load. Lab tests must be made to determine elastic modulus as a function of deviator stress for the subgrade.

Card Type 8 designates that this option has been specified where:

ND = Number of pairs of lab data points (elastic modulus vs. corresponding deviator stress, Col. 9-10, integer, right justify). A minimum of two points and a maximum of 10 may be specified.

Card Type 9 is used to designate the value of elastic modulus vs. deviator stress for each lab data point (read in consecutive 10 column fields, real, four pairs of values per card) where:

E_i = Elastic modulus at point, psi.

DS_i = Deviator stress at point, psi.

Card Type 10: Overlay Card

This card defines the type of overlay to be used. With it, the designer specifies the material type and properties of the overlay and also the presence or absence of a bond breaker layer, where:

EOV = Modulus of overlay, psi (Col. 11-20, real).
VOV = Poisson's ratio of overlay (Col. 21-25, real, default value based on material type).
FCV = Concrete flexural strength for overlay (if PCC). (Col. 25-30, real, default value = 690. psi).
OVTYP = Material type as follows:
"AC " - Asphaltic concrete overlay.
"CRCP" - Continuously reinforced concrete pavement.
"JCP " - Jointed concrete pavement.
BCON = Bond breaker condition as follows:
Blank - AC overlay
"BOND" - Bonded PCC overlay.
"UNBD" - Unbonded PCC overlay (bond breaker will be used, reduces maximum allowable number of layers in existing pavement from four to three).

Card Type 11: Bond Breaker Card

This card is required only if the overlay is to be unbonded (i.e., BCON = "UNBD") is specified and if the default values for the bond breaker (see below) are inappropriate.

EBB = Modulus of bond breaker, psi (Col. 11-20, real, default value = 100,000. psi)
THBB = Thickness of bond breaker, inches (Col. 21-25, real, default value = 1.0 inch)
VBB = Poisson's ratio for bond breaker (Col. 26-30, real, default value = 0.3)

Card Type 12: Corner to Interior Stress Ratio Card

This card is not required. It is used only with JCP existing pavement, and provides a measured ratio of corner deflection to interior deflection for a given pavement section. This ratio is used to obtain the load location (stress adjustment) factor for the determination of remaining life and, for JCP overlays, of estimated overlay life. The load location factor is determined using interpolation in a curve of stress ratio versus deflection ratio. The default value of the load location factor for JCP existing pavement and JCP overlays on JCP existing pavements is 1.5.

CTIRAT = Ratio of the deflection measured at a corned (of JCP existing pavement) to that measured at an interior point (Col. 11-20, real).

Card Type 13: Rut Card

This card is not required. It is used only for AC existing pavement, and only when rutting is to be considered as an alternative failure mode. The regression equation used to predict rutting is applicable only to pavements with no remaining life (Type 2 or Type 3 cracking) and to those with less than 25 percent remaining life, for which the Type 2 cracking analysis is applied.

DT64 = Number of days per year with average temperature greater than 64°F.

ARE = Allowable rut depth before failure.

Card Types 14 and 15: Traffic Cards

These cards are not required unless the user wishes to determine the overlay thicknesses required for some specified design traffic values. To predict these thicknesses, interpolation is performed in a curve of overlay thickness versus the logarithm of predicted pavement life after overlay.

Card Type 13 designates the number of design traffic values to be read and used for interpolation (maximum of 5):

NT = Number of design traffic values (Col. 9-10, integer, right justify).

Card Type 14 designates the magnitudes of these design traffic values, $TRAF_i$ (in consecutive 10 column fields, real).

Card Type 16: End Card

This card informs the program that no more problems are to be executed in this run. Every input deck must contain one at the end of the data, even if only one problem is to

APPENDIX H

POD1 COMPUTER OUTPUT FOR ILLUSTRATIVE OVERLAY DESIGN PROBLEMS

```
PPPP     OOO    DDDD     1
P   P   O   O   D   D   11
PPPP    O   O   D   D    1
P       O   O   D   D    1
P        OOO    DDDD    111
```

NOTICE:

THIS PAVEMENT OVERLAY DESIGN COMPUTER PROGRAM WAS DEVELOPED BY AUSTIN RESEARCH ENGINEERS INC (2600 DELLANA LANE, AUSTIN, TEXAS 78746, PHONE (512) 327-3520, TWX 910-874-1324 ARE INC AUS) UNDER FEDERAL HIGHWAY ADMINISTRATION CONTRACT NO. DOT-FH-11-8544 IN AUGUST 1977. DEVELOPMENT OF THE DESIGN PROCEDURES IS PRESENTED IN FEDERAL HIGHWAY ADMINISTRATION REPORTS NO. FHWA-RD-75-75 AND NO. FHWA-RD-77-66 AND USE OF THE PROCEDURES IS DESCRIBED IN REPORT NO. FHWA-RD-77-XX.

POD1 - PAVEMENT OVERLAY DESIGN PROGRAM - VERSION 1.0
LATEST REVISION - OCTOBER 1977 - AUSTIN RESEARCH ENGINEERS INC

PROBLEM 1 ILLUSTRATIVE OVERLAY DESIGN PROBLEM 1: BONDED JCP OVERLAY ON JCP EXISTING PAVT.

I N P U T   V A R I A B L E S

EXISTING PAVEMENT
****

CONDITION	TYPE 1 AND 2 CRACKING WITH NO VOIDS
CONCRETE FLEXURAL STRENGTH, PSI	690.0
EQUIVALENT 18 KIP SINGLE AXLE LOADS TO DATE	300000.

LAYER NO.	THICKNESS (IN.)	POISSON/S RATIO	ELASTIC MODULUS (PSI)	TYPE OF MATERIAL
1	8.0	.150	4000000.	JCP
2	7.0	.350	33000.	GRANULAR BASE
3	SEMI-INFINITE	.450	10000.	SUBGRADE

DEFLECTION DATA
****

INTERIOR DESIGN DEFLECTION, INCHES	.001056
RATIO OF CORNER TO INTERIOR DEFLECTION	1.40
LOAD MAGNITUDE, POUNDS	500.0
TIRE PRESSURE, PSI	167.0

	X,Y COORDINATES, INCHES
LOAD 1 LOCATION	(0.00 , 0.00)
LOAD 2 LOCATION	(20.00 , 0.00)
DEFLECTION LOCATION	(10.00 , 0.00)

LABORATORY TESTS OF SUBGRADE SAMPLES
****

DATA DETERMINED FROM REPETITIVE LOAD TRIAXIAL TESTING
MEAN SUBGRADE MODULUS FOR EACH DEVIATOR STRESS.

DEVIATOR STRESS (PSI)	ELASTIC MODULUS (PSI)
3.00	123500.
5.00	91500.
7.00	86400.
9.00	69500.
11.00	67900.

OVERLAY CHARACTERISTICS
****

OVERLAY TYPE	BONDED JCP
ELASTIC MODULUS, PSI	4000000.
POISSON/S RATIO	.15
CONC. FLEXURAL STRENGTH, PSI	690.0

DESIGN TRAFFIC
****

EQUIVALENT 18 KIP SINGLE AXLE LOADS ANTICIPATED ON OVERLAY. (TO BE USED IN CALCULATING CORRESPONDING REQUIRED OVERLAY THICKNESSES.)

1	2000000.
2	4000000.
3	6000000.

S Y S T E M   R E S U L T S

OVERLAY LIFE PREDICTIONS
****

PAVEMENT SYSTEM DESCRIPTION FOR WHICH OVERLAY LIFE PREDICTIONS WERE MADE.

LAYER NO.	THICKNESS (IN.)	POISSON/S RATIO	ELASTIC MODULUS (PSI)	TYPE OF MATERIAL
1	VARIES	.150	4000000.	JCP
2	8.00	.150	4000000.	JCP
3	7.00	.350	33000.	GRANULAR BASE
4	SEMI-INFINITE	.450	3544.	SUBGRADE

PREDICTED LIFE OF ORIGINAL PAVEMENT (EQUIVALENT 18 KIP SINGLE AXLE LOADS)	703993.
REMAINING LIFE OF ORIGINAL PAVEMENT, PERCENT	57.4

TABLE OF OVERLAY THICKNESS VS. FATIGUE LIFE USED IN PLOT ON NEXT PAGE.

OVERLAY THICKNESS (IN.)	CALCULATED FATIGUE LIFE (EQUIVALENT 18 KIP SAWL)
3.0	1833000
6.0	6187000
9.0	17471000
12.0	43216000

PLOT:

```
                         OVERLAY THICKNESS VS. PAVEMENT LIFE

                            PAVEMENT LIFE (18 KIP ESAWL)
               0.     1.00E+07  2.00E+07  3.00E+07  4.00E+07  5.00E+07
 OVERLAY
THICKNESS      I---------I---------I---------I---------I---------I
(INCHES)     >                                                    <
             >                                                    <
  12.00      >                                           F        <
             >                                                    <
             >                                                    <
   9.00      >                  F                                 <
             >                                                    <
             >                                                    <
   6.00      >       F                                            <
             >                                                    <
             >                                                    <
   3.00      >  F                                                 <
             >                                                    <
             >                                                    <
   0.00        I---------I---------I---------I---------I---------I

               0.     1.00E+07  2.00E+07  3.00E+07  4.00E+07  5.00E+07


                                        LEGEND:
                                                   F - FATIGUE CURVE
```

TABLE OF INTERPOLATED OVERLAY THICKNESSES FOR
REQUESTED DESIGN PAVEMENT LIVES.

REQUESTED PAVEMENT LIFE (EQUIVALENT 18 KIP SAWL)	INTERPOLATED OVERLAY THICKNESS (IN.) FROM FATIGUE CURVE
2000000	3.2
4000000	4.9
6000000	5.9

```
POD1 - PAVEMENT OVERLAY DESIGN PROGRAM - VERSION 1.0
LATEST REVISION - OCTOBER 1977 - AUSTIN RESEARCH ENGINEERS INC

PROBLEM   2   ILLUSTRATIVE OVERLAY DESIGN PROBLEM 2:  AC OVERLAY
              ON JCP EXISTING PAVEMENT.

          I N P U T   V A R I A B L E S

EXISTING PAVEMENT
*****************

  CONDITION                                      TYPE 1 AND 2 CRACKING
  EQUIVALENT 18 KIP SINGLE AXLE LOADS TO DATE                300000.

  LAYER  THICKNESS  POISSON/S  ELASTIC        TYPE OF
   NO.     (IN.)      RATIO    MODULUS        MATERIAL
                                (PSI)
    1       8.0       .150    4000000.          JCP
    2       7.0       .350      33000.     GRANULAR BASE
    3  SEMI-INFINITE  .450      10000.        SUBGRADE


DEFLECTION DATA
***************

  INTERIOR DESIGN DEFLECTION, INCHES          .001056
  RATIO OF CORNER TO INTERIOR DEFLECTION         1.40
  LOAD MAGNITUDE, POUNDS                        500.0
  TIRE PRESSURE, PSI                            167.0

                         X,Y COORDINATES, INCHES
  LOAD  1 LOCATION      (   0.00   ,   0.00   )
  LOAD  2 LOCATION      (  20.00   ,   0.00   )
  DEFLECTION LOCATION   (  10.00   ,   0.00   )


LABORATORY TESTS OF SUBGRADE SAMPLES
************************************


  DATA DETERMINED FROM REPETITIVE LOAD TRIAXIAL TESTING
  MEAN SUBGRADE MODULUS FOR EACH DEVIATOR STRESS.

        DEVIATOR      ELASTIC
         STRESS       MODULUS
         (PSI)         (PSI)
          3.00       123500.
          5.00        91500.
          7.00        86400.
          9.00        69500.
         11.00        67900.
```

OVERLAY CHARACTERISTICS
****

OVERLAY TYPE	AC
ELASTIC MODULUS, PSI	450000.
POISSON/S RATIO	.30

DESIGN TRAFFIC
****

EQUIVALENT 18 KIP SINGLE AXLE LOADS ANTICIPATED ON OVERLAY. (TO BE USED IN CALCULATING CORRESPONDING REQUIRED OVERLAY THICKNESSES.)

1	2000000.
2	4000000.
3	6000000.

S Y S T E M   R E S U L T S

OVERLAY LIFE PREDICTIONS
****

PAVEMENT SYSTEM DESCRIPTION FOR WHICH OVERLAY LIFE PREDICTIONS WERE MADE.

LAYER NO.	THICKNESS (IN.)	POISSON/S RATIO	ELASTIC MODULUS (PSI)	TYPE OF MATERIAL
1	VARIES	.300	450000.	AC
2	8.00	.150	4000000.	JCP
3	7.00	.350	33000.	GRANULAR BASE
4	SEMI-INFINITE	.450	3544.	SUBGRADE

PREDICTED LIFE OF ORIGINAL PAVEMENT (EQUIVALENT 18 KIP SINGLE AXLE LOADS)	703993.
REMAINING LIFE OF ORIGINAL PAVEMENT, PERCENT	57.4

TABLE OF OVERLAY THICKNESS VS. FATIGUE LIFE USED IN PLOT ON NEXT PAGE.

OVERLAY THICKNESS (IN.)	CALCULATED FATIGUE LIFE (EQUIVALENT 18 KIP SAWL)
3.0	682000
6.0	1444000
9.0	3085000
12.0	6364000

PLOT:

```
                    OVERLAY THICKNESS VS. PAVEMENT LIFE

                       PAVEMENT LIFE (18 KIP ESAWL)
           0.     2.00E+06  4.00E+06  6.00E+06  8.00E+06  1.00E+07
 OVERLAY
THICKNESS  I---------I---------I---------I---------I---------I
(INCHES)  >                                                   <
          >                                                   <
  12.00   >                               F                   <
          >                                                   <
          >                                                   <
   9.00   >              F                                    <
          >                                                   <
          >                                                   <
   6.00   >      F                                            <
          >                                                   <
          >                                                   <
   3.00   >  F                                                <
          >                                                   <
          >                                                   <
   0.00    I---------I---------I---------I---------I---------I

           0.     2.00E+06  4.00E+06  6.00E+06  8.00E+06  1.00E+07

                              LEGEND:
                                         F = FATIGUE CURVE
```

TABLE OF INTERPOLATED OVERLAY THICKNESSES FOR REQUESTED DESIGN PAVEMENT LIVES.

REQUESTED PAVEMENT LIFE (EQUIVALENT 18 KIP SAWL)	INTERPOLATED OVERLAY THICKNESS (IN.) FROM FATIGUE CURVE
2000000	7.3
4000000	10.1
6000000	11.8

POD1 - PAVEMENT OVERLAY DESIGN PROGRAM - VERSION 1.0
LATEST REVISION - OCTOBER 1977 - AUSTIN RESEARCH ENGINEERS INC

PROBLEM 3 ILLUSTRATIVE OVERLAY DESIGN PROBLEM 3: AC OVERLAY ON AC EXISTING PAVEMENT.

I N P U T   V A R I A B L E S

EXISTING PAVEMENT
****

CONDITION — TYPE 3 CRACKING
EQUIVALENT 18 KIP SINGLE AXLE LOADS TO DATE — 1.

LAYER NO.	THICKNESS (IN.)	POISSON/S RATIO	ELASTIC MODULUS (PSI)	TYPE OF MATERIAL
1	4.0	.300	450000.	AC
2	6.0	.350	20000.	GRANULAR BASE
3	8.0	.350	10000.	GRANULAR BASE
4	SEMI-INFINITE	.450	10000.	SUBGRADE

DEFLECTION DATA
****

INTERIOR DESIGN DEFLECTION, INCHES .001750
LOAD MAGNITUDE, POUNDS 500.0
TIRE PRESSURE, PSI 167.0

	X,Y COORDINATES, INCHES
LOAD 1 LOCATION	(0.00 , 0.00)
LOAD 2 LOCATION	(20.00 , 0.00)
DEFLECTION LOCATION	(10.00 , 0.00)

LABORATORY TESTS OF SUBGRADE SAMPLES
****

DATA DETERMINED FROM REPETITIVE LOAD TRIAXIAL TESTING
MEAN SUBGRADE MODULUS FOR EACH DEVIATOR STRESS.

DEVIATOR STRESS (PSI)	ELASTIC MODULUS (PSI)
2.00	30000.
4.00	20000.
6.00	10000.
8.00	5000.

OVERLAY CHARACTERISTICS
****

```
  OVERLAY TYPE                          AC
  ELASTIC MODULUS, PSI             500000.
  POISSON/S RATIO                      .30
```

RUTTING DESIGN DATA
****

```
  ALLOWABLE RUT DEPTH, INCHES                                 .5000
  NO. OF DAYS PER YEAR MEAN TEMP. EXCEEDS 64 DEGREES F        200.
```

DESIGN TRAFFIC
****

EQUIVALENT 18 KIP SINGLE AXLE LOADS ANTICIPATED ON OVERLAY. (TO BE USED IN CALCULATING CORRESPONDING REQUIRED OVERLAY THICKNESSES.)

1	1000000.
2	3000000.
3	10000000.

S Y S T E M   R E S U L T S

OVERLAY LIFE PREDICTIONS
****

PAVEMENT SYSTEM DESCRIPTION FOR WHICH OVERLAY LIFE PREDICTIONS WERE MADE.

LAYER NO.	THICKNESS (IN.)	POISSON/S RATIO	ELASTIC MODULUS (PSI)	TYPE OF MATERIAL
1	VARIES	.300	500000.	AC
2	4.00	.300	20000.	AC
3	6.00	.350	20000.	GRANULAR BASE
4	8.00	.350	10000.	GRANULAR BASE
5	SEMI-INFINITE	.450	2666.	SUBGRADE

TABLE OF OVERLAY THICKNESS VS. CALCULATED FATIGUE AND RUTTING LIFE USED IN PLOT ON NEXT PAGE.

OVERLAY THICKNESS (IN.)	CALCULATED PAVEMENT LIFE (EQUIVALENT 18 KIP SAWL) FATIGUE	RUTTING
3.0	40000	166000
6.0	640000	3561000
9.0	6110000	16130000
12.0	37216000	33780000

```
PLOT:
                   OVERLAY THICKNESS VS. PAVEMENT LIFE

                      PAVEMENT LIFE (18 KIP ESAWL)
            0.    8.00E+06  1.60E+07  2.40E+07  3.20E+07  4.00E+07
  OVERLAY
 THICKNESS  I---------I---------I---------I---------I---------I
 (INCHES)  >                                                   <
           >                                                   <
   12.00   >                                          R    F   <
           >                                                   <
           >                                                   <
    9.00   >        F           R                              <
           >                                                   <
           >                                                   <
    6.00   > F  R                                              <
           >                                                   <
           >                                                   <
    3.00   >*                                                  <
           >                                                   <
           >                                                   <
    0.00    I---------I---------I---------I---------I---------I

            0.    8.00E+06  1.60E+07  2.40E+07  3.20E+07  4.00E+07

                                LEGEND:
                                           F - FATIGUE CURVE
                                           R - RUTTING CURVE
```

TABLE OF INTERPOLATED OVERLAY THICKNESSES FOR
REQUESTED DESIGN PAVEMENT LIVES.

REQUESTED PAVEMENT LIFE (EQUIVALENT 18 KIP SAWL)	INTERPOLATED OVERLAY THICKNESS (IN.) FATIGUE CURVE	RUTTING CURVE
1000000	6.6	4.3
3000000	8.0	5.7
10000000	9.8	7.9

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3. Austin Research Engineers Inc, "Asphalt Concrete Overlays of Flexible Pavements, Volume 2--Design Procedures" Report FHWA-RD-75-76, August 1975.

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8. "The AASHO Road Test, Report 5, Pavement Research", Special Report 61E, Highway Research Board, 1962.

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