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16. Abstract

In this report, several of the factors that affect Dynaflect deflections in rigid pavements are analyzed. Findings from this study are incorporated into a recommended procedure for the use of the Dynaflect. The Slab-49 program is used to simulate voids of various sizes under a continuously reinforced concrete pavement. The effect of a placement error in the deflection measurement device is also studied. Distances from the pavement edge at which the Dynaflect should be placed are recommended for both materials characterization and void detection. A discussion about the effect of environmental factors on deflections in rigid pavements is also presented.

Statistical analysis is considered for determining the required number of Dynaflect deflections to obtain representative results. Finally, the results from this report are combined into a recommended procedure for Dynaflect deflection measurements, which, it is hoped, will result in improvements to the determination of input data for rigid pavement overlay design computer programs.

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EFFECT OF ENVIRONMENTAL FACTORS AND LOADING POSITION ON DYNAFLECT DEFLECTIONS IN RIGID PAVEMENTS

by

Victor Torres-Verdin
B. Frank McCullough

Research Report Number 249-4

Implementation of Rigid Pavement Overlay
and Design System
Research Project 3-8-79-249

conducted for

Texas
State Department of Highways and Public Transportation

in cooperation with the
U. S. Department of Transportation
Federal Highway Administration

by the

Center for Transportation Research
Bureau of Engineering Research
The University of Texas at Austin

November 1982

PREFACE

This is the fourth in a series of reports which describe work done on Research Project 3-8-79-249, "Implementation of Rigid Pavement Overlay and Design System." The findings from this study have led to the development of a recommended procedure for Dynaflect deflection measurements.

The authors wish to express their thanks to Dr. W. Ronald Hudson, who reviewed this report. Thanks are extended to Lyn Gabbert, Elaine Hamilton, and Sue Tarpley for typing the drafts of the manuscript. Special acknowledgement is make to Manuel Gutierrez de Velasco for his invaluable comments throughout the development of this study. Gratitude is expressed to Ana Aronofsky who drew all the figures in this report.

Victor Torres Verdin

B. Frank McCullough

February 1982

LIST OF REPORTS

Report No. 249-1, "Improvements to the Materials Characterization and Fatigue Life Prediction Methods of the Texas Rigid Pavement Overlay Design Procedure," by Arthur Taute, B. Frank McCullough, and W. Ronald Hudson, presents certain improvements to the Texas Rigid Pavement Overlay Design Procedure (RPOD2) with regard to materials characterization and fatigue life predictions. March 1981.

Report No. 249-2, "A Design System for Rigid Pavement Rehabilitation," by Stephen Seeds, B. Frank McCullough, and W. Ronald Hudson, describes the developement, use and applicability of a Rigid Pavement Rehabilitation Design System, RPRDS, developed for use by the Texas State Department of Highways and Public Transportation. June 1981.

Report No. 249-3, "Void Detection and Grouting Process," by Francisco Torres and B. Frank McCullough, presents the results of an experiment and a theoretical analysis to determine an optimum procedure for detecting voids beneath CRC pavements. February 1982.

Report No. 249-4, "Effect of Environmental Factors and Loading Position on Dynaflect Deflections in Rigid Pavements," by Victor Torres-Verdin and B. Frank McCullough, discusses several of the factors that affect Dynaflect deflections in rigid pavements and provides a recommended procedure for Dynaflect deflection measurements which can be implemented on the rigid pavement overlay design procedures. February 1982.

ABSTRACT

In this report, several of the factors that affect Dynaflect deflections in rigid pavements are analyzed. Findings from this study are incorporated into a recommended procedure for the use of the Dynaflect. The Slab-49 program is used to simulate voids of various sizes under a continuously reinforced concrete pavement. The effect of a placement error in the deflection measurement device is also studied. Distances from the pavement edge at which the Dynaflect should be placed are recommended for both materials characterization and void detection. A discussion about the effect of environmental factors on deflections in rigid pavements is also presented.

Statistical analysis is considered for determining the required number of Dynaflect deflections to obtain representative results. Finally, the results from this report are combined into a recommended procedure for Dynaflect deflection measurements, which, it is hoped, will result in improvements to the determination of input data for rigid pavement overlay design computer programs.

KEYWORDS: Dynaflect, deflection, continuously reinforced concrete pavement, void detection, materials characterization, sampling.

SUMMARY

Pavement layer moduli are commonly estimated from Dynaflect deflection measurements. These elastic moduli are some of the required input data for overlay thickness design. Therefore, the Dynaflect should be efficiently used to obtain these pavement properties with an acceptable accuracy. Some of the factors affecting Dynaflect deflections in rigid pavements are studied. Environmental factors are divided into two groups: temperature effect and seasonal effect.

The influence of void size and position of the Dyanflect with respect to the pavement edge is also analyzed. The Slab-49 Computer Program is used to simulate voids of different sizes underneath a CRCP. Dynaflect placement error was found to considerably affect deflections, especially close to the pavement edge. Maximum acceptable placement errors for both void detection and materials characterization are proposed. Additional application of the information generated includes the evaluation of undersealing operations for filling voids beneath the pavement.

Statistical analysis is used to determine the required number of Dynaflect deflections to obtain representative results. Data from the state of Texas are analyzed ad it is concluded that systematic sampling can be used to obtain representative results in an inexpensive way when deflection data concerning a particular project are available. If the deflection data can be assumed to be normally distributed, the required number of deflections can be

easily estimated by specifying a level of confidence and selecting an allowable error. This allowable error is expressed as a percentage of the sensor mean deflection and is related to the variation in pavement thickness due to construction. An example is presented in Table 4.1.

A recommended procedure for Dynaflect deflection measurements is given in Appendix C. It is expected that this report will produce significant improvements to the use of the Dynaflect for estimating pavement layer moduli, which are required input data for rigid pavement overlay design computer programs.

IMPLEMENTATION STATEMENT

This document presents an analysis of some of the factors that affect Dynaflect deflections in rigid pavements. The use of statistical analysis to divide the roadway into design sections is also discussed. It is hoped that the results from this study will be incorporated in the rigid pavement overlay design programs.

It is suggested that the recommended procedure for Dynaflect deflection measurements be implemented on future overlay designs.

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CHAPTER 1. INTRODUCTION

BACKGROUND

Analysis of an existing rigid pavement for overlay thickness design requires that the existing PCC be represented by an effective elastic modulus based on its structural condition. Structural performance can be measured by a number of nondestructive testing devices that are being used as a part of the overlay-design methodologies of many organizations. Most of these devices provide some measure of surface deflection. Deflection measurements are widely used for the estimation of pavement layer stiffness.

In recent years the Dynaflect has been extensively used in the state of Texas to assist in evaluating pavements. The Dynaflect is a trailer-mounted device which applies a dynamic load to the pavement and measures the deflection response. The entire load applied to the pavement consists of the weight of the trailer, about 1600 pounds, and the dynamic force which alternately adds and subtracts from the trailer weight.

The dynamic force is generated by two counterrotating eccentric flywheels. It varies sinusoidally from 500 pounds upward to 500 pounds downward during each rotation of the flywheels at the proper speed. Thus, the load applied to the pavement varies from about 1100 pounds to 2100 pounds.

A lift mechanism in the trailer moves the force generator up or down to contact the ground. When the generator is lifted, the trailer is supported on rubber tires for travel at normal driving speeds. With the force generator in contact with the ground, the unit may be moved on its steel wheels from one measuring point to another at speeds up to 5 mph.

The vertical velocity of the pavement system is sensed by an array of geophones in contact with the pavement surface (Fig 1.1). The first geophone is placed midway between the load wheels; four additional geophones are spaced at one-foot intervals along the longitudinal centerline of the trailer. The geophones produce a voltage proportional to the vertical velocity of the pavement slab, which is processed through a narrow-band filter to eliminate extraneous vibrations. The filtered signal is integrated electronically to obtain deflection (Ref 18). Figure 1.1 illustrates the Dynaflect loading and deflection measurement layout.

The effect on deflections of Dynaflect placement, environment and possible voids beneath the pavement has often been neglected despite the fact that these factors may have a great influence on the resulting observed deflections.

It is important to quantify these factors in order to provide recommendations for a more effective use of the Dynaflect device.

OBJECTIVES

The general objectives of this study are to identify the factors that may affect Dynaflect deflections in rigid pavements and to develop a procedure for reliably measuring deflections in the field at minimum cost.

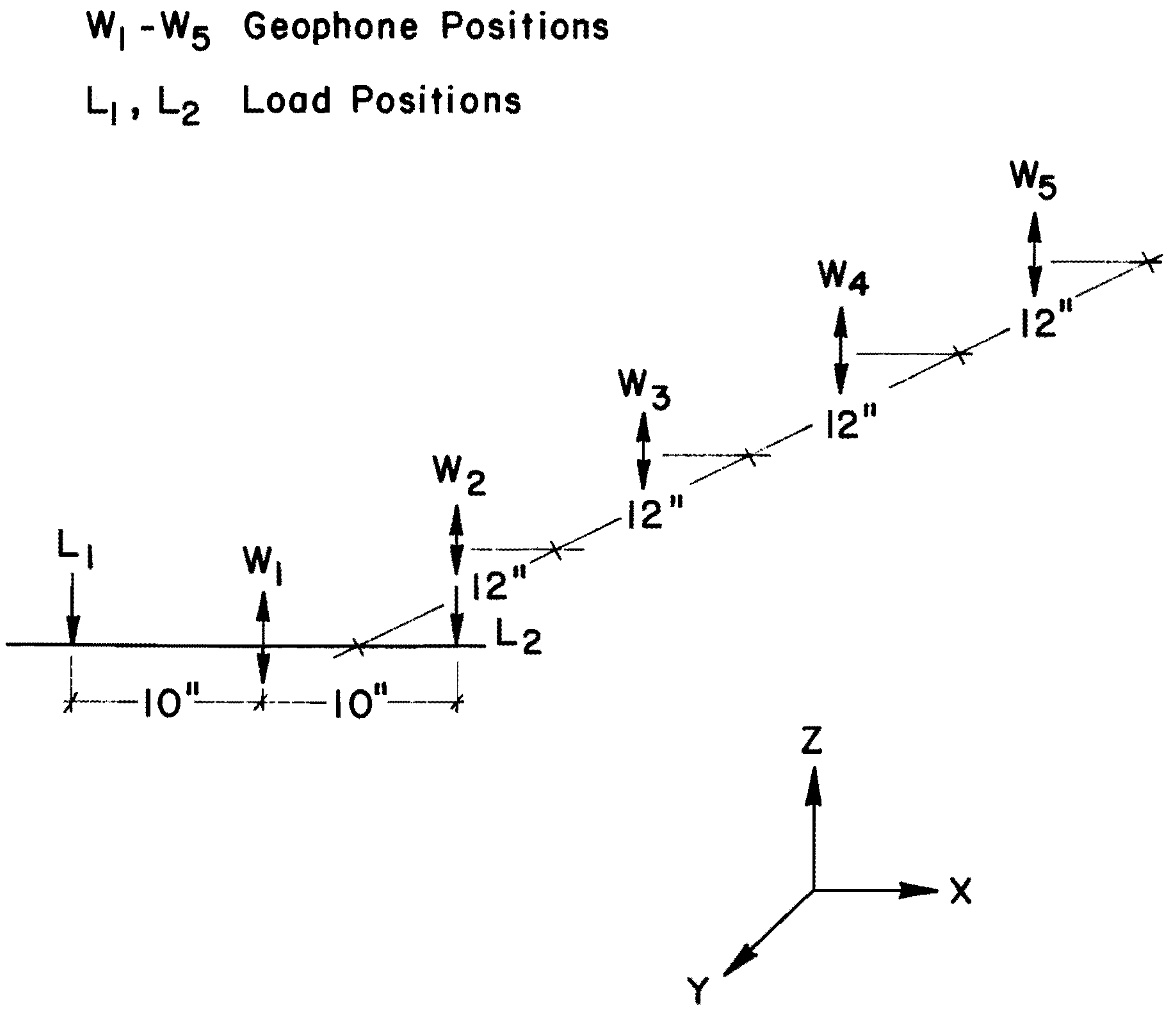


Fig 1.1. Dynaflect loading and deflection measurement layout.

Findings from the theoretical analysis to study the effect of Dynaflect position should help to understand the importance of an accurate placement of a deflection device. The information generated will be used to determine the Dynaflect placement both for materials characterization and for detecting voids underneath the pavement.

The use of statistical analysis to divide the road into sections and to determine the required number of deflections will be discussed. The results from this study will be considered in the development of a brief procedure for using the Dynaflect.

WORK PLAN

The Slab-49 program (Ref 2) was used to model a continuously reinforced concrete pavement with various support conditions. Crack spacings and longitudinal joints will also be considered.

The simulated Dynaflect load was placed at different positions to account for the effect of the pavement edge when there is a void underneath the slab as well as for the full support condition. A discussion on the effect of environmental factors based on a literature review is also presented.

Statistical analysis was used to estimate the number of Dynaflect deflections that are necessary to obtain representative results. This was based on measurements taken in the state of Texas for continuously reinforced concrete pavements.

SCOPE OF REPORT

This report describes the effect of several factors on the deflections recorded from the Dynaflect. Chapter 2 is devoted to a discussion of the effect of environmental factors, and for this purpose it is divided into two parts:

(1) temperature effect and
(2) seasonal effect.

Temperature is the most important environmental factor which affects the mechanical state of a pavement. Temperature in a concrete pavement constantly changes due to variations in air temperature. These temperature variations can lead to volume change stresses and curling and warping stresses in concrete pavements. In addition, moisture tends to have both seasonal and daily variations which cause the pavement to warp.

In Chapter 3, the effect of the Dynaflect position will be analyzed considering the following conditions:

(1) effect of void size,
(2) effect of the pavement edge, and
(3) effect of cracks and joints.

Voids are commonly developed along the edge of the pavement and produce an increase in the deflection value. It is important not only to know where a void exists but also to evaluate its effect. At the present time, a report is being prepared in the Center for Transportation Research of The University of Texas at Austin on a study of the effect of voids on overlay thickness as well as the effectiveness of the grouting operation for filling voids underneath the pavement. If circumstances do not permit one to locate the void, it is advisable to reduce such effect by placing the Dynaflect at greater distance from the edge.

Position of the Dynaflect with respect to the pavement edge should be varied according to the purpose of the measurements. If the pavement layers are to be characterized, it may be advisable to place the Dynaflect at the middle of the slab. If the purpose is void detection, the best results can be obtained by positioning the Dynaflect closer to the pavement edge. The effect of cracks and joints on deflections will also be discussed in Chapter 3.

Chapter 4 presents a statistical analysis to determine the required number of Dynaflect measurements to obtain representative results. This is to be accomplished by testing the difference between the means of two samples, one sample being the whole data with the original spacing between measurements. The second sample's size will be varied considering different spacings between measurements. Since the universe standard deviations are not known, the theoretical sampling distribution of differences is assumed to be a student's t distribution.

Chapter 5 is a brief discussion of results and Chapter 6 concludes the report with the summary of the findings.

CHAPTER 2. EFFECT OF ENVIRONMENTAL FACTORS

In this chapter, a discussion of the environmental factors that affect deflections in a pavement is presented. The environmental factors having the most influence on the behavior and performance of a pavement are related to temperature and moisture changes. The periodic and cyclic variations in the temperature and moisture can have substantial influence on the behavior and performance of the structural section and the underlying subgrade to a considerable depth below the pavement surface (Ref 7).

Deflections measured along the road change due to seasonal changes of moisture and temperature. With CRC pavements, changes in the environment affect the deflection measurements in two ways. First, cold temperatures cause the concrete surface layer to contract resulting in an increase of the transverse-crack widths. The increased crack widths result in less load transfer and, consequently, higher deflection. Second, periods of increased rainfall result in slightly higher moisture contents in the subgrade and a corresponding lower subgrade modulus and deflection (Ref 13).

TEMPERATURE EFFECT

Based on work by Thompson (Ref 8), factors which influence temperatures in a pavement can be divided into extrinsic and intrinsic categories. The extrinsic factors are those which are outside but which act directly on the soil. These factors specify the nature of the climate and modify the influence of climate on the temperature in a pavement. The major intrinsic factors influencing pavement temperatures are those governed by the properties of the soil and its cover. They include the state of the soil mass, the physical properties of the soil, and, most important, the thermal properties of the soil.

The climatic factors influencing temperatures in a pavement may be further categorized as follows:

(1) temperature factors, which directly affect the transfer of heat to or from the earth, such as air temperature, short-wave solar radiation received at the earth's surface, long-wave radiation emitted from the earth, and wind.

(2) hydrologic factors, which exert an indirect influence on the temperature of the earth because of the effect on the soil or its cover, such as precipitation, evaporation, and condensation.

(3) geographical location factors, which exert a direct influence on weather and its outcome, such as elevation, latitude, degree of exposure, and nearness to bodies of water.

Temperature in a concrete pavement constantly changes due to variations in air temperature, which take place at a relatively rapid rate. These changes in slab temperature may be divided into two parts:

(1) the daily and seasonal variations in the average temperature of the slab and

(2) daily variations between the top surface and the bottom (Ref 9).

The above statements provide an indication that the temperature can also be classified as a seasonal factor that affects pavement deflections. However, temperature effect, disregarding whether it is seasonal or not, will be covered in this section.

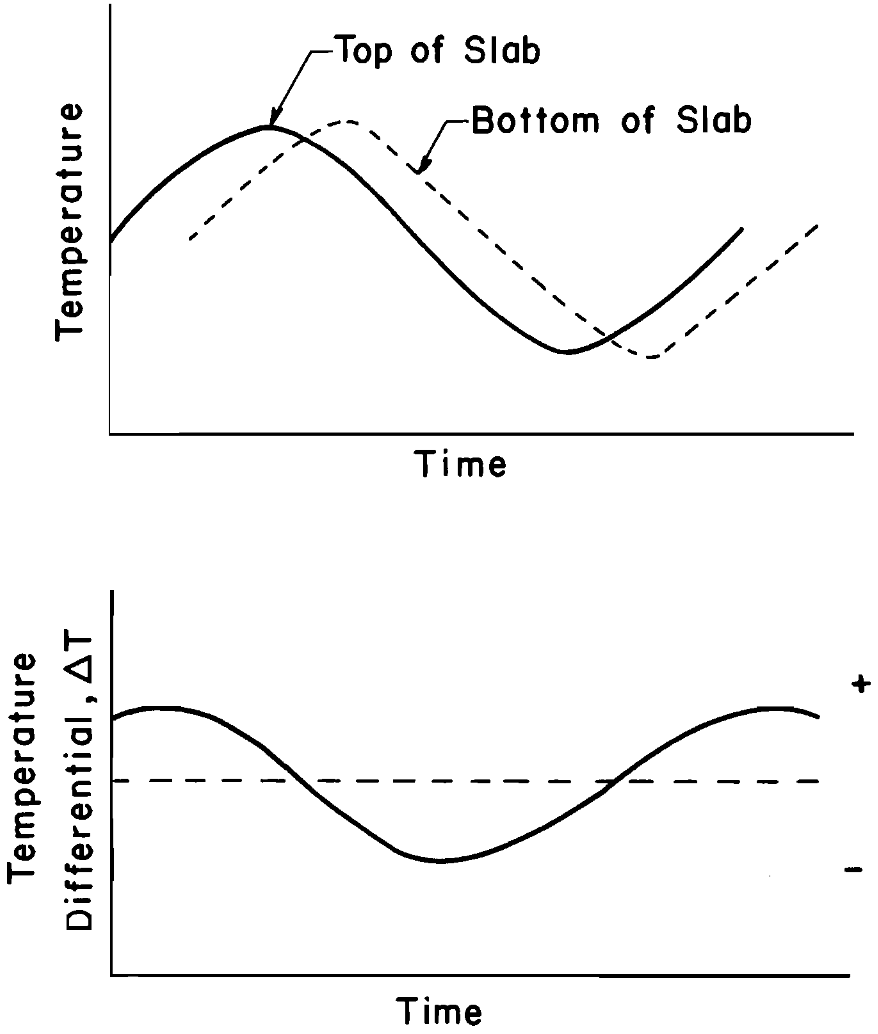
It has been observed that the daily change in average slab temperature is generally less than the daily change in the air temperature and the relation between the two is influenced by the season of the year and by the particular climatic conditions. Also, it has been observed experimentally that in general the maximum daily change in the average slab temperature is less during the cold months of the year than during the warm months (Ref 9).

In a study conducted by McCullough et al (Ref 5), it was found that in a CRC pavement the mid-depth temperature of the pavement computed from the average of the top and bottom temperatures of the slab correlated well with the crack width. The crack width, in turn, is one of the variables affecting the deflections of CRCP.

Differential temperature occurs when the temperature at the top surface of a slab is different from the temperature at the bottom surface with the magnitude difference being termed the temperature differential. The same concept can be applied to define differential moisture.

Figure 2.1 illustrates the daily variation in the temperature at the top and the bottom of the slab and in the temperature differential. The temperature differential is obtained by subtracting the temperature at the bottom of the slab from the temperature at the top of the slab. Above the dashed line in Fig 2.1, temperature differential is positive, while, below such line, temperature differential is negative.

Warping is defined as the distortion or displacement of a pavement slab from its proper plane caused by temperature differential between the two



$$\Delta T = T_T - T_B$$

T_T = Temperature at the Top of Slab

T_B = Temperature at the Bottom of Slab

Fig 2.1. Daily variation in the temperature at the top and the bottom of the slab and in the temperature differential.

surfaces of the slab. Curling is defined as the distortion of a pavement slab from its proper plane caused by differential expansion or contraction resulting from a difference in moisture content between the top and bottom of the slab. As the top of the pavement surface becomes warmer than the bottom, the deflection is reduced (Ref 10).

AASHO Road Test curling studies showed that points on the upper surface of pavements slabs were in continuous vertical motion during periods of changing air temperature (Ref 18). This phenomenon occurred because concrete is a relatively slow conductor of heat, and a temperature differential was created by the lag in time required for heat to transfer through the slab.

In a typical daily cycle a pavement slab will curl both upward and downward, especially in the spring and fall when there are greater ranges in daily temperature. At night, when the surface of the slab is cooling, the surface length decreases and the slab curls upward; this tends to lift the corners and edges off the base. The corners and edges normally reach their maximum elevation early in the morning. The reverse occurs in the daytime when the surface is heated by the warmth of the day and the sun's rays. The surface then expands and curls the slab downward. Usually, in the late afternoon the lowest elevation is reached at the corners and edges while the center of the slab has risen to its maximum elevation (Ref 17).

At the AASHO Road Test (Ref 18), twenty-four hour studies of the effect of fluctuating air temperatures showed that the deflection of panel corners under vehicles traveling near the pavement edge at times increased several fold from afternoon to early morning. Values of differential temperatures as high as 30°F were occasionally observed at the Road Test; the corresponding estimated range of corner displacements is from 0.09 to 0.15 in.

SEASONAL EFFECT

The results of field measurements have indicated that deflections are affected by seasonal variations of pavement conditions. The seasonal deflection changes are mostly due to moisture variation in the base and subgrade (Ref 10).

Moisture is a fundamental variable in all problems of soil stability. It has special significance in pavements since the shallow foundation of these structures is constructed in the surface soil, which is usually subject to large variations in moisture content.

The prediction of the moisture conditions in a pavement for a given time, climate, and topographical location is a complicated matter (Ref 8).

Moisture in a pavement can come from several sources:

(1) Moisture may permeate the sides, particularly where coarse-grained layers are present or where surface drainage facilities within the vicinity are inadequate.

(2) The water table may rise (this can be expected in the winter and spring seasons).

(3) Surface water may enter joints and cracks in the pavement, penetrate at the edges of the surfacing, or percolate through the surfacing and shoulders.

(4) Water may move vertically in capillaries or interconnected water films.

(5) Moisture may move in vapor form, depending upon adequate temperature gradients and air void space (Ref 7).

Curling due to moisture differential between the upper and lower surfaces of a slab occurs slowly and is not detectable in a daily cycle like that resulting from temperature differential. Moisture curling is more apparent from seasonal changes. Many pavement slabs in service are wet on the bottom surface and probably never dry out or lose appreciable moisture under normal conditions. This keeps the bottom surface of the slab saturated or nearly saturated and in an expanded condition almost constantly. On the other hand, the upper surface is usually drier and in a contracted state relative to the bottom surface. This vertical differential of moisture thus tends to curl the slab upward and add to any upward curling that is due to temperature differential. However, curling due to moisture differential would compensate downward curling due to temperature differential. In the spring, when the subgrade is the wettest and the temperature differential is the greatest, the most critical combination of these two types of deformation is probably reached. The magnitude of the distortion from moisture curling alone is more difficult to measure, especially on slabs in service. Curling due to moisture differential may have effects on the slab of equal magnitude to those from temperature differential (Ref 17).

From a deflection study of CRC pavements in Texas, McCullough and Treybig (Ref 6) concluded that the deflections during fall and winter were generally greater than in the summer, whereas the spring deflections were significantly different from the summer. Thus the deflection might in some way be related to the season; however, for the fall and winter there was not very much difference in the data.

A wet winter will result in an increase in deflection compared to other seasons. This will be due to the wet, soft subgrade and due to the low effective modulus of the surface layer caused by shrinkage and the resulting relatively wide transverse cracks. A dry summer will result in a decrease in the sensor 1 Dynaflect deflection due to the dry, stiff subgrade and the high effective surface modulus, caused by expansion and the resulting narrowing of the transverse cracks in the CRC pavement. Wet summers or dry winters may not appreciably change this deflection relative to other seasons, due to the counterbalancing effects of the environment on the different layer moduli.

If, on the other hand, the sensor 5 Dynaflect deflection is considered, environmental factors affecting the subgrade and surface may be distinguishable. Moisture effects on the subgrade should affect the sensor 5 deflection (Ref 13).

SUMMARY

A methodology for incorporating the effects of environmental parameters (temperature, moisture) into the pavement analysis-design process must include:

(1) ability to predict in-service environmental conditions,

(2) ability to predict the temperature and moisture regimes that exist in a pavement as a function of time and space,

(3) proper and realistic assessment of the effects of temperature and moisture on pertinent mechanical properties of the materials in a pavement,

(4) expression of pertinent mechanical properties as a function of temperature and moisture conditions, i.e., models or constitutive equations relating mechanical properties to temperature and moisture (Ref 7).

From the foregoing discussion, it can be recommended that when deflection measurements of a given section taken at a different time are to be compared, careful consideration should be given to the effect of the environmental factors.

It would be very useful to record the temperature at which a deflection is taken as well as the other existing climatic conditions.

CHAPTER 3. EFFECT OF DYNAFLECT POSITION

Void size, position of the Dynaflect with respect to the edge of the pavement, and locations of cracks and joints are among the most important factors that affect deflections of rigid pavements. The aim of this chapter is to determine the significance of the above-mentioned factors and to provide with some information to be used when taking deflection measurements.

EFFECT OF VOID SIZE

Voids can develop in a number of ways, but the most significant factors are

(1) pumping of the subbase material,
(2) deep soil movements, such as a swelling or settlement action,
(3) slabjacking, which causes the pavement to rise excessively, thus producing a high point with a void on each side.

Figure 3.1 illustrates the loss of support due to swelling clay and settlement. If voids begin to develop beneath the pavement, higher deflections and stresses occur, consequently producing higher distress in the pavement slab. A void does not necessarily have to be very deep to have an adverse effect on the fatigue life of a PCC pavement. A nonuniform support

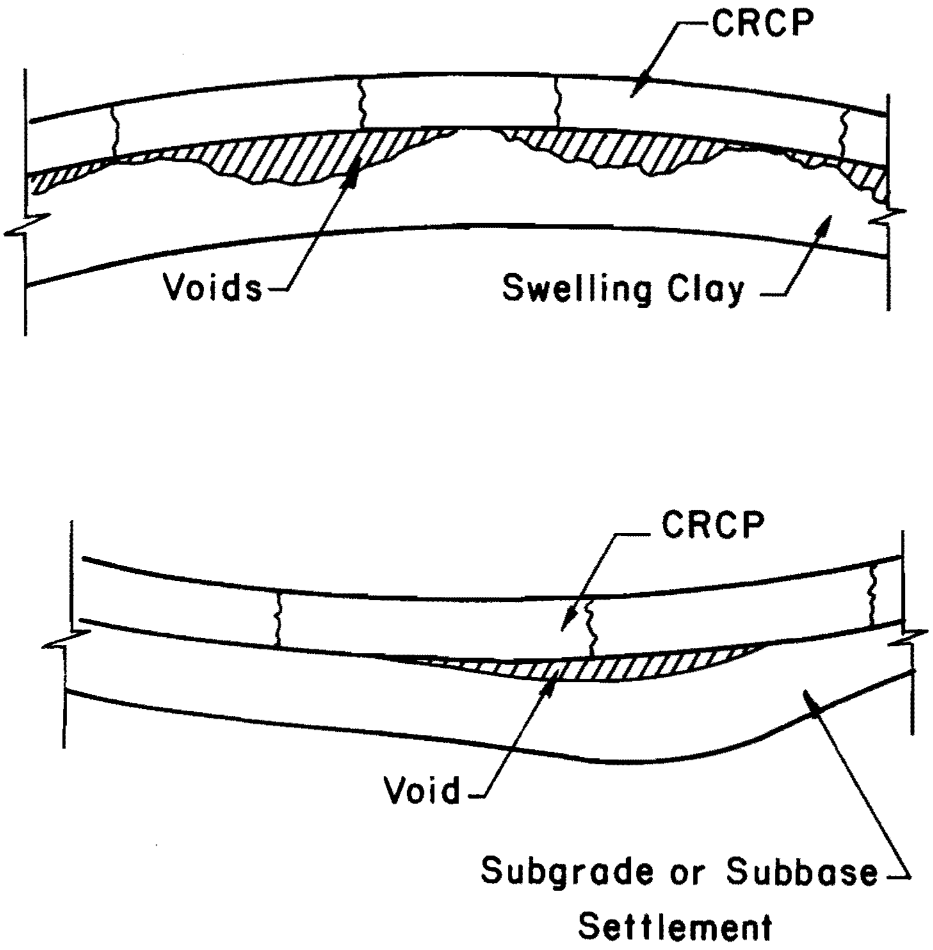


Fig 3.1. Void creation under CRC pavements due to (a) swelling clay and (b) settlement.

condition may cause cracks to develop. The dimensions of the voids in Fig 3.1 have been augmented for illustration purposes.

The initial step in pumping of subbase (or subgrade) soils is the creation of a void space under the pavement where free water may accumulate after repeated loads are applied to the pavement. The void space may be small and discontinuous and can be caused by two principal factors. First, loads imposed on the soil may result in a small space between the soil and pavement due to plastic deformation of the soil after the more elastic slab rebounds. Warping of the slab due to its temperature differentials may also create a small space under the slab. The next step in the sequence of events occurs when water enters the space under the pavement. The principal source of the water is from surface infiltration at the pavement edge and joints. The water generally will not remain under the pavement but will move through the subbase. If the subbase is not free draining, subsequent deflection of the slab will cause the water to be ejected from under the pavement. This generally occurs at the pavement edge just ahead of a joint or crack.

After additional deflections of the slab, the soil may go into suspension with the water, and muddy water will be ejected. After many loads have been applied, the pumping action may continue until a relatively large void space is created under the slab. The slab will then generally fault a small amount. Next, the pavement may crack and fault (Ref 11).

To demonstrate the effect of void size on deflections in rigid pavements, the Slab-49 Computer Program (Ref 2) was used. A continuously reinforced concrete pavement was modeled, and, based on performance studies of CRCP, a crack spacing of 8 feet was selected. A longitudinal joint was also considered. Figure 3.2 shows the dimensions of the simulated CRCP.

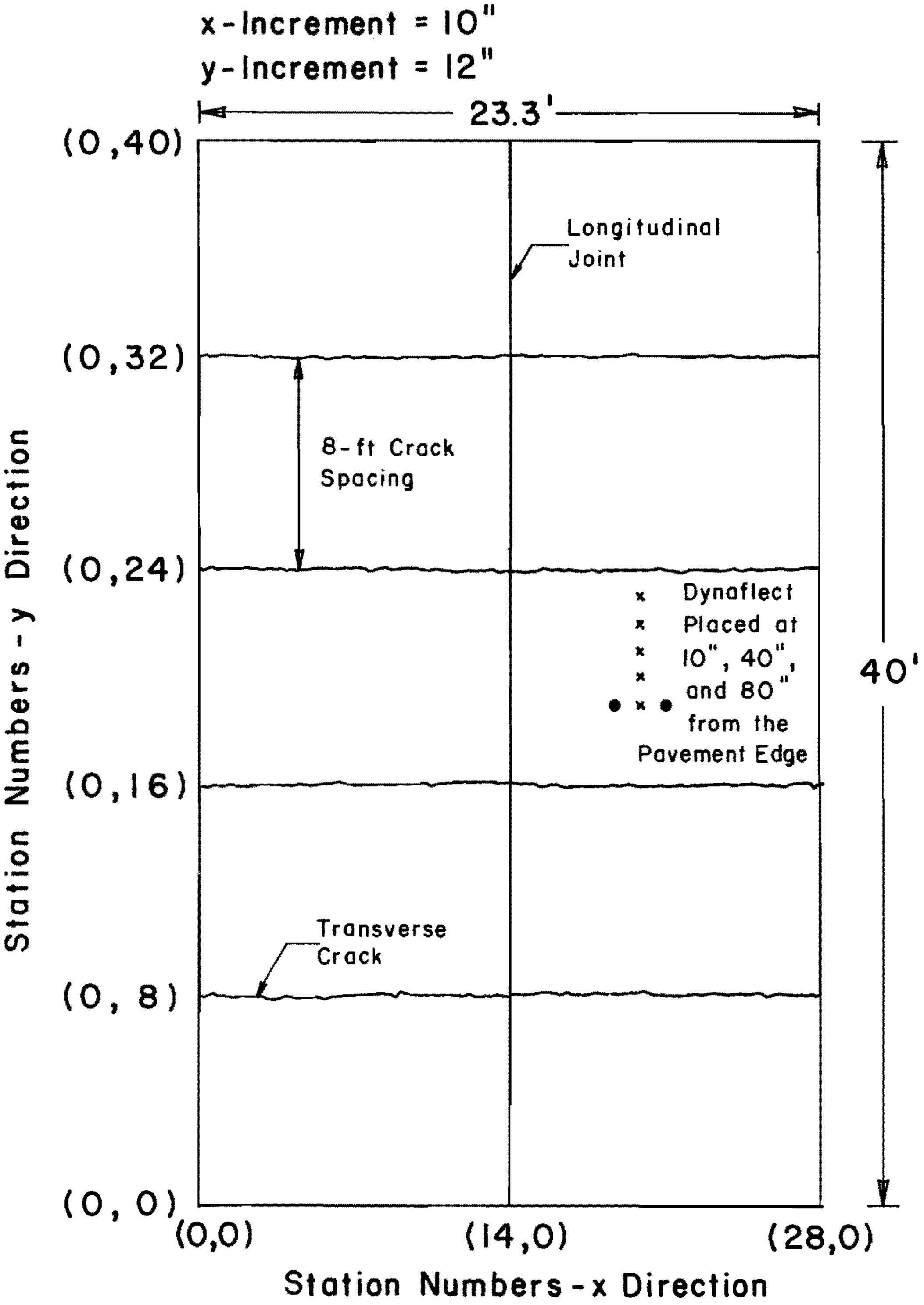


Fig 3.2. The slab layout with the load, transverse cracks and longitudinal joint used in the computational experiment.

The increment in the X direction was fixed by the spacing between the Dynaflect wheel loads. The total length of the slab in the X direction is 23.3 feet. This distance is approximately equal to the width of a two-lane roadway. Once the crack spacing was set to 8 feet, it was decided to have as many small slabs in the Y direction as the Slab-49 Program capability allowed. Furthermore, the effect of the boundary condition at both ends in the Y direction was reduced to its minimum by selecting a 40-foot total length.

The Slab-49 Computer Program allows for nonlinear input, discontinuities in the slab and the subgrade, and varying support in the subgrade. The Dynaflect loading was simulated considering two wheel loads of 500 pounds each. Based on the results from Ref 1, the amount of stiffness reduction applied at the transverse cracks and longitudinal joints was 90 percent of the original bending stiffness value. Table 3.1 presents the values of the variables used in the analysis.

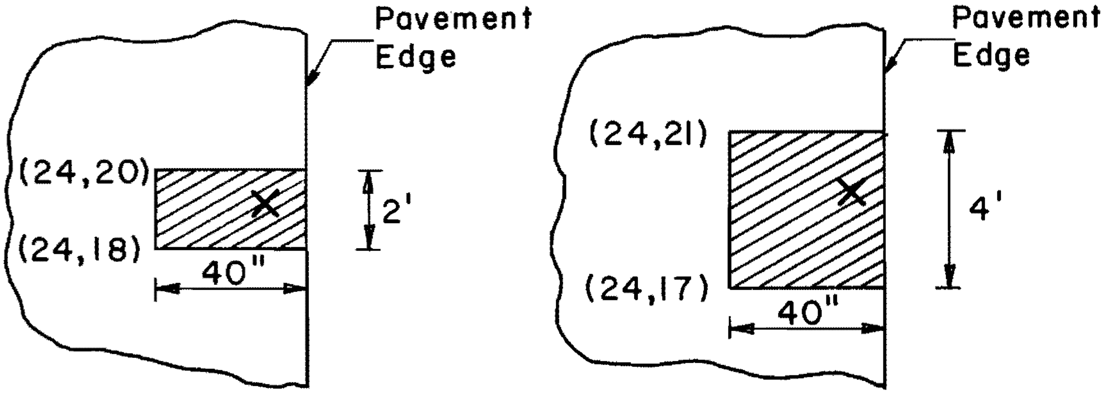
Most of the voids develop along the edge of the pavement, and for that reason voids in this analysis were considered at that location. In order to simplify the input data concerning void simulation, voids of rectangular shape were assumed. Both the Dynaflect and the voids were located on the pavement as shown in plan view in Fig 3.2.

The dimensions of the voids and their orientation are given in Fig 3.3. It should be noticed that in the field voids have a wide variety of shapes, but, for an analytical study in which the main objective is to analyze the effect of voids underneath the pavement, the assumption of a rectangular void shape provides enough information concerning the variation of deflection with void size.

TABLE 3.1. VALUES OF THE VARIABLES USED IN THE ANALYSIS

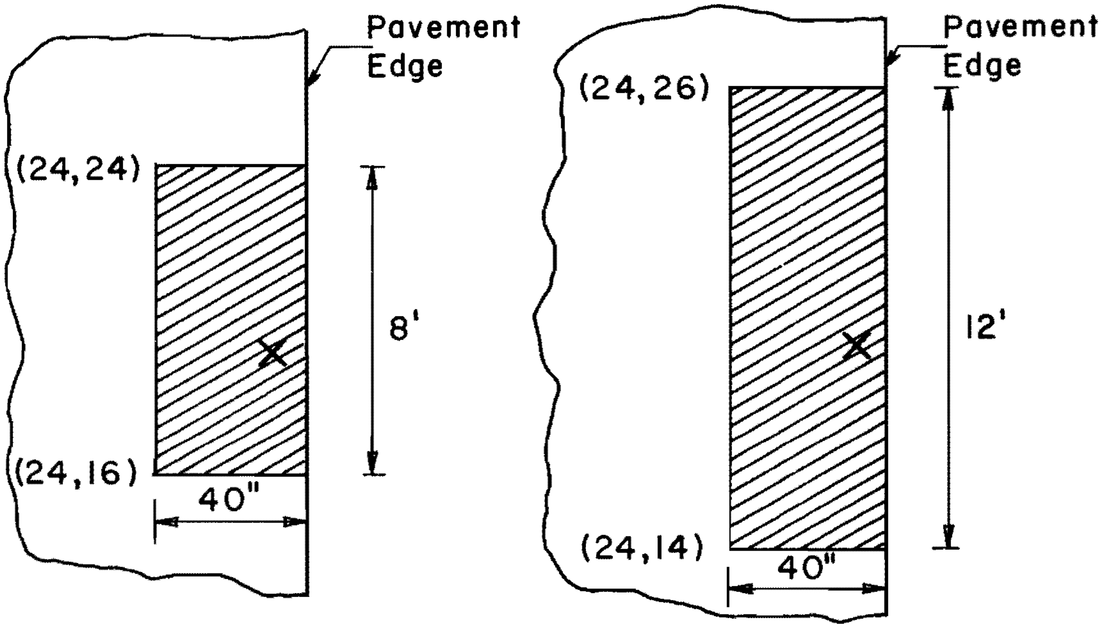
(a) Variables	Values for Levels				
	1	2	3	4	5
Void size (sq ft)	0	7	13	27	40
K-Value (psi/in)	100	400	800		
Distance from the pavement to Dynaflect sensors (in)	10	40	80		

(b) Parameters Held Constant	Values
Slab size (ft)	23.3 x 40.0
Crack spacing (ft)	8
Pavement thickness (in)	8
Concrete modulus of elasticity (psi)	5×10^6
Poisson's ratio	0.20
Two wheel loads spaced at 20 in (lb)	500 each



Void Area = 7 sq ft

Void Area = 13 sq ft



Void Area = 27 sq ft

Void Area = 40 sq ft

Station Numbers Shown Refer to Fig 3.2 at Coordinate × Sensor I Location (10" From Pavement Edge), (27, 19)

Fig 3.3. Different void sizes considered in the analysis.

Dynaflect sensors were located parallel to the pavement edge at three different distances from it: 10, 40, and 70 inches. Table 3.2 gives the sensors' locations using the station numbers in Fig 3.2. The location of sensor 1 when all the Dynaflect sensors are placed at 10 inches from the pavement edge is indicated in Fig 3.3. This was done to show the location of the sensors relative to the void. The location of the Dynaflect sensors remains the same for the four different void sizes when a particular distance from the pavement edge is considered, as can be observed in Table 3.2.

The Slab-49 Computer Program was run 45 times, and the deflections obtained for sensors 1 and 5 are presented in Appendix A.

All the graphs presented in this section are for the simulated sensor 1 readings.

Figure 3.4 is a plot of deflection vs distance from the pavement edge for five different void conditions. Note that deflections for the 40 square-foot void are higher than deflections for the other void conditions, especially when the Dynaflect is placed close to the pavement edge.

It may be concluded that voids produce higher deflections than the fully supported pavement. Thus, if these deflections are used to characterize the materials for the different layers of the pavement, misleading results can be obtained.

The farther the Dynaflect is placed from the pavement edge the less the effect of the void. Based on this concept, if the purpose of the deflection measurements is materials characterization, it is recommended the Dynaflect be placed at the center of a lane. Especially for pavements experiencing pumping, this recommendation should be followed. Likewise, if there are visual indications of vertical movement along the pavement edge, precautions should be taken since voids may be present.

TABLE 3.2. LOCATION OF THE DYNAFLECT SENSORS AND WHEELS ACCORDING TO FIG 3.2.

Distance from the Pavement Edge to the Dynaflect Sensors, in.	Location of						
	Sensor 1	Sensor 2	Sensor 3	Sensor 4	Sensor 5	Wheel 1	Wheel 2
10	(27,19)	(27,20)	(27,21)	(27,22)	(27,23)	(26,19)	(28,19)
40	(24,19)	(24,20)	(24,21)	(24,22)	(24,23)	(23,19)	(25,19)
80	(20,19)	(20,20)	(20,21)	(20,22)	(20,23)	(19,19)	(21,19)

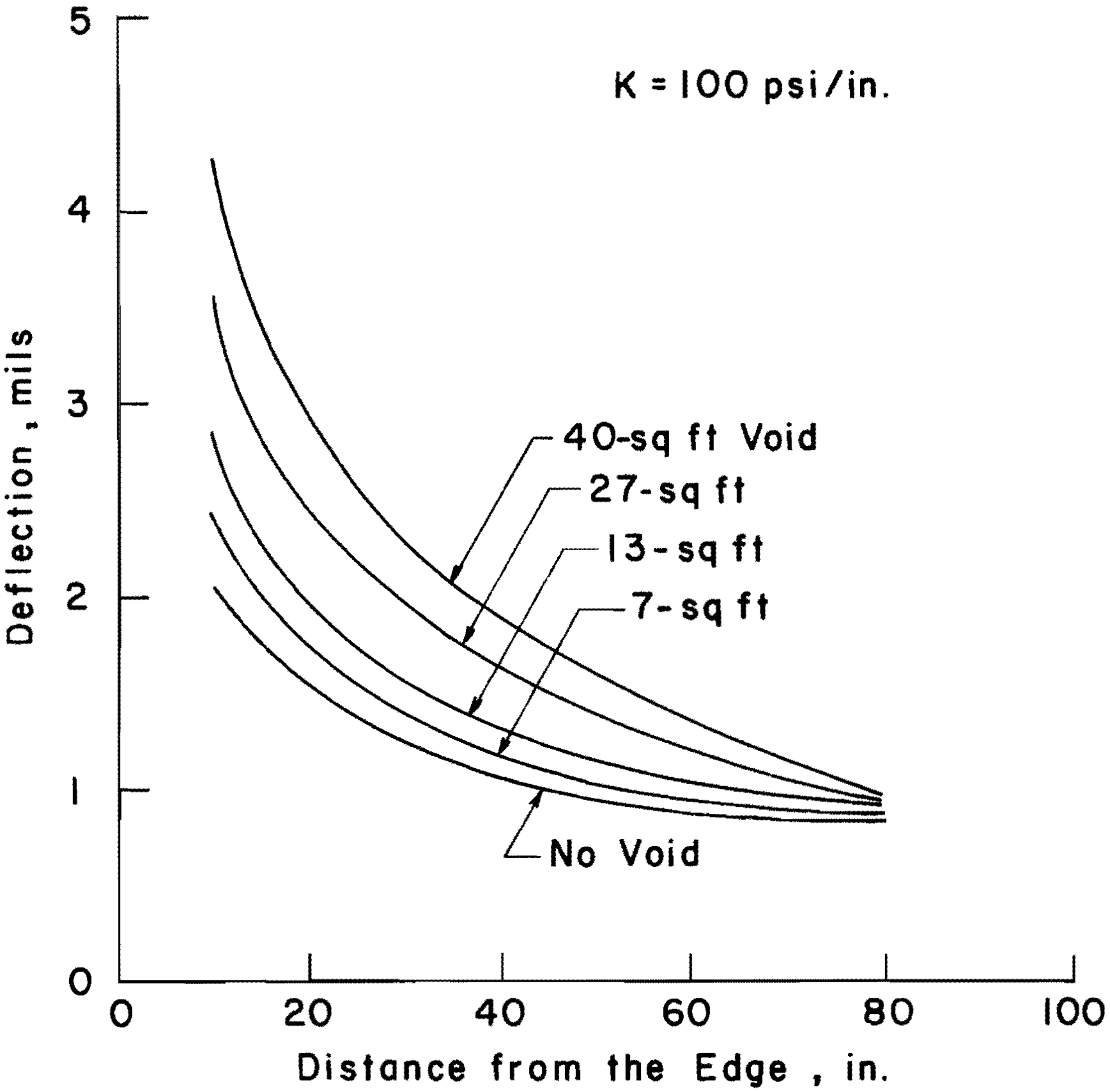


Fig 3.4. Deflection vs distance from the pavement edge for five different void conditions.

In contrast, if the purpose of the Dynaflect measurements is void detection, the Dynaflect should be positioned where the void effect is high, i.e., close to the pavement edge. The effect of void size on deflections is more important in pavements with high K-values than in low-strength pavements. For example, if, in Fig 3.5, the deflections for each K-value are normalized (divided by the no-void deflection), greater normalized deflections are obtained for a K-value of 800 psi than for the other two K-values. These normalized deflections are a measure of the increase in deflection due to the presence of a void of a certain size related to the deflection for a no-void condition in a concrete pavement.

EFFECT OF THE PAVEMENT EDGE

When there is a uniform support condition for a pavement, the maximum deflections are obtained close to the pavement edge. These maximum deflections may increase because of the presence of a void beneath the pavement, as shown in Fig 3.6. If the Dynaflect sensors are aligned parallel to the pavement edge at 80 inches from it, the effect of any void, for the range considered in this analysis, may be neglected.

On the other hand, if the Dynaflect sensors are placed at 10 inches from the pavement edge, the presence of voids has a tremendous effect on deflections.

As it was previously pointed out, the purpose of the Dynaflect measurements should determine the distance from the pavement edge where the Dynaflect should be placed. In a void-detection process, the Dynaflect should be placed as close to the pavement edge as practical, always having both wheels inside the pavement.

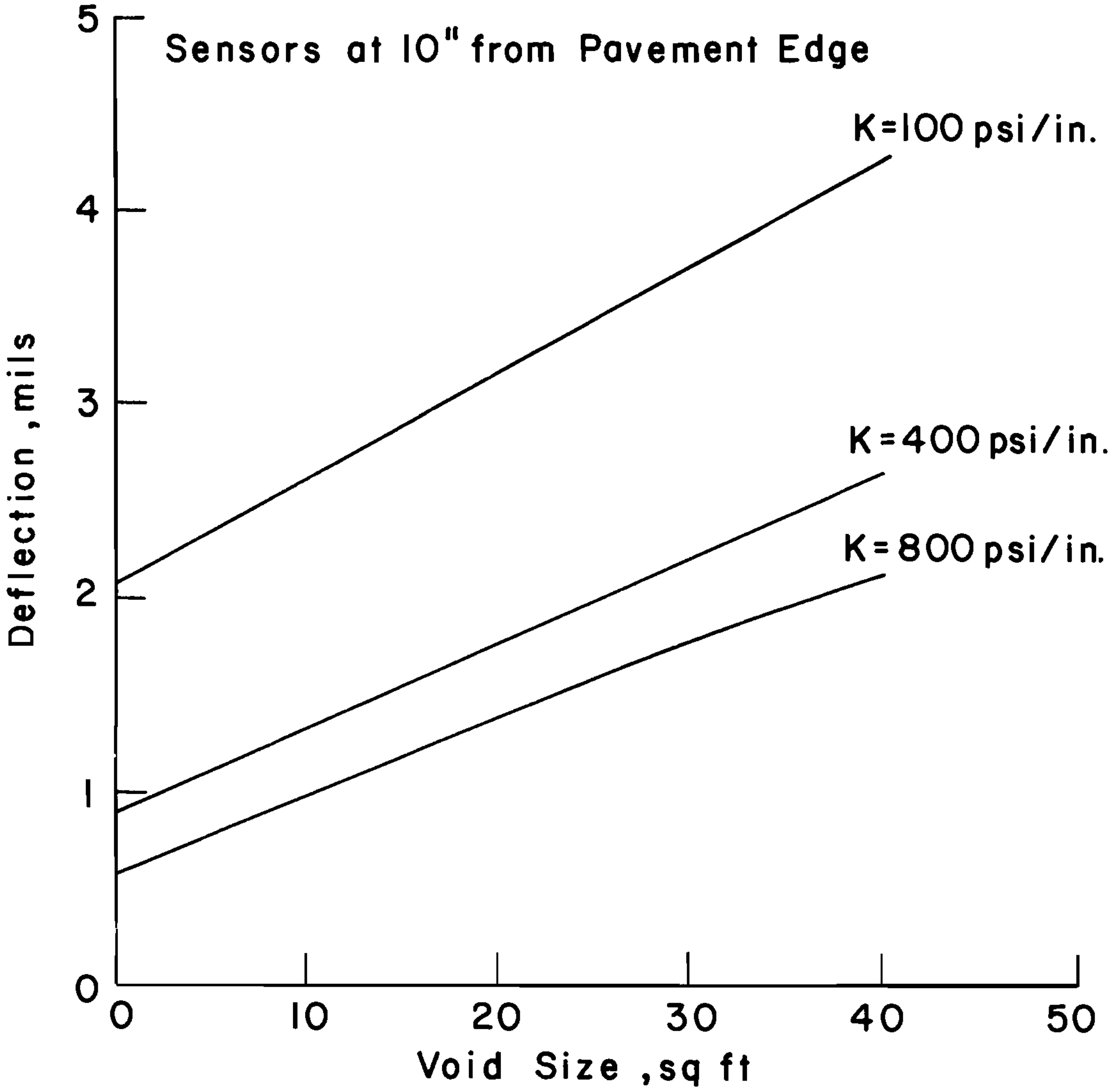


Fig 3.5. Void size vs deflection for three different K-values.

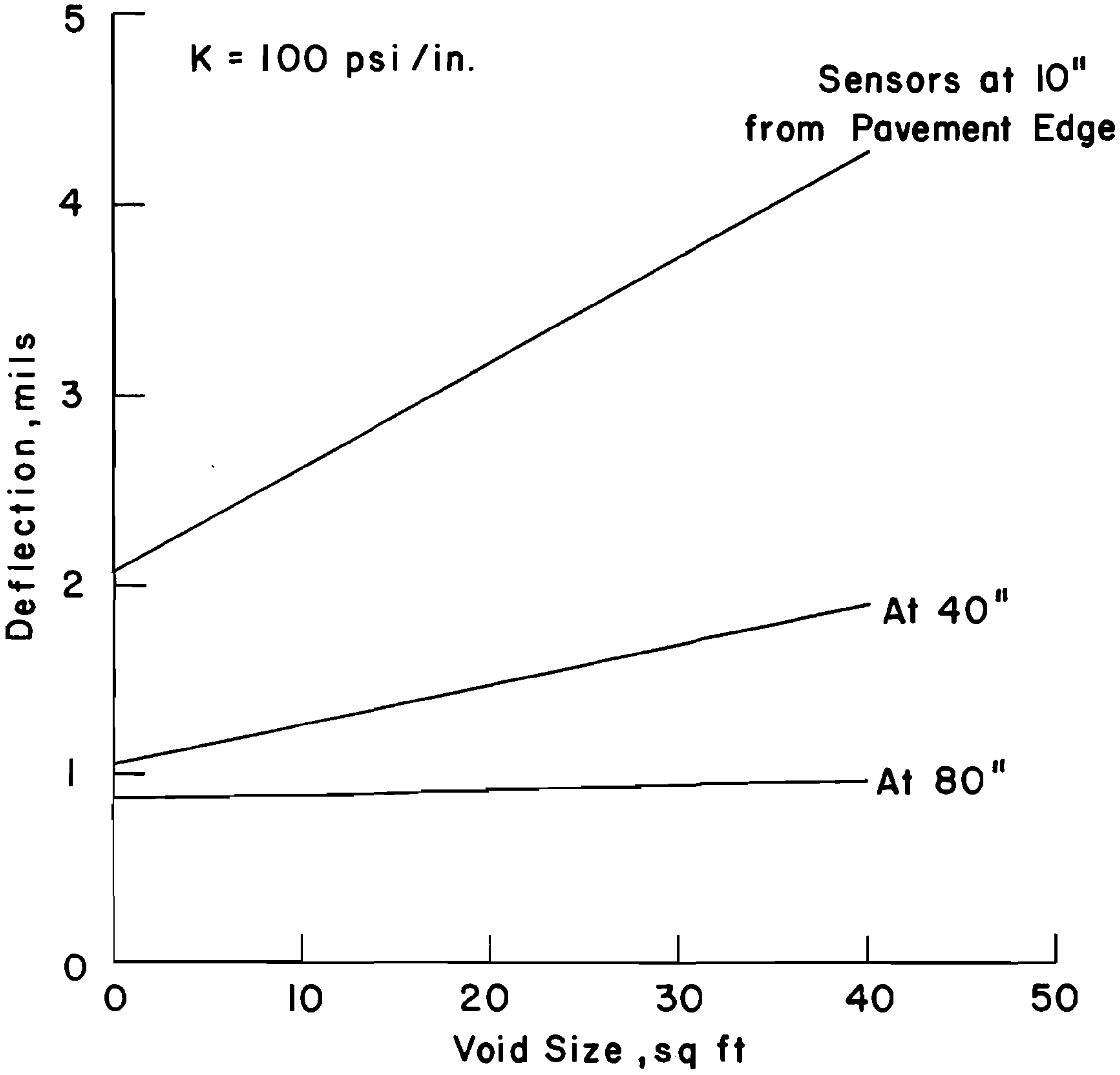


Fig 3.6. Void size vs deflection for three different Dynaflect positions.

The distance from the pavement edge at which the Dynaflect sensors are placed should be recorded on the forms for the sensors deflections in order to compare these deflections with future measurements. Therefore, the need for accuracy in the Dynaflect placement arises.

The effects of two different types of errors that can exist in the Dynaflect deflections are shown in Fig 3.7. In this case, it was assumed that the sensors should be positioned at 10 inches from the pavement edge. Since one of the point loads used to simulate the Dynaflect load was applied at the very edge of the pavement the only possible placement error that could be made if both loads are located on the pavement would be that of placing the Dynaflect farther than 10 inches from the pavement edge. For this particular situation, the difference between the deflection at any distance greater than 10 inches and the deflection at 10 inches is considered as a placement error.

The variation of a 5-inch placement error with void size is illustrated in Fig 3.7 by the dashed line. This would be a negative error because the deflection at 15 inches would be smaller than the required deflection at 10 inches. Placement errors were normalized by dividing them by the zero-void deflection (Wo).

The second type of error is the one caused by the presence of a void underneath the pavement, and it is called an error due to void size. This error is the difference between the deflection for a given void area and the zero-void deflection. This error is always positive and is expressed graphically in Fig 3.7 by the solid line.

It can be observed that the 5-inch placement error is greater than the error due to the void size up to a certain void area, beyond which the error due to the void size is more important.

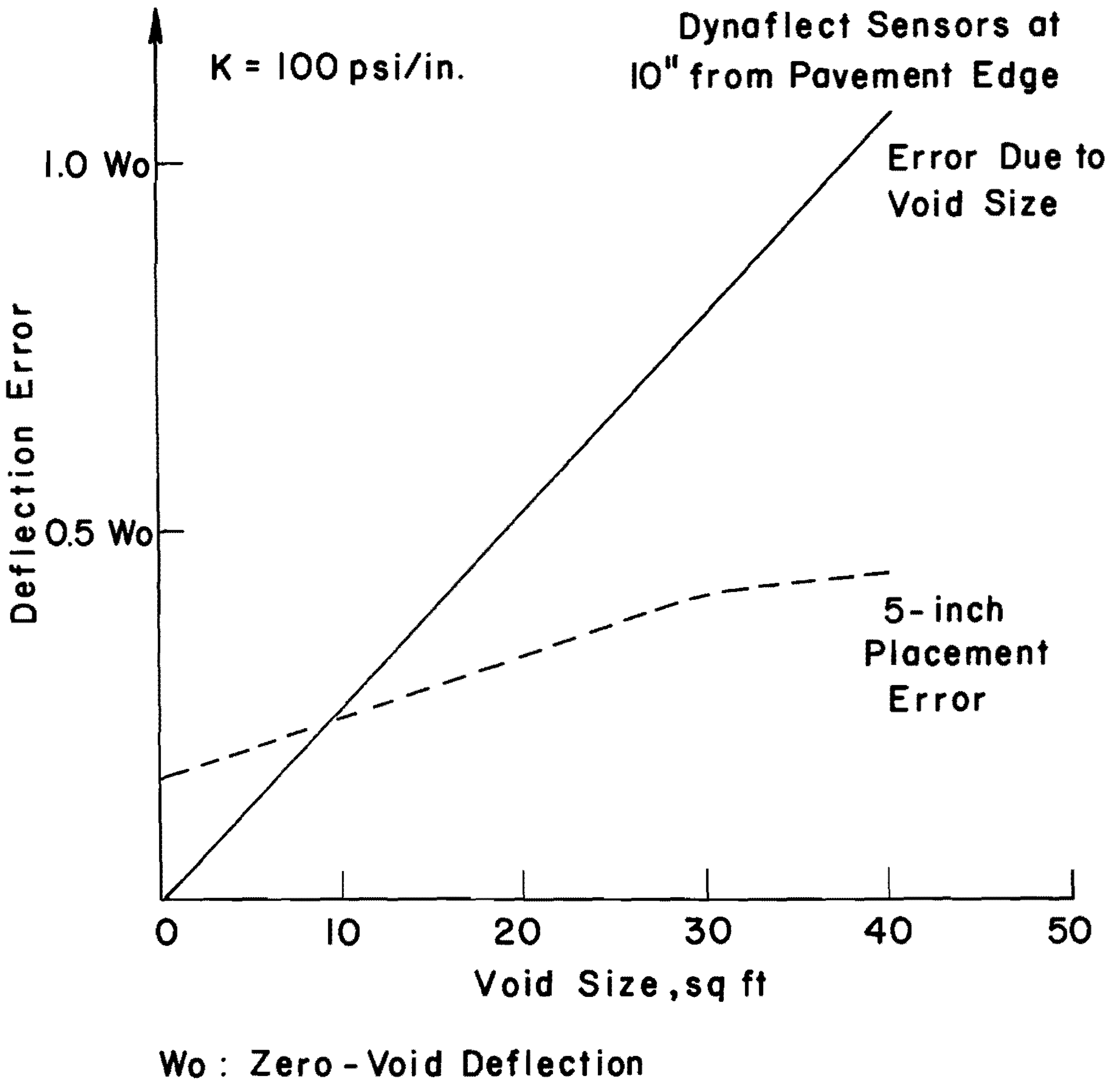


Fig 3.7. Deflection errors due to variations in Dynaflect placement as well as void size.

In Fig 3.8, the Dynaflect sensors were considered to be placed at 20 inches from the pavement edge. Placement errors of 10 and 5 inches were analyzed. In this instance the placement error could be either positive or negative depending on the actual position of the Dynaflect with respect to the pavement edge.

Since the Dynaflect is placed farther from the pavement edge than in the previous case, both the error due to void size and the 5-inch placement error are smaller.

From Fig 3.8 the importance of the magnitude of the placement error is readily seen. The placement error should be kept as small as possible, especially close to the pavement edge. A placement error greater than 5 inches is not acceptable.

Figure 3.9 shows the same analysis for a Dynaflect placed at 40 inches from the pavement edge. The 5-inch placement error is insignificant for the void-size range considered. Likewise, the error due to void size is smaller than the ones for the other two Dynaflect positions. Thus, for measurements greater than 40 inches from the pavement edge, the placement position is not important.

EFFECT OF CRACKS AND JOINTS

The bending resistance of structural members is considerably influenced by the presence of discontinuities, such as joints and cracks. These discontinuities can be effectively modeled by a reduction in the bending stiffness.

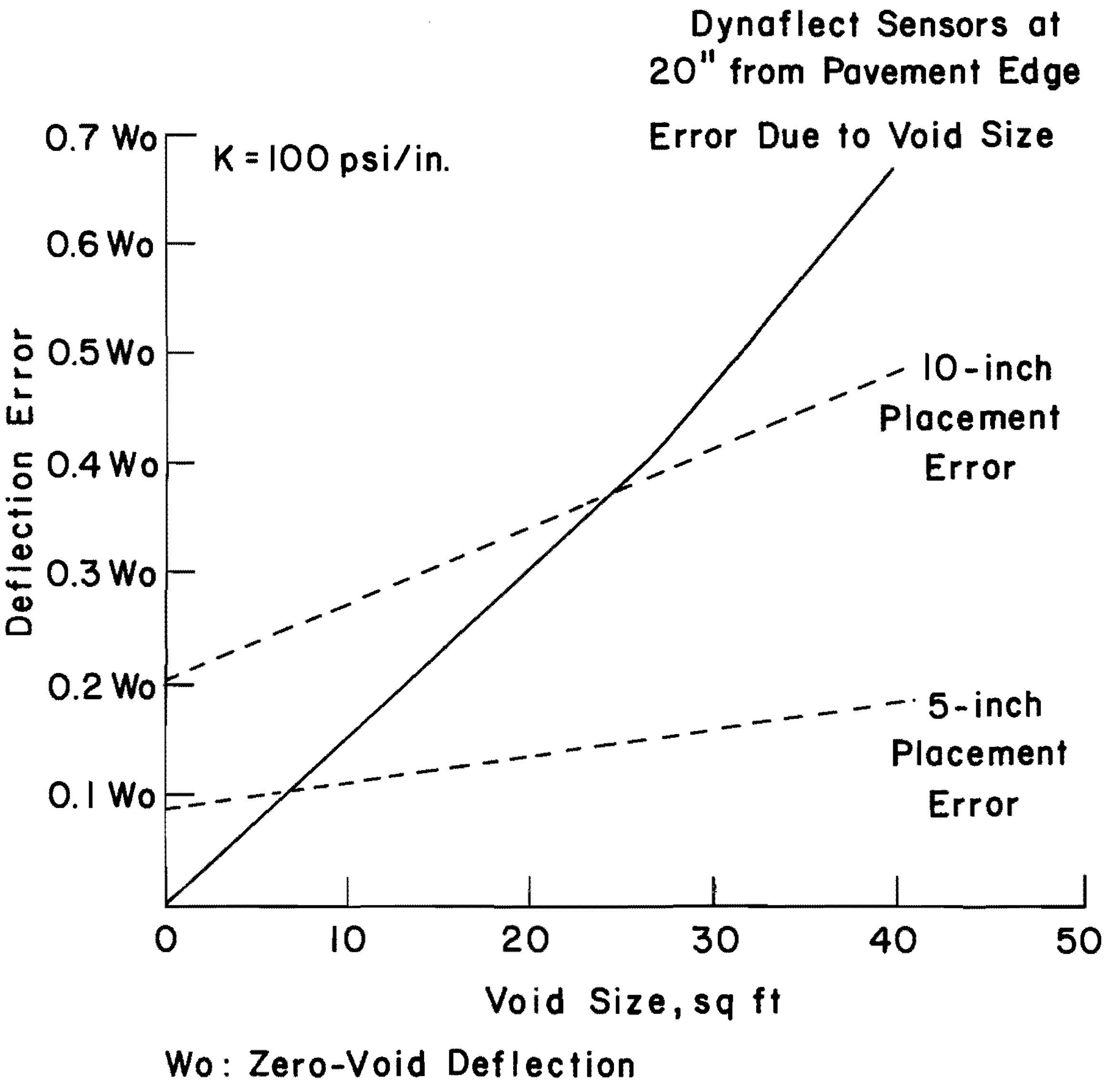


Fig 3.8. Deflection errors due to variations in Dynaflect placement as well as void size.

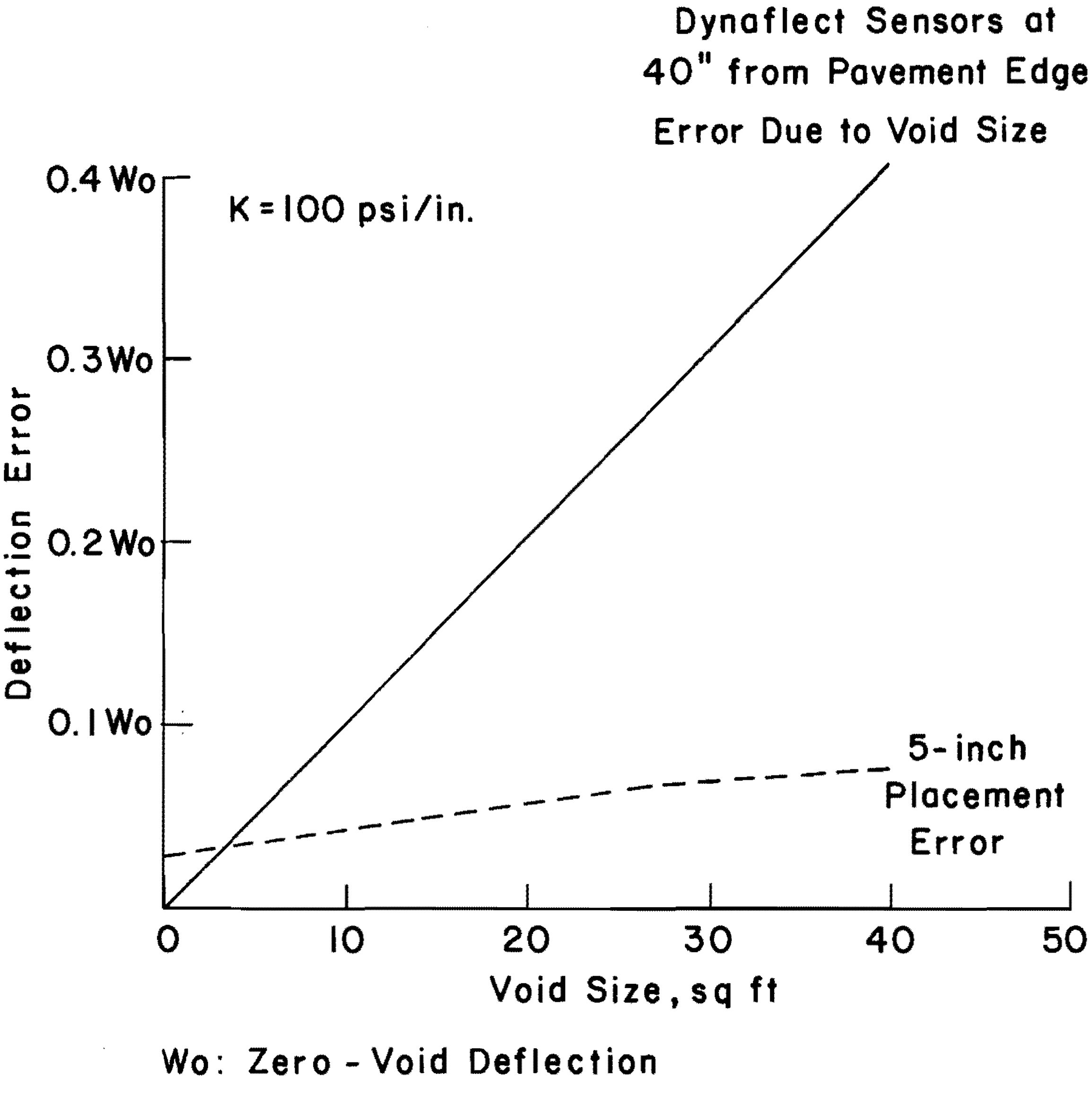


Fig 3.9. Deflection errors due to variations in Dynaflect placement as well as void size.

In this study, the amount of stiffness reduction applied to the transverse cracks and longitudinal joint was 90 percent of the original stiffness value. In CRC pavements the field experiments have indicated that deflection is a function of crack opening and crack spacing (Ref 10).

Cracks in the rigid pavement layer may have an effect on deflections if some loss of load transfer is caused by the crack. With CRC pavements, the cracks are tightly closed, resulting in very little loss of load transfer. A drop in temperature can cause these cracks to open, thus some loss of load transfer may result, causing an increase in the deflection.

As is expected under uniform support conditions, deflections taken close to a transverse crack will be greater than deflections between cracks, and the difference between both deflections will increase with increasing crack width. The effect of a longitudinal joint on deflections is similar to that of a transverse crack.

Based on the foregoing factors, it is recommended that Dynaflect wheel loads be applied between cracks to minimize the effect of such discontinuities. Furthermore, special care should be taken in areas where the widths are large.

If the loss of load transfer across a crack or a joint needs to be determined, the Dynaflect wheel loads should be placed both at the crack or joint and between cracks or joints in order to make a comparison.

As the load transfer across the crack decreases, the deflection at the crack increases. One definition of load transfer is as follows:

$$LT = W_u/W_1 \tag{3.1}$$

where

LT = load transfer,

W_u = deflection at the unloaded side of the joint or crack, in.,

W_l = deflection at the load side of the joint or crack, in., and

$W_d = W_l - W_u$ = differential deflection.

However, it is more practical to relate the total deflection at the crack or joint to the interior deflection for an uncracked portion of the pavement. In this manner, field deflections at cracks may be related to interior deflections, and the results of the analysis can be used to determine the stress conditions in portions of the pavement with high at-crack deflections (Ref 13).

ADDITIONAL APPLICATIONS OF THE INFORMATION GENERATED

There are several processes for filling voids underneath the pavement with undersealing being one of the methods currently used for that purpose. In order to evaluate how effective the grouting is in a particular pavement section, Dynaflect deflections are usually taken before and after the voids are filled. Then deflections before the grouting are plotted against deflections after the grouting. By inspecting this graph, the efficiency of the process for a pavement section can be determined.

Using the output data generated for the previous graphs, it was possible to prepare Fig 3.10, which compares before and after deflections. Since the distinct void sizes were known, the deflections for certain percents of the

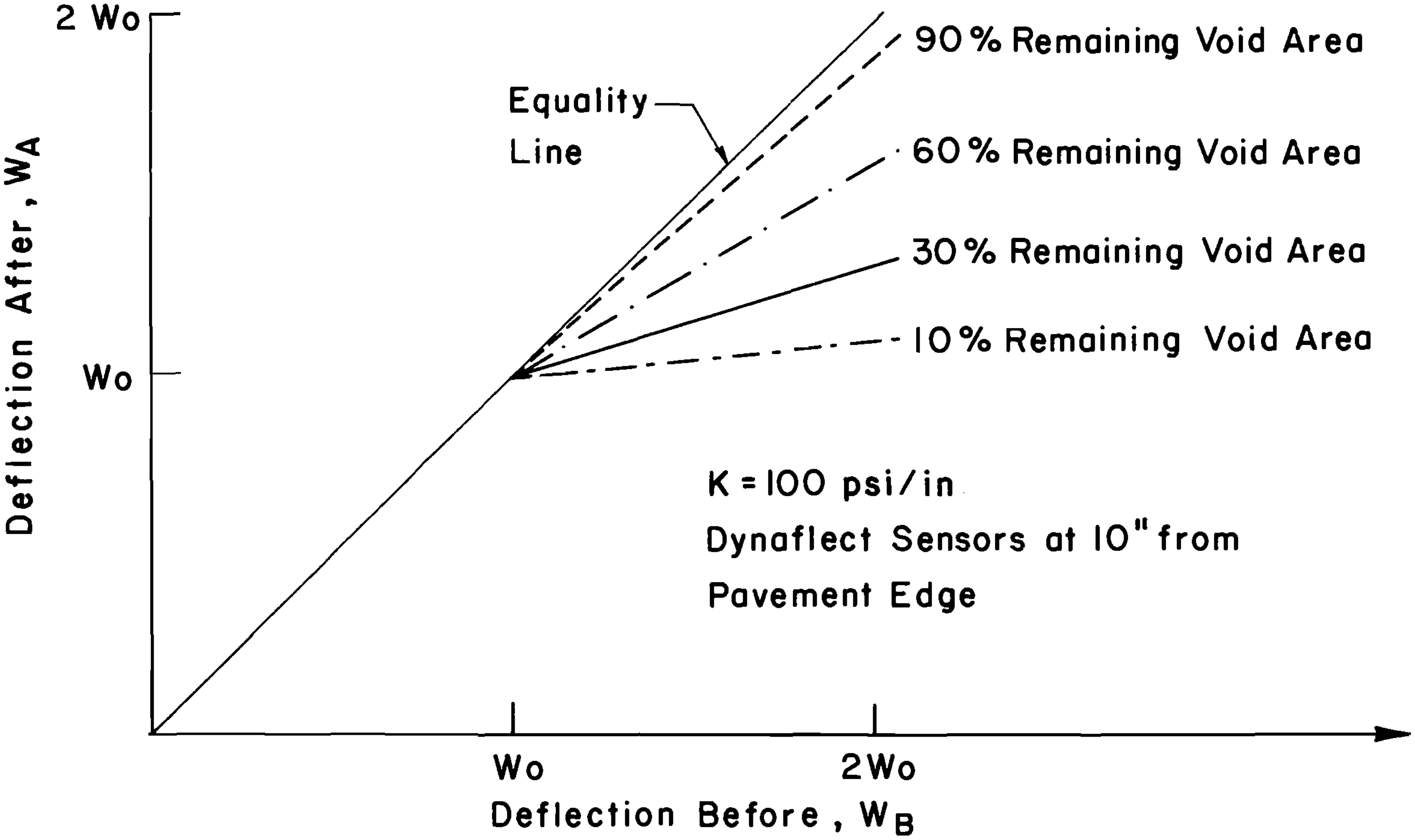


Fig 3.10. Deflections after a certain void area has been reduced by a given percent compared to deflections for the original void area. Deflections are expressed as a function of zero-void deflection, Wo.

original void areas could be determined and then plotted as shown. It should be noticed that all the lines converge at the point (Wo,Wo), which is the only point plotted on the line of equality. This means that the minimum deflection to be expected equals Wo. Furthermore, the closer the line is to horizontal the more effective the undersealing operation.

After plotting deflections before the grouting against deflections after the grouting with the data from the pavement, the approximate percent of void area filled could be estimated.

The recommended procedure is given below along with an example.

Using Fig 3.10 a slope for each condition of percent of void area filled can be developed:

TABLE 3.3. PERCENT OF VOID AREA FILLED AS A FUNCTION OF SLOPE, m

m	Percent of Void Area Filled
1.0	0
0.8	20
0.6	40
0.4	60
0.2	80
0.0	100

Note that this table is valid for the values assigned to the variables in this analysis. However, results may be generalized because of the use of normalized deflections.

The steps to follow are

(1) Plot deflections after the undersealing operation versus deflections before such process. These data are represented by the dots in Fig 3.11.

(2) Fit a regression line (dashed) having its origin in the area where the greatest concentration of dots near the line of equality (solid) exists. These values approximately represent the mean deflection of a given pavement section.

(3) Compute the slope of the dashed line.

(4) Compare the computed slope to the values shown in Table 3.3 for estimating the effectiveness of the undersealing operation.

It is noteworthy that the effect of such variables as temperature, placement error and season of the year was neglected to facilitate the explanation of this procedure. If adequate data and corresponding methods are available, corrections should be made.

SUMMARY

The findings from the analysis in this chapter can be summarized as follows:

(1) Deflection increases when a void is present underneath the pavement slab. Likewise, deflection increases as void area increases.

(2) Deflection decreases if the loading device is moved away from the pavement edge towards the center of the lane. This trend is also observed when there is a void underneath the pavement.

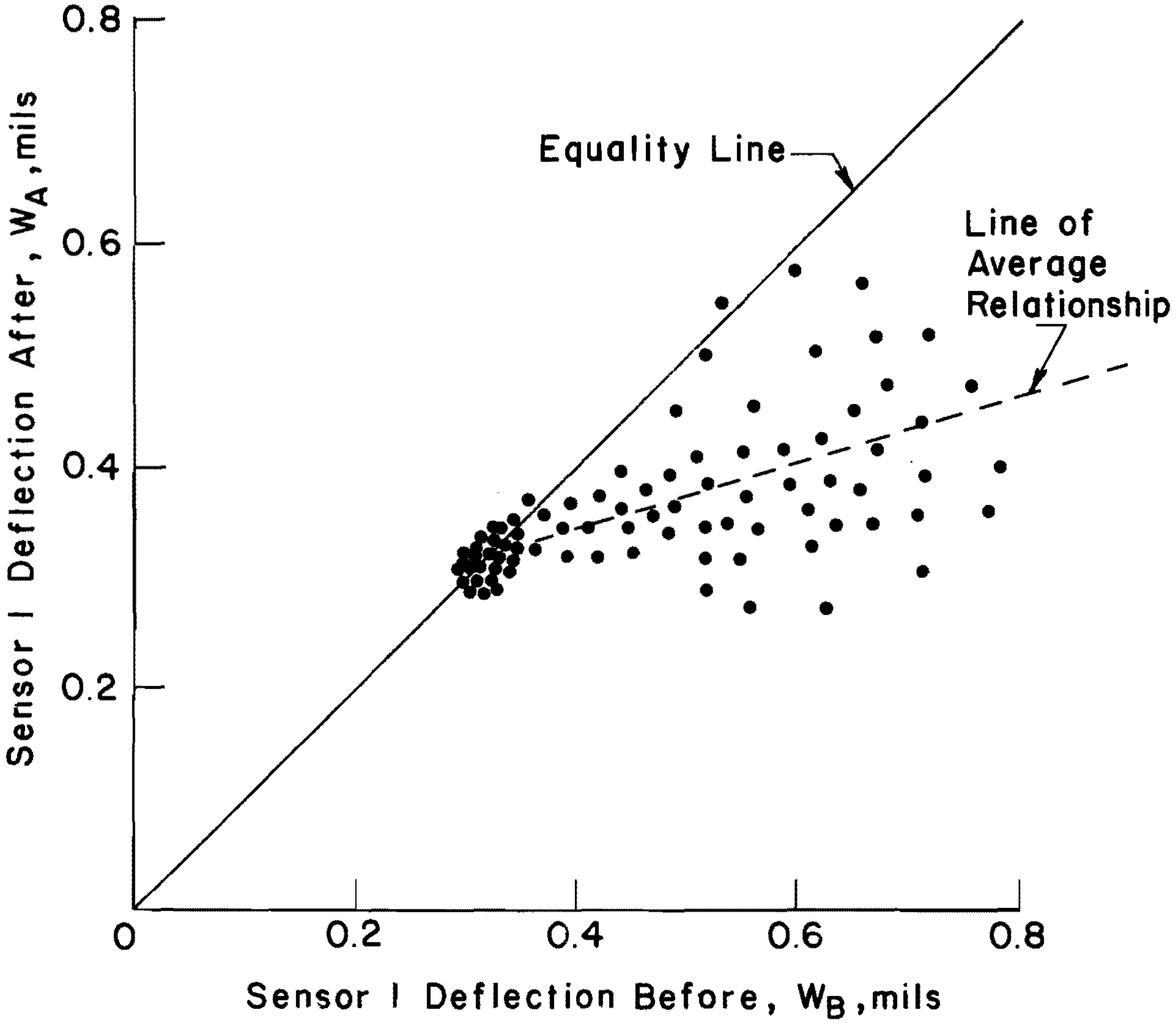


Fig 3.11. Example plot used in the recommended procedure for estimating the effectiveness of undersealing operations.

(3) The purpose of the deflection measurement defines the distance from the edge at which the deflections should be taken. If the purpose is void detection the Dynaflect sensors should be positioned at approximately one foot from the pavement edge. For design or evaluation, they should be placed at 3 to 9 feet from the pavement edge.

(4) Placement error should be kept as small as possible, without ever exceeding 5 inches.

(5) The error due to the void size is generally greater than the placement error, except for small void sizes. For void detection and pavement evaluation the maximum placement errors are 5 and 10 inches, respectively.

(6) Under uniform support conditions, deflections taken close to a transverse crack will be greater than deflections between cracks. The effect of a joint on deflections is similar to that of a transverse crack. For materials characterization, the deflections should be taken mid-way between cracks or joints.

(7) For evaluating joint or crack load transfer, the Dynaflect wheel loads should be placed both at the crack or joint and between cracks or joints.

(8) The effectiveness of processes for filling voids could be evaluated by means of the percent of void area filled using the procedure outlined in Fig 3.11 and criteria in Table 3.3.

CHAPTER 4. DETERMINATION OF THE REQUIRED NUMBER OF DYNAFLECT DEFLECTIONS TO OBTAIN REPRESENTATIVE RESULTS

One of the best methods for evaluating the condition of the pavement structure along the length of a road is with deflection measurements taken at fixed intervals along the road. By using this information, it is possible to divide the road into sections as well as to determine overlay thickness along the highway.

The principal objective of any deflection measurement method is to obtain enough representative pavement condition information at a small cost. To achieve this, several sampling methods are generally used.

The purpose of a sample survey is to make inferences about the "sampled" population. the population in this case may be either a given highway or the whole highway network (Ref 12). In any sampling process, two factors affect the usefulness of the data contained in the sample: the size of the sample and the variability of the data within the sample. The goal of most sample surveys is to keep the sample size as low as possible while keeping the variability of the data below some maximum acceptable limit.

To accomplish the above goal, careful consideration should be given to the sample survey design. Such surveys are generally inexpensive when compared to other data collection procedures but can still represent a significant investment. Some of the sample survey methods available are

(1) <u>Simple Random Sampling.</u> This method provides that every sample has an equal probability of being chosen from a population.

(2) <u>Stratified Random Sampling.</u> This is the sampling process whereby a population is divided into strata and the random samples are obtained within the described strata.

(3) <u>One-Stage Cluster Sampling.</u> This process first groups elements within a population together and then the elements are randomly sampled.

(4) <u>Multi-Stage Cluster Sampling (Multi-Stage Sampling).</u> This method is similar to One-Stage Cluster Sampling but takes the process further. Multi-Stage Clustering allows for larger areas to be clustered together and then randomly sampled. The elements within these clusters are also randomly sampled.

(5) <u>Systematic Sampling.</u> This process samples every k-th element of a set of data.

When deflection measurements are plotted to scale as a function of distance, the roadway can be divided into sections based on stratified variation of deflection data. Sections are selected subjectively, according to the plotted profile of the deflection parameters. Figure 4.1 is an example of such a plot.

After different design sections are selected , it is recommended that the student's t test be used to determine whether a particular section is significantly different from the adjacent sections. This is carried out at a specific confidence level (Ref 13).

A statistical analysis was made on Dynaflect deflection measurements from IH-10 in Jefferson County, Texas. Figure 4.1 is a plot of stationing vs

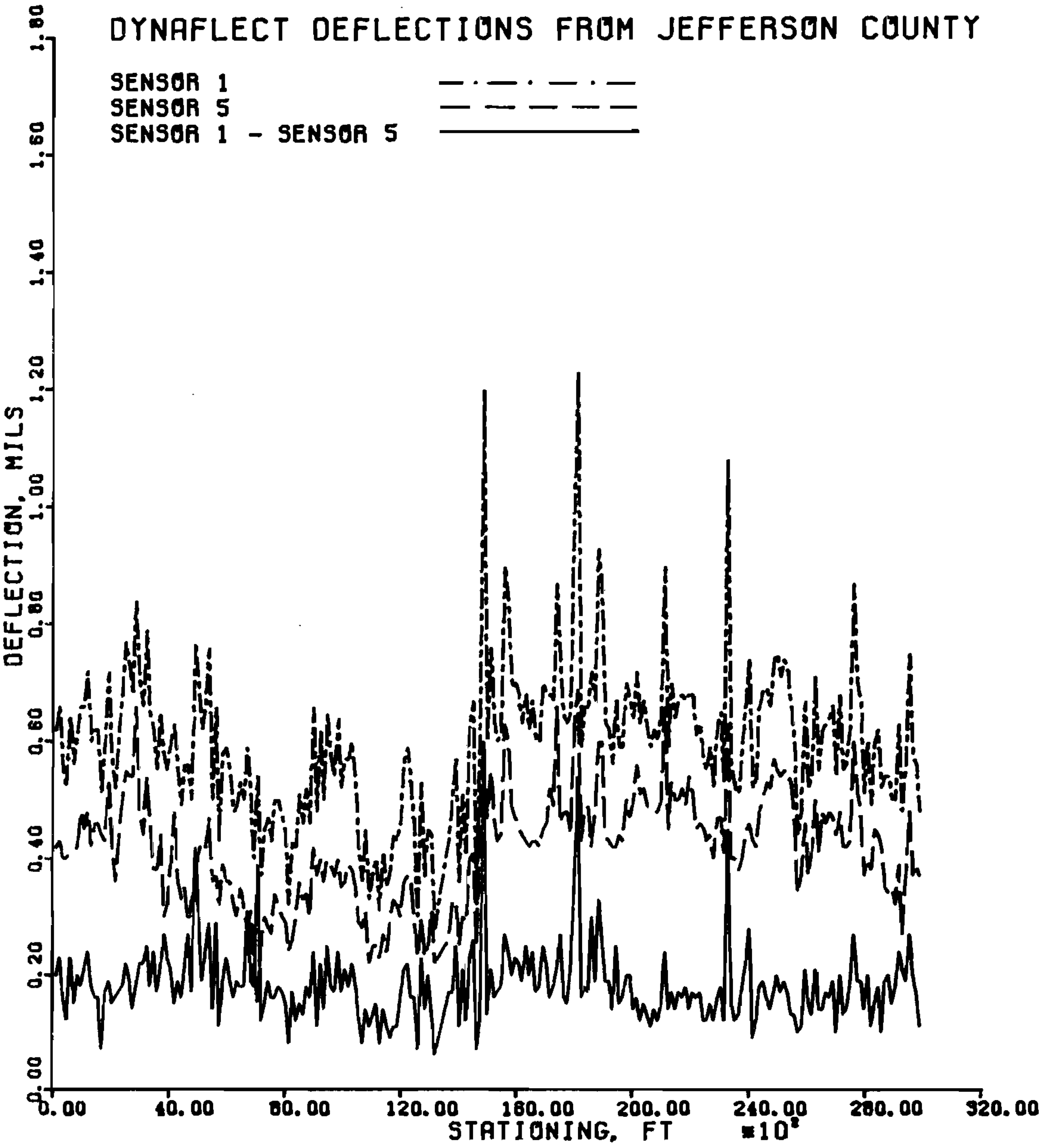


Fig 4.1. Sensor 1, sensor 5, and sensor 1 - sensor 5 deflections vs stationing from Jefferson County.

three different deflection parameters for the above project. These are sensor 1 and sensor 5 deflections and sensor 1 - sensor 5 deflection. Later in this chapter, the characteristics of the deflection data and the way the roadway was divided into design sections are discussed. A less detailed analysis was made on data from Victoria and Harrison Counties, also located in Texas.

TEST OF SIGNIFICANCE OF THE DIFFERENCE BETWEEN THE MEANS OF TWO SAMPLES (Ref 14)

In any test of significance, there are always two possible states of the universe. These are often called states of the world or states of nature. For a given test, only these two and no other states are possible, and when one exists, the other cannot exist.

The hypothesis Ho is usually called the null hypothesis. This hypothesis assumes that there is "no significant difference" between the value of the universe parameter being tested and the value of the statistic computed from a sample drawn from that universe.

Hypothesis Ha is called the alternate Hypothesis, which will be accepted if statistical testing leads to a rejection of Ho .

The five steps listed below may be used in conducting systematically any test of significance:

Step 1. Set up a null hypothesis (Ho) to be tested.

Step 2. Set up an alternate hypothesis (Ha) that can be accepted if Ho is rejected.

Step 3. Assume an appropriate level for the test. Select the proper probability distribution for the test.

Step 4. Use statistical theory to write a criterion stating the conditions under which Ho will be rejected.

Step 5. Apply the information provided by the sample to make a decision and to determine the action to be taken.

If two samples of sizes n_1 and n_2 have means $\bar{x}_1$ and $\bar{x}_2$, respectively, the null hypothesis may be stated as follows:

$$Ho : \mu_1 = \mu_2 \qquad (4.1)$$

where

μ_1 = mean of universe 1 and
μ_2 = mean of universe 2.

If this hypothesis is not rejected, a decision has been made that the two samples were drawn from a single universe with a mean, μ , and that any difference in the sample means is a sampling difference and is not significant.

Tests of significance involving two sample means are often made under conditions where the universe standard deviations are not known, but are assumed to be equal. The sample standard deviations must be used as estimates. In such cases the theoretical sampling distribution of differences is assumed to be a student's t distribution with a mean equal to zero and a standard deviation that is the estimated standard error of the difference:

$$\hat{\sigma}_{\bar{x}_1 - \bar{x}_2} = \sqrt{\frac{n_1 s_1^2 + n_2 s_2^2}{n_1 + n_2 - 2}} \sqrt{\frac{n_1 + n_2}{n_1 n_2}} \qquad (4.2)$$

where

s_1 = standard deviation of sample 1 ,

s_2 = standard deviation of sample 2 ,

$\hat{\sigma}_{\bar{x}_1 - \bar{x}_2}$ = unbiased estimate of the standard error of the difference between the two samples means .

The t value can then be computed as

$$t = \frac{(\bar{x}_1 - \bar{x}_2) - (\mu_1 - \mu_2)}{\hat{\sigma}_{\bar{x}_1 - \bar{x}_2}} \text{ or } \frac{\bar{x}_1 - \bar{x}_2}{\hat{\sigma}_{\bar{x}_1 - \bar{x}_2}} \qquad (4.3)$$

where

degrees of freedom are $n_1 + n_2 - 2$.

If the computed t is larger than the tabular value, the hypothesis is false at the confidence level, and the two sets of data come from universes with different means.

ANALYSIS OF DYNAFLECT DEFLECTION DATA

Dynaflect deflections were taken at every 120 feet (systematic sampling) in order to design an overlay for the existing continuously reinforced concrete pavement (Ref 15). Based on this information, the project was divided into 6 subsections (westbound direction).

The deflection data consist of 246 Dynaflect measurements spaced at 120 feet. In this analysis both sensor 1 and sensor 5 mean deflections were tested for significance, and, for that purpose, a 90 percent confidence level was considered. Two-tail tests of significance were made on the mean deflections.

The effect of increasing the spacing between measurements within the whole section was studied. Results are shown in Appendix B, Tables B.1 and B.2. In these tables, sample 1 (column 1) was considered to be the complete section while the size of sample 2 (column 2) was varied as the spacing between measurements was increased. The sampling distance ranges from 240 feet for 123 tests to 11,280 feet for two samples.

According to the resulting student's t values, representative mean deflections (both for sensor 1 and sensor 5) can be obtained by using systematic sampling. It is important to note that the obtained t value does not necessarily increase with increasing spacing between Dynaflect measurements. Nevertheless, a minimum number of deflections should be taken along a given section length.

It was verified that the six design subsections were correctly selected. This was accomplished by testing the mean deflections of adjacent subsections. Results are given in Tables B.3 and B.4. These corroborate the division originally made. As an additional step, the mean deflections for the whole section were compared with the mean deflections for each subsection. This is also shown in Tables B.3 and B.4. These tables show that the sensor 1 and sensor 5 deflection means corresponding to some subsections were drawn from the same universe as the deflection means for the complete section.

Each subsection was separately analyzed to determine the effect of increasing spacing between deflection measurements and results similar to those for the complete section were obtained, as can be observed in Table B.5 through Table B.16. These tables prove that, by using systematic sampling, representative results can be obtained.

In some instances, for a given subsection and for a specific spacing between measurements, two mean deflections for one sensor can be said to be significantly different, whereas the opposite can be true for the other two mean deflections corresponding to the other sensor. This confirms the criteria used for selecting design sections in Reference 13.

In general, the information resulting from the analysis of the deflection data from Victoria and Harrison Counties showed the same trend as the results from Jefferson County. No information concerning these projects is provided in this study.

The mean deflections for the difference between sensor 1 and sensor 5 were also studied, but results did not correlate very well with the results corresponding to either sensor 1 or sensor 5, especially when adjacent subsections were tested to determine if they were significantly different.

DETERMINATION OF THE SAMPLE SIZE

If the deflection measurements are normally distributed, a statistical formula can be used to determine the sample size.

If the value of σ (universe standard deviation) is known, a level of confidence is specified, and the allowable error (E) in estimating (universe mean) is given, a confidence interval of μ can be produced by selecting a sample of the correct size (Ref 14).

The formal expression to determine the size of a sample is written

$$n = \left[\frac{Z_\alpha \sigma}{E} \right]^2 \tag{4.4}$$

where

n = sample size,

Z_α = the abscissa of the normal curve which cuts off an area (level of significance) at the tails,

E = allowable error.

If previous records of the deflection data of a given pavement section are available, then σ can be easily estimated. The value of Z_α depends on the confidence level selected. The allowable error, E , is sometimes expressed as a percentage of the mean deflection.

A factorial experiment was prepared to propose values for this allowable error. In this case, the allowable error was related to the increase or decrease in sensor 1 deflections due to variations in the surface layer thickness for various subgrade conditions. The values considered in the factorial experiment are shown in Fig 4.2

The Elastic Layered System Computer Program, ELSYM5 (Ref 16), was used to obtain the deflections corresponding to the simulated Dynaflect loads for the set of conditions for the factorial experiment.

Sensor 1 deflections as a function of both the slab thickness and the subgrade modulus of elasticity are given in Table B.17. Then, for example, if the thickness of a 9-in. slab were varied by ± 0.25 in. (9.25 and 8.75 in.), two deflections, one smaller and one greater than the deflection corresponding to the 9-in. slab would be obtained:

$$W_{9.25''} < W_{9.00''} < W_{8.75''} \tag{4.5}$$

where

$W_{8.75''}$ = sensor 1 deflection for an 8.75-in. slab,
$W_{9.00''}$ = sensor 1 deflection for a 9.00-in. slab,
$W_{9.25''}$ = sensor 1 deflection for a 9.25-in. slab.

Then, if the absolute values of $(W_{9.25''} - W_{9.00''})$ and $(W_{9.00''} - W_{8.75''})$ are averaged, the ratio of average change in sensor 1 deflection corresponding to a ± 0.25-in. variation in a given slab thickness to the sensor 1 deflection for such slab thickness, $\text{Ratio}_{0.25''}$, can be computed as follows:

$$\text{Ratio}_{0.25''} = \frac{|W_{9.25''} - W_{9.00''}| + |W_{9.00''} - W_{8.75''}|}{2W_{9.00''}} \tag{4.6}$$

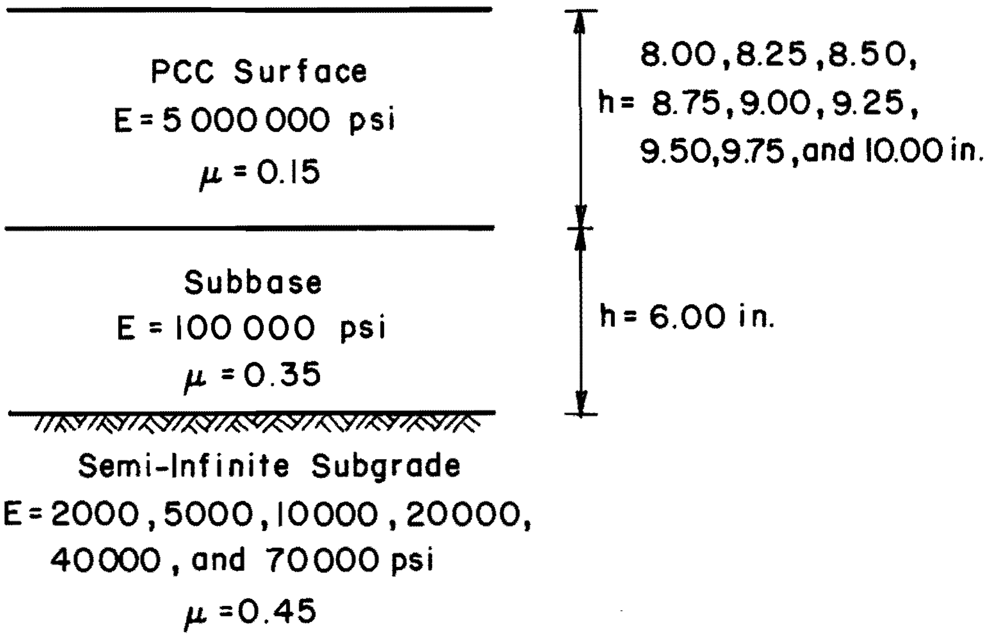


Fig 4.2. Values of the parameters used in the factorial experiment.

Table B.18 shows the values for the ratio of average change in sensor 1 deflection corresponding to a 0.25-in. variation in a given slab thickness to the sensor 1 deflection for such slab thickness. The values for the same type of ratio when the slab thickness is varied by ± 0.50 in. are given in Table B.19.

As mentioned before, the allowable error can be expressed as a percentage of the mean deflection. If the results from Tables B.18 and B.19 are studied, it can be concluded that a change in slab thickness of ± 0.25 in. causes a variation in sensor 1 deflection of approximately 2.5 percent in the sensor 1 deflection for the thickness analyzed, whereas a change in slab thickness of ± 0.50 in. produces a variation in sensor 1 deflection of about 5.0 percent.

The above statement may also be interpreted in a different way, if a pavement is going to be designed based on the information provided by the deflection data, an allowable error of 2.5 percent for the sensor 1 mean deflection will result in a pavement thickness within ± 0.25 in. of the required thickness. Likewise, an allowable error of 5.0 percent in the sensor 1 mean deflection will give a design within ± 0.50 in. of the required thickness.

Once the sample size is determined, the spacing between deflection measurements can be calculated. The shortest section selected should be long enough so that it is practical and important to construct a distinct set of pavement thicknesses and materials over the length of the section. Implementation of the RPOD2 design procedure has indicated that this length is approximately 1000 feet (Ref 13).

For a new project, design sections need to be obtained. To accomplish this, the number of deflection measurements should be determined, either by selecting an allowable error or by following the guidelines established by the agency in charge of the design.

If deflection data for an old project are available, the design sections already defined can be analyzed to determine the optimum number of deflections that are required.

Data from the Texas Highway Department (Ref 21) for 8-inch CRC pavements show a standard deviation in the thickness of about 0.23 in. Based on this information, an allowable error resulting in a pavement thickness variation approximately equal to the variation due to construction should be considered.

It was previously found that an allowable error of 2.5 percent in the sensor 1 deflection causes a pavement thickness variation of 0.25 in., which in turn is approximately equal to the variation observed in the field. In Table 4.1, an example of the determination of the required number of deflections is presented. Data from Appendix B are considered for several levels of confidence. Typical values can be assumed when no information is available. A value of 0.6 mils will be used as the sensor 1 mean deflection. A sensor 1 standard deviation of 0.1 mils will be considered, and the allowable error will be equal to 2.5 percent in the sensor 1 mean deflection.

TABLE 4.1. REQUIRED NUMBER OF DYNAFLECT DEFLECTIONS FOR VARIOUS LEVELS OF CONFIDENCE

Level of Confidence, %	Z_α	Required Number of Deflections
70	1.04	48
80	1.28	73
90	1.64	120
95	1.96	171
99	2.58	296

The deflection data in Appendix D, from Jefferson County, Texas, included 246 deflection measurements. This number of deflection measurements can be obtained by using a high level of confidence. In general levels of confidence of 90 percent or more are considered.

SUMMARY

The following paragraphs constitute a summary of the material covered in this chapter. Conclusions relative to the analysis are also presented.

(1) Systematic sampling can be used to obtain representative pavement condition information in an inexpensive way. This sampling method should be applied on the selected sections. Systematic sampling provides representative results even for small sample sizes, as demonstrated in this chapter. Nevertheless, the sample size should be chosen according to the purpose of the deflection measurements.

(2) If the deflection data can be assumed to be normally distributed, the sample size can be easily determined. The allowable error can be expressed as a percentage of the sensor 1 mean deflection. An error of 2.5 percent the sensor 1 mean deflection can be considered to be equivalent to an accuracy of ± 0.25 in. with respect to the required pavement thickness, whereas an allowable error of 5.0 percent the sensor 1 mean deflection will result in a pavement thickness within ± 0.50 in. of the needed thickness. The procedure followed to obtain these allowable errors has been explained in this chapter and the information generated is shown in Tables B.17

through B.19. An example of the application of this concept is presented in Table 4.1.

(3) It was found that both sensor 1 and sensor 5 deflections provide representative information about the pavement condition. However, they should always be used in conjunction in order to obtain the best possible results.

(4) To divide the roadway into sections, the deflection measurements (both sensor 1 and sensor 5) should be plotted to scale as illustrated in Fig 4.1. The sections should be selected subjectively, based on the plotted profile of the deflection parameters.

(5) After the roadway is divided into sections, adjacent design sections should be checked to see if they are significantly different. A student's t test can be used for that purpose. Table B.3 is an example of the way this test should be performed.

CHAPTER 5. DISCUSSION OF RESULTS

This chapter presents a brief discussion of results. The findings from this study are basically the result of theoretical analyses and a review of the available literature, and they are grouped together in a recommended procedure for Dynaflect deflection measurements, which is described in Appendix C.

The initial step to take when deflections of a given pavement section are needed should be that of defining the purpose of the testing. Second, the proper measurement program should be selected. Nowadays, deflections are generally used for void detection, materials characterization, and evaluation of load transfer at cracks or joints.

It was found that for void detection purposes, the Dynaflect sensors should be placed at approximately one foot from the pavement edge. A tentative procedure for evaluating the effectiveness of undersealing processes has been proposed.

If the pavement layers are to be characterized, the effect of the pavement edge should be minimized. This can be accomplished by placing the Dynaflect sensors at 3 to 9 feet from the pavement edge. Furthermore, this device should be placed between transverse cracks or joints.

The need for accuracy in the Dynaflect placement was pointed out. In general, placement error should never exceed 5 inches.

The use of systematic sampling results in an inexpensive way of obtaining information on the pavement condition once the highway has been divided into design sections. These design sections can be established by analyzing existing deflection data. Guidelines for selecting the sampling allowable error have been provided.

The following chapter is devoted to the summary, conclusions, and recommendations of this study.

CHAPTER 6. SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

SUMMARY

The effect of some of the factors that have an influence on deflections of rigid pavements has been analyzed. A discussion about temperature and moisture changes, which are the environmental factors having the most influence on the behavior and performance of a pavement, has been provided.

A theoretical analysis in which a CRC pavement was modeled has been made. several voids of various sizes underneath the slab were simulated for different support conditions. The Dynaflect load wheels were also simulated, and the Dynaflect sensors were positioned at several distances from the pavement edge. the effect of an error in the placement of the Dynaflect device was evaluated. Plots were prepared to show results.

The use of statistical techniques to determine the required number of Dynaflect deflections to obtain representative results was discussed. If the assumption is made that the Dynaflect deflections are normally distributed, the number of required measurements can be computed by selecting a confidence level and by choosing an allowable error. The choice of a given allowable error was given as a function of slab thickness.

CONCLUSIONS

Some of the most important conclusions that stem from this study are the following:

(1) When deflection measurements of a given pavement section are to be compared, the influence of environmental factors such as temperature and moisture should be accounted for.

(2) The purpose of the deflection measurement program should always be defined. Deflections may be required for void detection, materials characterization, or load transfer evaluation.

(3) If the Dynaflect device is used to detect voids underneath the pavement surface layer, the Dynaflect sensors should be aligned parallel to the pavement edge at approximately one foot from it. If the pavement layers are to be characterized, the Dynaflect should be placed between cracks (or joints), at 3 to 9 feet from the pavement edge.

(4) The Dynaflect placement error should be kept as small as possible, without at any time exceeding 5 in. It is extremely important to record the distance from the edge at which the Dynaflect is placed in order to compare deflections. For void detection and materials characterization the maximum placement errors are 5 and 10 in., respectively.

(5) The effectiveness of undersealing operations could be evaluated by means of the percent of void area filled using the procedure outlined in Chapter 3 and criteria in Table 3.3.

(6) For evaluating joint or crack load transfer, the Dynaflect wheel loads should be placed both at the crack or joint and between cracks or joints.

(7) To divide the roadway into sections, the variation of both sensor 1 and sensor 5 deflections along the highway should be considered. This can be accomplished by plotting such deflection parameters to subjectively select the road sections.

(8) It was found out that once the division of the roadway is made, systematic sampling can be used to obtain representative results in an inexpensive way. The spacing between measurements could be determined by analyzing existing deflection data.

(9) If it is valid to assume a normal distribution for the Dynaflect deflections, a simple expression can be used to determine the number of deflections required in a given section of the road, based on a selected allowable error. Allowable errors of 2.5 percent and 5.0 percent in the sensor 1 mean deflection were studied and converted to equivalent variation in thickness of the pavement surface layer.

RECOMMENDATIONS

It is believed that more effort should be directed toward better understanding of the effect of environmental factors on the pavement, and the ability to predict in-service environmental conditions should be improved. This would result in the determination of seasonal and daily adjustment factors for Dynaflect deflections. Likewise, the recommended procedure for

Dynaflect deflection measurements described in Appendix C should be implemented.

A field experiment should be conducted in which the void size would be a controlled variable. Several values for such variables as subgrade strength and slab thickness could be considered. Likewise, it would be very useful to simultaneously keep a record of the environmental conditions present at the time of that experiment. The effect of voids on the fatigue life of a rigid pavement could also be studied. The Dynaflect could be used in the experiment.

Finally, the available deflection data for a given highway or a certain road network should be analyzed to determine the required number of deflections that would give representative results of the pavement condition. This would produce a reduction in the total cost of the deflections that are routinely taken.

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APPENDIX A

RESULTS FROM THE SLAB-49 COMPUTER PROGRAM USED IN CHAPTER 3 TO EVALUATE THE EFFECT OF VOID SIZE AND DYNAFLECT POSITION ON DEFLECTIONS

TABLE A.1. SENSOR 1 DEFLECTIONS (W_1), MILS

K-Value, psi/in.	Void Area, sq ft	Distance from the Pavement Edge to the Dynaflect Sensors, in.		
		10	40	80
100	0	2.069	1.045	0.853
	7	2.411	1.174	0.871
	13	2.811	1.326	0.893
	27	3.564	1.611	0.932
	40	4.283	1.883	0.967
400	0	0.906	0.442	0.409
	7	1.168	0.516	0.414
	13	1.499	0.608	0.419
	27	2.106	0.766	0.426
	40	2.614	0.890	0.430
800	0	0.592	0.294	0.282
	7	0.819	0.352	0.285
	13	1.124	0.423	0.287
	27	1.688	0.540	0.289
	40	2.115	0.619	0.290

TABLE A.2. SENSOR 5 DEFLECTIONS (W_5), MILS

K-Value, psi/in.	Void Area, sq ft	Distance from the Pavement Edge to the Dynaflect Sensors, in.		
		10	40	80
100	0	1.143	0.537	0.426
	7	1.338	0.608	0.436
	13	1.584	0.699	0.448
	27	2.346	0.987	0.486
	40	2.991	1.223	0.513
400	0	0.323	0.134	0.129
	7	0.422	0.159	0.131
	13	0.570	0.196	0.132
	27	1.139	0.341	0.138
	40	1.579	0.442	0.139
800	0	0.151	0.062	0.063
	7	0.214	0.074	0.063
	13	0.323	0.096	0.064
	27	0.819	0.196	0.065
	40	1.185	0.259	0.065

APPENDIX B

RESULTS FROM THE STUDY DESCRIBED IN CHAPTER 4

APPENDIX B. RESULTS FROM THE STUDY DESCRIBED IN CHAPTER 4.

The terms used in Table B.1 to Table B.16 are explained below:

n_1 = number of deflection measurements in sample 1 (size of sample 1)

n_2 = number of deflection measurements in sample 2 (size of sample 2)

$\bar{x}_1$ = either sensor 1 or sensor 5 deflection mean for sample 1, mils

$\bar{x}_2$ = either sensor 1 or sensor 5 deflection mean for sample 2, mils

s_1 = standard deviation of the deflection measurements (either sensor 1 or sensor 5) in sample 1, mils

s_2 = standard deviation of the deflection measurements (either sensor 1 or sensor 5) in sample 2, mils

$|t|$ = absolute value of the statistic t, which is computed for the test of significance of the difference between the means of two samples

Two-tail tests were made on the data considering a 90 percent confidence level.

TABLE B.1. TEST OF SIGNIFICANCE FOR SENSOR 1 MEAN DEFLECTIONS COMPLETE SECTION

n_1	n_2	$\bar{x}_1$	$\bar{x}_2$	s_1	s_2	$\|t\|$	Both Samples were Drawn from the Same Universe
246	123	0.597	0.584	0.134	0.128	0.889	True
	82		0.596		0.119	0.060	True
	49		0.586		0.115	0.535	True
	35		0.592		0.143	0.204	True
	24		0.570		0.112	0.952	True
	16		0.587		0.123	0.290	True
	12		0.567		0.115	0.759	True
	10		0.584		0.142	0.299	True
	8		0.567		0.107	0.624	True
	6		0.587		0.051	0.182	True
	4		0.570		0.127	0.398	True
	2		0.470		0.198	1.323	True

TABLE B.2. TEST OF SIGNIFICANCE FOR SENSOR 5 MEAN DEFLECTIONS COMPLETE SECTION

n_1	n_2	$\bar{x}_1$	$\bar{x}_2$	s_1	s_2	$\lvert t \rvert$	Both Samples were Drawn from the Same Universe
246	123	0.414	0.412	0.096	0.095	0.189	True
	82		0.416		0.094	0.164	True
	49		0.416		0.088	0.135	True
	35		0.415		0.099	0.057	True
	24		0.410		0.089	0.195	True
	16		0.416		0.092	0.081	True
	12		0.397		0.090	0.598	True
	10		0.429		0.119	0.520	True
	8		0.412		0.098	0.058	True
	6		0.338		0.057	0.658	True
	4		0.400		0.119	0.287	True
	2		0.335		0.163	1.146	True

TABLE B.3. TEST OF SIGNIFICANCE FOR SENSOR 1 MEAN DEFLECTIONS ALL SUBSECTIONS

Subsection Number	n_1	$\bar{x}_1$	s_1	Subsection Number	n_2	$\bar{x}_2$	s_2	$\lvert t \rvert$	Both Samples were Drawn from the Same Universe
1	51	0.622	0.085	2	23	0.469	0.059	7.718	False
2	23	0.469	0.059	3	13	0.573	0.058	4.967	False
3	13	0.573	0.058	4	29	0.428	0.082	5.623	False
4	29	0.428	0.082	5	94	0.674	0.131	9.474	False
5	94	0.674	0.131	6	36	0.586	0.090	3.681	False
Complete Section	246	0.597	0.134	1	51	0.622	0.085	1.276	True
				2	23	0.469	0.059	4.523	False
				3	13	0.573	0.058	0.640	True
				4	29	0.428	0.082	6.622	False
				5	94	0.674	0.131	4.754	False
				6	36	0.586	0.090	0.475	True

TABLE B.4. TEST OF SIGNIFICANCE FOR SENSOR 5 MEAN DEFLECTIONS ALL SUBSECTIONS

Subsection Number	n_1	x_1	s_1	Subsection Number	n_2	x_2	s_2	$\|t\|$	Both Samples were Drawn from the Same Universe
1	51	0.423	0.073	2	23	0.293	0.047	7.733	False
2	23	0.293	0.047	3	13	0.380	0.022	6.118	False
3	13	0.380	0.022	4	29	0.285	0.044	7.204	False
4	29	0.285	0.044	5	94	0.484	0.070	14.336	False
5	94	0.484	0.070	6	36	0.416	0.065	5.015	False
Complete Section	246	0.414	0.096	1	51	0.423	0.073	0.631	True
				2	23	0.293	0.047	5.956	False
				3	13	0.380	0.022	1.270	True
				4	29	0.285	0.044	7.122	False
				5	94	0.484	0.070	6.426	False
				6	36	0.416	0.065	0.121	True

TABLE B.5. TEST OF SIGNIFICANCE FOR SENSOR 1 MEAN DEFLECTIONS SUBSECTION 1

n_1	n_2	$\bar{x}_1$	$\bar{x}_2$	s_1	s_2	$\|t\|$	Both Samples were Drawn from the Same Universe
	25		0.610		0.094	0.551	True
	12		0.617		0.110	0.170	True
51	8	0.622	0.596	0.085	0.125	0.735	True
	6		0.620		0.150	0.048	True
	3		0.613		0.050	0.178	True
	2		0.735		0.049	1.832	False

TABLE B.6. TEST OF SIGNIFICANCE FOR SENSOR 5 MEAN DEFLECTIONS SUBSECTION 1

n_1	n_2	$\bar{x}_1$	$\bar{x}_2$	s_1	s_2	$\|t\|$	Both Samples were Drawn from the Same Universe
	25		0.423		0.081	0.000	True
	12		0.436		0.103	0.501	True
	8		0.420		0.106	0.099	True
51	6	0.423	0.437	0.073	0.144	0.382	True
	3		0.397		0.093	0.578	True
	2		0.480		0.099	1.046	True

TABLE B.7. TEST OF SIGNIFICANCE FOR SENSOR 1 MEAN DEFLECTIONS SUBSECTION 2

n_1	n_2	$\bar{x}_1$	$\bar{x}_2$	s_1	s_2	$\lvert t \rvert$	Both Samples were Drawn from the Same Universe
23	11	0.469	0.483	0.059	0.038	0.697	True
	7		0.456		0.052	0.506	True
	4		0.505		0.062	1.076	True
	2		0.490		0.071	0.455	True

TABLE B.8. TEST OF SIGNIFICANCE FOR SENSOR 5 MEAN DEFLECTIONS SUBSECTION 2

n_1	n_2	$\bar{x}_1$	$\bar{x}_2$	s_1	s_2	$\lvert t \rvert$	Both Samples were Drawn from the Same Universe
23	11	0.293	0.293	0.047	0.055	0.000	True
	7		0.296		0.037	0.150	True
	4		0.310		0.035	0.665	True
	2		0.220		0.099	1.790	False

TABLE B.9. TEST OF SIGNIFICANCE FOR SENSOR 1 MEAN DEFLECTIONS SUBSECTION 3

n_1	n_2	$\bar{x}_1$	$\bar{x}_2$	s_1	s_2	$\|t\|$	Both Samples were Drawn from the Same Universe
	6		0.560		0.060	0.425	True
13	4	0.573	0.578	0.058	0.043	0.150	True
	2		0.585		0.021	0.270	True

TABLE B.10. TEST OF SIGNIFICANCE FOR SENSOR 5 MEAN DEFLECTIONS SUBSECTION 3

n_1	n_2	$\bar{x}_1$	$\bar{x}_2$	s_1	s_2	$\|t\|$	Both Samples were Drawn from the Same Universe
	6		0.377		0.016	0.283	True
13	4	0.380	0.380	0.022	0.022	0.000	True
	2		0.385		0.007	0.297	True

TABLE B.11. TEST OF SIGNIFICANCE FOR SENSOR 1 MEAN DEFLECTIONS SUBSECTION 4

n_1	n_2	$\bar{x}_1$	$\bar{x}_2$	s_1	s_2	$\|t\|$	Both Samples were Drawn from the Same Universe
	14		0.431		0.085	0.108	True
	9		0.418		0.082	0.311	True
29	7	0.428	0.430	0.082	0.071	0.058	True
	4		0.390		0.062	0.865	True
	2		0.540		0.042	1.852	False

TABLE B.12. TEST OF SIGNIFICANCE FOR SENSOR 5 MEAN DEFLECTIONS SUBSECTION 4

n_1	n_2	$\bar{x}_1$	$\bar{x}_2$	s_1	s_2	$\|t\|$	Both Samples were Drawn from the Same Universe
	14		0.286		0.047	0.067	True
	9		0.276		0.047	0.513	True
29	7	0.285	0.281	0.044	0.053	0.201	True
	4		0.265		0.039	0.837	True
	2		0.330		0.042	1.357	True

TABLE B.13. TEST OF SIGNIFICANCE FOR SENSOR 1 MEAN DEFLECTIONS SUBSECTION 5

n_1	n_2	$\bar{x}_1$	$\bar{x}_2$	s_1	s_2	$\|t\|$	Both Samples were Drawn from the Same Universe
94	47	0.674	0.662	0.131	0.117	0.527	True
	31		0.665		0.131	0.329	True
	18		0.699		0.166	0.702	True
	11		0.709		0.176	0.797	True
	7		0.711		0.130	0.714	True
	4		0.765		0.179	1.323	True
	2		0.570		0.071	1.108	True

TABLE B.14. TEST OF SIGNIFICANCE FOR SENSOR 5 MEAN DEFLECTIONS SUBSECTION 5

n_1	n_2	$\bar{x}_1$	$\bar{x}_2$	s_1	s_2	$\|t\|$	Both Samples were Drawn from the Same Universe
94	47	0.484	0.482	0.070	0.064	0.163	True
	31		0.478		0.079	0.397	True
	18		0.487		0.057	0.170	True
	11		0.507		0.074	1.015	True
	7		0.526		0.090	1.483	True
	4		0.522		0.127	1.006	True
	2		0.430		0.000	1.080	True

TABLE B.15. TEST OF SIGNIFICANCE FOR SENSOR 1 MEAN DEFLECTIONS SUBSECTION 6

n_1	n_2	$\bar{x}_1$	$\bar{x}_2$	s_1	s_2	$\lvert t \rvert$	Both Samples were Drawn from the Same Universe
36	18	0.586	0.571	0.090	0.072	0.604	True
	12		0.619		0.080	1.106	True
	7		0.566		0.051	0.557	True
	4		0.587		0.097	0.020	True
	2		0.610		0.099	0.355	True

TABLE B.16. TEST OF SIGNIFICANCE FOR SENSOR 5 MEAN DEFLECTIONS SUBSECTION 6

n_1	n_2	$\bar{x}_1$	$\bar{x}_2$	s_1	s_2	$\lvert t \rvert$	Both Samples were Drawn from the Same Universe
36	18	0.416	0.411	0.065	0.053	0.277	True
	12		0.434		0.052	0.853	True
	7		0.411		0.035	0.193	True
	4		0.420		0.079	0.111	True
	2		0.415		0.092	0.020	True

TABLE B.17. SENSOR 1 DEFLECTION (W_1), MILS, AS OBTAINED FROM ELSYM5 PROGRAM

Slab Thickness, in.	Subgrade Modulus of Elasticity, psi					
	2000	5000	10000	20000	40000	70000
8.00	2.604	1.339	0.833	0.520	0.323	0.220
8.25	2.551	1.305	0.810	0.507	0.315	0.215
8.50	2.501	1.274	0.789	0.494	0.308	0.210
8.75	2.454	1.245	0.770	0.482	0.300	0.205
9.00	2.409	1.218	0.751	0.470	0.294	0.201
9.25	2.367	1.192	0.733	0.458	0.287	0.196
9.50	2.326	1.168	0.716	0.448	0.280	0.192
9.75	2.287	1.145	0.700	0.437	0.274	0.188
10.00	2.250	1.124	0.685	0.428	0.268	0.184

TABLE B.18. RATIO OF AVERAGE CHANGE IN SENSOR L DEFLECTION CORRESPONDING TO A ±0.25-IN VARIATION IN A GIVEN SLAB THICKNESS TO THE SENSOR 1 DEFLECTION FOR SUCH SLAB THICKNESS

Slab Thickness, in.	Subgrade Modulus of Elasticity, psi					
	2000	5000	10000	20000	40000	70000
8.00	0.020	0.025	0.028	0.025	0.025	0.023
8.25	0.020	0.025	0.027	0.026	0.025	0.023
8.50	0.019	0.024	0.025	0.025	0.024	0.024
8.75	0.019	0.022	0.025	0.025	0.023	0.022
9.00	0.018	0.022	0.025	0.026	0.022	0.022
9.25	0.018	0.021	0.024	0.024	0.024	0.023
9.50	0.017	0.020	0.023	0.023	0.023	0.021
9.75	0.017	0.019	0.022	0.023	0.022	0.021
10.00	0.016	0.019	0.022	0.021	0.022	0.022

TABLE B.19. RATIO OF AVERAGE CHANGE IN SENSOR 1 DEFLECTION CORRESPONDING TO A ±0.50-IN VARIATION IN A GIVEN SLAB THICKNESS TO THE SENSOR 1 DEFLECTION FOR SUCH SLAB THICKNESS

Slab Thickness, in.	Subgrade Modulus of Elasticity, psi					
	2000	5000	10000	20000	40000	70000
8.00	0.040	0.049	0.053	0.050	0.046	0.045
8.59	0.039	0.047	0.052	0.051	0.047	0.045
9.00	0.036	0.044	0.049	0.049	0.048	0.045
9.50	0.034	0.040	0.046	0.047	0.046	0.044
10.00	0.034	0.039	0.045	0.047	0.045	0.043

APPENDIX C

RECOMMENDED PROCEDURE FOR DYNAFLECT DEFLECTION MEASUREMENTS

APPENDIX C. RECOMMENDED PROCEDURE FOR DYNAFLECT DEFLECTION MEASUREMENTS

This appendix presents recommendations to collect Dynaflect deflections with the purpose of characterizing the materials of a pavement structure. The recommendations are based on findings from this report. Similar procedures should be developed to collect deflections for other purposes than material characterization as new information becomes available.

Among the objectives of taking deflections, the following can be mentioned: materials characterization, voids detection under PCC slabs, evaluation of maintenance methods (grouting, shoulder addition, etc.), and evaluation of load transfer at cracks and joints. The information required for the design of an overlay may involve several of these activities.

When collecting deflections, it is important to determine beforehand the purpose of such measurements since the specific procedure to be followed may be different in each case. Understanding the principles underlying a specific procedure will be of great help to consider other conditions not covered in the available recommendations.

A procedure to collect Dynaflect deflections needs to cover items such as (1) the location of the Dynaflect with respect to the pavement edge, (2) the allowable tolerance in locating the Dynaflect, (3) the number and spacing of readings, and (4) the time of the day and the season of the year when the information should be collected.

Figure C.1 presents a flow diagram of the entire process of taking Dynaflect deflections and analyzing the data collected to derive input information for an overlay design.

General Information

The Dynaflect deflection measurements data are to be recorded on SDHPT Form 1112-1 Rev. 5/75 (Fig C.2), and 1112-1 Rev. 5/75 (Fig C.3). These forms are included as a part of Appendix B (Rev. June 9, 1975), Stiffness Coefficient Program, of the Texas Highway Department Pavement Design System, Part I, Flexible Pavement Designer's Manual, Highway Design Division, 1972, Rev. June 1974.

Particular attention should be paid to the coding of location informAtion. On Interstate Highways, as a minimum, the beginning and ending points of measurements should be reference by milepost number. Also, some sequential numbering such as stations, odometer readings, etc., should be coded for each measurement.

DYNAFLECT DEFLECTIONS FOR MATERIALS CHARACTERIZATION

Procedure

The following procedure applies only when the purpose of collecting deflection measurements is to characterize the materials in a rigid pavement structure, and where a previous detailed condition survey has indicated that voids and load transfer are not a problem.

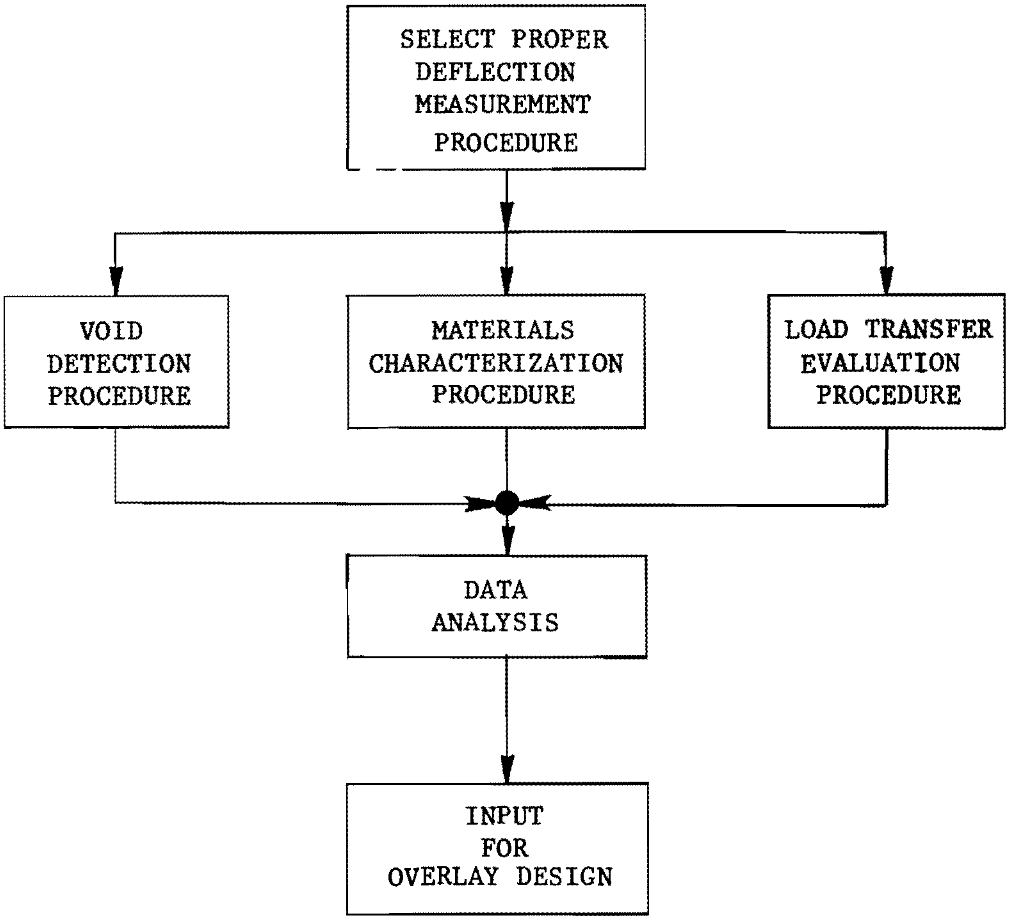
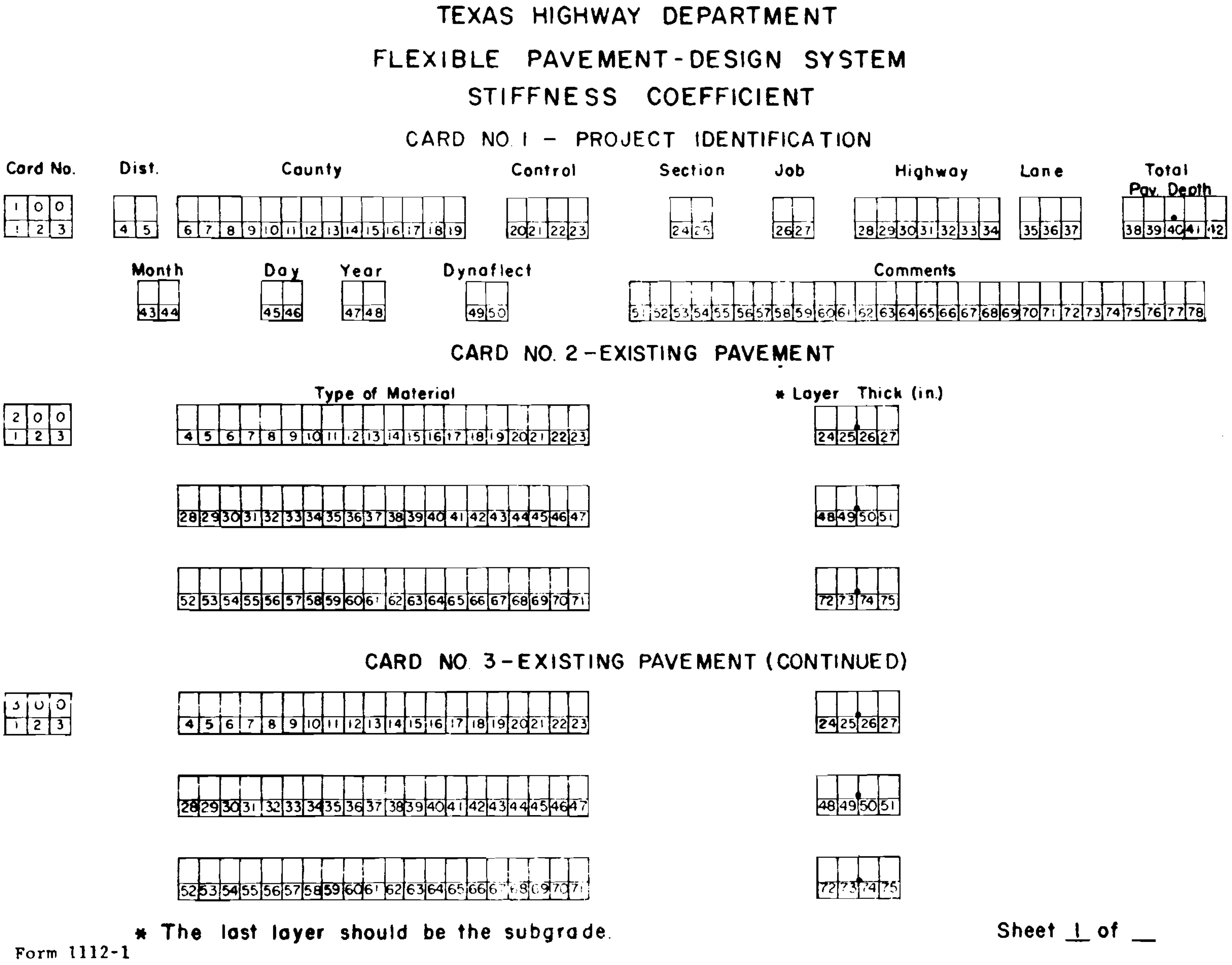


Fig C.1. Flow diagram of the process of taking Dynaflect deflection measurements and analyzing the data for an overlay design.



TEXAS HIGHWAY DEPARTMENT

FLEXIBLE PAVEMENT-DESIGN SYSTEM

STIFFNESS COEFFICIENT

CARD NO. 1 - PROJECT IDENTIFICATION

Card No.	Dist.	County	Control	Section	Job	Highway	Lane	Total Pav. Depth
1 0 0 1 2 3	4 5	6 7 8 9 10 11 12 13 14 15 16 17 18 19	20 21 22 23	24 25	26 27	28 29 30 31 32 33 34	35 36 37	38 39 . 40 41 42

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

CARD NO. 2 - EXISTING PAVEMENT

	Type of Material	* Layer Thick (in.)
2 0 0 1 2 3	4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23	24 25 . 26 27
	28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47	48 49 . 50 51
	52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71	72 73 . 74 75

CARD NO. 3 - EXISTING PAVEMENT (CONTINUED)

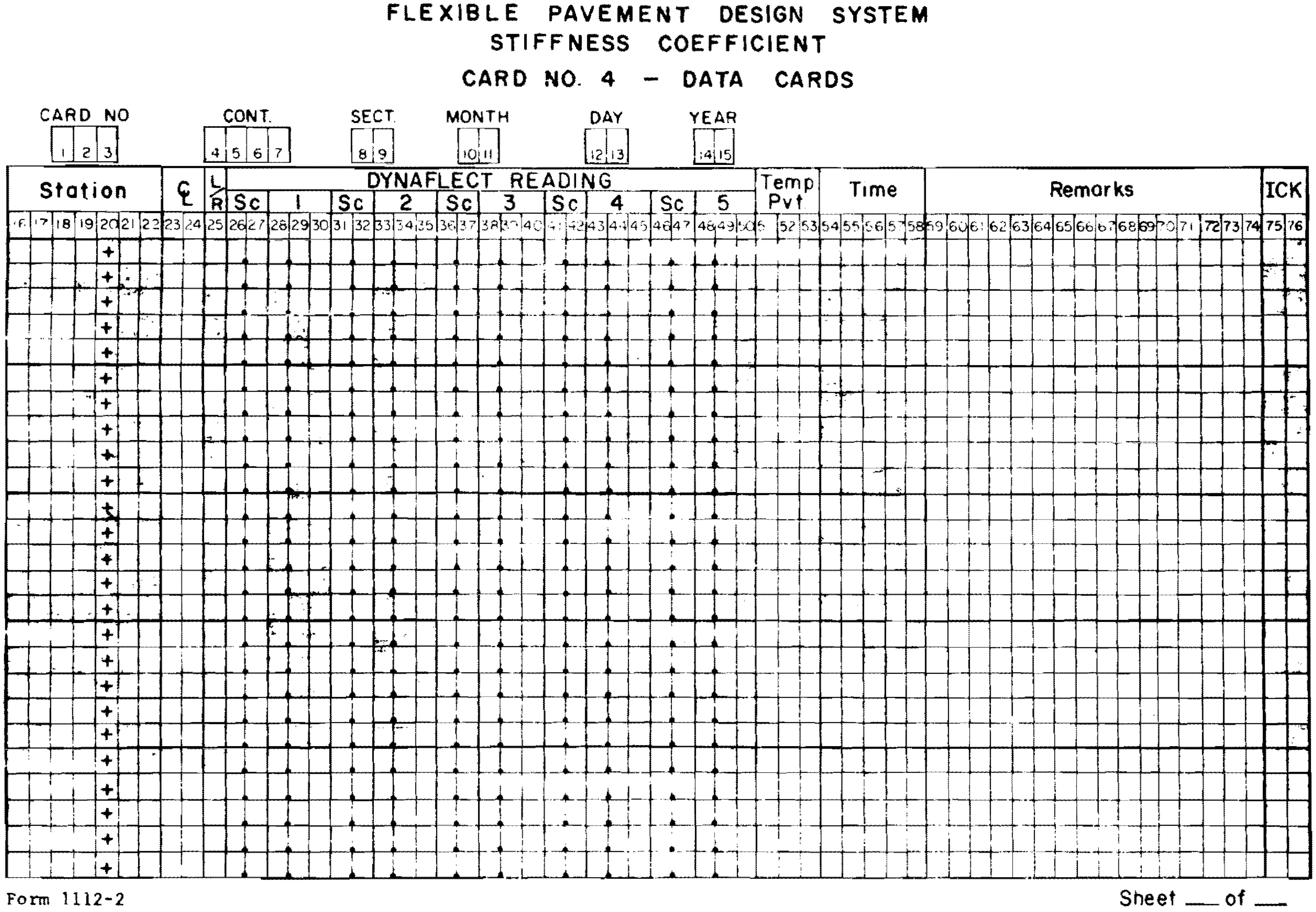
3 0 0 1 2 3	4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23	24 25 . 26 27
	28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47	48 49 . 50 51
	52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71	72 73 . 74 75

* The last layer should be the subgrade.

Sheet 1 of __

Form 1112-1

Fig C.2. The SDHPT standard form to record pavement information for Dynaflect deflection measurements.



FLEXIBLE PAVEMENT DESIGN SYSTEM
STIFFNESS COEFFICIENT
CARD NO. 4 – DATA CARDS

CARD NO 1 2 3
CONT. 4 5 6 7
SECT. 8 9
MONTH 10 11
DAY 12 13
YEAR 14 15

Station	℄	L/R	DYNAFLECT READING Sc	1	Sc	2	Sc	3	Sc	4	Sc	5	Temp Pvt	Time	Remarks	ICK
16 17 18 19 20 21 22	23 24	25	26 27	28 29 30	31 32	33 34 35	36 37	38 39 40	41 42	43 44 45	46 47	48 49 50	51 52 53	54 55 56 57 58	59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74	75 76
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Form 1112-2

Sheet ___ of ___

Fig C.3. The SDHPT standard form to record Dynaflect deflection measurements.

Location of Measurements. It is intended that all measurements be taken three to six feet from the outside edge of the concrete pavement. The distance from the pavement edge should always be recorded in order to facilitate comparisons with deflections taken at a different time.

Commentaries. To determine the material properties in a rigid pavement, the best location of the Dynaflect appears to be the middle of the slab, in the outside lane, because

(a) If there is a void under the slab, it is more likely to occur in the zone between the wheelpath and the pavement edge. By placing the Dynaflect away from this zone, the risk of having a void underneath is minimized.

(b) The estimate of the subgrade support is made using elastic layered theory which assumes infinite dimensions in the horizontal directions; therefore, the middle of the slab approaches better such condition than the edge of the pavement.

Tolerance. The Dynaflect should be placed with an accuracy of ± 10-inches of the specified distance from the pavement edge.

Commentaries. In order to minimize errors and to assure repeatability of measurements, it is necessary to specify a position tolerance for the Dynaflect. This tolerance become more restrictive when measurements are taken near to the pavement edge and the presence of voids is a factor to be considered.

Frequency of Measurements. The number of deflection measurements that should be taken can be determined from statistical considerations once a previous sample or a preliminary sample of deflections is available.

The following guidelines for deflection measurements are recommended when no previous information is available on a pavement section; the results of such measurement should be corroborated to determine if additional measurements are required. The guidelines are based on the type of terrain (Ref 20):

(a) For rolling terrain or in sections with numerous cut to fill transitions, deflection measurements should be taken every 100-ft as a minimum.

(b) In a level section with uniform soil, measurements should be taken at least every 250-ft.

Commentaries. If the assumption of a normal distribution for the Dynaflect deflection is valid, the number of deflection measurements that should be taken can be determined from statistical considerations. Once a previous sample or a preliminary sample of deflections is obtained, the sample mean and the standard deviation can be computed. By specifying both a confidence level and an allowable error, it is possible to verify if the sample size is representative or if additional measurement are required using the equation

$$n = \left[\frac{Z \cdot S}{\overline{X} \cdot PE} \right]^2$$

where

n = number of measurements in a section,

$\overline{X}$ = mean sensor 1 deflection,

s = standard deviation of the sensor 1 deflections,

PE = allowable percent error, and

z = constant depending on the confidence level required as follows

Confidence Level	Z
80	1.28
90	1.64
95	1.96
99	2.58

Example. A sample of deflection has been taken every 50-ft in a 1,000-ft section (20 measurements) and the following statistics have been calculated

$x = 0.605$

$s = 0.112$

Determine if the sample is adequate for an allowable 10 percent error with a 95 percent confidence level.

$$n = \left[\frac{1.96 \times 0.112}{0.605 \times 0.10}\right]^2 = 13 < 20 \text{ observations}$$

The number of required measurements is less than the actual number in the sample; therefore, the sample is adequate.

Environmental Considerations. Environmental effects, mainly temperature differential between the upper and lower part of the slab and moisture content in the layers forming the pavement structure, affect the Dynaflect readings. Therefore, the following recommendations should be followed to account for such effects.

(a) Time of day - Dynaflect deflections should be taken in the morning (from about two hours after sunrise) to early in the afternoon to minimize the effects of the temperature differential between top and bottom of the slab.

(b) Season of the year - Dynaflect deflections should be collected in both dry and wet seasons.

Commentaries. Research is being carried out in CTR Research Project 256 "The Study of New Technologies for Pavement Evaluation," to estimate the effects of temperature differentials in the deflection readings, estimate the effect of temperature differentials in the deflection readings, and to develop correction factors. At the present time, the only recommendation which can be made is to take deflections when the temperature differential is minimum, i.e., from the mid-morning to early in the afternoon. It would be very useful to record the air temperature corresponding to each deflection measurement for future comparisons.

The moisture content of the various pavement layers varies with the seasons of the year. In order to assess the change in pavement properties, the approach recommended seems appropriate.

Additional Testing Required

The Dynaflect deflections are not intended to be used alone in characterizing pavement structures, but need to be complemented with some laboratory test to

(a) correlate and compare Dynaflect deflections with lab properties;

(b) define the variations of subgrade properties with depth, and to check the presence of underlying rigid stratums; and

(c) test the stress sensitivity of the materials.

The estimates of materials characteristics made from deflections alone, i.e., without materials testing, require good engineering judgement and might not be accurate.

Analysis of Information

The procedure for characterizing the material properties of a pavement structure using elastic layered computer programs has been presented in detail in Ref 13, and can be summarized as follows:

(a) An initial assumption of the pavement layer moduli needs to be made.

(b) Using the assumed moduli, the layer thicknesses and the Dynaflect load as an input to the computer program, a deflection configuration of the structure is calculated.

(c) If the deflection configuration calculated using the computer program fits the configuration measured in the field, the assumed layer moduli are correct; otherwise, a different set of layered moduli needs to be tried.

(d) Modifications to be computed values need to be made to account for the change in subgrade modulus with depth.

For a more detailed explanation, refer to Ref 13. The results from the analysis are used as an input in the overlay design procedure.

THE AUTHORS

Victor Torres-Verdin received the degree of Bachelor of Science in Civil Engineering with honors at the National Polytheonic Institute of Mexico, in July 1980. In September of 1980, he entered the Graduate School of The University of Texas at Austin. He also joined the Center for Transportation Research as a Graduate Research Assistant in the fall of 1980. He is a registered Professional Engineer in Mexico.

B. Frank McCullough is a Professor of Civil Engineering at The University of Texas at Austin, and is Director of the Center for Transportation Research. He has strong interests in pavements and pavement design and has developed design methods for continuously reinforced concrete pavements currently used by the State Department of Highways and Public Transportation, U. S. Steel Corporation, and others. He has also developed overlay design methods now being used by the FAA, U. S. Air Force, and FHWA. During nine years with the State Department of Highways and Public Transportation he was active in a variety of research and design activities. He worked for two years with Materials Research and Development, in Oakland, California, and for the past nine years for The University of Texas at Austin. He participates in many national committees and is the author of over 250 publications that have appeared nationally.