TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FHWA/TX-90+472-5		

4. Title and Subtitle	5. Report Date
A STATEWIDE DIAGNOSTIC SURVEY OF CONTINUOUSLY REINFORCED CONCRETE PAVEMENTS IN TEXAS	August 1989
	6. Performing Organization Code
7. Author(s)	8. Performing Organization Report No.
Angela Jannini Weissmann and Kenneth Hankins	Research Report 472-5
9. Performing Organization Name and Address	10. Work Unit No.
Center for Transportation Research The University of Texas at Austin Austin, Texas 78712-1075	11. Contract or Grant No. Research Study 3-8-86-472
	13. Type of Report and Period Covered Interim
12. Sponsoring Agency Name and Address Texas State Department of Highways and Public Transportation; Transportation Planning Division P. O. Box 5051 Austin, Texas 78763-5051	14. Sponsoring Agency Code

15. Supplementary Notes

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

Research Study Title: "Rigid Pavement Data Base"

16. Abstract

This report documents a diagnostic survey undertaken in 1988 to collect the following data on a statewide sample of continuously reinforced concrete pavements (CRCP): (1) deflections, (2) pavement temperatures, (3) crack widths, and (4) rut depths (in some test sections). The data will be used to back-calculate pavement properties necessary to calibrate a performance prediction model for CRCP in Texas. The development of procedures for data collection is documented in a previous report.

This report documents the field work and the preparations for it. These preparations consisted of (1) checking operator repeatability and reproducibility for the crack width measurements, (2) verifying reproducibility and accuracy of the devices in measuring temperature at the pavement surface, (3) casting temperature blocks, also called portable slabs, to take to the field, and (4) checking the accuracy and reproducibility of the thermocouples that were put into the portable slabs.

The field work, with emphasis on the practical conditions encountered in the field, is described, and data collected are presented. It is expected that the documentation of the experience gained with the preparations for and collection of the diagnostic data will not only serve to report the progress of the project but will also be valuable guidance for any agency needing to undertake a similar survey.

17. Key Words	18. Distribution Statement
Falling Weight Deflectometer, deflections, continuously reinforced concrete pavement, nondestructive testing, crack width, diagnostic survey, evaluation, thermocouple, repeatability	No restrictions. This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161.

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	36	

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by

Angela Jannini Weissmann
Kenneth Hankins

Research Report Number 472-5

Research Project 3-8-86-472

Rigid Pavement Data Base

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

August 1989

The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily represent the official views or policies of the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

PREFACE

This report describes the preparations for and the conducting of a statewide diagnostic survey of continuously reinforced concrete pavements. The field work was conducted by crews from the Center for Transportation Research and from the Texas State Department of Highways and Public Transportation. We are indebted to the Texas SDHPT personnel, whose cooperation played a key role in the feasibility of this data collection effort.

We would also like to express our gratitude to Mr. Ernest F. Barth III, Technical Assistant, from The University of Texas at Austin Civil Engineering Department, for lending all the Type J thermocouple wire that was needed and for building the thermocouple junctions.

We are also indebted to Mr. Johnnie Williams and Mr. Paul Walters, from the Engineering Materials Laboratory and the Soil Mechanics Laboratory, respectively, of the Civil Engineering Department, for their prompt help in making equipment and materials available for casting the portable slabs.

LIST OF REPORTS

Research Report 472-1, "Evaluation of Proposed Texas SDHPT Design Standards for CRCP," by Mooncheol Won, B. Frank McCullough, and W. R. Hudson, presents the results of an evaluation of proposed CRCP design standards for various coarse aggregates used, describes the theoretical models used in the study, and discusses several important design parameters of CRCP.

Research Report 472-2, "Development of a Long-Term Monitoring System for Texas CRC Pavement Network," by Chia-pei J. Chou, B. Frank McCullough, W. R. Hudson, and C. L. Saraf, presents the application an experimental design method for developing a long-term monitoring system in Texas. Development of a distress index and a decision criteria index for determining the present and terminal conditions of pavements are also discussed.

Research Report 472-3, "A Twenty-Four Year Performance Review of Concrete Pavement Sections Using Silicious and Lightweight Coarse Aggregates," by Mooncheol Won, Kenneth Hankins, and B. Frank McCullough, presents the results of statistical analyses over a twenty-four year performance period of continuously reinforced concrete pavements made with lightweight and conventional/standard aggregates. The performance variables include pavement deflections and visual condition survey data. Recommendations and directions for future research emanating from the study are also presented for consideration by CRCP designers.

Research Report 472-4, "Development of Procedures for a CRCP Diagnostic Survey," by Angela Jannini Weissmann and Kenneth Hankins, describes and discusses the studies carried out to arrive at procedures for collecting diagnostic data.

Research Report 472-5, "A Statewide Diagnostic Survey of Continuously Reinforced Concrete Pavements in Texas," by Angela Jannini Weissmann and Kenneth Hankins, describes the preparations for and the conducting of a statewide diagnostic survey of continuously reinforced concrete pavements. It also presents a summary of the data and discusses the results.

ABSTRACT

This report documents a diagnostic survey undertaken in 1988 to collect the following data on a statewide sample of continuously reinforced concrete pavements (CRCP):

(1) deflections,

(2) pavement temperatures,

(3) crack widths, and

(4) rut depths (in some test sections).

The data will be used to back-calculate pavement properties necessary to calibrate a performance prediction model for CRCP in Texas. The development of procedures for data collection is documented in a previous report.

This report documents the field work and the preparations for it. These preparations consisted of

(1) checking operator repeatability and reproducibility for the crack width measurements,

(2) verifying reproducibility and accuracy of the devices in measuring temperature at the pavement surface,

(3) casting temperature blocks, also called portable slabs, to take to the field, and

(4) checking the accuracy and reproducibility of the thermocouples that were put into the portable slabs.

The field work, with emphasis on the practical conditions encountered in the field, is described, and data collected are presented. It is expected that the documentation of the experience gained with the preparations for and collection of the diagnostic data will not only serve to report the progress of the project but will also be valuable guidance for any agency needing to undertake a similar survey.

KEYWORDS: Falling Weight Deflectometer, deflections, continuously reinforced concrete pavement, nondestructive testing, nondestructive evaluation, crack width, diagnostic survey, field evaluation, operator reproducibility, operator repeatability, thermocouple, pavement temperature.

SUMMARY

The importance of periodic monitoring of a pavement network as the basis for making efficient managerial decisions cannot be overemphasized. For that reason, the Center for Transportation Research, in cooperation with the Texas State Department of Highways and Public Transportation, is conducting a study of the performance of continuously reinforced concrete pavements. An important part of this study includes the collection of data for the structural evaluation of the pavement layers, in what was termed the diagnostic survey.

This report documents the preparations for and the conducting of a diagnostic survey on continuously reinforced concrete pavements, undertaken during the summer of 1988. It also presents comments about the field work conditions and presents the data. This report is meant to be useful not only as the documentation of an important phase of this study but also as guidance for future surveys of the same kind.

IMPLEMENTATION STATEMENT

The data collected in this survey will be added to the already existing condition survey data base and will be used to study the performance of Texas continuously reinforced concrete pavements. Other reports in this series describe the data base and the results of the performance studies. This document can be used as guidance for future surveys of the same kind.

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CHAPTER 1. INTRODUCTION

BACKGROUND

Periodic condition surveys are part of the data feedback system which is necessary in providing a serviceable highway system. The Texas State Department of Highways and Public Transportation (SDHPT) has noted the necessity for a data feedback system, and statewide condition surveys of rigid pavements were conducted in 1974, 1978, 1980, 1982, and 1984. The information from these surveys has contributed significantly to the development of rigid pavement design systems, in addition to providing criteria for prioritization and scheduling of overlays on rigid pavements. Recently completed research projects, 3-8-75-177, "Development and Implementation of the Design, Construction, and Rehabilitation of Rigid Pavements," and 3-8-79-249, "Implementation of the Rigid Pavement Overlay and Design System," have pointed to the need for continued condition survey observations. This research study was developed to respond to the need for an additional condition survey. This report responds to a specific objective of the study, that of establishing methods for measurement of the various items to be included in future condition surveys.

It had been observed during the past years that the AASHTO's present serviceability index (PSI) was not a reliable indicator of pavement performance of the Texas continuously reinforced concrete pavement (CRCP) network (Ref 1), and development of a better way to evaluate the CRCP terminal condition was imperative.

Earlier in this research project, a new decision-aid tool, termed the Z distress index (Ref 1), was developed to replace PSI for CRCP in Texas. This distress index, a function of punchouts and patches in the pavement, was developed to provide the SDHPT with guidelines for evaluating the present pavement conditions and for scheduling rehabilitation (Ref 1). However, the problem of a more adequate performance prediction model for Texas CRCP still remains. In essence, such a model would predict the deterioration of the pavement due to the combination of traffic and environmental effects. The calibration of this model would require appropriate data for the explicative variables. Among those, elasticity modulus of the portland cement concrete (E_c), flexural strength of the PC concrete (f_f), modulus of reaction on top of subbase (K), and load transfer coefficient (J) are important candidates for inclusion in the model.

Research Project 422 is now developing a computer program for predicting cracking characteristics (spacing and width) of CRCP. The program will take into consideration the random variability of the spacing and width when the material properties are used.

The existence of the historical condition survey data allows the calibration of the crack spacing and crack width models; however, data relating to materials stiffness (E_c, f , and K), load transfer (J), and crack width were not available in the data base. A field survey to obtain these data, termed a diagnostic survey, was thus an important effort of this research project. Deflection measurements were taken in order to back-calculate E_c, f_f, and K. The basic idea underlying the process of back-calculating these parameters from deflections is that, since stiffness of the layers, load, geometric characteristics, and deflections are related, the E_c, f_f, and K can be estimated from the rest. Load transfer (J) can also be estimated through deflections on both sides of discontinuities, which were also taken during the diagnostic survey. Pavement temperature was collected because previous studies have shown (Ref 2) that this parameter is important for better use of deflection and crack width data. Generally, as the pavement temperature cycles from cold to hot, the slab expands, the crack closes, better aggregate interlock at the crack is achieved, and the deflection of the pavement is affected.

OBJECTIVES

The objective of this report is to document the preparations for and collection of the diagnostic data. The tasks are listed below:

(1) Crews were to be trained in crack width measurement.

(2) Portable slabs for estimating temperatures along pavement thickness were to be cast.

(3) Reproducibility and repeatability of data gathered by the operators were to be checked.

(4) The accuracy of the surface temperature measurement devices was to be verified.

(5) The field work was to be conducted.

This report contains a comprehensive description of those items and a brief presentation of the data, with comments about the practical aspects, data accuracy, and overall results.

CHAPTER 2. PREPARATIONS FOR MEASURING CRACK WIDTH

BACKGROUND AND OBJECTIVES

A previous study conducted under this project (Ref 2) determined that some training of the operators is important to ensure repeatability of results, especially crack width measurements. The study reported that a small amount of well-supervised training is enough to enable a novice operator to take readings as reliable as those obtained by a highly skilled field engineer. However, when different operators are used to collect experimental data, it is desirable that their ability to gather repeatable and reproducible data be checked.

This chapter describes the training lesson given to novice crew members hired to take crack width data. It also describes a short experiment undertaken after the lesson, to check the reproducibility.

DESCRIPTION OF THE TEST FACILITY

The test site used for the crack width training lesson and experiment was constructed at Balcones Research Center (BRC), under Project 1530 (Ref 3), to study the problem of the operation of overweight vehicles on Texas roadways. One of the tasks in this project was the construction of test sections that would represent the most common pavement types in Texas. The test sections were built to fail from overloading, to provide evidence to be used in pending court cases. The test sections consisted of three paved tracks of different characteristics, which were cracked by the traffic loads imposed during testing. Figure 2.1 (Ref 3) depicts a layout of the test facility.

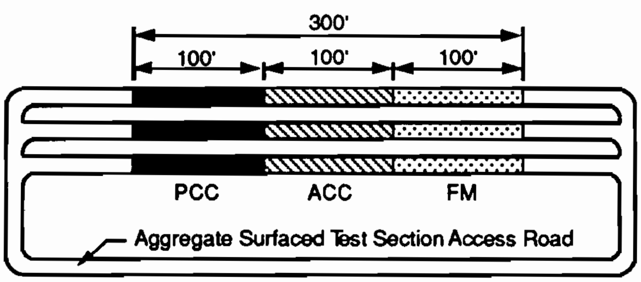


Fig 2.1. Layout of test site at Balcones Research Center (Ref 3).

THE TRAINING LESSON FOR CRACK WIDTH READINGS

The experiments described in a previous report of this study (Ref 2), to develop a procedure for reading crack width, concluded that training of the operators is very important, to ensure not only good individual reliability but also consistency among different operators. It also showed that it is not possible, from a practical standpoint, to obtain a sufficient number of readings on the same types of cracks to ensure a low error. The training given to inexperienced operators is outlined below.

(1) Large-scale spalling is often associated with CRCP. The depths can approach 3/4 to 1 inch and the widths can be from 1 to 6 inches. However, small-scale spalling, such as that depicted in the right-hand drawing of Fig 2.2, occurs frequently. This spalling can be of minute size, but, when crack width measurements are obtained with a microscope, the small-scale spalling makes it difficult to obtain correct crack widths. The operator will often focus the microscope on the spalled surface rather than on the interior of the crack. Therefore, the operators were instructed in recognizing minutely spalled locations along a crack, in determining the loss of reproducibility of measurements, and in developing the technique of sliding the microscope along the crack until a viable location can be found.

(2) Another source of reading error is shown in the left-hand drawing of Fig 2.2. At some locations the crack forms leaving a small aggregate protruding into the crack void. In focusing the microscope, the operator observes the top lip of the crack and the protruding face of the aggregate. This width can be much smaller than the actual width. The operators were instructed to bypass these locations.

(3) Concrete changes volume as temperature vary. This results in horizontal movement of a pavement slab. This movement affects the crack width. The operators collected crack width information at various temperatures. The operators were instructed in the importance of collecting pavement temperatures and in the changes in pavement temperature that can be expected with time.

The training was given to three crew members by the CTR staff member who was responsible for development of the crack width measurement procedure (Ref 2).

At the test site the CTR supervisor selected cracks representing several types of faulting, spalling, and aggregate pull-off, and the trainees learned how to recognize these situations. Good locations were then selected and viewed for comparison, while an explanation of the problems described above was given. Next, readings were taken of several "easy" and "difficult" cracks, and quick repeatability and reproducibility checks were repeatedly done with a pocket calculator, until full understanding of the nature of the crack width data collection was achieved.

Once the crew members were considered trained enough to know how they were supposed to take the readings, an experiment (Ref 3) was undertaken to check their ability to gather data that are reproducible and repeatable.

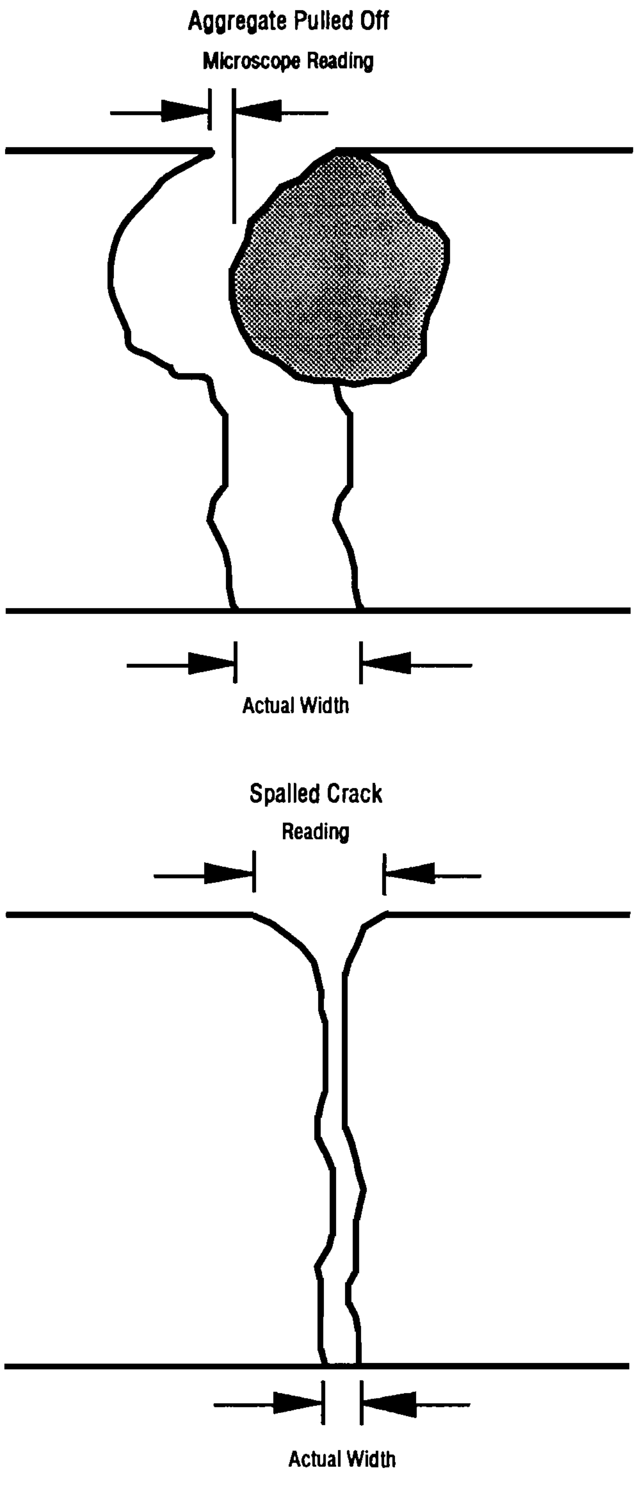


Fig 2.2. Situations to avoid in crack width readings.

ANALYSIS OF REPRODUCIBILITY AND REPEATABILITY

On 28 June 1988, the three CTR crew members and the CTR supervisor went to the BRC test facility, where they took width measurements of three pre-selected cracks in the test site. Previous results of an experiment (Ref 2) conducted on crack width revealed that the crack type has a considerable influence on the reproducibility of width measurements. Thus, in order to better analyze what to expect from actual field readings, where ideal cracks may not be often found, the cracks were selected to represent

Crack 1 - Difficult
Crack 2 - Average
Crack 3 - Easy

where the ease of reading is based on the amount of spalling and faulting, as described above. Table 2.1 summarizes the raw data and their statistical summary.

The specific objectives of the experiment (Ref 3) are listed below:

(1) The standard deviation and coefficient of variation of every operator's result, at every crack, was to be inspected to see if they were satisfactory.
(2) The homogeneity of the means and variances for every crack was to be tested (reproducibility of data among operators).
(3) Strategies to improve overall capability to take crack width data in the field were to be recommended.

Table 2.1 shows that this experiment confirmed the conclusions of Ref 2, that is, the data for crack #1 (the most difficult to measure) had the highest variance and the worst reproducibility, whereas data for crack #3 (the easiest to measure) had the least and best of those two parameters.

Table 2.1 shows that, in spite of the fact that some cracks were easy to measure, the coefficient of variation was higher than desirable. Additional training should alleviate this problem.

The Burr-Foster test of homogeneity of variances (Ref 5) was carried out for the nine samples. It consists of calculating the statistic

$$q = \frac{\sum^{n} s_i^4}{\left(\sum^{n} s_i^2\right)^2} \qquad (2.1)$$

This tests for the significance of differences among a set of variances. Table 2.2 depicts the results of this test for each crack.

The critical values for q (Ref 5) indicate that there were no significant differences among the variances of the operators, in every crack, which is a good indication that the amount of error is independent of the operator.

TABLE 2.1. CRACK WIDTH READINGS (10^{-3} INCH)

	Crack 1			Crack 2			Crack 3		
Operators	1	2	3	1	2	3	1	2	3
Readings	90	15	90	52	71	80	16	14	20
	82	33	80	90	94	65	20	14	28
	35	47	75	92	74	65	25	17	15
	47	50	70	95	57	64	23	31	20
	42	56	46	—	—	—	25	19	28
	35	32	42	—	—	—	35	14	29
Mean	55.2	38.8	67.8	82.3	74.0	68.5	24.0	18.2	23.3
Standard Deviation	24.4	15.1	19.6	20.2	15.3	7.7	6.4	6.6	5.8
Coefficient of Variation	44%	38%	29%	25%	21%	11%	27%	36%	25%

TABLE 2.2. TEST OF HOMOGENEITY OF VARIANCES

	Crack 1			Crack 2			Crack 3		
Operators	1	2	3	1	2	3	1	2	3
Variance	597	227	383	411	233	59	40	44	33
q-value	—	0.381	—	—	0.459	—	—	0.338	—

TABLE 2.3. TEST OF NORMALITY (LEVELS OF W-VALUE IN PERCENT)

Operators	Crack 1	Crack 2	Crack 3
1	7	3.3	55.2
2	60	71	**1.4**
3	34	**0.1**	20.8

TABLE 2.4. REPRODUCIBILITY OF OPERATORS - ANOVA RESULTS

Crack	F-Value	Signficance Level (%)	Interpretation
1 — Difficult	0.95	34.4	No difference
2 — Average	1.79	21.1	No difference
3 — Easy	0.03	86.5	No difference

Another indicator of bias is the test of normality. Table 2.3 depicts the results of the Shapiro-Wilks normality test of the data (Ref 5). The test is based on the statistical significance of a coefficient that attempts to capture two measures of symmetry of the sample distribution. For an even sample size, the Shapiro-Wilks statistic is

$$W = \frac{\left[\sum_{i=1}^{n/2} a_{n-i+1}(y_{n-i+1} - y_i)\right]^2}{\sum_{i=1}^{n} (yi - \bar{y})} \qquad (2.2)$$

where

y_i = i^{th} term of the sorted sample,
n = sample size,
$\bar{y}$ = sample mean, and
a = critical values from table in Ref 5.

It would be expected that the readings would be normally distributed, i.e., that they would have a central tendency affected only by random error. However, the boldface numbers in Table 2.3 indicate non-normal data. On the other hand, lack of normality tended to concentrate on crack 2, which had some faulting.

Reproducibility was checked by means of the one way analysis of variance (ANOVA) applied to the data. According to Ref 5, when one variance is up to nine times larger than another, the confidence level of the ANOVA may increase only about 1 percent. In addition, the ANOVA is robust for failures in the assumption of normality of data. Therefore, the ANOVA was carried out for every crack, using the software Statistical Analysis System (SAS) (Ref 6). The results are summarized in Table 2.4, which shows that the hypothesis of equal means cannot be rejected for any of the cracks, thus indicating a good reproducibility of crack width measurements among the operators.

Therefore, it is suggested that the microscope operator take six readings at each crack selected. The operator should attempt to place the microscope in what appears to be a non-spalled area, sliding the microscope along the crack until the distance between the crack walls appears to represent the actual width and is not influenced by minor spalling or aggregate protrusions.

CONCLUSIONS AND RECOMMENDATIONS

The ANOVA results show no statistical evidence of difference of means or of variances between operators for any of the cracks.

The coefficients of variation were somewhat larger than expected. The time constraints imposed on this diagnostic survey did not permit further training of the new crews, and it is advisable to consider this fact when analyzing the crack width data from their first few sections.

The experiment indicates that there is no need to worry about whether one operator is more reliable than another, but it also indicates that the overall expected error in the crack width data may be a little higher than the estimate from the first experiment on crack width measurements (Ref 2), especially for the first few sections. This shows that experience increases the individual operator's reliability. It is recommended that crack width data from the first two or three sections be regarded more carefully than later data.

CHAPTER 3. PREPARATIONS FOR THE TEMPERATURE MEASUREMENTS

BACKGROUND

A previous study in this project (Ref 2) determined correlations between pavement surface temperature and the temperatures near the top, middle, and bottom of a smaller portable slab. That study also confirmed previous findings that using the portable slab is the most accurate procedure for estimating in situ pavement temperatures.

The portable slab, also called a temperature block, is a PC concrete block which has thermocouples in the top, at mid-depth, and in the bottom and is designed to be movable by two men. Figure 3.1 depicts a plan of the portable slab, showing its dimensions and the thermocouple positions. The specifications for the PC concrete used in the slabs are documented in this chapter.

There were practical aspects, however, that restricted the use of portable slabs in the field for this study. The weight (about 150 lb) made hauling it difficult, and it sat on the ground at only one site during the survey of a given test section. Due to the distance from the portable slab location to the other measurement spots (usually at least 500 feet), it would have been necessary to have one field crew member permanently assigned to read only temperatures, which would have increased the costs of the diagnostic survey about 30 percent and was not feasible. An automatic device to read and record the temperatures in the portable slab would have been even more expensive. Consequently, it was decided to take surface temperatures, to guarantee that there would be some estimate of pavement temperature. A study was conducted to check the accuracy and test the reproducibility of the measurements by the different surface temperature devices available for the field work, and this is documented in this chapter.

The thermocouples in the portable slabs are widely used for a number of purposes, and they are considered very reliable; however, the lack of a specific study comparing the accuracy of the Type J (iron-constantan) thermocouple to that of a scientific thermometer led to an experiment to fulfill this need, which is described in this chapter.

SPECIFICATIONS FOR CASTING THE PORTABLE SLABS

Figure 3.1 shows the dimensions of the portable slabs, determined in the previous study (Ref 2) to be the smallest that can give reliable results. The thickness (8 inches) corresponds to the thickness encountered most frequently in Project 472 test sections. Limestone was chosen as the aggregate type because it is the prevalent aggregate type in Project 472 test sections (Ref 3).

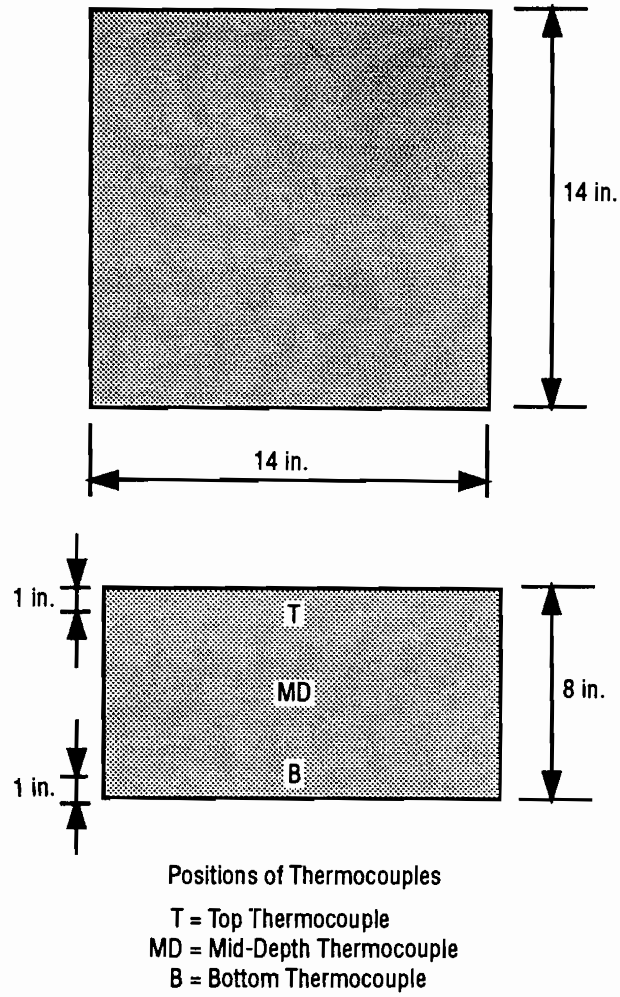


Fig 3.1. Scheme of the portable slabs.

Since it is known that the mix proportion can have an influence on the concrete thermal properties, it was decided that the mix used on Project 3-8-86-422 "Evaluation of Pavement Concrete Using Texas Coarse Aggregates" should be employed. This current project determined some PC concrete properties which could be used as estimates of the concrete properties of the portable slabs. This mix is described in Ref 8, and consists of the following quantities (pounds per cubic yard):

Cement	492
Sand	1279
Crushed Limestone	1838
Water	222

Unavailability of the mixer on the day the slabs were cast required that another proportion, which was richer in cement and water, be used. The proportion above is too dry to be mixed with shovels, and another mix was selected. Thus, the following quantities (pounds per cubic yard) were used for the portable slabs:

Cement	600
Sand	1320
Crushed Limestone	1780
Water	300

The thermocouples put inside the temperature blocks were made of Type J (iron-constantan) wire, 24 gauge, compatible with the available thermocouple reader (Fluke Model 51). The thermocouples were fixed to a wooden bar approximately one-half inch in diameter, at heights corresponding to the depths depicted in Fig 3.1. Each thermocouple wire was tagged with a mark of its polarity and its position inside the slab.

VERIFICATION OF THE ACCURACY OF THE TYPE J THERMOCOUPLES

Calibration of the thermocouples against a scientific thermometer (Ref 3) is described in this section. It is recommended that these findings be considered when thermocouple readings from the field are analyzed.

Three thermocouples were made of Type J (iron-constantan) 24-gauge thermocouple wire. They were connected to a multichannel digital thermometer (Omega brand), which was already calibrated for Type J wire. The maximum error specified by the Omega manufacturer is 1.5°F. A Fisher Scientific Thermometer, category 14-938-10B, with a range from -20°C to 110°C, with 0.5°C of specified tolerance, was used to check the thermocouples.

The experiment consisted of putting the thermocouples and the scientific thermometer in a bath, subjecting them to several randomly selected temperatures, and checking the readings of the thermocouples against those of the thermometer. The temperatures were chosen to represent the expected temperature range of pavements in all four seasons. The auto-correlation of temperature data would make a series of heating-up or cooling-down readings consist of a time-series, instead of a random sample. In order to avoid that, the bath was randomly heated up or cooled down before each reading, and the thermocouples were allowed to stand until equilibrium was reached, before every new set of readings. Table 3.1 presents the raw data. Figures 3.2 through 3.4 depict the plots of thermometer versus thermocouple readings.

The standard approach for cases in which a reliable instrument is checked against one whose reliability is under investigation is to build a calibration curve.

In this case, very little difference was expected between the two instruments, and the calibration curve was expected to be the zero intercept, 45° slope straight line. However, data indicated that the thermocouples consistently underestimated the bath temperatures by about 2°F. Table 3.1 data already indicated an outstanding reproducibility of thermocouples, and reproducibility was not checked.

A regression was run with the three thermocouple readings as the replicated independent variable and the scientific thermometer readings as the dependent variable. The output of this regression, performed with SAS (Ref 6), is depicted in Table 3.2. It shows that the calibration curve is well represented by a 45° straight line, with a 2.2°F intercept, i.e., the thermocouple readings should be increased 2.2°F, to obtain the corresponding scientific thermometer readings. No lack of fit is suggested in the residual analysis, as shown in Fig 3.5.

It was concluded that the Type J thermocouple could be considered accurate, and a consistent calibration curve could be developed with a standard thermometer. It was

TABLE 3.1. RAW TEMPERATURE DATA (°F)

Thermometer (Converted from °C)	Thermocouple 1	Thermocouple 2	Thermocouple 3	Difference Between Thermometer and Thermocouple
72.5	70	70	70	2.5
55.4	53	53	53	2.4
139.1	138	138	137	1.1 to 2.1
33.1	32	32	33	0.1 to 1.1
55.4	53	53	53	2.4
108.1	106	106	106	2.1
123.81	22	122	122	1.8
133.21	32	131	131	1.2 to 2.2
167.0	165	165	165	2.0
47.3	45	45	45	2.3
168.8	166	167	168	0.8 to 2.8
104.0	102	102	102	2.0
197.6	97	97	97	0.6 to 2.6
95.0	92	92	92	3.0

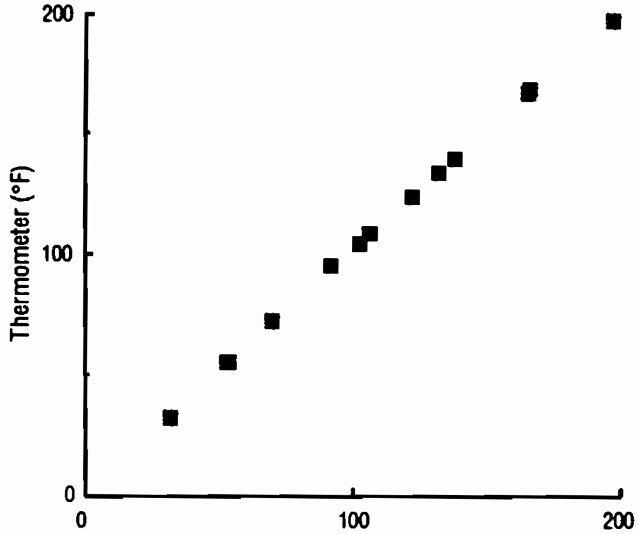


Fig 3.2. Thermometer vs. thermocouple 1.

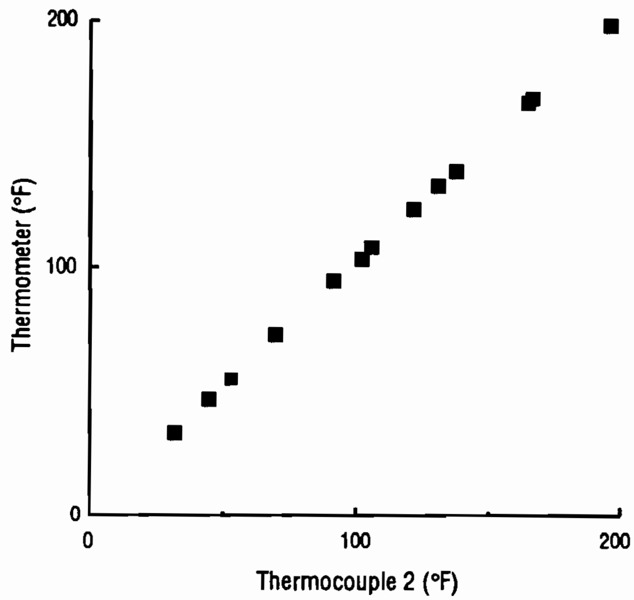


Fig 3.3. Thermometer vs. thermocouple 2.

not possible to determine whether the difference of 2.2°F was due either to the thermocouples themselves or to the reading device; recalibration of the latter would be required to clarify this point.

It is very important to emphasize that this experiment was run with all temperatures measured in a laboratory bath, which is homogeneous. Practical use, however, often requires utilization of thermocouples within heterogeneous materials. The diagnostic survey will use thermocouples to read concrete pavement temperatures in a portable slab, which represents the pavement. In this case, the two main possible sources of errors are listed below.

(1) A thermocouple could be placed within a void in the concrete.

(2) A thermocouple could suffer damage or displacement when the concrete was placed or vibrated.

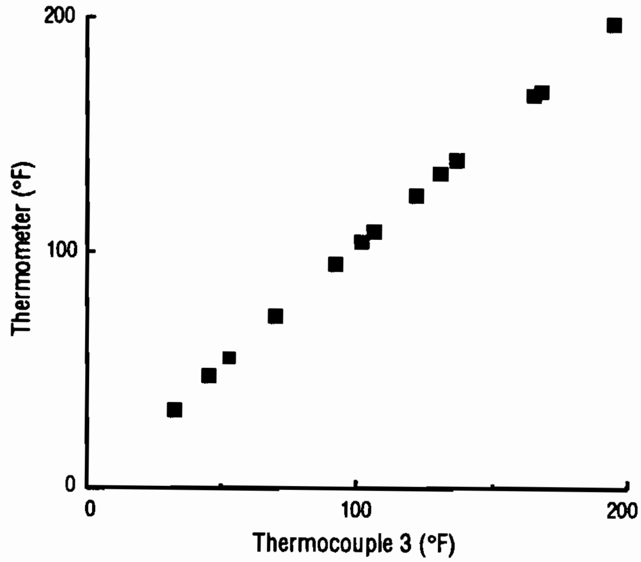


Fig 3.4. Thermometer vs. thermocouple 3.

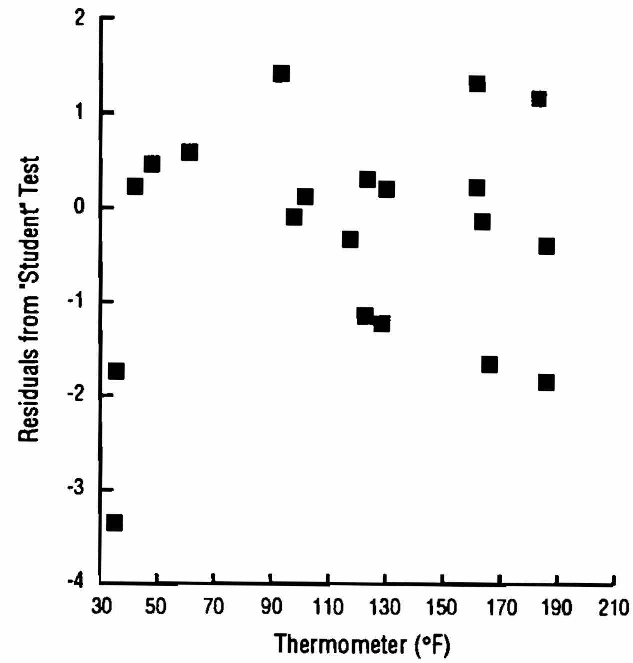


Fig 3.5. Residual plot of the calibration curve.

It is suggested that one day of temperature measurements, spaced every half hour, be taken and checked before using the slabs in the field.

ANALYSIS OF REPRODUCIBILITY OF SURFACE TEMPERATURE MEASUREMENTS BY AVAILABLE DEVICES

As discussed previously, since an operator could not be assigned to take the portable slab readings, it was decided to take surface temperature measurements. However, since the crews worked simultaneously at different sites, it was impossible to use the same device throughout the survey, and another study was necessary to verify the

TABLE 3.2. RESULTS OF REGRESSION MODEL FOR THERMOMETER TEMPERATURES

Dep Variable: Thermometer Analysis of Variance

Source	Degrees of Freedom	Sum of Squares	Mean Square	F-Value	Prob > F
Model	1	99949.440	99949.450	235114.443	0.0001
Error	40	17.004	0.425	—	—
C Total	41	99966.450	—	—	—
	Root Mse	0.6523		R-Square	0.9998
	Dep Mean	107.16		Adj R-Sq	0.9998
	C.V.	0.608			

Parameter Estimates

Variable	Degrees of Freedom	Parameter Estimate	Standard Error	T for HO: Parameter = 0	Prob > |T|
Intercept	1	2.235	0.23800	9.368	0.0001
Slope	1	0.998	0.002067	484.886	0.0001

reproducibility of the devices (Ref 3). The underlying idea was to check whether it was possible to use results from any of the available devices, because they all gave the same readings.

The following devices were available for field use during the survey and were thus analyzed in this study:

(1) A pyronometer, which indirectly estimates the surface temperature by means of the percent of radiation reflected by the surface, from a given amount emitted by the device was used.

(2) A disk, or surface, thermometer was used. This instrument is an ordinary thermometer which has a flat contact surface instead of the usual elongated thermometer shape. In order to maximize the contact area and ensure reliable readings, it was necessary to put this thermometer not on the rough pavement surface, but on a mixture of sand and oil, which was smoothed on the pavement, prior to taking any readings. Three thermometers of the same brand and specifications were available.

(3) A digital thermometer, which consists of a contact probe hooked to a digital reader, was used. During the data collection, the digital thermometer failed several times. However, it was decided to keep the device in the experiment, since it could be fixed, and used, later.

Three pairs of slabs were constructed under this research project for taking data for the studies described in (Ref 2). Each pair consisted of one slab made with limestone and the other with silicious river gravel. Thicknesses and coarse aggregate types used in the portable slabs are depicted in Table 3.3.

The thermocouples within these slabs were located as shown in Fig 3.1. They were hooked to a data acquisition system capable of automatically recording temperatures of up to 40 thermocouples. The data acquisition system is described in Ref 2. It was set up to take readings at 15-minute intervals. Readings were taken with the three surface measurement devices, at the same time as the automatic data recordings. Table 3.4 presents the raw data, and Figs 3.6 to 3.11 depict plots of output from the devices versus thermocouple readings, for each slab. Part of the data was collected on 28 June 1988 (afternoon) and the rest on 01 July 1988 (morning).

The experiment consisted of a three-way factorial, in which the factors of interest were:

(1) *aggregate type* (limestone and river gravel),

(2) *device type* (pyronometer, disk, and digital thermometers), and

(3) *slab thickness* (6, 10, and 14 inches).

The factors are abbreviated "mat" (for material), "dev," and "thick," respectively. All factors can be regarded as fixed, since this study is interested only in the devices studied and since the majority of aggregate types found in the CRCP test sections are either limestone or river gravel. In addition, the thicknesses used represent the range of thicknesses of the CRCP test sections. The interaction between thickness and aggregate type was included in the analysis because it was felt that temperature variations due to thickness may manifest themselves at different rates for different aggregate types. This ANOVA was done assuming that there is no difference between the readings of the three available disk thermometers, since they are supposed to be replicates of the same commercial device.

TABLE 3.3. CHARACTERISTICS OF PORTABLE SLABS USED IN THE EXPERIMENT

Coarse Aggregate Type	Thickness (in.)
Limestone (LS)	6, 10, 14
Silicious River Gravel (RG)	6, 10, 14

TABLE 3.4. RAW DATA FOR REPRODUCIBILITY CHECK OF DEVICES TO MEASURE PAVEMENT TEMPERATURE

		Temperature (°F)			
Thickness (in.)	Material	Pyrono Meter	Disk Thermometer	Top Thermocouple	Digital Thermometer
6	LS	106	107	101.12	*
6	LS	103	112	101.4	*
6	LS	108	*	101.26	*
6	LS	105	*	104.1	*
6	LS	92	97.8	85	90.5
6	LS	86	86	83	87
6	LS	89	90	85	87
6	LS	88	97	87	91
6	LS	94	99	89	93
6	LS	96	105	92	97
6	LS	102	108	94	98
6	LS	100	110	94	97
6	LS	102	113	97	101
6	LS	102	115	98	*
6	LS	107	117	100	*
6	LS	103	118	102	*
6	LS	110	119	103	*
6	LS	111	124	107	*
6	LS	110	123	108	*
6	RG	101	105	99	*
6	RG	98	108	99	*
6	RG	106	*	99	*
6	RG	105	*	101	*
6	RG	84	84	83	86
6	RG	90	96	83	93
6	RG	88	93	84	91
6	RG	92	101	86	95
6	RG	93	105	88	97
6	RG	94	108	90	98
6	RG	96	110	92	98
6	RG	99	113	94	100
6	RG	101	116	95	*
6	RG	105	117	97	103
6	RG	103	119	98	*
6	RG	106	119	100	*
6	RG	108	122	101	*

*Represents a missing observation.

(continued)

TABLE 3.4. (CONTINUED)

Thickness (in.)	Material	Temperature (°F) Pyrono Meter	Disk Thermometer	Top Thermocouple	Digital Thermometer
6	RG	107	125	104	*
6	RG	112	122	105	*
10	LS	104	105	99	*
10	LS	104	111	100	*
10	LS	107	*	99	*
10	LS	106	*	101	*
10	LS	90	93	83	91
10	LS	86	86	83	86
10	LS	88	89	84	88
10	LS	88	95	85	91
10	LS	92	99	87	92
10	LS	97	105	89	96
10	LS	98	109	92	97
10	LS	102	112	93	100
10	LS	100	113	94	100
10	LS	107	116	96	*
10	LS	105	117	98	*
10	LS	104	118	99	*
10	LS	108	119	101	*
10	LS	109	122	103	*
10	LS	114	123	104	*
10	RG	99	120	98	*
10	RG	102	104	98	*
10	RG	105	*	98	*
10	RG	102	*	100	*
10	RG	86	85	85	87
10	RG	91	91	84	91
10	RG	86	87	86	87
10	RG	92	99	86	94
10	RG	92	102	89	95
10	RG	98	108	91	99
10	RG	98	108	93	99
10	RG	97	113	94	100

*Represents a missing observation.

(continued)

TABLE 3.4. (CONTINUED)

Thickness (in.)	Material	Temperature (°F) Pyrono Meter	Disk Thermometer	Top Thermocouple	Digital Thermometer
10	RG	101	116	96	*
10	RG	103	117	97	*
10	RG	105	118	98	*
10	RG	105	119	100	*
10	RG	108	122	101	*
10	RG	106	124	103	*
10	RG	106	122	104	*
14	LS	98	98	100	*
14	LS	104	117	100	*
14	LS	107	120	95	*
14	LS	108	120	101	*
14	LS	86	83	84	86
14	LS	89	89	83	91
14	LS	88	90	85	89
14	LS	91	96	85	92
14	LS	91	99	87	93
14	LS	94	107	89	97
14	LS	96	109	91	98
14	LS	99	113	93	101
14	LS	102	114	95	101
14	LS	101	116	96	*
14	LS	105	118	98	*
14	LS	104	118	99	*
14	LS	109	121	101	*
14	LS	108	122	103	*
14	LS	108	121	105	*
14	RG	104	102	99	*
14	RG	104	121	99	*
14	RG	108	122	99	*
14	RG	106	122	101	*
14	RG	85	85	83	86
14	RG	88	91	83	89

*Represents a missing observation.

(continued)

TABLE 3.4. (CONTINUED)

Thickness (in.)	Material	Temperature (°F) Pyrono Meter	Disk Thermometer	Top Thermocouple	Digital Thermometer
14	RG	85	87	85	87
14	RG	91	99	85	94
14	RG	92	98	87	93
14	RG	97	107	89	97
14	RG	96	108	91	99
14	RG	98	115	92	101
14	RG	100	115	93	102
14	RG	101	115	95	*
14	RG	105	119	97	*
14	RG	104	117	98	*
14	RG	108	121	95	*
14	RG	104	123	102	*
14	RG	110	123	103	*

TABLE 3.5. THREE-WAY ANOVA TO CHECK DIFFERENCES BETWEEN DEVICES

Source	DF	Sum of Squares	F-Value	Significance of F	R^2	Coefficient of Variance
Model	7	8,378.12	10.82	0.0001	0.17	10.22
Thickness (in.)	2	52.11	0.24	0.7982	—	—
Material	1	23.11	0.21	0.6478	—	—
Deviation	2	8,302.29	37.53	0.001	—	—
Thickness/Material	2	0.61	0.00	0.9972	—	—
Error	371	41,030.99	—	—	—	—
Total	378	49,409.11	—	—	—	—

Table 3.5 depicts the output of the ANOVA, which was run using the statistical software SAS (Ref 6). The F-value calculated by SAS for the main effect device corresponds to the correct F-test for a fixed effect. It can be seen in Table 3.5 that this F-value is highly significant, thus indicating the necessity to calibrate each device against the corresponding thermocouple readings, which are more accurate than the surface measurement devices. Inspection of Figs 3.6 through 3.11 shows that the disk thermometer readings differ from those taken with the other devices.

The observation of the behavior of the three different disk thermometers during the first day of measurements suggested that an analysis of the reproducibility of their data should be done. Thus, on the second day of measurements, the three disks were identified with a number. Table 3.6 depicts the raw data, and Table 3.7 depicts the output from the reproducibility analysis. The results reveal undesirable differences among the three disk thermometers. Figures 3.12, 3.13 and 3.14 depict plots of measurements taken with the disks. The figures show that a fairly linear correlation exists among them. In addition, the slope of the straight line is around one. Only the intercept varies, depending on the specific disk thermometer; it can be adjusted by changing the origin of the disk thermometer, and this would improve the reproducibility.

The variance between disks, depicted in Table 3.7, can be used as a rough estimate of the error to be expected from the readings with those instruments. It is also suggested that intercepts depicted in Figs 3.12 to 3.14 be used as guidance for adjusting the origins. This is especially important if estimates of temperatures themselves are needed in addition to estimates of temperature differentials.

Since the results of the ANOVA indicated that there are differences among the types of temperature measurement devices, regression models relating their readings to the thermocouple readings were developed. Since the data were collected in two different days, they do not consist of an equally spaced time series, which would be desirable for this sort of modeling. Therefore, the data had to be treated as an ordinary, non auto-regressive, sample, for the purposes of modeling. Since the plots depicted in Figs 3.6 to 3.11 suggest a linear correlation, the simple linear model was fitted to the data using the least squares

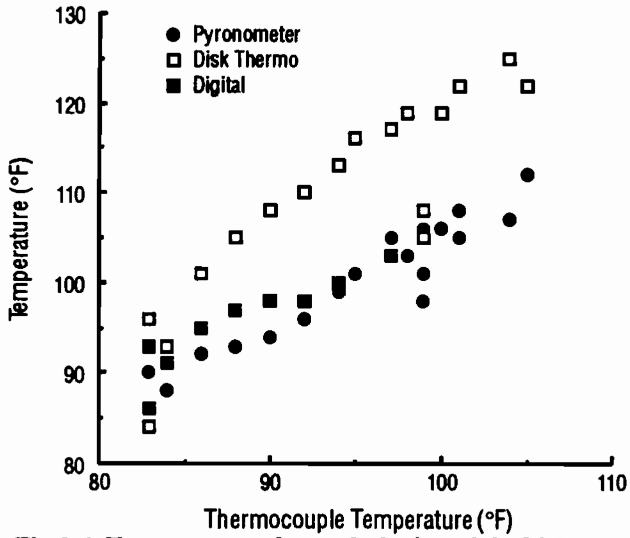


Fig 3.6. Temperatures for each device; slab thickness = 6 inches, aggregate = river gravel.

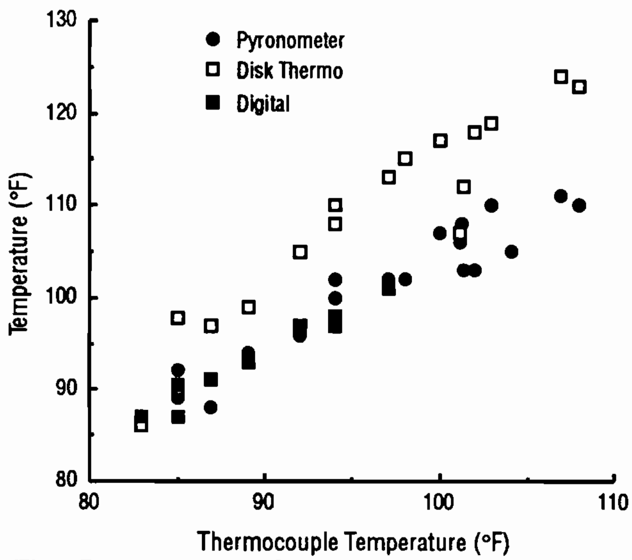


Fig 3.7. Temperatures for each device; slab thickness = 6 inches, aggregate = limestone.

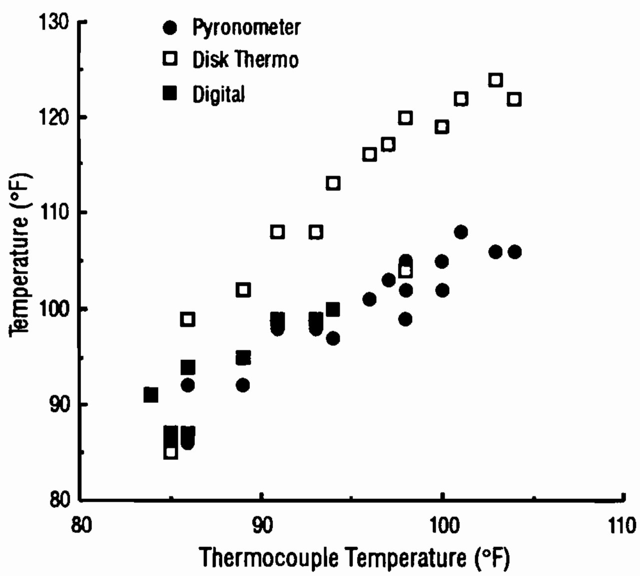


Fig 3.8. Temperatures for each device; slab thickness = 10 inches, aggregate = river gravel.

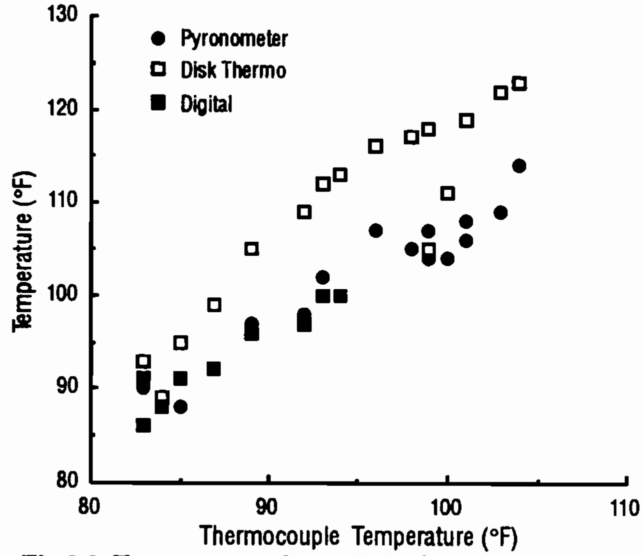


Fig 3.9. Temperatures for each device; slab thickness = 10 inches, aggregate = limestone.

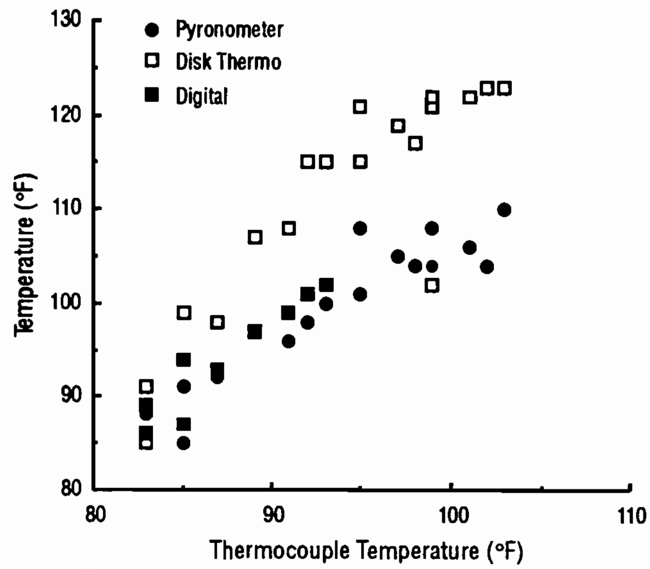


Fig 3.10. Temperatures for each device; slab thickness = 14 inches, aggregate = river gravel.

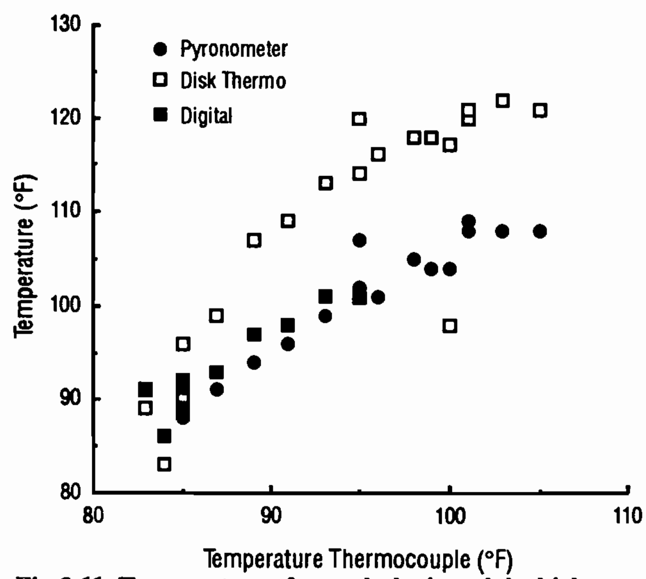


Fig 3.11. Temperatures for each device; slab thickness = 14 inches, aggregate = limestone.

TABLE 3.6. RAW DATA FROM THE THREE DISK THERMOMETERS (^{0}F)

Disk 1						Disk 2						Disk 3					
LS6	LS10	LS14	RG6	RG10	RG14	LS6	LS10	LS14	RG6	RG10	RG14	RG6	RG10	RG14	LS6	LS10	LS14
96	95	89	88	88	88	96	85	79	77	77	77	89	89	90	101	99	80
89	87	91	97	92	92	79	80	82	89	84	84	103	97	97	90	90	94
90	91	92	97	89	89	83	81	82	85	79	79	98	92	93	96	94	96
99	97	99	103	101	101	90	87	88	93	91	92	106	104	104	102	101	102
101	101	101	108	103	100	92	91	93	98	96	91	110	107	104	105	104	103
107	107	109	111	111	109	99	99	100	100	100	100	113	112	112	108	110	113
111	111	110	112	111	110	101	101	101	103	101	101	116	114	115	113	114	115
113	113	115	116	114	117	103	105	106	106	107	107	119	119	121	113	117	120
115	115	117	118	117	116	106	107	109	108	110	108	122	121	121	117	117	118
117	118	118	120	119	118	108	109	109	109	109	108	123	122	122	119	122	123
119	120	121	120	120	121	109	109	111	112	110	111	124	124	124	122	123	123
120	119	118	121	121	120	111	111	112	111	111	111	124	124	125	124	124	125
121	121	122	124	124	122	111	112	112	114	115	114	128	127	127	124	125	128
126	124	125	127	126	124	115	113	112	118	118	115	130	129	129	130	128	129
124	123	123	125	124	125	118	118	114	115	115	114	127	128	129	128	129	128

TABLE 3.7. THREE-WAY ANOVA TO CHECK DIFFERENCES BETWEEN DISKS

Source	DF	Sum of Squares	F-Value	Significance of F	R^2	Coefficient of Variance
Model	8	7,913.00	6.55	0.0001	0.16	11.31
Thickness (in.)	2	26.14	0.09	0.9172	—	—
Material	1	101.05	0.67	0.4142	—	—
Deviation	3	7,764.71	**17.13**	**0.001**	—	—
Thickness/Material	2	21.10	0.07	0.9326	—	—
Error	277	41,860.10	—	—	—	—
Total	285	49,773.10	—	—	—	—

TABLE 3.8. OUTPUT OF REGRESSION OF THERMOCOUPLE TEMPERATURES ON PYRONOMETER TEMPERATURES

Source	DF	Sum of Squares	Mean Square	F-Value	Probability > F
Model	1.00	4771.799	4771.799	885.861	0.0001
Error	112.00	603.30	5.387	—	—
C Total	113.00	5375.102	—	—	—
Root Mse	2.32	—	—	—	—
Dep Mean	94.62	—	—	—	—
C.V.	2.45	—	—	—	—
R^2	0.89	—	—	—	—
Adj R^2	0.89	—	—	—	—

Parameter Estimates

Variable	DF	Parameter Estimate	Standard Error	T for HO: Parameter = 0	Probability >|T|
Intercept	1.000	8.52	2.90	2.937	0.0040
TPYR	1.000	0.86	0.03	29.763	0.0001
Durbin-Watson D	1.990	—	—	—	—
(For Number of Obs)	114.00	—	—	—	—
1st Order Auto-correlation	00.005	—	—	—	—

TABLE 3.9. OUTPUT OF REGRESSION OF THERMOCOUPLE TEMPERATURES ON DISK THERMOMETER TEMPERATURES

Source	DF	Sum of Squares	Mean Square	F-Value	Probability > F
Model	1.00	3953.31	3953.31	371.221	0.0001
Error	104.00	1107.55	10.65	—	—
C Total	105.00	5060.86	—	—	—
Root Mse	3.26	—	—	—	—
Dep Mean	94.18	—	—	—	—
C.V.	3.46	—	—	—	—
R^2	0.78	—	—	—	—
Adj R^2	0.78	—	—	—	—

Parameter Estimates

Variable	DF	Parameter Estimate	Standard Error	T for HO: Parameter = 0	Probability >|T|
Intercept	1.000	37.53	2.96	12.692	0.0001
TPYR	1.000	0.52	0.03	19.267	0.0001
Durbin-Watson D	0.962	—	—	—	—
(For Number of Obs)	106.000	—	—	—	—
1st Order Auto-correlation	0.511	—	—	—	—

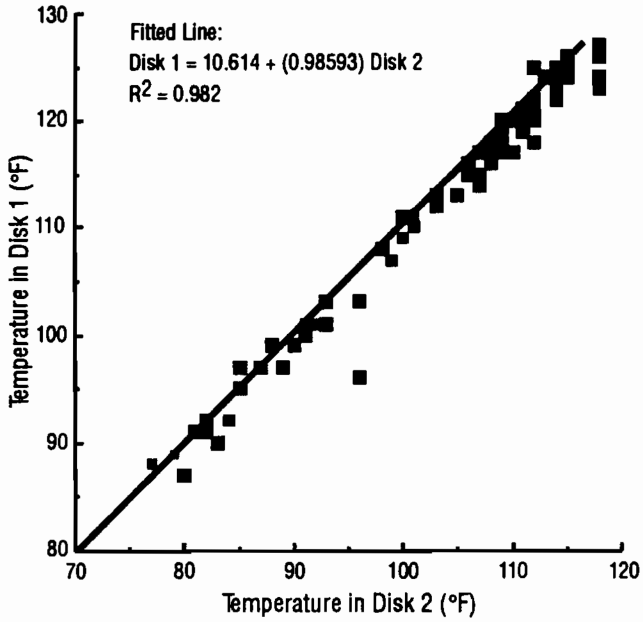


Fig 3.12. Temperature in disks.

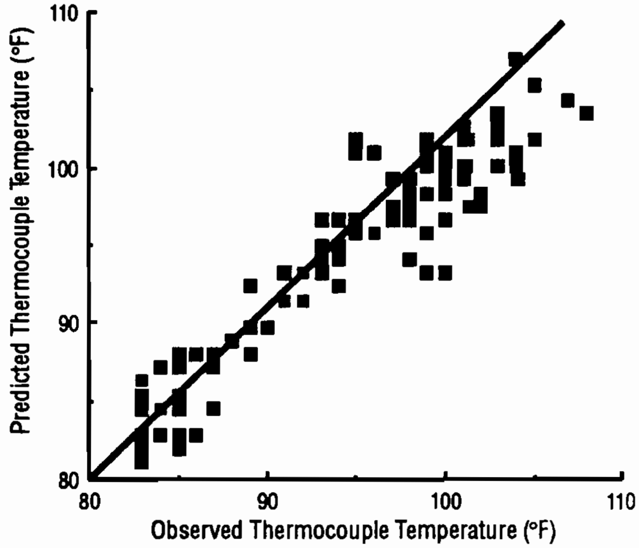


Fig 3.15. Predicted versus actual plot, Pyronometer model.

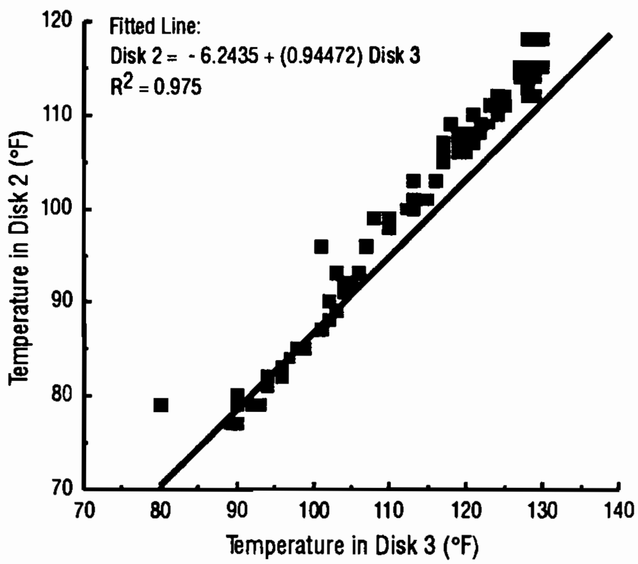


Fig 3.13. Temperatures in disks.

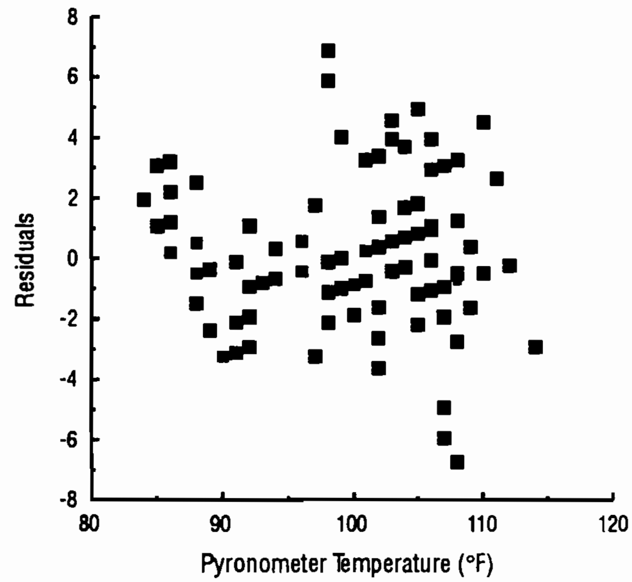


Fig 3.16. Residual plot from pyronometer model.

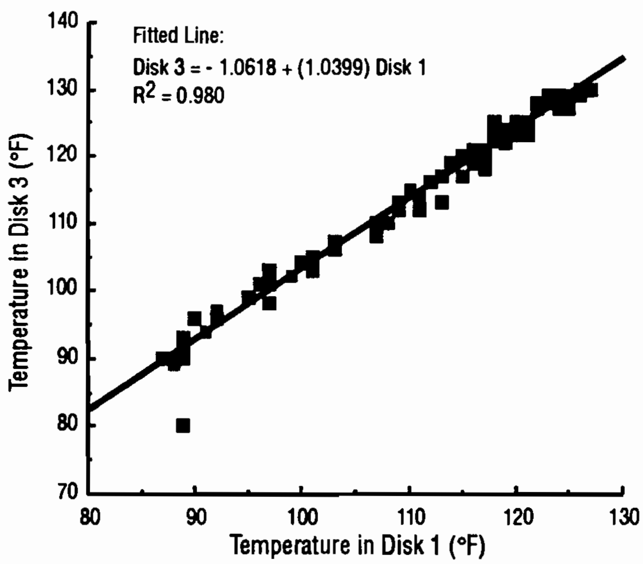


Fig 3.14. Temperatures in disks.

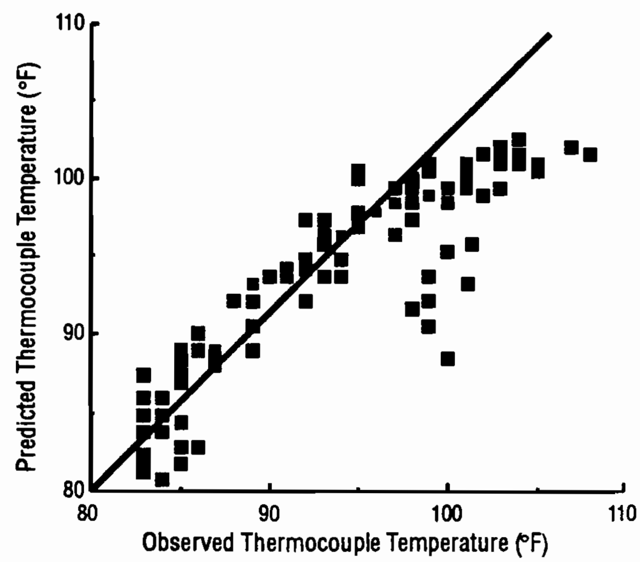


Fig 3.17. Predicted versus actual plot, disk linear model.

TABLE 3.10. OUTPUT OF REGRESSION OF THERMOCOUPLE TEMPERATURES ON DISK THERMOMETER QUADRATIC MODEL

Source	DF	Sum of Squares	Mean Square	F-Value	Probability > F
Model	2.00	4013.27	2006.63	197.29	0.0001
Error	103.00	1047.59	10.17	—	—
C Total	105.00	5060.86	—	—	—
Root Mse	3.19	—	—	—	—
Dep Mean	94.18	—	—	—	—
C.V.	3.38	—	—	—	—
R^2	0.79	—	—	—	—
Adj R^2	0.79	—	—	—	—

Parameter Estimates

Variable	DF	Parameter Estimate	Standard Error	T for HO: Parameter = 0	Probability >|T|
Intercept	1.00	103.340	27.2600	3.791	0.0030
TPYR	1.00	-0.750	0.5200	-1.431	0.1556
TDK2	1.00	0.006	0.0025	2.428	0.0169
Durbin-Watson D	107.00	—	—	—	—
(For Number of Obs)	106.00	—	—	—	—
1st Order Auto-correlation	0.47	—	—	—	—

method. The outputs are depicted in Table 3.8 for the pyronometer and in Table 3.9 for the disk thermometers. Figure 3.15 depicts the predicted versus actual values and Fig 3.16, the residual plot, for the pyronometer model. It can be seen that this model is fairly good, with highly significant parameters and a randomly scattered residual plot.

Figure 3.17 depicts the predicted versus actual values and Fig 3.18, the residual plot for the disk thermometer model. The inspection of the residual plot indicates that a quadratic model may be a better representation of the relationship. An attempt was thus made to fit a quadratic model to the disk thermometer data, and the results are depicted on Table 3.10. The model is significant, and so are the regression coefficients, but an undesirable lack of fit can still be seen in Figs 3.19 and 3.20. One possible explanation for this can be the Durbin-Watson statistic (DW), which shows evidence of auto-correlation.

CONCLUSIONS, COMMENTS, AND RECOMMENDATIONS

(1) The surface (disk) thermometers are the least accurate devices for measuring pavement temperature; ideally, they should be avoided in the field.

(2) There is no significant difference between the pyronometer and the digital thermometer readings.

(3) The use of the digital thermometer was avoided in the 1988 survey. It failed often during the experiment, and there was no time to have it fixed before the 1988 survey. For this reason, no model was calibrated for this device.

(4) Since using the portable slab gives the best pavement temperature estimates, and since the temperature variation on cloudy days may not be very different from the standard error of the regression models fitted to the surface measurement devices, it is recommended that at least three portable slab readings be taken each day.

(5) The top thermocouples are actually located one inch below the surface (see Fig 3.1), whereas the devices under study measure temperature exactly at the surface. Thus the following stepwise model would be more adequate:

$$TC_t = A + B * PYR_t + C * PYR_{t-1} + D * PYR_{t-2} + \ldots \quad (3.1)$$

where

TC = top thermocouple reading,
PYR = pyronometer reading,
A, B, C, D = regression parameters, and
t = instant of measurement.

In this experiment, since the data acquisition had to be made on two different days, continuous sampling of PYR was not available which would permit the application of the above model.

(6) The models obtained from the available data are

- for the pyronometer:

$$T_{tc} = 8.52 + 0.86*T_{pyr} \quad (3.2)$$

$(R^2 = 0.89, DW = 1.99)$

- for the disk thermometers

$$T_{tc} = 103.34 + 0.006*T_{dk}^2 \quad (3.3)$$

$(R^2 = 0.79, DW = 1.07)$

where

T_{tc} = temperature measured with the surface thermocouples,

T_{pyr} = temperature measured with the pyronometer, and

T_{dk} = temperature measured with the disk thermometer.

The model for the pyronometer is good and presents no evidence of lack-of-fit. The model for the disks, however, is only fairly reasonable, and use of this model for a range of temperatures other than that used in the test could lead to questionable results. Since both the test and the diagnostic survey were conducted in the summer, such an extrapolation was not necessary.

(7) Although three disk thermometers were available, and although the ANOVA results indicated that their measurements were significantly different, the model was fitted as if they were not, because, due to practical constraints, all disks were used, and proper identification was difficult.

(8) It seems that one of the causes for the imprecision in the disk thermometer readings is the necessity of putting them on a smooth surface. In the case of pavements, the only practical way to obtain this smooth surface is to apply a mixture of oil and sand on a small spot on the pavement. During the data collection, it was observed that this mixture tended to heat up faster than the pavement, because the mixture always had a darker color than the pavement. This trend can be clearly seen in Figs 3.6 through 3.11, the measurements with the disks are always higher than those obtained with the other devices.

(9) If a better correlation between the surface temperatures and the thermocouple readings becomes necessary, it is suggested that this experiment be repeated, but this time with data collected every 15 minutes, during at least 10 consecutive hours, in order to obtain an equally spaced time series of at least 40 elements. This time series will still be somewhat small, but it will permit better modeling than that obtained from a sample suited only for least squares fitting.

(10) Difficulties in taking the portable slab to the field, plus the already mentioned practical constraints on personnel availability, will not permit the procedure originally recommended for measuring pavement temperature (Ref 2) to be strictly applied; moreover, the alternative procedure - measuring surface temperatures - has proven to be considerably less accurate than the temperature block, especially if the disk thermometers are used. Awareness of those limitations is very important when the data are used and analyzed.

(11) It can be concluded from the studies that the use of a portable slab provides the best estimates of pavement temperatures, and ideally it should be used whenever possible.

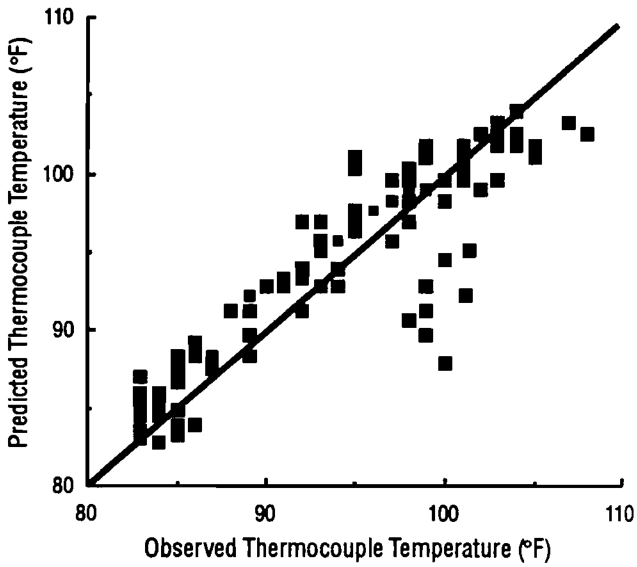


Fig 3.19. Predicted versus actual plot, disk quadratic model.

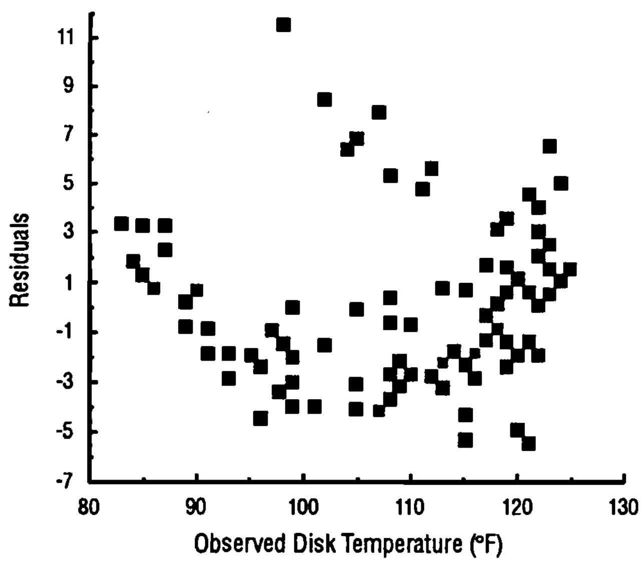


Fig 3.18. Residual plot, disk linear model.

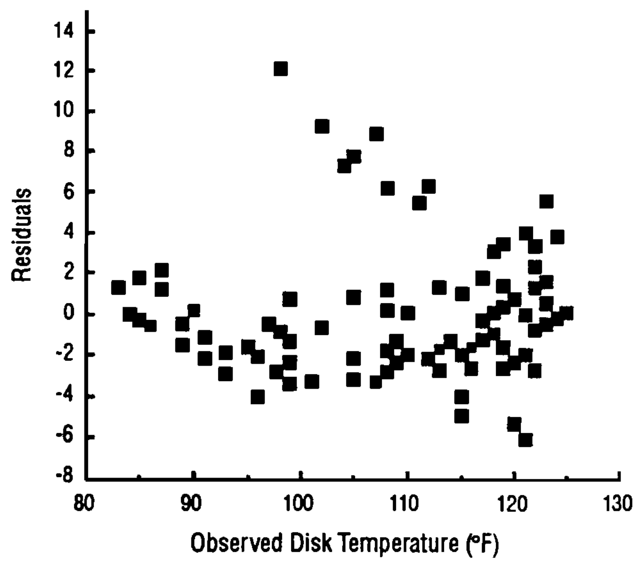


Fig 3.20. Residual plot, disk quadratic model.

CHAPTER 4. FIELD WORK AND PRESENTATION OF THE DATA

INTRODUCTION

The survey described in this report was planned well in advance (Ref 2), with specific research needs of this and other Projects in mind, and targets such as maximum accuracy and reliability of the data. The development of the procedures for this survey and the instruction manual are documented in Ref 2. A few unpredictable circumstances, such as constraints on the availability of personnel for the survey, required some adjustments to be made in the initially proposed data collection procedures. The purpose of this chapter is to document the field work, including the aforementioned adjustments, and to comment on the results, in order to provide guidance to similar surveys in the future.

This chapter also presents some examples of the data collected, in order to better document the nature of the diagnostic survey. These examples are intended to provide information on the amount and accuracy of the data collected. Printouts of all diagnostic data are not included in this report, because efficient examination of such a massive amount of data requires the use of a computerized data base management system.

TRAFFIC CONTROL SYSTEMS

Traffic control is a key factor in the success of any road survey; the ideal system should not only provide adequate safety for the crew, but also avoid unnecessary delays in the field work. In addition, any survey should disrupt the traffic as little as possible; for this reason, the measurements were confined to the right lane, and the others remained open to traffic.

In this survey, traffic control was provided by the district where measurements were being collected. It generally consisted of a two to four-man crew. A full traffic set up, with three sets of signs in front of a tapering line of cones and with cones at the lane line throughout the work area, was used in all but one district. District 1 used signs and two follow vehicles. One follow vehicle was just behind the Falling Weight Deflectometer (FWD), and had a crash cushion attached to the rear. Figures 4.1 and 4.2, respectively, depict the full traffic control set up and the system used in District 1.

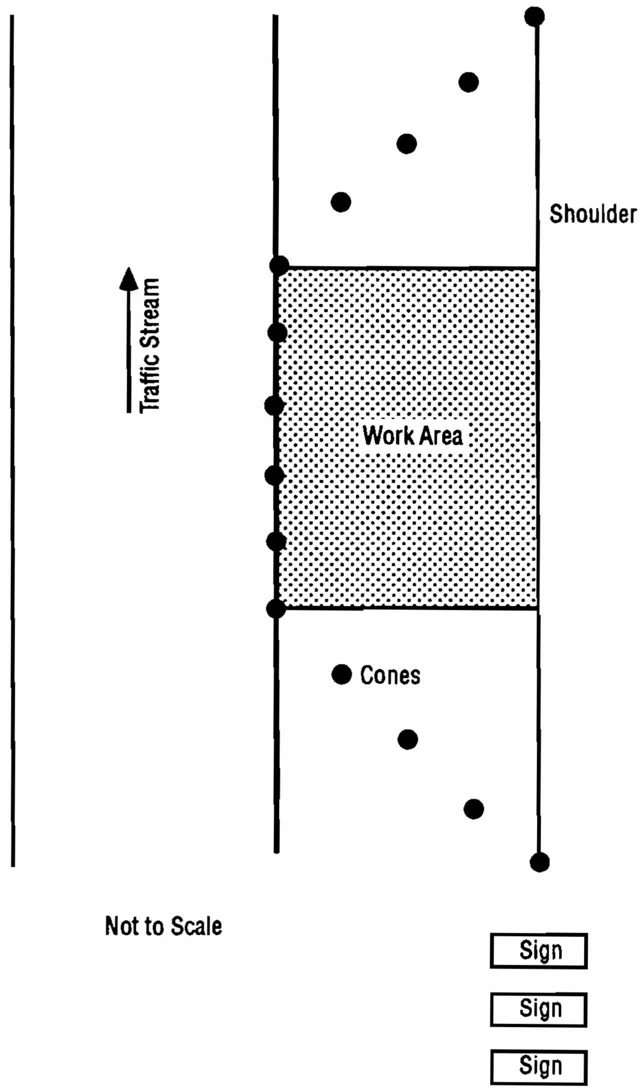


Fig 4.1. Full traffic control setup.

DESCRIPTION OF THE FIELD WORK AND SUMMARY OF THE DATA

OVERALL DATA

The diagnostic data were collected with two two-man crews from CTR. Each crew met and worked with a two-man crew from the SDHPT, who operated the FWD. These crews collected information on 242 CTR test sections during the summer months noted in Table 4.1. Every effort was made to collect the data exactly on the same test sections surveyed in 1987.

Table 4.1 presents the number of test sections surveyed in each district, separated into overlaid and non-overlaid. Dates and districts visited are also shown. It can be seen that 35.12 percent of the available test sections were overlaid. Some districts do not have any overlaid test sections, while others have only overlaid test sections. Thus, there was no practical possibility of sampling overlaid and non-overlaid pavements in each district. Nevertheless, the diagnostic survey took a good sample of both types of test sections on a statewide basis.

TABLE 4.1. SUMMARY OF THE TEST SECTIONS SURVEYED IN 1988

District Number	Dates	Test Sections: Non-Overlaid Number	Non-Overlaid Percent	Overlaid Number	Overlaid Percent	Totals Number	Totals Percent
1	July 11-15	5	2.07	15	6.2	20	8.26
2	July 25-29	46	19.01	15	6.2	61	25.21
	Aug 1-5	—	—	—	—	—	—
	Aug 12	—	—	—	—	—	—
3	Aug 15-19	29	11.98	0	0	29	11.98
4	Aug 1-5	13	5.37	0	0	13	5.37
	Aug 22-26	—	—	—	—	—	—
5	July 6-7	14	5.79	0	0	14	5.79
12	July 25-29	6	2.48	0	0	6	2.48
13	July 18-22	9	3.72	0	0	9	3.72
15	Aug 22-26	1	0.41	6	2.48	7	2.89
17	July 11-15	13	5.37	15	6.20	28	11.57
19	July 18-22	0	0	19	7.85	19	7.85
20		12	4.96	0	0	12	4.96
24		9	3.72	15	6.20	24	9.92
Totals		157	64.88	85	35.12	242	100

Grand Total = 242 Test Sections

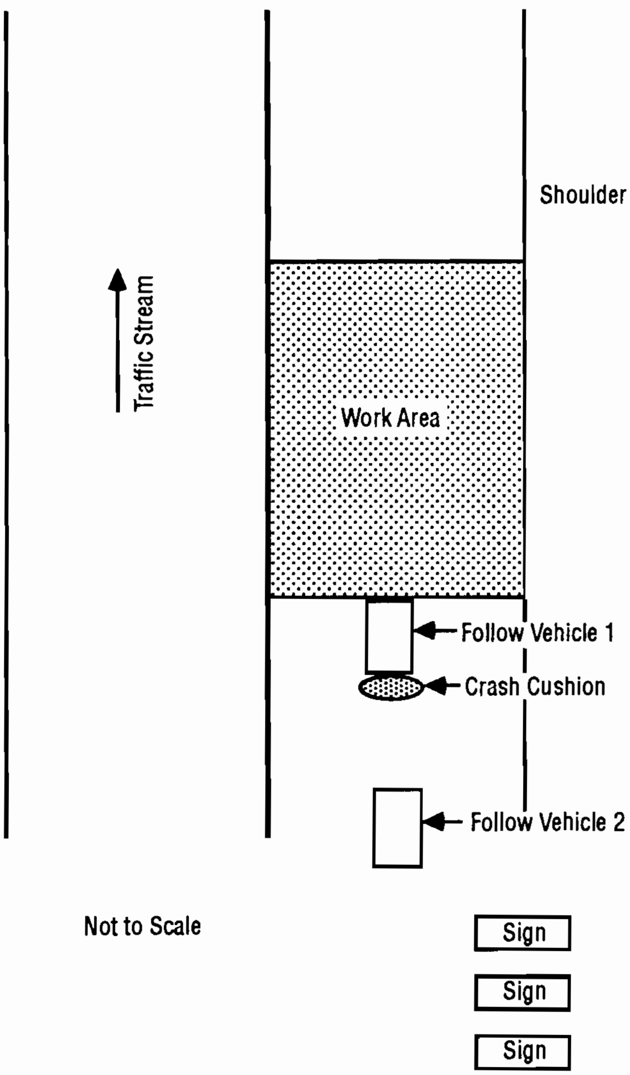


Fig 4.2. Traffic control used in District 1.

COLLECTION AND SUMMARY OF THE DEFLECTION DATA

Non-overlaid sections were divided into five replicates called subsections. At each subsection, the FWD load plate was positioned at the stations numbered 1 to 5, as depicted in Fig 4.3. Deflections at four drop heights were taken at each station. Overlaid sections were divided into ten replicates, also termed subsections. At each subsection, the FWD load plate was positioned at the two stations depicted in Fig 4.4. These procedures were strictly followed by the field crews. Ref 2 suggests a geophone configuration; however, since difficulties in changing an existing FWD geophone configuration were anticipated, the suggested configuration was optional. The actual field configurations were carefully recorded (Ref 3).

During the diagnostic survey, five different FWD units were used. Table 4.2 depicts the SDHPT Districts they came from, the districts where they were used, and the geophone configurations. Those configurations are sketched in Figs 4.5 and 4.6.

Four drop heights were used with the FWD at each measurement station. Attempts were made to obtain two

TABLE 4.2. FALLING WEIGHT DEFLECTOMETERS USED IN THE SURVEY

District 8 FWD — Fig 4.5
District 11 FWD — Fig 4.6.
District 14 FWD — Fig 4.6.
District 18 FWD — Fig 4.5.
District 10 FWD — Fig 4.6.

Configuration in Fig 4.5 used in Districts: 15, 17, and 20
Configuration in Fig 4.6 used in Districts: 1, 2, 3, 4, 5, 12, 13, 19, and 24

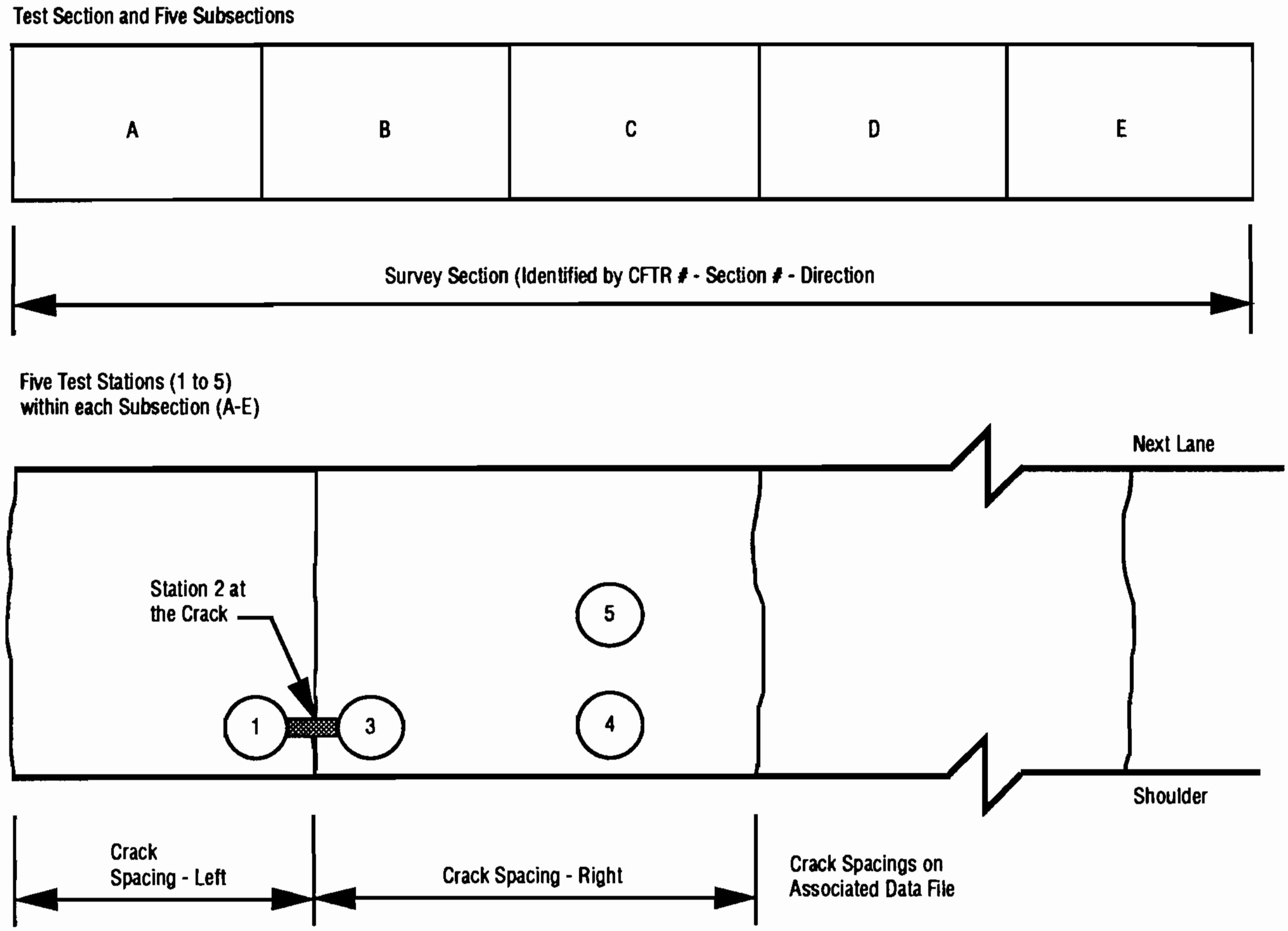


Fig 4.3. Non-overlaid test section: subsections and stations.

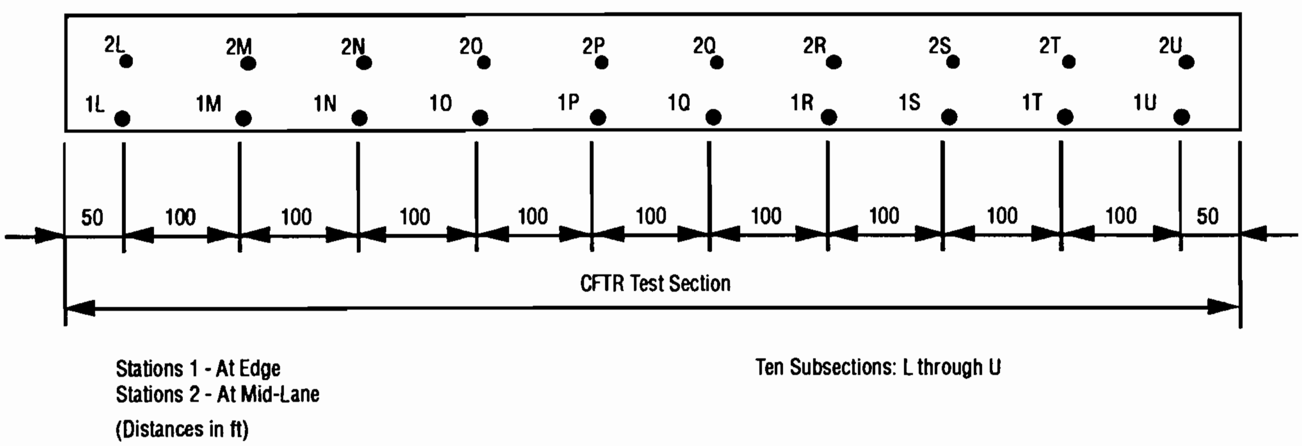


Fig 4.4. Overlaid test section: subsections and stations.

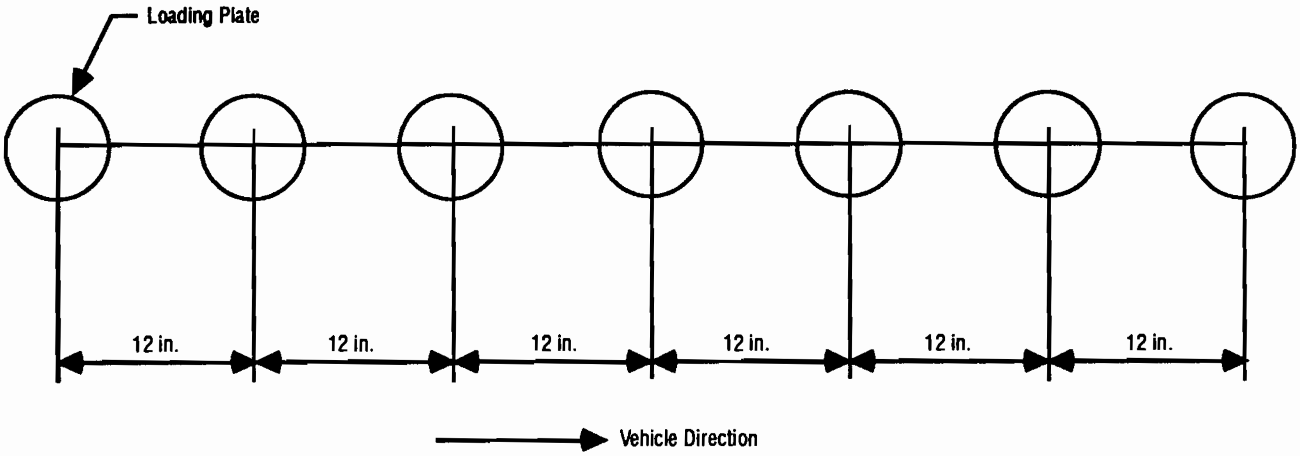


Fig 4.5. Geophone configuration - District 8.

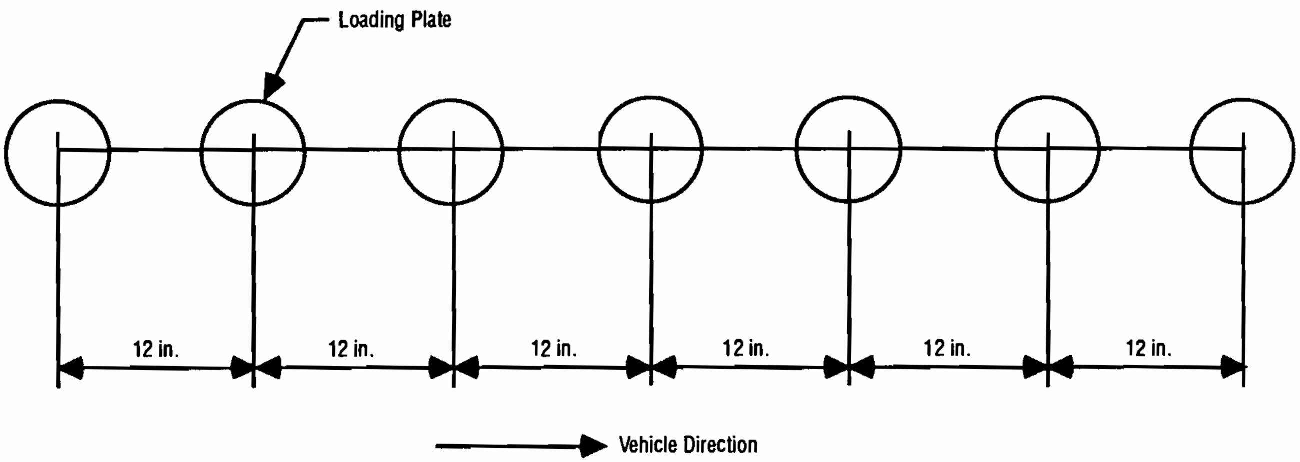


Fig 4.6. Geophone configuration - District 11.

TABLE 4.3. SUMMARY OF DEFLECTION DATA

Geophone Configuration C (Fig 4.5)

Drop Height	Number of Stations	Deflection at Load (0.001 in.) Maximum	Deflection at Load (0.001 in.) Minimum	Load (lb) Maximum	Load (lb) Minimum
1	4435	14.18	0.40	512	9360
2	4435	19.80	0.56	1016	12664
3	4435	37.19	0.68	1584	16096
4	4435	89.85	1.20	3704	22928

Geophone Configuration A (Fig 4.6)

Drop Height	Number of Stations	Deflection at Load (0.001 in.) Maximum	Deflection at Load (0.001 in.) Minimum	Load (lb) Maximum	Load (lb) Minimum
1	1558	10.88	0.32	4808	7776
2	1558	14.53	0.79	6144	12328
3	1558	19.16	1.06	9688	15848
4	1558	40.08	1.34	1272	20112

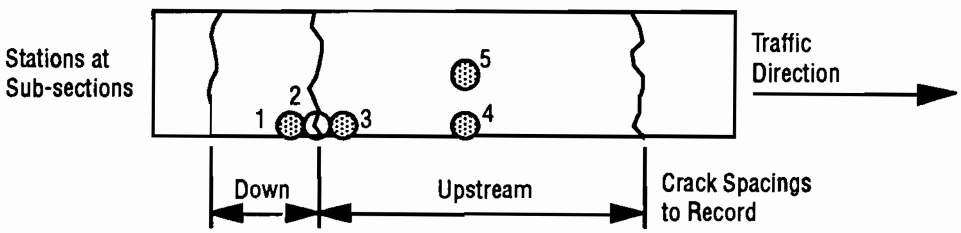
Crew:	Date	Test Section Identification			
	Mo/Day/Yr	Hwy	Bound	CFTR #	Section #
County:					

Sub-section Identification

Traffic Direction → N S E W

A	B	C	D	E

	Crack Spacing (ft)	
Sub-section	Down	Up
A		
B		
C		
D		
E		



Comments:

Fig 4.7. Station position form.

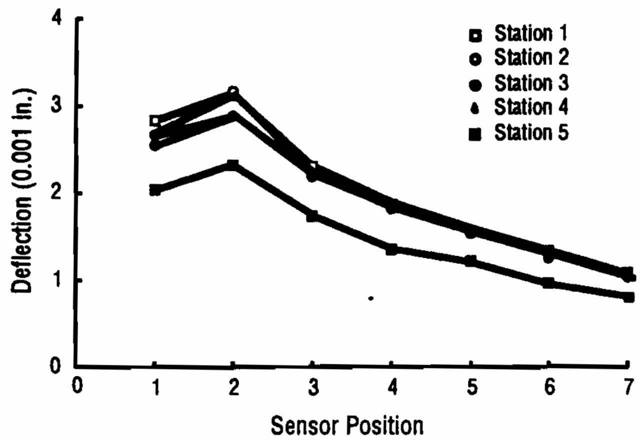


Fig 4.8. Deflection basins in a typical non-overlaid subsection.

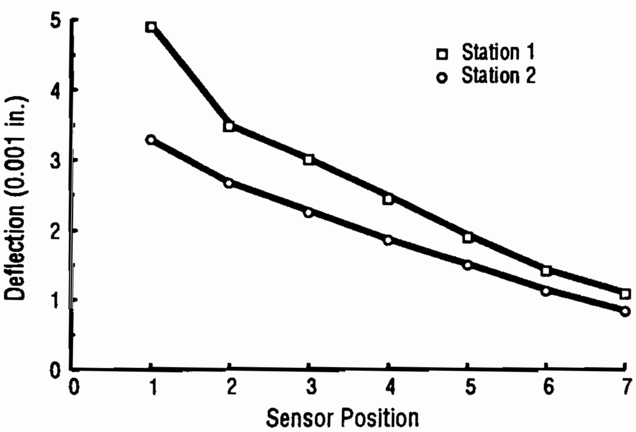


Fig 4.9. Deflection basins in a typical overlaid subsection.

drops with loads less than 10,000 pounds and one drop with a load greater than 10,000 pounds in an effort to have loads on each side of the legal limit (small loads, as well as over loads). However, it was necessary to use the drop heights that were set on the equipment, therefore, variation from the values above was found. Table 4.3 summarizes the deflection data, i.e., amount of data, ranges of loads, ranges of deflections, and other information.

While the SDHPT crew was measuring deflection with the FWD, a member of the CTR crew was completing the form depicted in Fig 4.7. This form was intended to record the distances between cracks around each measurement station, for further use in back-calculation of deflections. The crack spacings were measured with the rolo-tape. Figure 4.8 depicts typical deflection basins for subsections in a non-overlaid section, and Fig 4.9 shows the basins in an overlaid section.

COLLECTION AND SUMMARY OF THE CRACK WIDTH DATA

Each crew had a microscope with a linear scale which could provide distance measurements with a precision of 0.001 inch. This instrument was used to take crack width readings. Since one of the reasons for the crack width data is to study the interactions of crack width with crack spacing, the field crews were provided with a printout showing the minimum, average, and maximum crack spacings found in the condition survey of 1987 in order to help in locating those spacings in the field.

While the FWD was being operated, a member of the CTR crew selected cracks spaced as closely as possible to the figures in the data base; then, six width readings per crack were taken and recorded in the form depicted in Fig 4.10.

Crack width data were collected in every non-overlaid test section. Table 4.4 summarizes the crack width data collected. The accuracy obtained in the crack width measurements can be seen in Fig 4.11, which depicts the frequency counts of the observed coefficients of variation of the six readings taken at every crack, where the coefficient of variation (CV) is

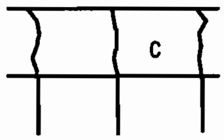
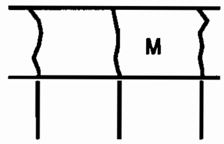
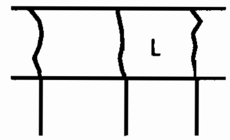
$$CV = (\text{Standard Deviation} / \text{Mean}) \times 100 \quad (4.1)$$

It can be seen in Table 4.4 that some difficulties did occur. For example, lack of cracks spaced according to the idealized criterion occurred in more than 9 percent of cases. Those cases will not be useful for studies of interactions between crack width and crack spacing, because the upstream and downstream spacings are too different from one another. The number of cracks with too large a standard deviation, represented in Table 4.4 by cracks where the maximum reading exceeded four times the minimum, is much larger for non-spalled cracks than for spalled ones. This fact may reflect the concern of the field crews with the imprecision associated with readings of spalled and faulted cracks. Figure 4.11 shows that the majority of the data had a coefficient of variation of between 20 percent and 50 percent. This supports previous findings (Refs 2 and 3) that the average of the crack width measurements cannot be viewed as a precise measurement of a unique linear dimension; instead, it represents an average value of a variable that has a large scatter.

COLLECTION AND SUMMARY OF PAVEMENT TEMPERATURE DATA

The portable-slab temperature was obtained periodically during the day, generally before work, at mid-morning, at noon, at mid-afternoon, and right after work. The three thermocouples – at top, at middepth, and at bottom – were read. In addition, surface temperature in the portable slab was taken with the available surface temperature measurement device. Figures 4.12 through 4.15 depict the frequency counts of the observed temperatures at those

Instructions for Filling Out the Crack Width Form	Date	Test Section Identification			
	Mo/Day/88	Hwy	CFTR Number	Test Section#	Bound

Crack	Closely Spaced	Medium Spaced	Widely Spaced
Crack Spacing			
Microscope Readings			

Special Situations				
	Tick if Applicable	☐ Spacing Smaller Than Expected	☐ Spacing Smaller Than Expected	☐ Spacing Smaller Than Expected
		☐ Spalled or Stepped Crack	☐ Spalled or Stepped Crack	☐ Spalled or Stepped Crack
		☐ Unable to Find - Big Patch	☐ Unable to Find - Big Patch	☐ Unable to Find - Big Patch
		☐ Overlay / Seal Coat	☐ Sealed Cracks	
		☐ Crack Spacing Approximately Constant		
		☐ Test Section Marks Were Not Visible		
	Other (Please Describe)			

Fig 4.10. Crack width form.

TABLE 4.4. SUMMARY OF CRACK WIDTH DATA

Number of test sections surveyed		157
Number of cracks surveyed		471
Percent of faulted or spalled cracks		36.09%
	Close:	28.24%
Percent of cracks spaced from their neighbors as	Average:	31.42%
	Wide:	31.00%
	Uneven:	9.34%
Statistical summary of crack width data (0.001 in.)	Grand Mean =	3.48
	Standard Deviation =	24.27
	Range =	[1,100]
Statistical summary of spacing data (ft) upstream:	Grand Mean =	4.0
	Range =	[0.1, 16]
Statistical summary of spacing data (ft) downstream:	Grand Mean =	4.2
	Range =	[0.3, 14]
Number of spalled cracks where (maximum reading) > (4 x minimum)		17
Number of non-spalled cracks where (maximum reading) > (4 x minimum)		126

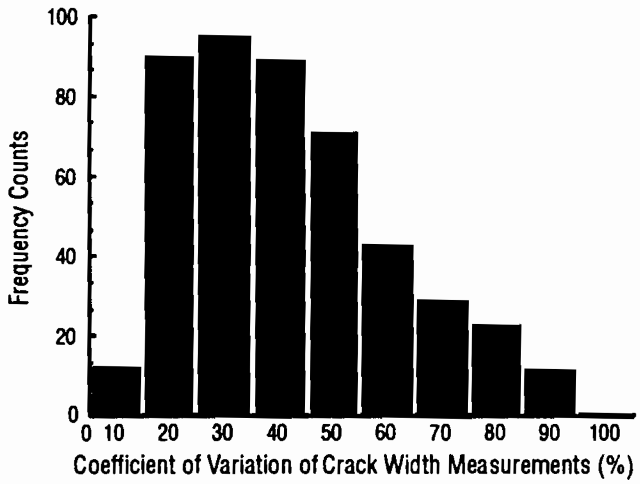


Fig 4.11. Frequency counts of the observed coefficients of variation of crack width measurements.

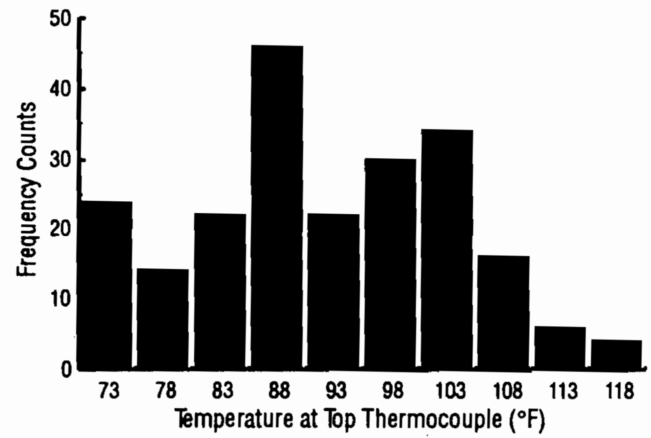


Fig 4.13. Frequency counts of temperature at top thermocouple.

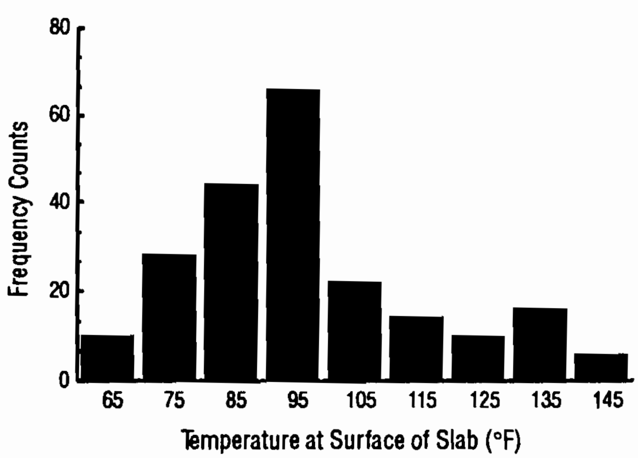


Fig 4.12. Frequency counts of temperature taken at surface.

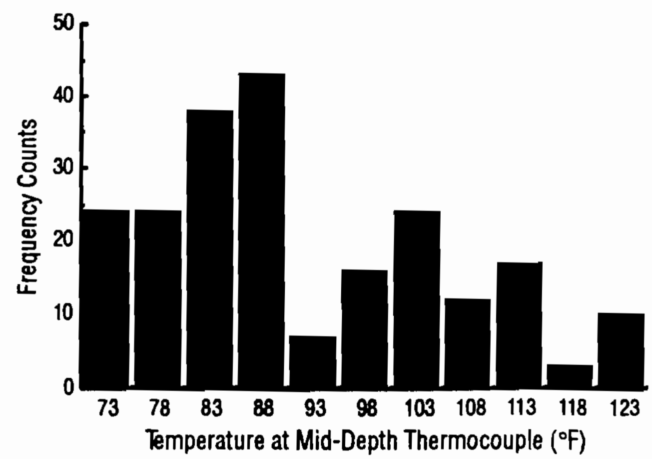


Fig 4.14. Frequency counts of temperature at middepth thermocouples.

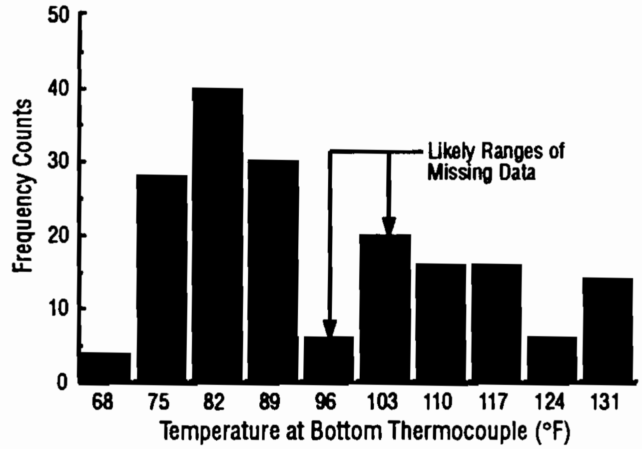


Fig 4.15. Frequency counts of temperature at bottom thermocouple.

four locations in the portable slab. It should be noted that the first set of temperature blocks had some malfunction in the bottom thermocouples right after the first few readings. New blocks were cast, and both crews started using the new set on August 9, 1988. Only a small amount of data was lost due to this problem. The ranges where missing data are likely to have occurred are depicted in Fig 4.15.

The pavement surface temperature was measured simultaneously with each deflection measurement, in a coordinated manner, so that each deflection basin would have a corresponding surface pavement temperature. Only one pyronometer was available for use, and only part time, because it was required on another project. This pyronometer was used by crew #2 part of the time; the remainder of the time crew #2 used a disk thermometer. Crew #1 used the other disk thermometer the entire data collection period. The amount of surface temperature data corresponds to the amount of deflection data, depicted in Table 4.3.

COMMENTS AND CONCLUSIONS

Data in Ref 3 presents a partial printout of the rigid pavement data base which was used to locate the test sections. Several penciled notes made during data collection are found on these sheets. These notes show a few discrepancies between field conditions and items listed in the data base:

(1) Suggested changes in the highway number, test section direction, and pavement depth were found.
(2) Locations of those sections that have tied concrete shoulders were compiled for adding to the data base, since most engineers believe concrete shoulders prolong pavement life.
(3) Sections which had been overlaid since the 1987 data collection were recorded for further updating of the data base.

During the initial planning for the 1988 deflection data collection, most of the emphasis was placed on the original or non-overlaid CRCP. This was due to the fact that deflection data were intended to be used for back-calculation of material characterization parameters and load transfer at the cracks, and both uses, especially the latter, require that the cracks be visible. Since 35 percent of the sections had been overlaid with ACP, it was necessary to develop the following testing procedure for the overlaid sections:

(1) Where transverse (reflective) cracking is found, obtain deflection information similar to that described for the non-overlaid CRCP (Fig 4.3).
(2) Where no transverse cracks that appear to repeat the crack pattern from pavement underneath are found, obtain the deflection measurements according to Fig 4.4.
(3) Do not collect crack width measurements, and to obtain surface temperature values.

No transverse reflective cracking was observed in any of the overlaid sections surveyed. There were three sections where some transverse cracks were observed, but these were associated with obvious punch-outs which were being reflected up from the slab below. It was believed that these could not be used in the usual manner for a load transfer study, so measurements at each side and on the crack were not obtained at these locations.

Most of the overlays seemed relatively new, so it is possible that reflective cracking had not been initiated. At least one of the older overlays in District 4 (Amarillo) could have been cracked, but an additional very thin overlay had recently been applied, covering most of the cracks in the older overlay. It is concluded that the asphalt concrete overlays are working well on CRCP. Rut depth measurements were taken in the overlaid sections. Due to the good condition of the overlays, almost all of the rut depths were zero; the few non-zero values were very small.

CHAPTER 5. COMMENTS AND RECOMMENDATIONS

The initial plan for the 1988 diagnostic survey was to collect data on the entire sample of sections that were surveyed in 1987 (Ref 1). However, time and budget constraints limited the sections surveyed to those given in Chapter 4. In addition, because closing the rightmost lane is very disruptive to urban traffic, not all test sections in urban areas could be surveyed. The final phase of this project, which will use these data to study and model performance of CRC pavements, may reveal that more data would be desirable. In addition, periodic diagnostic surveys for at least two years would be required for a detailed study of seasonal variations of moduli of pavement layers.

The results of the crack width measurements confirmed the findings of Ref 2, that good data reproducibility by different operators requires training, but a small amount of training is sufficient. Therefore it is recommended that personnel collecting crack width information receive training on the use of the microscope on CRCP cracks prior to data collection.

The deflection measurements were taken by the SDHPT personnel, and it was not possible to check reproducibility of FWD data taken by different machines and different operators. It was assumed that the extensive experience of SDHPT personnel in operating the FWD was enough to ensure good data reproducibility. Reproducibility between different FWD units was also assumed. It is recommended that the geophone configuration shown in Fig 4.5 be used in future condition surveys.

Although the current state-of-the-art in pavement temperature estimation suggests that the portable slab procedure is the most reliable for estimating pavement temperature, a considerable amount of practical difficulties arose from the use of temperature blocks in the field. On the other hand, measuring surface temperature poses no problems. This suggests that development of a reliable theoretical model to calculate pavement temperatures as a function of surface temperature and concrete properties would be desirable. However, such a model would need temperatures under the pavement as a boundary condition, and those are as difficult to obtain as the pavement temperatures themselves, although they are likely to show much less variation. Reference 2 presents some suggestions for a study to clarify this point, which seems worthy of further investigation. Until such a model can be developed, it is recommended that pyronometer-type temperature sensing devices be used to obtain surface temperatures and that these temperatures be augmented with the use of the portable slab estimation procedure.

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