TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FHWA/TX-89+1124-1F		

4. Title and Subtitle	5. Report Date
A STUDY OF THE INFLUENCE OF THE TEMPERATURE OF THE SUBSTRATE ON THE CONSTRUCTION OF BONDED PORTLAND CEMENT CONCRETE OVERLAYS	November 1988
	6. Performing Organization Code
7. Author(s) Soetjipto Koesno, C. G. Papaleontiou, A. H. Meyer, and D. W. Fowler	8. Performing Organization Report No. Research Report 1124-1F
9. Performing Organization Name and Address Center for Transportation Research The University of Texas at Austin Austin, Texas 78712-1075	10. Work Unit No.
	11. Contract or Grant No. Research Study 3-9-87-1124
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	13. Type of Report and Period Covered Final
	14. Sponsoring Agency Code

15. Supplementary Notes

Study conducted in cooperation with the U. S. Department of Transportation, Federal Highway Administration. Research Study Title: "A Study of the Influence of the Temperature of the Substrate on the Construction of Thin Bonded Portland Cement Concrete Overlays"

16. Abstract

This is the final report written under Research Study 1124, "A Study of the Influence of the Temperature of the Substrate on the Construction of Bonded Portland Cement Concrete Overlay." This report describes the research activities related to the temperature effect on overlays and summarizes the findings.

The research included constructing a test section at State Highway 225 in Houston to obtain the field conditions and also to construct 24 slabs in the laboratory with simulated field conditions to permit a more extensive study on the variables.

The result of this study was analyzed using General Linear Models (GLM) to find out the significance of the variables or their interactions.

17. Key Words	18. Distribution Statement
CRCP, overlay, interface bond, temperature, construction variables, grout, moisture	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	54	

Form DOT F 1700.7 (8-69)

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by

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Research Report Number 1124-1F

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Research Project 3-9-87-1124

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 1988

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 reflect the official views or policies of the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

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PREFACE

This is the final report produced under Research Study 1124, "A Study of the Influence of Temperature of the Substrate on the Construction of Bonded Portland Cement Concrete Overlays." The objectives of this study is to help the Texas State Department of Highways and Public Transportation (SDHPT) in determining the influence of the temperature of the substrate on the curing of Portland cement concrete (PCC) in thin bonded concrete overlays (BCO) and developing appropriate criteria for field placement of PCC for TBO.

This report presents the results of tests conducted both in the field and the laboratory. The tests were to evaluate the bond strength at the interface for several different construction variables. Interface bond strength was tested both in tension and shear.

LIST OF REPORTS

Research Report 1124-1F, "A Study in the Influence of the Temperature of the Substrate on the Construction of Bonded Portland Cement Concrete Overlays," by Soetjipto Koesno, A. H. Meyer, and D. W. Fowler presents the results of tests conducted both in the field and the laboratory. The tests were to evaluate the bond strength at the interface for several different construction variables. Interface bond strength was tested both in tension and shear. November 1988.

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This is the final report written under Research Study 1124, "A Study of the Influence of the Temperature of the Substrate on the Construction of Bonded Portland Cement Concrete Overlay." This report describes the research activities related to the temperature effect on overlays and summarizes the findings.

The research included constructing a test section at State Highway 225 in Houston to obtain the field conditions and also to construct 24 slabs in the laboratory with simulated field conditions to permit a more extensive study on the variables.

The result of this study was analyzed using General Linear Models (GLM) to find out the significance of the variables or their interactions.

KEYWORDS: CRCP, overlay, interface bond, temperature, construction variables, grout, moisture.

SUMMARY

A series of laboratory and field experiments was conducted to study the effect of temperature of substrates on bond strength at the interface. The study was to evaluate the effect of temperature and its interaction with other construction variables such as grout condition, moisture level, and location.

For the laboratory phase, twenty 3-foot x 3-foot x 8-inch slabs were cast to serve as bases for overlays. Bond strengths were tested using direct shear test and tension bond tests. For the field evaluation phase, eight slabs of 5-foot x 12-foot were placed as overlays on State Highway 225 in Houston. The bond strengths were tested using the direct shear test. Curling movements during the curing period for both laboratory and field phases were recorded and analyzed.

IMPLEMENTATION STATEMENT

This study generated recommendations that can be incorporated into construction specifications for bonded concrete overlays. First, surfaces should be dry during overlay construction for maximum bond strength; the use of grout is not recommended. Second, the overlays should be placed at cooler temperatures to obtain higher tension bond strength. Third, the ACI evaporation rate limit should be used as the upper limit of overlay placement temperatures.

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CHAPTER 1. INTRODUCTION

This chapter presents the background of bonded concrete overlays, the objective of the study, and the scope of the report.

BACKGROUND

As the Interstate highway system is close to completion and the existing highways have reached the end of their design life, highway industry emphasis has shifted from construction to maintenance, rehabilitation and resurfacing of the existing pavements.

The feasibility and performance of bonded concrete overlays are very encouraging. Concrete overlays have several advantages compared to asphalt overlays, such as good thermal and structural compatibility between the base and overlay material, asphalt's increasing cost and uncertain future availability, and the ability of the concrete overlays to handle higher traffic volume than asphalt overlays.

These factors also influence the type of the interface that will be used. There are basically three types of interfaces that are characterized by the degree of bond between existing pavements and the overlays: non-bonded, partially-bonded, and bonded monolithic overlays.

The technique of resurfacing concrete with concrete can be traced back to as early as 1900 (Ref 1). Concrete resurfacings have been used for several reasons:

(1) restoring ride quality,
(2) improving skid resistance of the old pavements, and
(3) restoring the structural capacity of the old pavements.

There are several types of concrete overlays that are commonly used, such as plain concrete, fibrous concrete, conventionally reinforced concrete, continuously reinforced concrete, and prestressed concrete. It appears that the final selection of resurfacing type is based on the existing pavement conditions and future traffic forecast, the distress mechanism, and most importantly the economic feasibility.

OBJECTIVE OF THE STUDY

The objective of the study is to evaluate the effect of varying substrate temperatures on the construction of the overlay. The effect will be evaluated in terms of bond strength, both in shear and in tension. The study will also evaluate the interaction among other construction variables: moisture levels, grout conditions, and location with regard to sides and corners.

This study covers both the field and laboratory work. The field work was performed to simulate the actual field conditions and was done on State Highway 225 in Houston. The laboratory study was designed to evaluate more closely the effect of temperature of substrates on the development of the interface bond.

SCOPE OF THE REPORT

Chapter 2 presents the experimental variables that were used both in the field and in the laboratory and also discusses the methods used to evaluate the interface bond strength.

Chapter 3 defines the problem and provides details of the experimental programs.

Chapter 4 discusses the laboratory work: the preparation, the construction, and the data collection.

Chapter 5 discusses the field evaluation work: the construction and the data acquisition.

Chapter 6 presents the data and the statistical analysis results.

Chapter 7 summarizes the conclusions of the study and presents recommendations for implementation.

CHAPTER 2. EXPERIMENTAL VARIABLES AND BOND EVALUATION METHODS

This chapter presents the construction variables used in the experiments and describes the methods used to evaluate bond strength at the interface.

CONSTRUCTION VARIABLES

Past experience has shown that the bond performance of overlays is greatly influenced by the conditions prior to, during, and after the construction. This study will investigate the significance of some construction variables and interactions among them on the development of the interface bond.

TEMPERATURE

Temperature during placement and curing is known to have significant effects on the properties of the concrete and consequently on the development of the interface bond. According to past experiences, curing operations should be planned so that the new concrete does not go through great changes in temperature in its earlier age (Ref 2).

If there is a temperature differential between top and bottom of the concrete pavement, the slab tends to curl. When curling is restrained, as by the weight of the slab itself, large stresses can be created at the interface. This condition is especially critical during the early time after placement because the bond is not fully developed yet.

The experiments included several placement temperatures to study the effect on bond development. The interactions of temperature with other variables were also studied.

SURFACE PREPARATIONS

Overlays generally are used to increase the structural capacity of the existing pavement. The goal will be reached only if the overlays act monolithically with the old pavement. Good surface preparation is very essential to insure good bond between the old pavement and the overlay. Before choosing a certain surface preparation, a study is usually performed both on the old pavement conditions and on the economic feasibility of the choices available.

Surface preparation usually includes proper scarification and cleaning. The purpose of scarification is to remove the unsound or damaged concrete and to provide a roughened surface which will permit adequate bond to avoid separation of concrete at weak planes. After scarification, the pavement needs to be cleaned to remove dust, grease, and other contaminants. All the preparations are to be completed before the placement of the concrete overlay, and it is best that the overlay is placed in the same day as the surface preparations.

Two types of surface preparations were used on the project: coldmilling and sandblasting.

Coldmilling

Coldmilling is widely used to increase the skid resistance of pavements and also to scarify the pavement surface before placing of overlays. The scarification is done using a rotating drum with steel studs. The debris is loaded onto a truck by using a conveyor belt. The scarification using coldmilling can take up to 5 inches of the old pavement. After coldmilling, a light sandblasting and airblasting are usually employed to clean the surface. This process is done just before the overlay is placed. Figure 2.1 shows the equipment. Considerable dust is generated with coldmilling.

Sandblasting

Sandblasting is usually used as a mechanical means of cleaning. This method employs sand particles blown on to the surface at high velocity to abrade the concrete, and to remove grease and other contaminants. The disadvantage of this system is the airborne dust that it generates.

Fig 2.1. Coldmilling machine.

SURFACE CONDITIONS

Good surface conditions improve the bond development. This experimental program will study surface conditions and their interactions with other variables to determine which will give the best results. Two surface conditions were considered:

(1) moisture levels and
(2) grout conditions.

Most pavement overlay construction is performed on completely dry surfaces. There is little experience from the past on overlays on wet surfaces. This experimental program will study the performance of dry and wet surfaces. Previous research (Refs 3 and 4) showed that wet surfaces will reduce the bond capacity. The program will also look at the benefit of using grout as a bonding agent before the placement. According to previous work (Ref 3) the grout will increase the bond capacity on wet surfaces.

BOND EVALUATION METHODS

Interface bond is very critical for a bonded concrete overlay (BCO) system; the bond contributes significantly to the success and economic feasibility of the system. If the

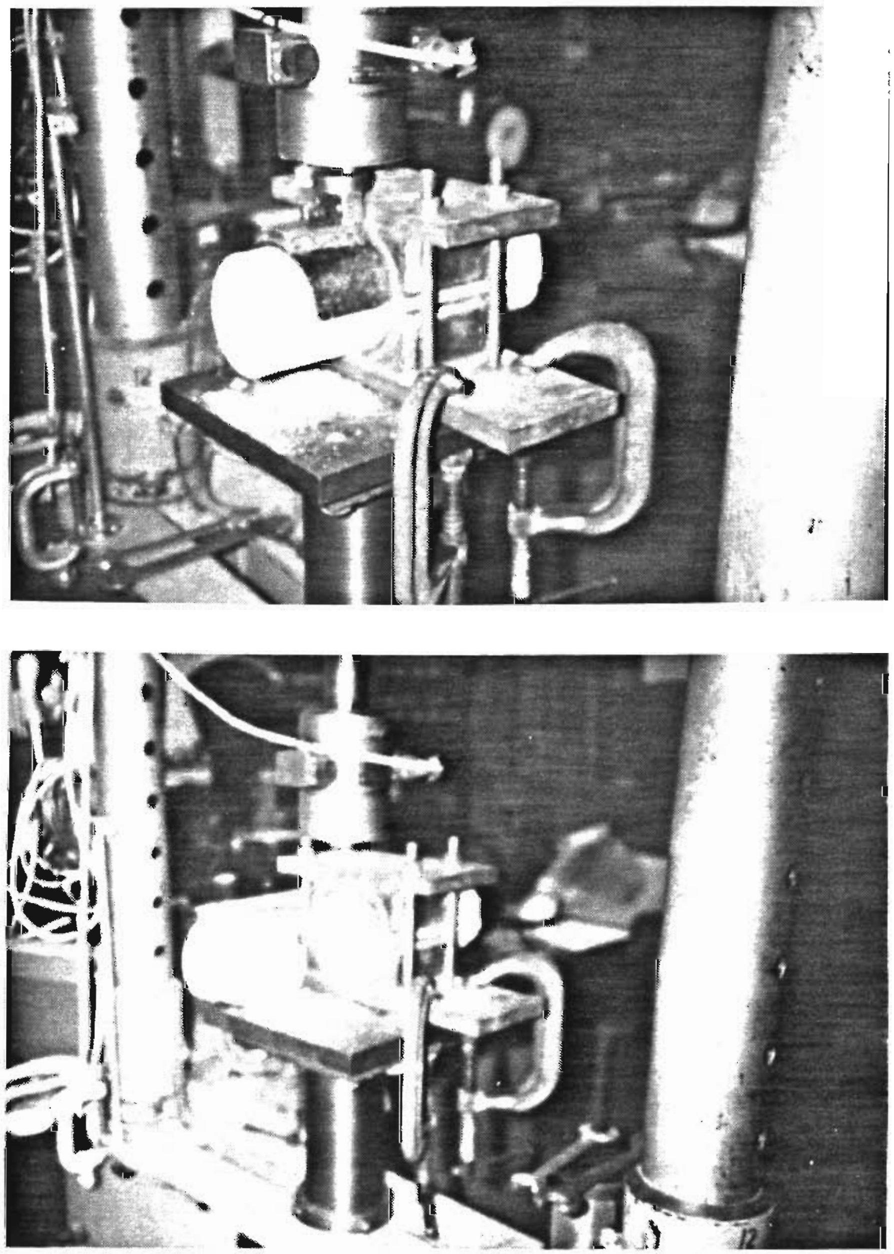


Fig 2.2. Direct shear test.

bond strength is less than the actual stress at the interface caused by traffic or differential movement between the old and new slabs, the interface bond will fail. Thus, the system will not be considered as a BCO system.

Direct shear and bond pull-out tests were chosen since they are the most widely used tests. Another important reason was to permit comparison with results from previous studies.

Direct Shear Test

The shear strengths of the cores from both the field and the laboratory work were obtained using a direct shear test (Fig 2.2). This device consists of two 7/16 inch plates with a 4-inch semi-circular pipe welded to each of the plates. The plates were held together by 4-7/16-inch-high strength steel bolts. The load is applied at the interface using a universal testing machine (Fig 2.3).

Test Procedure

(1) Clamp the test device to the loading machine using four C-clamps.

(2) Insert the core between the two semi-circular pipes, placing the interface at the end of the circular pipe.

(3) Load with a rate of 2-inch/minute until failure.

(4) Record the load at failure. The shear strength is calculated as

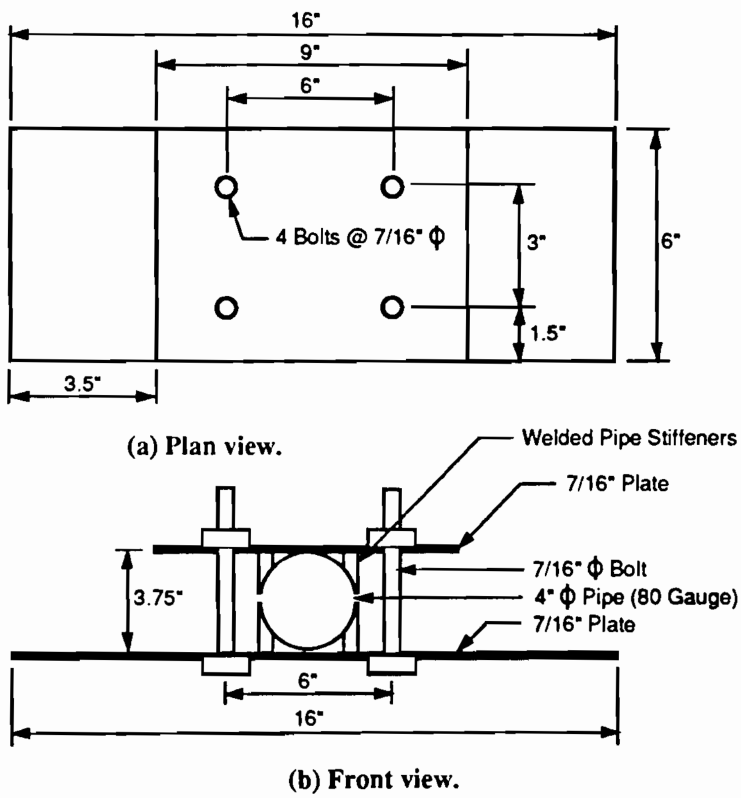
$$V = P_u/A$$

where

V = shear strength, psi;
P_u = load at failure, lb; and
A = area of the specimen at the interface, square inches.

Tension Bond Test

This method is to determine the interface bond in tension and is an ACI standard (Ref 6). The load is applied on a 2-inch-diameter core that is drilled past the interface and the failure load is recorded by a dynamometer. The test device is illustrated in Fig 2.4. A schematic for the test is shown in Fig 2.5.



(b) Front view.

Fig 2.3. Plant and front views of direct shear testing device.

Test Procedure

(1) Clean the area where epoxy is going to be applied.
(2) Mix the epoxy and apply a test patch. The test patch must cover the surface that is going to be drilled.
(3) After the epoxy hardens, core drill through the overlay slightly past the interface.
(4) Bond a 1.5-inch-diameter pipe cap which has been machined to the surface of the cored specimen using a rapid curing epoxy.
(5) Apply tension with a rate of 100 pounds per 5 seconds until the specimen fails:

$$Ts=F/A$$

where

Ts =tensile strength, psi;
F =bond at failure, lb; and
A=area of the core, square inches.

There are three possible failure locations:

(a) failure at the interface,
(b) failure in either the old or new concrete, and
(c) failure in the epoxy.

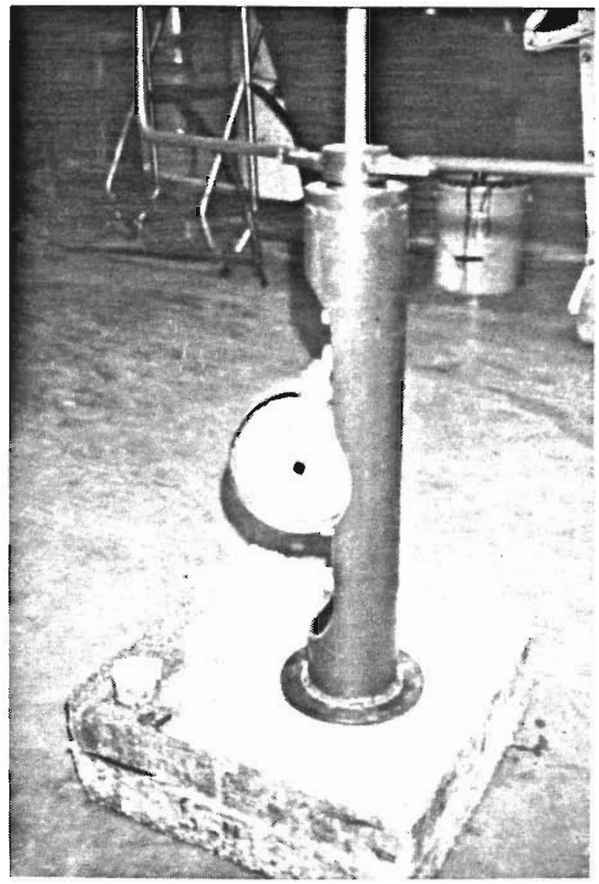


Fig 2.4. Bond pull-out testing device.

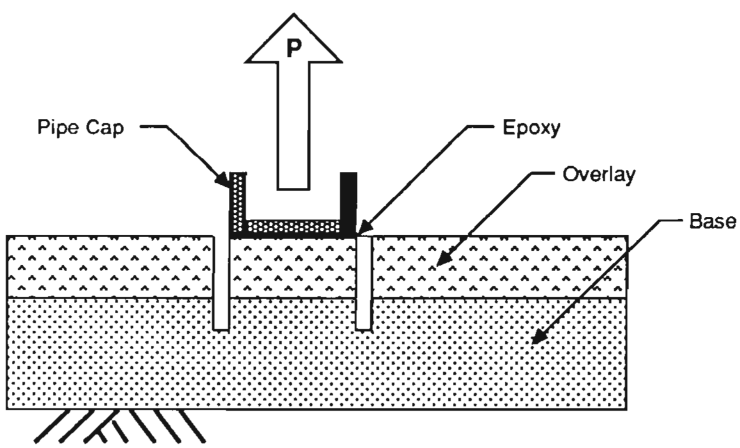


Fig 2.5. Schematic for tension bond test.

CHAPTER 3. EXPERIMENTAL PROGRAM

This chapter describes the selection of the construction variables for both the field and laboratory phases. The field phase was performed to simulate the real field conditions, and a study on the temperature effect during the placement of overlays was conducted.

PROBLEM DEFINITION

The main goal of most bonded concrete overlay projects is to increase the structural capacity of the existing pavements. The success of the system depends greatly on the degree to which the shear stress can be transferred from the overlay to the base slab. There are several significant factors that will be considered in this study:

(1) temperature during placement,
(2) moisture levels,
(3) grout conditions, and
(4) location of cores.

FIELD EVALUATION PHASE

The purpose of the field test was to simulate the actual conditions during overlay construction. The field evaluation covered several construction variables (Fig 3.1):

(1) seasons: winter and summer;
(2) moisture levels: dry and wet;
(3) grout conditions: grout and no grout; and
(4) location of cores: center, side, and corner.

During curing, the temperature and the curling movement of the overlay slab were monitored. The curling was also monitored periodically after the initial curing period. Interface bond strength was evaluated using the direct shear test.

LABORATORY PHASE

The main purpose of the laboratory study was to verify the results from the field study and also to investigate the broader range of temperature variables. In this study, the curling movement and the temperature gradient during the curing period were continuously monitored using an electronic data acquisition system. The study covered the variables shown in Fig 3.2:

(1) temperatures of placement: 60, 75, 90, and 100°F;
(2) moisture levels: wet and dry;
(3) grout conditions: grout or no grout;
(4) locations of cores: center and corner; and
(5) bond evaluation devices: direct shear test and tension bond test.

Moisture Levels	Dry		Wet	
Grout Conditions	Grout	No Grout	Grout	No Grout
Seasons				
Summer	X	X	X	X
Winter	X	X	X	X

Fig 3.1. Factorial design for the field study.

Moisture Levels	Dry		Wet	
Grout Conditions	Grout	No Grout	Grout	No Grout
Temperatures				
60	X	X	X	X
75	X	X	X	X
90	X	X	X	X
100	X	X	X	X

Fig 3.2. Factorial design for laboratory study.

CHAPTER 4. LABORATORY WORK

This chapter describes the details of the laboratory work. It discusses the construction of the laboratory test sections, the placement of overlays, the curling movement and temperature data collection, and the testing program. The laboratory work was performed at the Balcones Research Center of The University of Texas at Austin.

CONSTRUCTION OF THE LABORATORY TEST SECTIONS

Twenty 3-foot x 3-foot x 8-inch slabs were cast to serve as bases for overlays. The mix design used was five sacks of cement per cubic yard with 5/8-inch maximum size of siliceous river gravel. Readymixed concrete was used. After placement, the concrete was vibrated with pencil vibrators. While the concrete was still plastic, the surface was tined to to create a rough surface. Tining was chosen because other scarification means after the concrete hardened were impractical due to the panel size. After tining, the concrete was covered with wet burlap and left to cure in the field.

The panels were spaced one foot apart. The spaces were filled with sand to simulate the continuity of the pavement for heat transfer purposes.

THE PLACEMENT OF OVERLAYS

Before the overlays were placed, the base slabs were sandblasted to remove any dirt, oil film, and laitance. After sandblasting, the panels were vacuumed with an industrial vacuum cleaner. Then, 4-inch-thick overlays were placed. The concrete mix design used seven sacks of cement per cubic yard with 3/4-inch maximum size of siliceous river gravel. The water-cement ratio was 0.35. The concrete was then vibrated using pencil vibrators. A curing compound was sprayed afterward to prevent moisture loss.

DATA COLLECTION DURING CURING PERIOD

The temperature gradient is a very important factor in pavement design. According to a previous study done on the subject, a 4°F per inch temperature differential is able to produce a stress of 308 psi (Ref 7). In this study the temperature gradient of the concrete was monitored continuously for 24 hours after placement of the overlay to evaluate how the temperature at placement affects the bond development at the interface. A computer program was used to generate the temperature profile in the slab, but the results were not satisfactory. Instead the temperature gradient was measured with thermocouples which were embedded in the concrete at different depths and connected to an electronic data acquisition system. The data are presented in Tables B.2-B.7, Appendix B.

The curling movement on a slab is caused by the temperature differential and moisture gradient in the concrete. This study measured only the temperature effect on curling movement of the slab. The movement of the slab was measured using direct current displacement transducers (DCDTs) that were mounted on a wooden frame (Fig 4.1), and the data are summarized in Tables B.8-B.13, Appendix B.

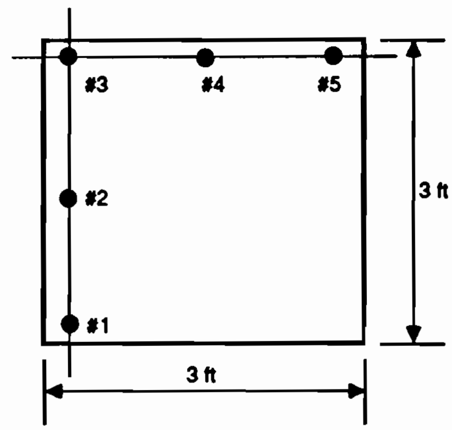


Fig 4.1. Location of the DCDTs.

THE TESTING PROGRAM

The coring was done seven days after placement of the overlay using a portable coring machine. The corner and center locations were picked to compare the location effect on bond strength development. For the direct shear test, a 4-inch-diameter core barrel was used, and for the tension bond test, a 2-inch-diameter core barrel was used (Fig 4.2). The test methods are described in detail in Chapter 2.

The results from the direct shear test and tension bond test are presented in Table B.1, Appendix B.

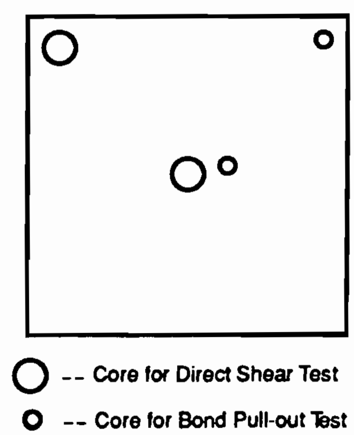


Fig 4.2. Typical core locations.

CHAPTER 5. FIELD EVALUATION WORK

The field work was conducted on State Highway 225 in Houston in conjunction with Project 457 which studied the effect of construction variables on the development of the interface bond. This chapter describes the details of test section construction and the data acquisition program.

TEST SECTION CONSTRUCTION

The construction of test slabs was done on a stub-out of State Highway 225 (Fig 5.1). The existing pavement was coldmilled to remove the top 1/4 to 1/2 inch of the concrete. The coldmilling was performed by District 12. For the field work, eight test sections each 5 feet x 12 feet were placed as overlays. The design mix used was seven sacks of cement per cubic yard with 3/4-inch maximum size siliceous river gravel.

Winter Test Sections

Brushes and compressed air were employed to clean the debris and dust left by the coldmilling. The cleaning was not fully effective, and dust was trapped in the corners and sides of the formwork. The dust caused some debonding at the corner areas. Before overlays were placed, the substrate was cooled using ice cubes to lower the temperature of the substrate. For the wet sections, ice was placed and permitted to melt on the surface. For the dry sections, polyethylene sheets were used to cover the pavement before ice was poured to prevent the surface from getting wet. The temperature of the substrate at placement was about 65°F. A typical layout of the test sections is shown in Fig 5.2.

After the concrete truck arrived, the overlay was placed on the wet sections first to give the dry sections more time to cool down. On the grouted sections, grout was applied just before the overlay was placed and spread uniformly with a stiff brush. After the concrete was placed, it was vibrated with 2-inch-diameter vibrators. The surface was finished with a vibrating screed mounted on a 2 x 8 wood board. After screeding, the surface was broomed, sprayed with water, and covered with a polyethylene membrane to prevent moisture loss.

Summer Test Section

For the summer test section, a more effective cleaning method was required because soil and other contaminants had already been deposited in the grooves from the previous March coldmilling. Then a strong sandblast and airblast were employed to clean the surface. After that, the overlay was placed. The temperature of the substrate at placement was about 110°F. The concrete was then vibrated using 2-inch-diameter internal vibrators and the surface was finished

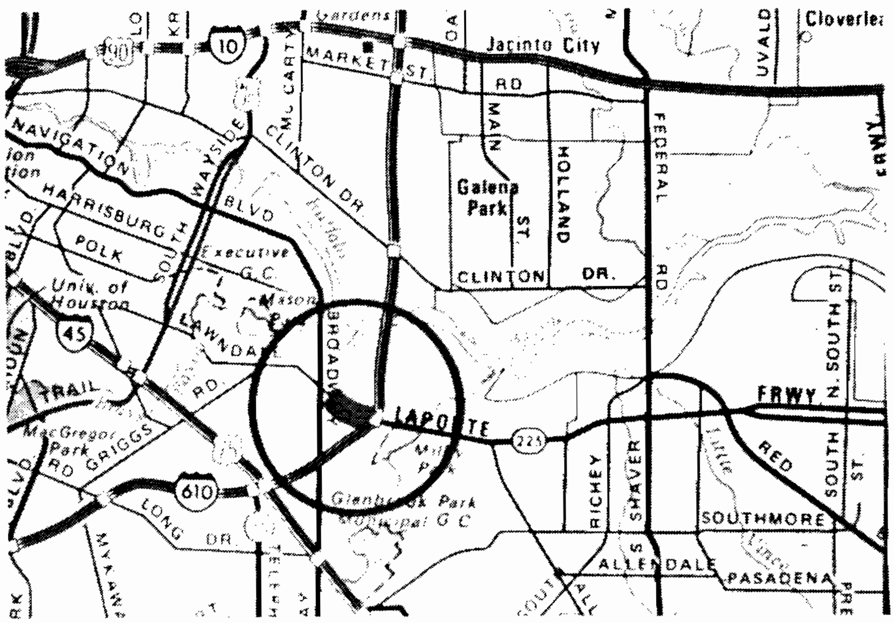


Fig 5.1. Location of field evaluation work in Houston.

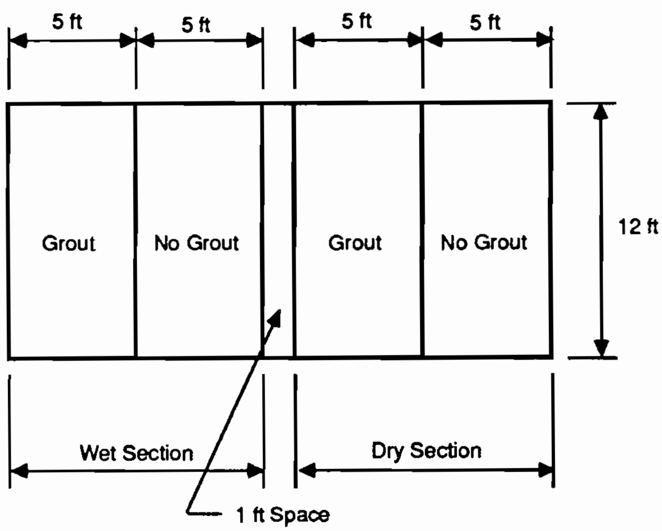


Fig 5.2. Typical test sections.

using a roller screed vibrator. Curing compound was sprayed afterward to prevent moisture loss.

DATA COLLECTION PROGRAM

The curling movements were monitored periodically. For each season, one from the dry sections and one from the wet were evaluated for comparison. The movements were measured using 0.001-inch-accuracy dial gages that were mounted on a 2 x 8 lumber frame (Fig 5.3). The measurements were recorded at a half-hour intervals. The data are summarized in Tables A.3-A.6 and A.11-A.15, Appendix A.

For the summer test section the overlay temperatures during the first 24 hours after placement were monitored using thermocouples. The data are listed in Tables A.7 and A.9, Appendix A.

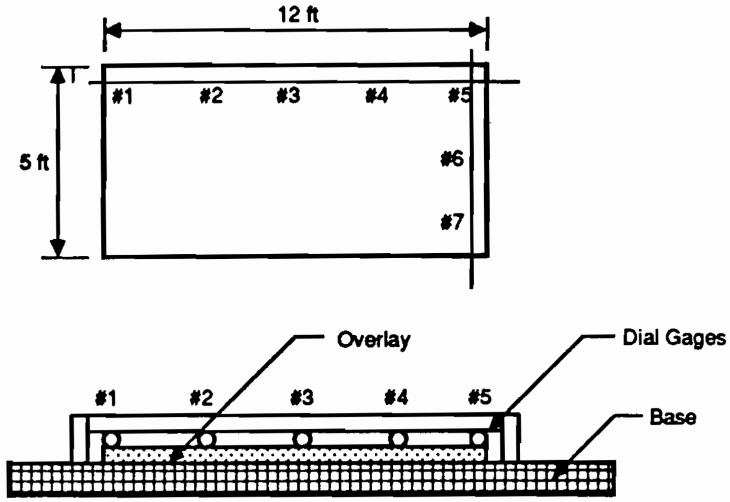


Fig 5.3. Positions of dial gages.

THE TESTING PROGRAM

The coring locations were chosen to study the effect of location on bond strength. The locations were the corner, the middle, and the side of the overlay (Fig 5.4). Bond strength was evaluated using the direct shear test and the results are presented in Tables A.1 and A.2, Appendix A.

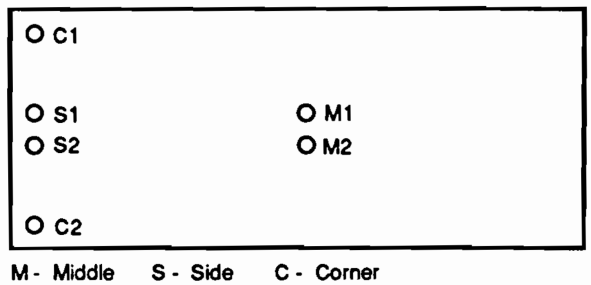


Fig 5.4. Typical field slab with core locations.

CHAPTER 6. RESULTS OF LABORATORY AND FIELD EXPERIMENTS

LABORATORY EXPERIMENT

Laboratory Shear Bond Strength

A laboratory experiment was conducted in order to examine the effect of a number of construction variables and a wide range temperature levels not easily obtained in a field study on the shear bond strength at the interface of the overlay and base slab. The shear bond test is described in detail in Chapter 2.

The following variables and levels of each were examined:

Variable	Levels
1. Moisture level	Wet, dry (2)
2. Grout condition	Grout, no grout (2)
3. Temperature	60, 78, 85, 96°F (4)
4. Location of core	Middle, corner (2)

The statistical experiment was designed as a full completely randomized factorial experiment. A full factorial indicates that all the treatment combinations are obtained at least once, meaning that there are no missing observations. A completely randomized factorial design assumes no restriction on randomization of treatment combinations. As a result an average error variance is calculated for the whole experiment by considering repeated measures of each treatment combination.

The completely randomized factorial experiment provides the capability of inferring over all the ranges of factors considered since all levels are represented in combination with all levels of every other factor. As a result it allows the investigation of all main factors, such as moisture or grout, as well as the effects of factors or combinations of factors on another factor or factors. This is defined as interaction. In this experiment there are four main factors or variables, and six 2–way, four 3–way, and one 4–way interaction. The 4–way interaction is not measurable because repeated measures at the fourth level were not obtained. It is therefore assumed that this interaction is non-significant, or zero, and its residual error is pooled into the error term.

The factors considered in the experiment are tested for significance by the "F"$_{statistic}$. The "F"$_{statistic}$ is equal to the mean square (or average variance) of the source of variation in question (e.g., temperature, moisture-grout interaction, etc.) divided by the error variance. This value is tested against the "F"$_{critical}$ at the specified α level to determine significant differences between the levels of the source of variance. In most cases an alpha level of 5 to 10 percent is used. If the null hypothesis is accepted at $\alpha = 0.10$ and also at $\alpha = 0.25$ then the β error is very small because the α and β errors are inversely proportional. In this case the tested error variance can be assumed equal to zero and pooled together with the experimental error. The pooled error variance becomes the new error term that will test the remaining factors (Ref 10). The technique gives a better estimate of the experimental error by pooling nonsignificant variances into the true error. Additionally, the increased degrees of freedom result in easier rejection of the null hypothesis.

Table 6.1 shows the layout of the experiment and the shear bond strength per treatment combination. All shear strength data are presented in Table B.1 in Appendix B.

The analysis of data was performed on an IBM mainframe computer using the Analysis of Variance (ANOVA) procedure of the Statistical Analysis System (SAS) of the SAS Institute (Ref 8).

All main effects (moisture, grout, temperature, and location) and their two- and three-way interactions were specified in a preliminary analysis model. The results of the analysis, as shown in Table 6.2, indicate that all three-way interactions are not significant at an α level of 0.10. This means that the null hypothesis of equal means can not be rejected at a probability of committing a wrong decision 10 percent of the time. In addition to that, all three-way interactions are not significant at an α level of 0.25. This allows pooling of the three-way variance into the error term without the chance of increasing the β error (probability of accepting a wrong null hypothesis) at unacceptable levels.

The results of the second analysis are shown in Table 6.3. Comparing Tables 6.2 and 6.3 shows that there is a net change in the nonsignificant terms after pooling. The moisture and grout main effects become significant only when pooling is considered. All two-way interactions stay nonsignificant. In the following paragraphs are discussed (1) the results from the statistical analysis and (2) the graphs of shear strength with the variables. It should be pointed out that the analysis of variance compares mean values of the same treatment combinations and levels (e.g., wet vs. dry strength) in order to detect probable statistical differences between the treatments or levels under consideration. The individual data points within a treatment combination are used to determine the distribution of the values around the mean (e.g., the variance), and enter into the calculations when computing the "F"$_{statistic}$. Consequently, it is harder to detect mean differences when individual points have a wide scatter around the mean. The following figures represent plots of mean strength values at various combinations and levels and are merely graphical representation of the results from the analysis of variance. Individual points are plotted only to show their dispersion around the mean values.

Figure 6.1 shows the effect of moisture on shear bond strength. The statistical analysis has indicated a strength difference between the two moisture levels. The mean wet strength was 420 psi and the mean dry strength was 520 psi. This difference amounted to a 20 percent higher strength when the base slab was dry before it was overlaid.

The shear bond strength versus grout condition is shown in Fig 6.2. The presence of grout before applying an overlay has been shown to result in a lower shear bond strength. Mean strengths were 430 psi with grout and 510 psi without grout, or 20 percent less when grout was used.

The effect of temperature on the shear bond is shown in Fig 6.3. The shear bond strength level was found to be insensitive to temperature changes. The highest difference was found to be between temperatures 60 and 78°F (520 and 410 psi, respectively), but this was not a significant difference primarily due to the large variance in the results as indicated by the plot of the individual data points.

The plot of shear bond versus core location (Fig 6.4) indicated no statistical difference between middle and center core shear strengths. A plot of the two means shows an almost flat curve.

Figures 6.5 to 6.8 show plots of interactions between the variables. As stated earlier, none of the two- or three-way interactions were found significant. Figure 6.5 shows that a wet surface condition will always result in a lower shear strength irrespective of the presence or absence of grout, while Fig 6.6 shows that a no-grout condition will always result in a higher strength irrespective of the presence or absence of moisture.

Figure 6.7 shows the interaction between temperature and moisture conditions. The wet and dry curves are parallel meaning that the shear bond strength is higher when the base slab is dry before overlaying. This is true at any temperature. Figure 6.8 shows the temperature-grout interaction. The shear bond is lower when grout is applied before the overlay at temperatures between 60 and 85 degrees. The shear bond is shown not to be significantly affected by grout application at a 95°F temperature.

Laboratory Tensile Bond Strength

This experiment is similar to the shear bond strength experiment. Cores were taken from the same slabs cast for

TABLE 6.1. LAYOUT OF LABORATORY EXPERIMENT AND SHEAR BOND STRENGTH RESULTS PER TREATMENT COMBINATION

		Temperature (°F)							
		60		78		85		96	
		Moisture		Moisture		Moisture		Moisture	
Grout	Location	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry
Yes	Middle	557	462	374	338	505	513	398	601
	Corner	577	792	438	597	501	609	286	665
No	Middle	302	496	318	497	501	418	414	613
	Corner	525	473	334	358	227	589	509	318

TABLE 6.2. ANALYSIS OF VARIANCE ON SHEAR BOND TEST RESULTS FROM LABORATORY EXPERIMENT

Source of Variation	DF	Mean Square	F-Value	Probability [1]	Significance $\alpha = 0.10$ [2]
Temperature	3	20,000	0.81	0.57	No
Moisture	1	77,500	3.35	0.16	No
Grout	1	54,500	2.36	0.22	No
Location	1	7,500	0.33	0.61	No
Temperature*Moisture	3	2,500	0.11	0.94	No
Temperature*Grout	3	5,500	0.24	0.86	No
Temperature*Location	3	14,250	0.62	0.64	No
Moisture*Grout	1	3,000	0.13	0.74	No
Moisture*Location	1	6,000	0.26	0.65	No
Grout*Location	1	27,750	1.20	0.35	No
Temperature*Moisture*Grout	3	14,000	0.61	0.65	No
Temperature*Moisture*Location	3	12,500	0.54	0.69	No
Temperature*Grout*Location	3	2,500	0.11	0.95	No
Moisture*Grout*Location	1	39,500	1.72	0.28	No
Error	3	23,000	-	-	-

1 Probability of significance associated with the F-value
2 Probability of rejecting a correct null hypothesis

TABLE 6.3. ANALYSIS OF VARIANCE (AFTER POOLING) ON SHEAR BOND TEST RESULTS FROM LABORATORY EXPERIMENT

Source of Variation	DF	Mean Square	F-Value	Probability [1]	Significance $\alpha = 0.10$ [2]
Temperature	3	18,500	1.23	0.33	No
Moisture	1	77,500	5.12	0.04	Yes
Grout	1	54,500	3.61	0.08	Yes
Location	1	7,500	0.50	0.49	No
Temperature*Moisture	3	2,500	0.17	0.92	No
Temperature*Grout	3	5,500	0.37	0.77	No
Temperature*Location	3	14,250	0.95	0.45	No
Moisture*Grout	1	3,000	0.20	0.66	No
Moisture*Location	1	6,000	0.39	0.54	No
Grout*Location	1	27,750	1.84	0.20	No
Error	13	15,000	-	-	-

1 Probability of significance associated with the F-value
2 Probability of rejecting a correct null hypothesis

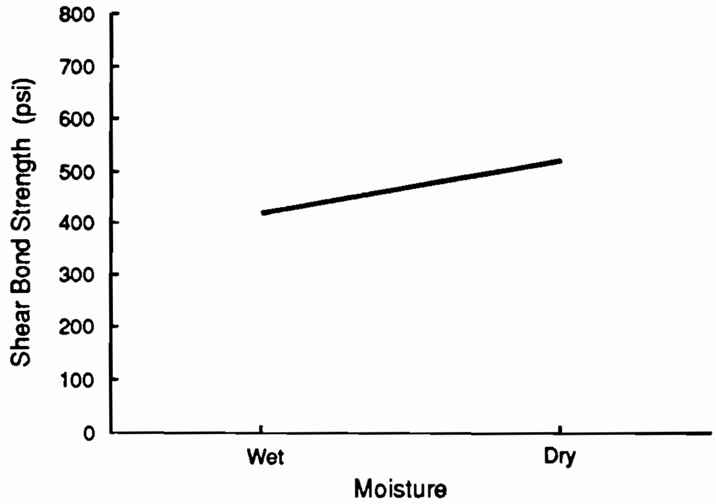


Fig 6.1. Shear bond vs. moisture condition.

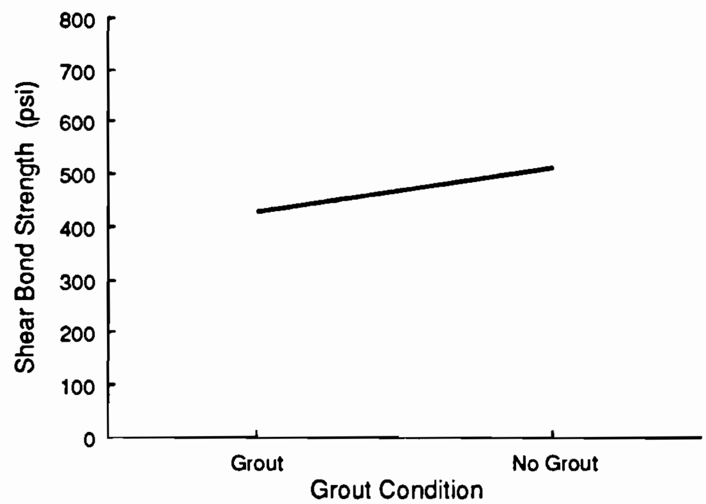


Fig 6.2 Shear bond vs. grout condition.

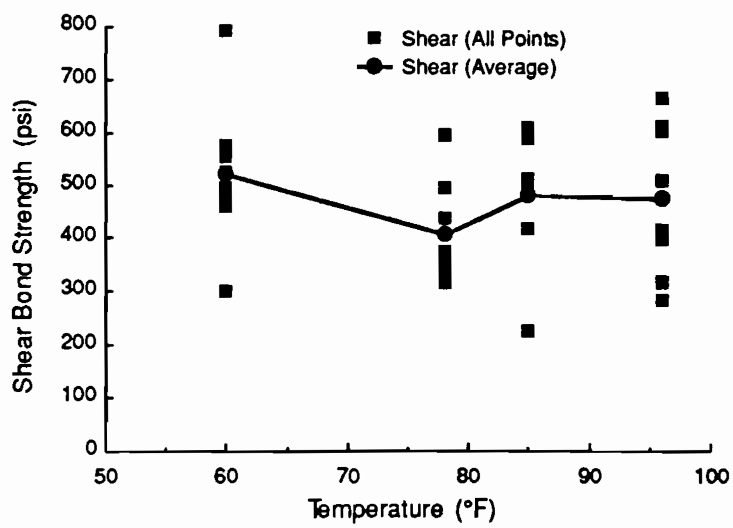


Fig 6.3. Shear bond vs. temperature.

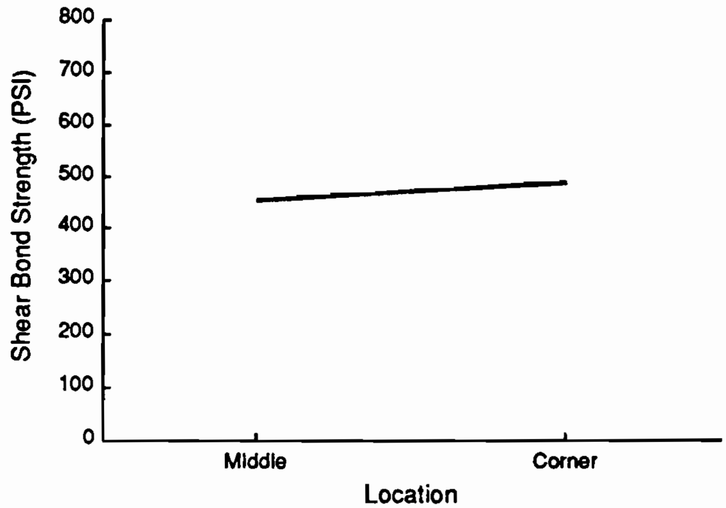


Fig 6.4. Shear bond vs. core location.

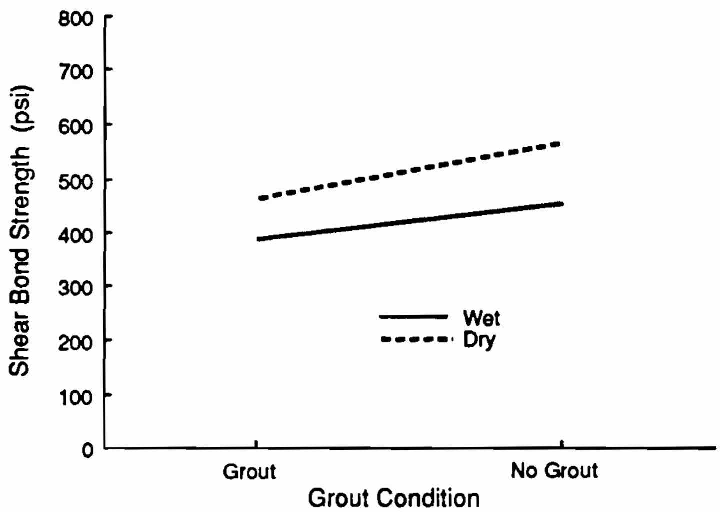


Fig 6.5. Shear bond strength vs. grout-moisture condition

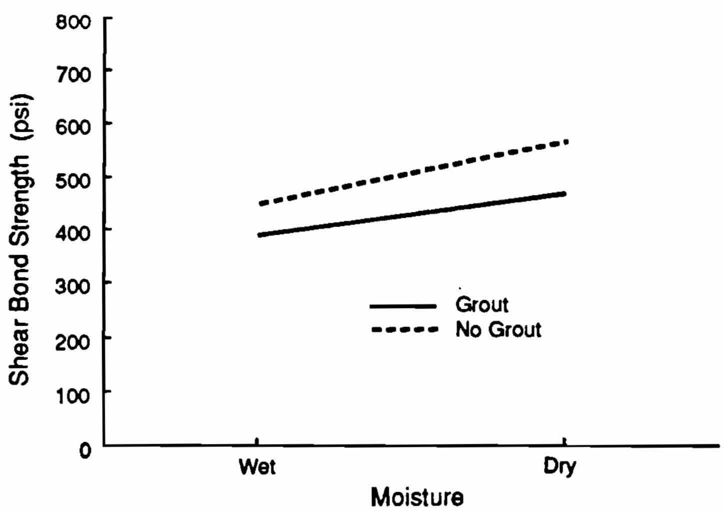


Fig 6.6. Shear bond strength vs. moisture-grout interaction.

the shear bond experiment, and the tensile bond strength at the interface of the overlay and the base slab was measured. The test is an ACI standard described in detail in Chapter 2. Table 6.4 shows the layout of the experiment and the individual strength data per treatment combination. The data are also shown in a tabulated form in Table B.1 in Appendix B. The same construction variables and temperature levels as in the shear bond experiment were examined.

The results of a preliminary statistical analysis, in which the four-way interaction is assumed negligible, are shown in Table 6.5. No condition has shown significance mainly due to the small number of degrees of freedom in the error variance. The pooling technique was employed as in the shear bond experiment by considering three of the three-way interactions which were not significant at $\alpha = 0.25$ as part of the error term. The results of the second analysis are shown in Table 6.6. The temperature and location main effects and interactions of moisture-location, temperature-location, temperature-grout, and temperature-moisture-location are shown to be significant. The fact that the same variables were found significant at both the main and interaction levels prevents any conclusion being made for the main effects until a plot of the results is made. Furthermore, interactions can be interpreted only by applying additional statistical techniques like the student Newman-Keuls test (SNK) (Ref 10).

The following is a discussion on the results from the statistical analysis and the graphs of average values.

The temperature was found to be a significant variable in the analysis. Figure 6.9 shows a plot of the average tensile strength at each temperature level. The individual data are also shown in the plot. The SNK test indicated that tensile strengths are equal at 60 and 78°F and higher than the strengths at 85 and 96°F. When the interaction of temperature-location is plotted (Fig 6.10) the above statement turns out not exactly true. Corner strengths are nearly equal at 60 and 78°F and lower at 85 and 95°F. But middle strengths appeared not to be affected by the temperature variation.

The interaction of temperature and grout is shown in Fig 6.11. Overlaying without grout application resulted in higher tensile strengths at 60 and 96°F than with grout application. The strength at 78°F was higher when grout was applied, but strength level was insensitive to grout application at 85°F.

The temperature-moisture interaction has not shown any significance (Fig 6.12) which means that presence or absence of moisture before casting an overlay at any base temperature does not have any significant effect on the strength level. It seems, though, that for a wet condition the average strength drops with increasing temperature. The

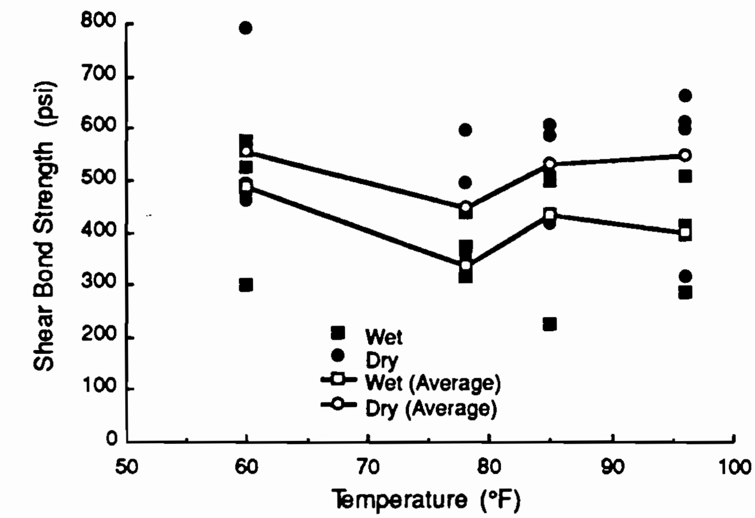


Fig 6.7. Shear bond strength vs. temperature-moisture interaction.

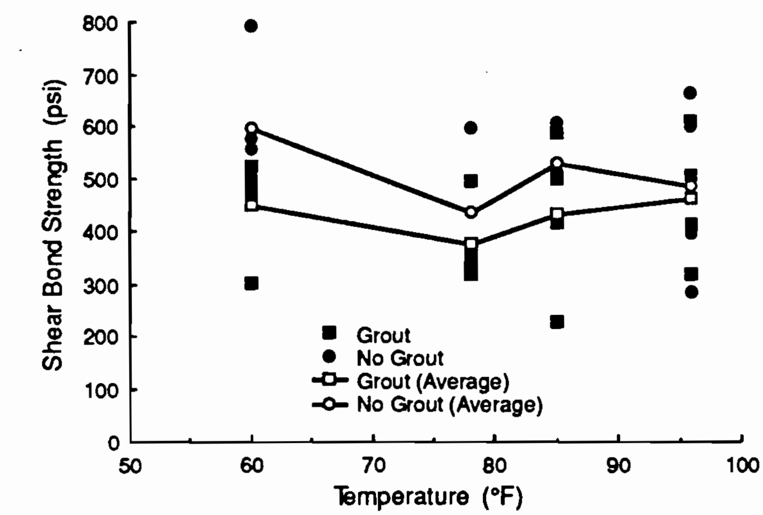


Fig 6.8. Shear bond strength vs. temperature-grout interactions.

TABLE 6.4. LAYOUT OF LABORATORY EXPERIMENT AND TENSILE BOND STRENGTH RESULTS PER TREATMENT COMBINATION

		Temperature (°F)							
		60		78		85		96	
		Moisture		Moisture		Moisture		Moisture	
Grout	Location	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry
Yes	Middle	295	215	207	96	191	159	119	154
	Corner	358	334	151	310	88	72	159	263
No	Middle	88	191	215	72	167	199	111	135
	Corner	239	175	199	581	151	96	111	154

TABLE 6.5. ANALYSIS OF VARIANCE ON TENSILE BOND TEST RESULTS FROM LABORATORY EXPERIMENT

Source of Variation	DF	Mean Square	F-Value	Probability [1]	Significance α = 0.10 [2]
Temperature	3	20,500	3.97	0.14	No
Moisture	1	4,000	0.77	0.44	No
Grout	1	2,500	0.50	0.53	No
Location	1	21,500	4.13	0.14	No
Temperature*Moisture	3	4,250	0.82	0.56	No
Temperature*Grout	3	15,500	3.02	0.19	No
Temperature*Location	3	19,500	3.84	0.15	No
Moisture*Grout	1	2,500	0.50	0.53	No
Moisture*Location	1	15,000	2.97	0.18	No
Grout*Location	1	1,500	0.32	0.61	No
Temperature*Moisture*Grout	3	1,750	0.34	0.80	No
Temperature*Moisture*Location	3	22,250	4.30	0.13	No
Temperature*Grout*Location	3	5,000	0.99	0.50	No
Moisture*Grout*Location	3	500	0.09	0.79	No
Error	3	5,000	-	-	-

[1] Probability of significance associated with the F-value
[2] Probability of rejecting a correct null hypothesis

TABLE 6.6. ANALYSIS OF VARIANCE (AFTER POOLING) ON TENSILE BOND TEST RESULTS FROM LABORATORY EXPERIEMENT

Source of Variation	DF	Mean Square	F-Value	Probability [1]	Significance α = 0.10 [2]
Temperature	3	20,500	5.61	0.02	Yes
Moisture	1	4,000	1.09	0.32	No
Grout	1	2,500	0.70	0.42	No
Location	1	21,500	5.83	0.03	Yes
Temperature*Moisture	3	4,250	0.16	0.37	No
Temperature*Grout	3	15,500	4.26	0.04	Yes
Temperature*Location	3	20,000	5.42	0.02	Yes
Moisture*Grout	1	2,500	0.70	0.42	No
Moisture*Location	1	15,000	4.19	0.07	Yes
Grout*Location	1	1,500	0.45	0.52	No
Temperature*Moisture*Location	3	22,000	6.07	0.01	Yes
Error	10	3,500	-	-	-

[1] Probability of significance associated with the F-value
[2] Probability of rejecting a correct null hypothesis

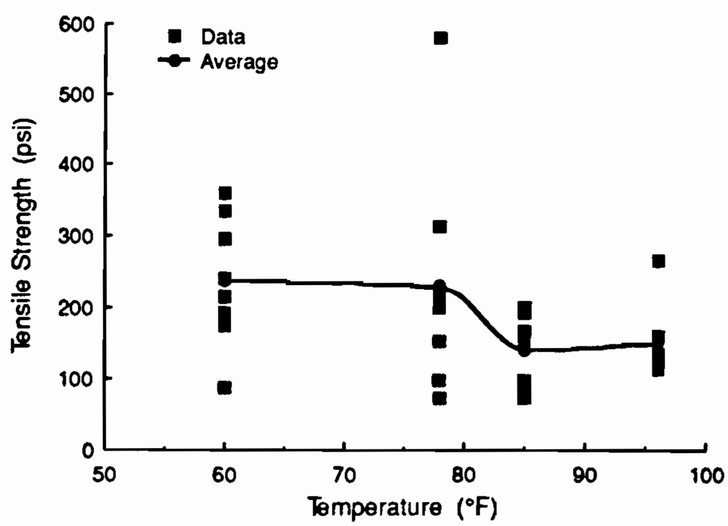


Fig 6.9. Tensile bond strength vs. temperature.

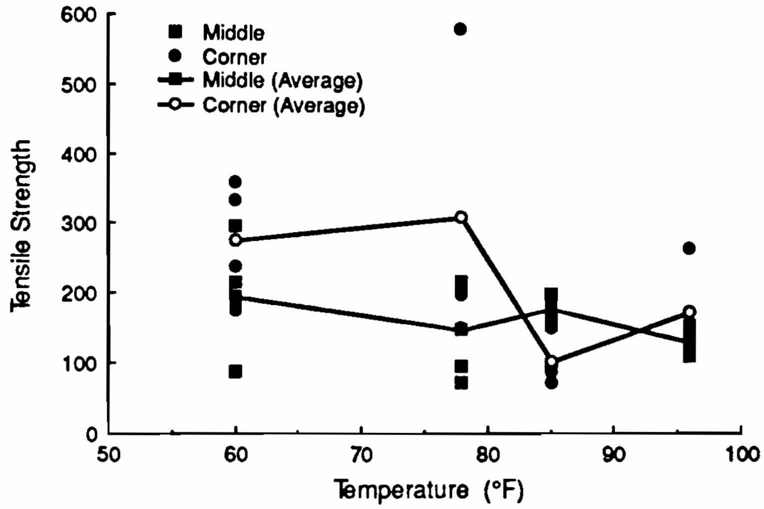


Fig 6.10. Tensile bond strength vs. temperature-location

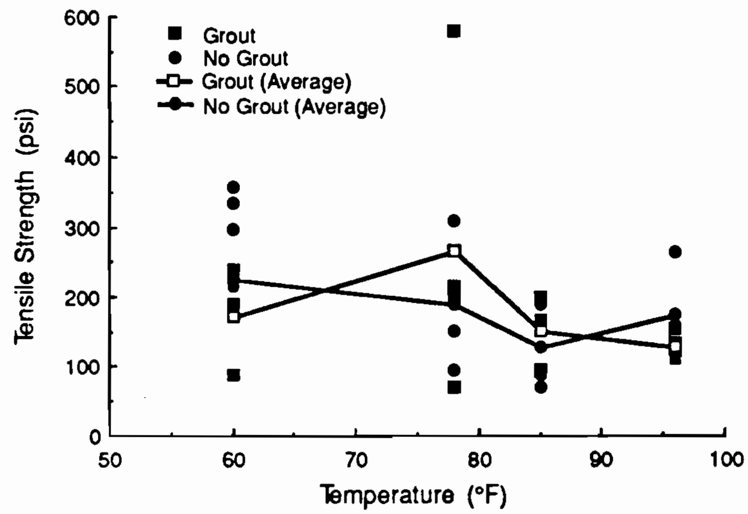


Fig 6.11. Tensile bond strength vs. temperature-grout interaction.

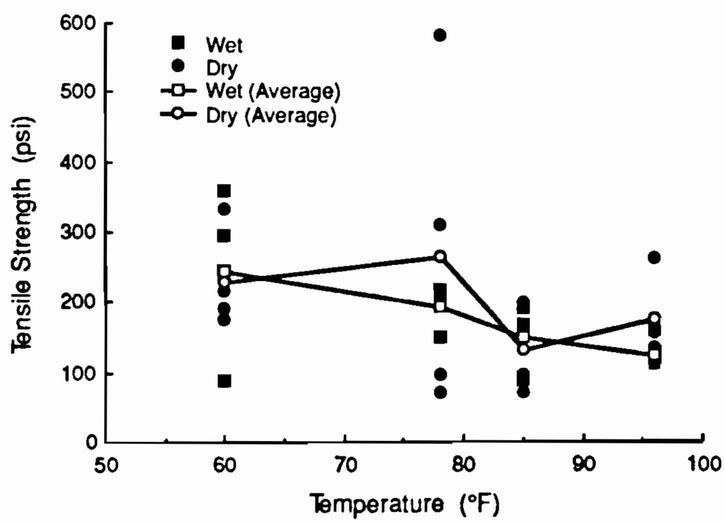


Fig 6.12. Tensile bond strength vs. temperature-moisture interaction.

moisture-grout interaction (Fig 6.13) was also not significant meaning that any combination of the two does not contribute to a higher or lower strength.

Figure 6.14 is a plot of tensile strength versus location. The analysis has indicated that corner strength is higher than middle strength. However, since the location-moisture interaction is significant the results should be interpreted inconjunction with that interaction. Figure 6.15 shows the interaction of location and moisture. As shown from the graph and as verified by the SNK test, significantly higher strengths are found at the corner only when the base surface is dry. Equal strengths at the corner and middle were obtained when the base surface was wet.

Finally, grout application did not have any significance on the tensile bond strength level of an overlay (Fig 6.16).

FIELD EXPERIMENT

Field Shear Bond Strength

A field experiment was conducted in order to investigate the effect of construction variables on shear bond strength developed between the overlay and base slab. A field experiment simulates better the conditions during actual construction. On the other hand, variables can be controlled better in the laboratory. The results of this experiment will be compared with the laboratory results in the final conclusions.

The experiment was carried out as described in Chapter 5. The following variables and levels were examined.

Variable	Levels
1.Season	Summer, winter (2)
2.Moisture condition	Wet, dry (2)
3.Grout condition	Grout, no grout (2)
4.Location of core	Edge, middle, corner (3)

The experiment was treated as a completely randomized factorial experiment. Two cores were obtained per treatment combination. The complete set of data is shown in Table A.1 in Appendix A. As shown in this table, most of the corner values are missing. All missing values are the result of broken cores during the drilling operation. All breaks occurred at the interface of the overlay and the base slab and were the result of some degree of debonding mainly at the corners, as evidenced by the ASTM test D4580 for detecting delamination with a steel bar. What is not known is whether there was complete debonding at the corners, meaning zero bond strength, or partial debonding that reduced the

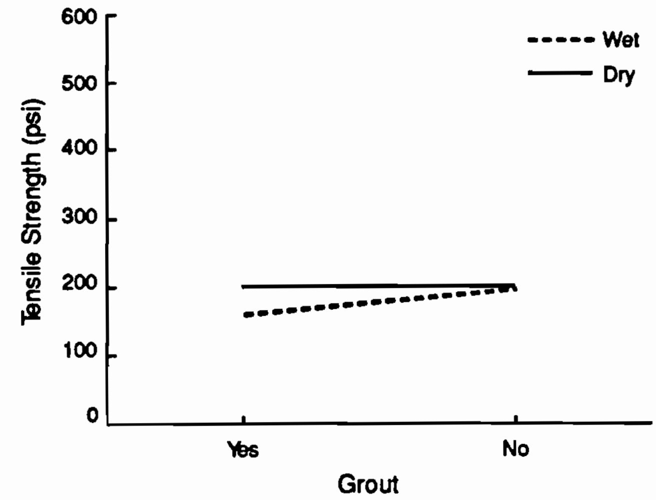


Fig 6.13. Tensile bond strength vs. grout-moisture interaction.

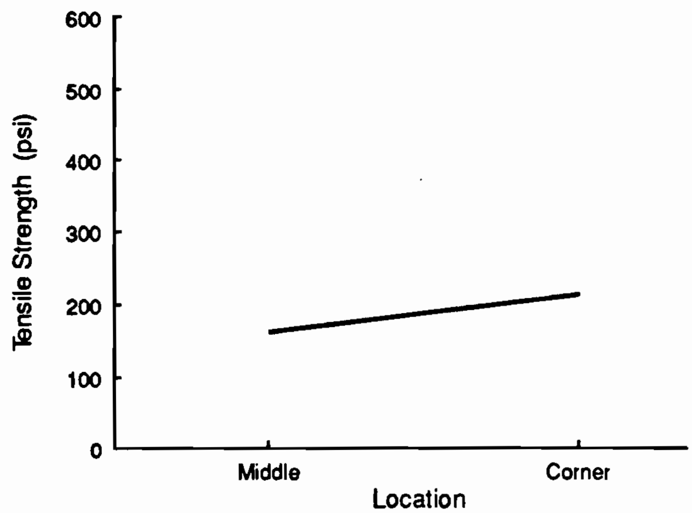


Fig 6.14. Tensile bond strength vs. location.

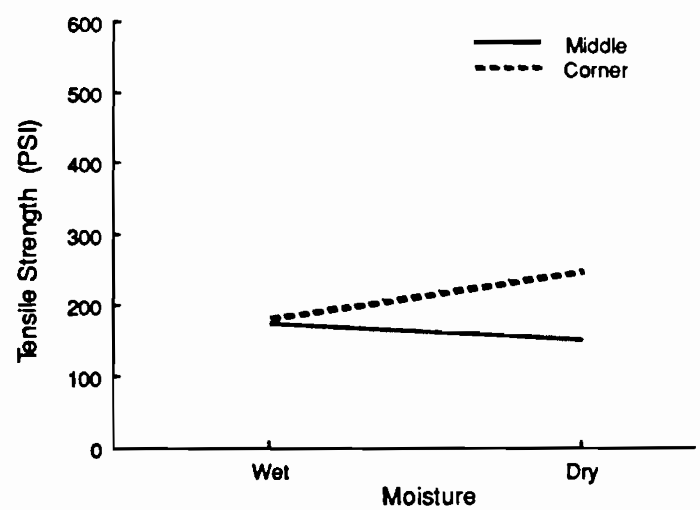


Fig 6.15. Tensile bond strength vs. moisture-location

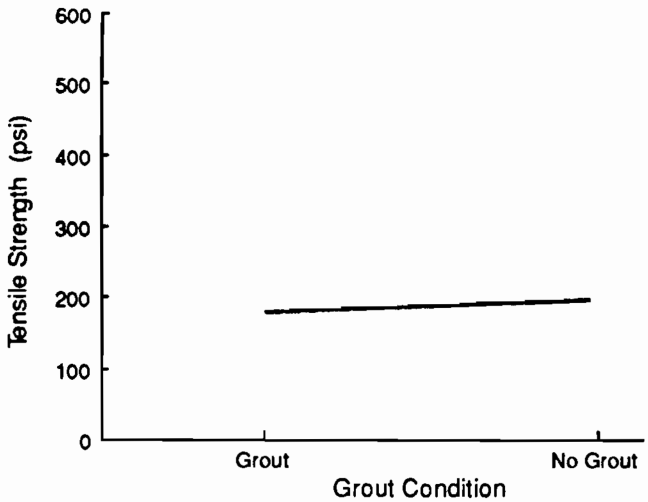


Fig 6.16. Tensile bond strength vs. grout application.

strength of the bond to such levels that fracture could not be prevented during the drilling operation. If missing data due to breaks are considered as missing points in the analysis it would result in inflated strengths at the corners. The reason is that if only those random occurrences that resulted in high strengths are selected, their average value (which basically is the value compared in the analysis of variance) will be much higher than the average value of all the strengths including the missing points which presumably have very low strengths. Due to this peculiarity, the decision was made to run the analysis by assigning a range of values to missing points that were likely to be tested if the breaks during drilling did not occur. The range was selected to be 0 to 100 psi. A zero value indicates complete debonding. A maximum value of 100 psi was selected because this is slightly lower than the minimum strength obtained from all the cores which is 113 psi.

The analysis was first run by assigning a value of 100 psi to all the missing points and then a value of 0 psi. Tables 6.7 and 6.8 show the layout of the experiment and the average values for the two cases. The results of the analysis of variance are shown in Tables 6.9 and 6.10. Pooling was not necessary with this analysis because two cores were obtained per treatment combination and the resulting error term had enough degrees of freedom to detect significant differences among the other sources of variation. When 100 psi was assumed the significant effects found were season, location, season-location, and location-moisture-grout interactions. These same effects were also found significant when a zero value was as-

TABLE 6.7. FIELD EXPERIMENT AND AVERAGE SHEAR BOND STRENGTH RESULTS PER TREATMENT COMBINATION (ASSUMING 100 PSI FOR THE MISSING POINTS)

		Season			
		Summer		Winter	
		Moisture		Moisture	
Grout	Location	Wet	Dry	Wet	Dry
Yes	Middle	337.5	455.0	251.5	436.0
	Corner	418.5	317.0	100.0	100.0
	Side	387.5	309.0	290.5	281.0
No	Middle	474.0	366.0	249.5	375.5
	Corner	220.0	470.0	140.5	100.0
	Side	176.5	209.0	224.0	276.0

TABLE 6.8. FIELD EXPERIMENT AND AVERAGE SHEAR BOND STRENGTH RESULTS PER TREATMENT COMBINATION (ASSUMING 0 PSI FOR THE MISSING POINTS)

		Season			
		Summer		Winter	
		Moisture		Moisture	
Grout	Location	Wet	Dry	Wet	Dry
Yes	Middle	337.5	455.0	251.5	436.0
	Corner	418.5	317.0	0.0	0.0
	Side	387.5	309.0	290.5	281.0
No	Middle	474.0	366.0	249.5	375.5
	Corner	170.0	470.0	90.5	0.0
	Side	126.5	159.0	224.0	276.0

TABLE 6.9. ANALYSIS OF VARIANCE ON SHEAR BOND TEST RESULTS FROM FIELD EXPERIMENT[3]

Source of Variation	DF	Mean Square	F-Value	Probability [1]	Significance $\alpha = 0.10$ [2]
Season	1	144,250	18.88	0.00	Yes
Moisture	1	15,000	1.97	0.17	No
Grout	1	13,500	1.77	0.19	No
Location	2	78,000	10.22	0.00	Yes
Season*Moisture	1	3,500	0.44	0.51	No
Season*Grout	1	4,000	0.51	0.48	No
Season*Location	2	62,000	8.11	0.00	Yes
Moisture*Grout	1	3,250	0.43	0.52	No
Moisture*Location	2	6,750	0.88	0.43	No
Grout*Location	2	11,500	1.51	0.24	No
Season*Moisture*Grout	1	6,250	0.82	0.37	No
Season*Moisture*Location	2	15,000	1.98	0.16	No
Season*Grout*Location	2	7,500	1.00	0.38	No
Moisture*Grout*Location	2	24,000	3.17	0.06	Yes
Error	26	7,500	-	-	-

1 Probability of significance associated with the F-value
2 Probability of rejecting a correct null hypothesis

sumed except from location-moisture-grout interaction that turned out to be non-significant. These results point out that even when a conservative value of 100 psi (as compared to zero) is assumed for the missing points, this value is low enough to depict significant differences among mean values for the significant effects. It should be mentioned that if the analysis was performed using only zero values for the missing points then inferences about any significant effects could not be extended to values up to 100 psi.

TABLE 6.10. ANALYSIS OF VARIANCE ON SHEAR BOND TEST RESULTS FROM FIELD EXPERIEMENTS

Source of Variation	DF	Mean Square	F-Value	Probability [1]	Significance $\alpha = 0.10$ [2]
Season	1	191,395	16.34	0.00	Yes
Moisture	1	15,016	1.28	0.27	No
Grout	1	21,042	1.80	0.19	No
Location	2	138,640	11.84	0.00	Yes
Season*Moisture	1	842	0.07	0.79	No
Season*Grout	1	14,387	1.23	0.28	No
Season*Location	2	124,507	10.63	0.00	Yes
Moisture*Grout	1	3,317	0.28	0.60	No
Moisture*Location	2	6,751	0.58	0.57	No
Grout*Location	2	18,610	1.59	0.22	No
Season*Moisture*Grout	1	11,687	1.00	0.33	No
Season*Moisture*Location	2	22,323	1.91	0.17	No
Season*Grout*Location	2	13,051	1.11	0.34	No
Moisture*Grout*Location	2	24,233	2.07	0.15	No
Error	26	11,711	-	-	-

[1] Probability of significance associated with the F-value
[2] Probability of rejecting a correct null hypothesis

The analysis has indicated that the significant effects are season, location, and season-location interaction. Figures 6.17 to 6.22 show the results of the experiment in graphical form. The solid lines represent average strengths obtained by assuming 100 psi for every missing point, and the intermittent lines represent strengths obtained by assuming zero strength for every missing point. The two lines are in most cases almost parallel which means that assuming zero strength for each missing point does not give rise to significant interactions among the factors, other than the ones obtained by assuming 100 psi. Therefore, the use of zero strength only enforces the results obtained by using 100 psi in that it depicts difference at higher significance. Figure 6.17 shows the effect of season on shear bond strength. Summer strengths were significantly higher than winter strengths. In terms of location, corner strengths were the lowest and middle strengths the highest (Fig 6.18). A plot on the season-location interaction is shown in Fig 6.19. Middle strengths were higher than corner and side strengths, irrespective of the season. During the winter placement the corner strength was much lower than the middle and side strengths. However, in the summer placement the corner strength was higher than the side strength.

Finally, Figures 6.20 to 6.22 show the nonsignificant effects. Grout and moisture conditions did not seem to affect shear bond strength development at the overlay-base interface.

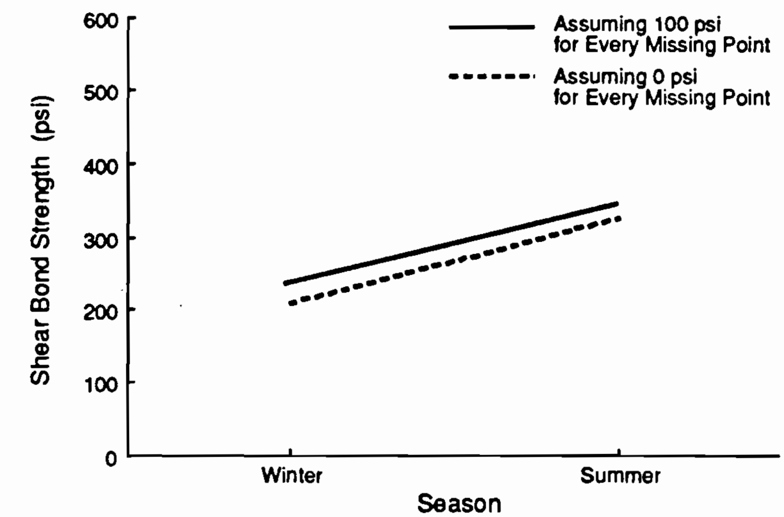


Fig 6.17. Shear bond strength vs. season.

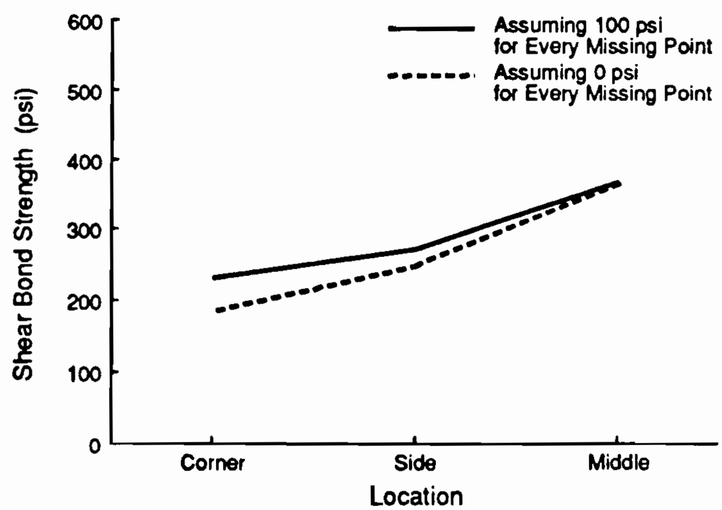


Fig 6.18. Shear bond strength vs. location.

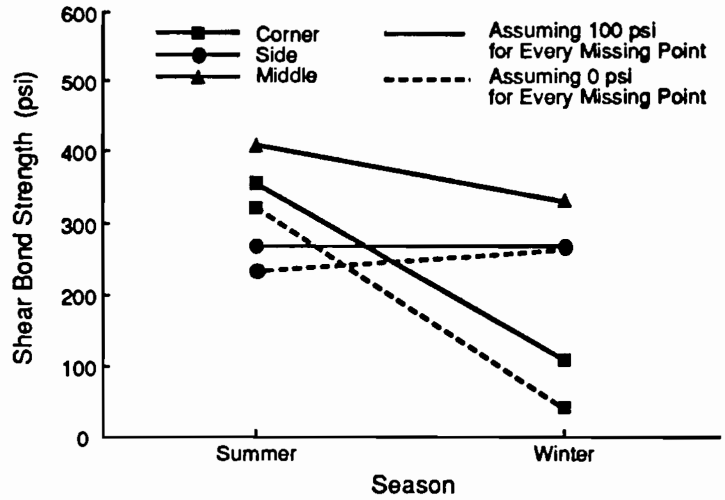


Fig 6.19. Shear bond strength vs. season-location interaction.

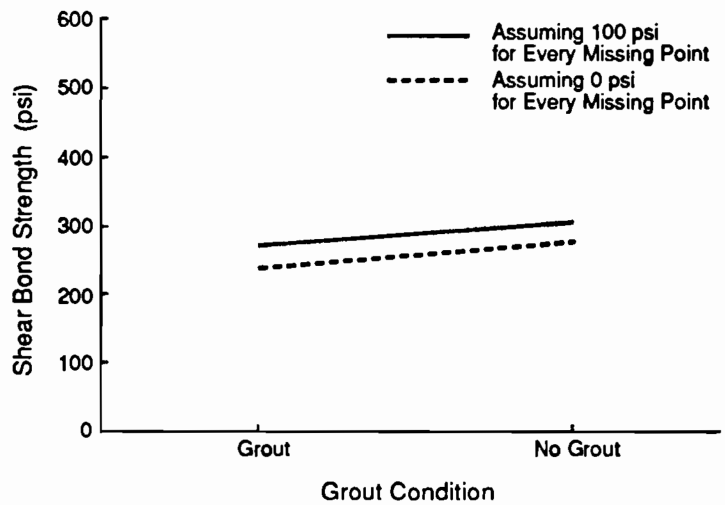


Fig 6.20. Shear bond strength vs. grout condition.

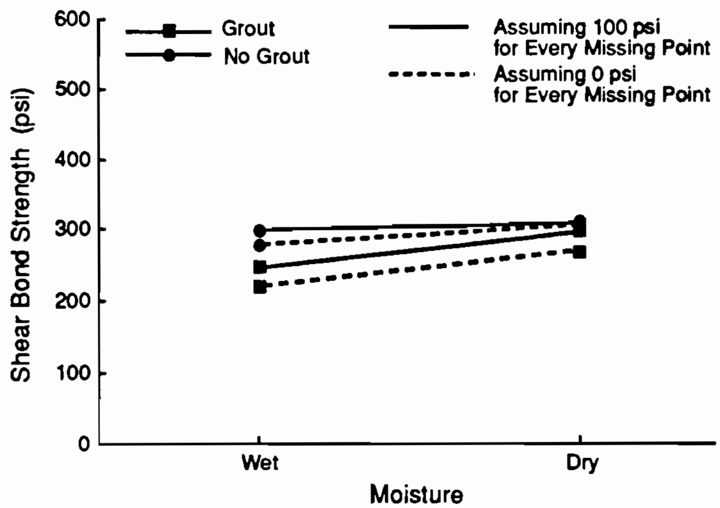


Fig 6.21. Shear bond strength vs. moisture-grout interaction.

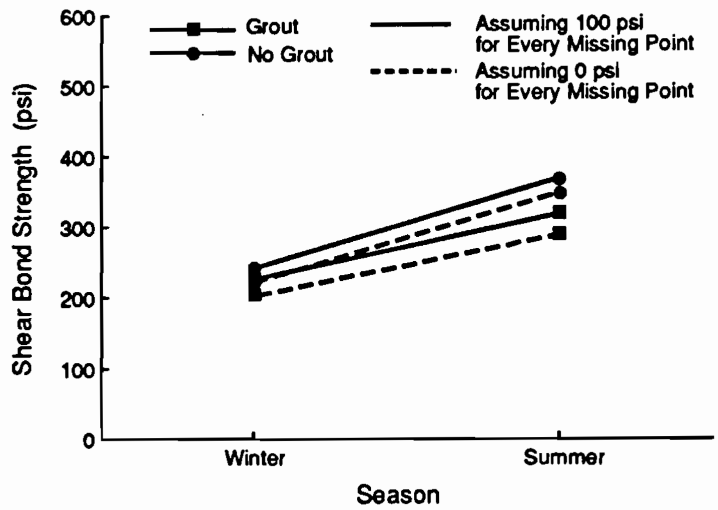


Fig 6.22. Shear bond strength vs. season-grout interaction.

CURLING STUDY

The purpose of this phase of the project was to study the curling movement of concrete overlays which takes place during 24-hour periods, and relate this cyclic movement to the bond strength. Overlay field test slabs were placed during the summer and winter months, with or without moisture underneath. The slabs were monitored for movement for a few days for 24 hours and the results are tabulated and plotted in Appendix A. Laboratory slab results are given in Appendix B.

Typical gradients of field slabs ranged between 0.004 and 0.007 inch/feet, but no definite movement trends could be deduced from the graphs. In some cases the slabs exhibited warping (upward movement of the center relative to the corners) and in other cases curling (upward movement of the corners relative to the center). These movements occurred at random and no constant pattern was observed between winter versus summer or wet versus dry placement.

Laboratory curling movements ranged between 0.002 and 0.007 inch/feet. Again, movement patterns could not be related to concrete temperature variation or to presence or absence of moisture before overlaying.

The field shear bond strength experiment described earlier has indicated significant loss of bond strength due to debonding at the corners. The random results from the curling study showed that slabs may warp or curl depending on the temperature gradient. If debonding is assumed to be largely affected by curling it might be expected that slabs would undergo more curling than warping movement. A more thorough study that would collect data on a daily basis, especially at the early ages of concrete, is probably needed to investigate the complex problem of curling and bond strength.

CHAPTER 7. CONCLUSIONS AND RECOMMENDATIONS

The following conclusions and recommendations for the construction of overlays were generated based on the results from the laboratory and field experiments. These apply only within the limit of the materials and conditions used in the study.

CONCLUSIONS

(1) The laboratory experiment suggested that grout application before an overlay placement results in lower shear bond strength when compared to a no-grout condition. Field shear bond and laboratory tensile bond strengths had no effect from the presence or absence of grout.

(2) A dry surface placement has shown greater shear bond strength in the laboratory experiment when compared to a wet surface. Field shear bond and laboratory tensile bond strengths had no influence from the presence or absence of moisture.

(3) Temperature played no role in the development of shear bond strength in the laboratory. Lower tensile bond strengths were measured in the laboratory at temperatures greater than 85°F. Higher tensile strengths were obtained at temperatures less than 80°F.

(4) In general, the winter placement in the field experiment showed lower shear bond strength than the summer placement. This finding may be the result of problems encountered during the winter placement.

(5) Shear bond at the middle of the slabs had the highest value in both the winter and summer placements in the field experiment. The lowest winter strengths were recorded at the corner position and the lowest summer strengths at the side. The laboratory shear bond strength was the same at both middle and corner positions.

(6) There was no consistent relationship between shear and tensile bond strength at the interface.

(7) There was no apparent relationship between concrete temperature or moisture presence or absence before overlaying and bond strength, as indicated by the limited data from the curling study.

RECOMMENDATIONS FOR CONSTRUCTION

(1) Base slab surfaces should preferably be dry during overlay construction for maximum bond strength.

(2) Overlays should be placed without the use of grout. This recommendation, based on test results obtained in this study, conflicts with a recommendation in Ref 11 which recommends the use of grout to prevent delamination.

RECOMMENDATIONS FOR FUTURE RESEARCH

(1) Additional studies should be conducted to investigate the effect of wind speed and relative humidity, especially their interactions with temperature, on the early life properties of concrete.

(2) Methods to reduce the effect of high temperature and evaporation, including the use of curing blankets and fogging, should be investigated.

(3) A systematic collection of curling and temperature gradient data is needed during the early ages of concrete overlays in order to study the effect of curling on bond strength.

REFERENCES

1. Gillette, Roy W., "A 10 Year Report on Performance of Bonded Concrete Resurfacings," Highway Research Record 94, Highway Research Board, 1965, pp 61-76.

2. Dhir, M. P., "A Study on the Effect of Temperature Variations on Bonding Concrete Overlay," ACI Journal, Vol 81, No. 2, March 1984, pp 172-179.

3. Felt, Earl J., "Repair of Concrete Pavement," ACI Journal, Proceedings, Vol 57, No. 2, August 1960, pp 139-154.

4. Kailasananthan, Kandiah, B. Frank McCullough, and D. W. Fowler, "A Study of the Effects of Interface Condition on Thin Bonded PCC Overlays," Research Report 357-1, Center for Transportation Research, The University of Texas at Austin, December 1984.

5. Solanki, Abdulrahman J. , B. Frank McCullough, and D. W. Fowler, "A Study of the Effect of Construction Variables on the Bond Behavior of CRCP Overlays," Research Report 457-4, Center for Transportation Research, The University of Texas at Austin, December 1987.

6. "Use of Epoxy Compounds with Concrete," Report 503 R-80, Revised 1984, American Concrete Institute, 1985.

7. Oglesley, H. C., and L. I. Hewes, *Highway Engineer*, New York: John Wiley and Sons, Inc., Third Printing, April 1965, pp 637-671.

8. "SAS Language Guide for Personal Computers," 6th Edition, SAS Institute, Cary, N.C., 1985.

9. Engineering Bulletin, 11th Edition, Portland Cement Association, Skokie, Ill., 1968.

10. Anderson, V. L., and R. A. McLean, *Design of Experiments - A Realistic Approach*, Marcel Dekker, Inc., 1974.

11. Suh, Y. C., J. L. Lundy, B. Frank McCullough, and David W. Fowler, "A Summary of Studies of Bonded Concrete Overlays," Research Report 457-5F, Center for Transportation Research, The University of Texas at Austin, November 1988.

APPENDIX A. FIELD STUDY RESULTS HIGHWAY 225, HOUSTON

TABLE A.1. TABULATION OF SHEAR STRENGTH DATA FOR WINTER TEST SECTIONS, HWY 225, HOUSTON

Observations	Bond Strength (psi)	Location	Moisture	Grout
1	-	Corner	Wet	Yes
2	181	Corner	Wet	Yes
3	335	Side	Wet	Yes
4	113	Side	Wet	Yes
5	277	Middle	Wet	Yes
6	222	Middle	Wet	Yes
7	-	Corner	Wet	No
8	-	Corner	Wet	No
9	231	Side	Wet	No
10	350	Side	Wet	No
11	198	Middle	Wet	No
12	305	Middle	Wet	No
13	-	Corner	Dry	Yes
14	-	Corner	Dry	Yes
15	246	Side	Dry	Yes
16	306	Side	Dry	Yes
17	340	Middle	Dry	Yes
18	-	Middle	Dry	Yes
19	-	Corner	Dry	No
20	299	Corner	Dry	No
21	263	Side	Dry	No
22	443	Side	Dry	No
23	429	Middle	Dry	No
24		Middle	Dry	No

TABLE A.2. TABULATION OF SHEAR STRENGTH DATA FOR SUMMER TEST SECTIONS, HWY 225, HOUSTON

Observations	Bond Strength (psi)	Location	Moisture	Grout
1	-	Corner	Wet	Yes
2	340	Corner	Wet	Yes
3	-	Side	Wet	Yes
4	253	Side	Wet	Yes
5	520	Middle	Wet	Yes
6	428	Middle	Wet	Yes
7	305	Corner	Wet	No
8	532	Corner	Wet	No
9	366	Side	Wet	No
10	409	Side	Wet	No
11	366	Middle	Wet	No
12	309	Middle	Wet	No
13	512	Corner	Dry	Yes
14	428	Corner	Dry	Yes
15	-	Side	Dry	Yes
16	318	Side	Dry	Yes
17	368	Middle	Dry	Yes
18	364	Middle	Dry	Yes
19	299	Corner	Dry	No
20	335	Corner	Dry	No
21	240	Side	Dry	No
22	378	Side	Dry	No
23	432	Middle	Dry	No
24	478	Middle	Dry	No

TABLE A.3. CURLING MOVEMENT FOR DRY TEST SECTION, WINTER CONDITION, MARCH 12, 1987

								Temperature (°F)	
Time	#1	#2	#3	#4	#5	#6	#7	Ambient	Surface
9:00 am	0	0	0	0	0	0	0	61	70
9:30	0	1	1	1	0	1	0	61	70
10:00	0	4	5	4	2	3	1	62	72
10:30	1	7	8	7	3	4	2	63	74
11:00	1	10	11	10	4	6	3	65	76
11:30	1	13	13	12	6	8	5	68	78
12:00 pm	1	17	17	15	7	9	7	69	80
12:30	1	19	20	18	8	10	9	70	82
1:00	2	22	22	20	9	13	10	72	85
1:30	3	24	25	21	10	14	11	72	85
2:00	3	25	27	22	10	16	12	72	87
2:30	3	25	28	23	11	16	13	74	88
3:00	3	25	28	23	11	16	13	74	86
3:30	3	21	28	21	12	17	13	74	86
4:00	2	20	26	20	11	17	14	74	85
4:30	2	17	24	18	11	18	15	72	85
5:00	2	15	22	17	11	18	15	70	84

Note: Values of curling movement are in 0.001 in.

TABLE A.4. CURLING MOVEMENT FOR WET TEST SECTION, WINTER CONDITION, MARCH 12, 1987

								Temperature (°F)	
Time	#1	#2	#3	#4	#5	#6	#7	Ambient	Surface
9:00 am	0	0	0	0	0	0	0	66	72
9:30	1	2	3	1	0	2	4	66	73
10:00	2	3	4	4	0	2	6	67	74
10:30	2	6	5	6	0	3	9	68	78
11:00	3	8	9	9	0	4	12	69	82
11:30	3	11	12	11	0	5	14	70	84
12:00 pm	4	12	13	13	0	5	16	72	84
12:30	4	12	13	13	0	7	18	72	84
1:00	4	12	16	13	1	8	19	74	85
1:30	5	14	17	14	1	9	20	74	85
2:00	5	14	18	14	1	10	20	72	85
2:30	5	14	19	15	1	11	22	72	85
3:00	5	14	19	16	1	11	22	72	85
3:30	5	10	16	14	1	12	22	70	80
4:00	5	10	15	14	1	12	21	70	80
4:30	5	7	12	13	2	12	21	68	80
5:00	5	4	9	11	2	12	20	68	78

Note: Values of curling movement are in 0.001 in.

TABLE A.5. CURLING MOVEMENT FOR DRY TEST SECTION, WINTER CONDITION, APRIL 26, 1987

								Temperature (°F)	
Time	#1	#2	#3	#4	#5	#6	#7	Ambient	Surface
9:00 am	0	0	0	0	0	0	0	68	69
9:30	1	6	2	1	1	2	3	70	73
10:00	2	11	6	4	2	5	5	72	74
10:30	3	14	10	8	2	7	7	76	79
11:00	3	17	15	12	5	9	9	78	83
11:30	3	20	18	16	5	11	11	80	85
12:00 pm	3	20	26	27	7	15	13	82	86
12:30	4	22	29	30	9	17	15	87	92
1:00	6	25	29	33	10	19	18	88	94
1:30	6	27	31	35	10	21	19	89	95
2:00	7	29	32	38	11	22	20	90	96
2:30	7	29	35	38	12	22	20	90	98
3:00	7	30	35	39	12	23	21	91	98
3:30	6	29	34	39	12	23	21	92	99
4:00	6	30	32	39	13	24	22	92	99
4:30	6	29	31	39	13	24	22	92	99
5:00	5	28	30	38	12	24	23	91	98

Note: Values of curling movement are in 0.001 in.

TABLE A.6. CURLING MOVEMENT FOR WET TEST SECTION, WINTER CONDITION, APRIL 26, 1987

Time	#1	#2	#3	#4	#5	#6	#7	Temperature (°F) Ambient	Temperature (°F) Surface
9:00 am	0	0	0	0	0	0	0	68	69
9:30	0	3	4	4	1	3	4	69	72
10:00	2	3	9	11	4	6	7	71	74
10:30	2	11	13	16	7	10	10	73	76
11:00	2	16	19	22	12	12	13	75	79
11:30	4	21	23	28	18	14	15	77	82
12:00 pm	6	25	28	35	22	17	17	79	85
12:30	6	27	29	39	26	20	19	80	87
1:00	8	30	34	43	30	21	19	80	88
1:30	8	30	36	46	32	22	21	84	89
2:00	9	31	35	51	34	23	23	86	90
2:30	9	31	29	54	34	24	23	88	94
3:00	9	31	29	54	34	25	23	90	96
3:30	9	31	29	54	35	25	23	90	96
4:00	9	30	29	54	34	25	23	88	93
4:30	10	30	32	51	35	26	24	88	93
5:00	10	24	30	53	32	29	25	88	93

Note: Values of curling movement are in 0.001 in.

TABLE A.7. CURLING TEMPERATURES FOR DRY TEST SECTION, SUMMER CONDITION, AUGUST 29, 1987

Time	Temperature (°F) Ambient	Bottom Middle	Middle Middle	Bottom Corner	Middle Corner	Top Corner
5:00 pm	85	106	106	109	108	95
6:00	81	111	111	114	114	101
7:00	79	111	111	113	112	104
7:30	78	110	109	111	110	102
8:00	78	109	107	110	108	102
8:30	77	107	105	109	107	101
9:00	77	106	104	108	106	100
9:30	74	105	101	106	105	98
10:00	74	102	97	105	102	96
10:30	73	100	95	103	100	95
11:00	73	98	94	102	99	93
11:30	73	97	93	101	98	93
12:00 am	74	97	93	100	97	93
12:30	74	97	94	100	97	93
1:00	74	97	93	99	97	92
1:30	74	95	92	97	95	91
2:00	74	94	91	97	94	91
2:30	74	93	90	96	94	90
3:00	74	93	90	96	93	90
3:30	74	92	90	95	93	90
4:00	74	92	90	95	92	89
4:30	74	92	90	94	92	89
5:00	74	92	90	93	91	88
5:30	74	92	90	93	91	88
6:00	74	92	90	93	91	87
6:30	74	92	90	92	90	87
7:00	75	91	89	91	89	86
7:30	76	91	89	91	89	86
8:00	77	91	89	91	89	87
8:30	77	92	90	91	90	88
9:00	77	92	90	91	90	88
9:30	78	92	90	91	90	88
10:00	80	92	91	91	90	88
10:30	83	92	91	91	91	91
11:00	85	93	93	92	92	92
11:30	88	94	95	93	93	96

TABLE A.8. CURLING MOVEMENT FOR DRY TEST SECTION, SUMMER CONDITION, AUGUST 29, 1987

Time	#1	#2	#3	#4	#5	#6	#7
4:30 pm	0	0	0	0	0	0	0
5:00	0	5	4	3	0	0	-1
6:00	2	11	11	7	0	0	-1
7:00	1	10	10	5	0	0	-3
8:00	0	4	3	-2	0	-1	-4
9:00	-2	-3	-6	-8	0	-4	-6
10:00	-3	-11	-15	-18	0	-8	-10
11:00	-5	-15	-20	-21	0	-10	-12
12:00 am	-5	-14	-21	-22	0	-10	-13
1:00	-5	-15	-21	-22	0	-10	-15
2:00	-5	-15	-21	-24	0	-10	-15
3:00	-5	-15	-22	-25	0	-11	-15
4:00	-5	-15	-22	-25	0	-11	-15
5:00	-5	-15	-22	-25	0	-10	-14
6:00	-5	-15	-22	-24	0	-10	-15
7:00	-5	-15	-22	-23	0	-10	-15
8:00	-5	-15	-24	-24	0	-11	-15
9:00	-5	-15	-25	-25	0	-12	-15
10:00	-4	-15	-24	-24	0	-11	-15
11:00	-4	-15	-24	-24	0	-12	-14

Note: Values of curling movement are in 0.001 in.

TABLE A.9. CURING TEMPERATURES FOR DRY TEST SECTION, SUMMER CONDITION, AUGUST 29, 1987

	Temperature (°F)					
Time	Ambient	Bottom Middle	Middle Middle	Bottom Corner	Middle Corner	Top Corner
5:00 pm	85	108	109	108	107	95
6:00	81	113	115	112	112	101
7:00	79	112	113	112	111	103
7:30	78	111	111	111	110	103
8:00	78	110	109	110	109	104
8:30	77	108	107	109	108	102
9:00	77	107	105	108	107	102
9:30	74	105	102	107	105	99
10:00	74	103	98	105	102	96
10:30	73	101	96	104	101	95
11:00	73	99	95	103	99	93
11:30	73	97	94	101	98	93
12:00 am	74	97	93	100	97	93
12:30	74	97	93	100	97	93
1:00	74	97	93	99	97	92
1:30	74	96	93	99	96	92
2:00	74	95	91	98	95	92
2:30	74	94	91	97	95	91
3:00	74	94	91	97	95	91
3:30	74	94	91	96	95	91
4:00	74	93	91	96	94	90
4:30	74	93	91	95	94	90
5:00	74	93	91	95	93	90
5:30	74	92	91	95	93	89
6:00	74	92	91	94	92	89
6:30	74	92	90	94	92	89
7:00	75	92	90	93	91	88
7:30	76	91	90	93	91	88
8:00	77	91	90	93	91	88
8:30	77	92	91	93	91	90
9:00	77	92	91	93	92	90
9:30	78	92	91	93	92	90
10:00	80	92	91	91	91	90
10:30	83	92	92	93	92	92
11:00	85	93	93	93	93	94
11:30	88	94	95	94	94	96

TABLE A.10. CURLING MOVEMENT FOR WET TEST SECTION, SUMMER CONDITION, AUGUST 29, 1987

Time	#1	#2	#3	#4	#5	#6	#7
4:30 pm	0	0	0	0	0	0	0
5:00	1	1	0	1	0	0	0
6:00	1	2	1	1	0	0	1
7:00	1	3	2	0	2	0	1
8:00	2	3	-1	0	6	1	1
9:00	2	3	-4	-1	6	0	1
10:00	2	4	-8	-6	7	-3	-2
11:00	2	4	-18	-10	9	-4	-3
12:00 am	2	4	-18	-11	7	-5	-4
1:00	2	3	-18	-11	6	-6	-4
2:00	2	-8	-20	-12	6	-7	-5
3:00	2	-8	-20	-12	5	-7	-5
4:00	2	-8	-20	-12	5	-8	-6
5:00	2	-8	-21	-13	4	-9	-6
6:00	2	-9	-21	-14	3	-10	-7
7:00	2	-9	-22	-14	3	-10	-8
8:00	2	-11	-24	-15	3	-11	-8
9:00	2	-12	-25	-16	1	-11	-9
10:00	2	-15	-27	-18	-2	-12	-10
11:00	1	-18	-29	-21	-4	-12	-10

Note: Values of curling movement are in 0.001 in.

TABLE A.11. CURLING MOVEMENT FOR DRY TEST SECTION, SUMMER CONDITION, SEPTEMBER 5, 1987

								Temperature (°F)	
Time	#1	#2	#3	#4	#5	#6	#7	Ambient	Surface
9:00 am	0	0	0	0	0	0	0	75	78
9:30	1	1	3	1	0	0	0	77	82
10:00	3	2	6	3	0	0	0	80	90
10:30	5	3	10	6	0	-1	0	84	93
11:00	7	5	14	8	0	-1	0	84	96
11:30	7	8	18	11	-1	-1	0	88	96
12:00 pm	7	11	22	15	-3	-1	-1	89	100
12:30	7	14	27	18	-3	-1	0	92	100
1:00	7	17	30	19	-3	0	0	94	104
1:30	7	20	32	21	-1	1	2	94	105
2:00	8	20	33	22	0	1	3	94	105
2:30	8	21	34	22	0	1	2	94	105
3:00	8	22	35	23	-1	0	2	95	107
3:30	8	26	36	23	-1	0	2	96	105
4:00	8	26	36	24	0	1	3	95	105
4:30	9	25	35	24	0	1	3	95	102
5:00	11	23	35	24	1	2	4	95	102

Note: Values of curling movement are in 0.001 in.

TABLE A.12. CURLING MOVEMENT FOR WET TEST SECTION, SUMMER CONDITION, SEPTEMBER 5, 1987

								Temperature (°F)	
Time	#1	#2	#3	#4	#5	#6	#7	Ambient	Surface
9:00 am	0	0	0	0	0	0	0	75	78
9:30	1	2	2	2	0	0	0	77	82
10:00	2	5	5	5	0	1	0	80	90
10:30	3	8	9	8	0	2	1	84	93
11:00	4	11	13	11	0	2	2	84	96
11:30	6	14	18	15	1	3	4	88	96
12:00 pm	7	17	22	19	2	3	5	89	100
12:30	7	20	25	23	2	6	6	92	100
1:00	9	22	29	25	3	8	6	94	104
1:30	11	24	31	28	4	9	7	94	105
2:00	10	25	33	29	5	9	7	94	105
2:30	11	26	34	30	5	11	8	94	105
3:00	12	28	37	32	5	11	9	95	107
3:30	13	30	40	35	6	12	9	96	105
4:00	12	32	43	37	6	11	10	95	105
4:30	12	32	44	38	6	12	10	95	102
5:00	13	33	45	39	7	13	10	95	102

Note: Values of curling movement are in 0.001 in.

TABLE A.13. CURLING MOVEMENT FOR DRY TEST SECTION, SUMMER CONDITION, NOVEMBER 14, 1987

								Temperature (°F)	
Time	#1	#2	#3	#4	#5	#6	#7	Ambient	Surface
9:00 am	0	0	0	0	0	0	0	70	69
9:30	1	1	1	1	0	2	0	71	70
10:00	1	1	2	2	1	4	2	72	71
10:30	2	3	3	4	2	4	4	73	74
11:00	2	3	5	4	2	8	17	74	70
11:30	2	5	6	10	4	8	2	76	73
12:00 pm	2	7	10	13	5	3	2	77	75
12:30	2	6	13	15	5	3	-16	76	76
1:00	3	6	14	15	5	5	-16	78	78
1:30	4	6	13	14	5	0	-16	78	77
2:00	4	4	14	15	5	3	-27	77	77
2:30	6	0	15	15	5	20	-23	78	79
3:00	6	-2	16	15	6	15	-33	78	79
3:30	6	-1	15	15	6	8	-37	74	76
4:00	6	0	14	15	7	25	-38	74	74
4:30	6	4	14	15	6	19	-38	72	72
5:00	5	5	13	15	6	17	-38	70	70

Note: Values of curling movement are in 0.001 in.

TABLE A.14. TEMPERATURE GRADIENT OF DRY TEST SECTION, SUMMER CONDITION, NOVEMBER 14, 1987

	Temperature (°F)					
Time	Ambient	Bottom Middle	Middle Middle	Bottom Corner	Middle Corner	Top Corner
9:00 am	70	79	77	79	75	69
9:30	71	80	78	80	76	70
10:00	72	81	79	81	78	71
10:30	73	81	79	80	77	74
11:00	74	85	81	83	79	70
11:30	76	85	82	84	79	73
12:00 pm	77	86	82	83	79	75
12:30	76	85	81	83	79	76
1:00	78	86	83	84	81	78
1:30	78	84	81	82	80	77
2:00	77	85	82	83	81	77
2:30	78	85	83	84	81	79
3:00	78	83	81	82	80	79
3:30	74	79	78	78	77	76
4:00	74	78	78	78	76	74
4:30	72	74	74	73	72	72
5:00	70	72	72	71	70	70

TABLE A.15. CURLING MOVEMENT FOR WET TEST SECTION, SUMMER CONDITION, NOVEMBER 14, 1987

								Temperature (°F)	
Time	#1	#2	#3	#4	#5	#6	#7	Ambient	Surface
9:00 am	0	0	0	0	0	0	0	70	69
9:30	0	1	1	0	0	0	0	71	70
10:00	0	3	1	1	1	1	0	72	71
10:30	1	6	2	2	1	1	0	73	74
11:00	0	6	2	0	0	2	1	74	70
11:30	0	10	3	-1	1	4	1	76	73
12:00 pm	1	12	4	-1	2	4	2	77	75
12:30	2	15	4	0	2	3	3	76	76
1:00	3	15	5	0	2	3	3	78	78
1:30	3	16	5	0	3	3	3	78	77
2:00	4	17	5	-4	3	1	3	77	77
2:30	5	20	6	-15	3	0	3	78	79
3:00	5	21	6	-14	4	0	4	78	79
3:30	4	21	6	-15	4	-1	5	74	76
4:00	4	21	6	-15	4	-1	5	74	74
4:30	4	20	7	-15	4	-2	6	72	72
5:00	4	19	7	-15	5	-2	6	70	70

Note: Values of curling movement are in 0.001 in.

TABLE A.16. TEMPERATURE GRADIENT OF WET TEST SECTION, SUMMER CONDITION, NOVEMBER 14, 1987

	Temperature (°F)					
Time	Ambient	Bottom Middle	Middle Middle	Bottom Corner	Middle Corner	Top Corner
9:00 am	70	79	76	79	75	69
9:30	71	80	77	80	76	70
10:00	72	81	78	81	77	71
10:30	73	80	79	80	77	74
11:00	74	83	80	83	78	70
11:30	76	84	81	84	78	73
12:00 pm	77	84	81	84	78	75
12:30	76	83	80	83	78	76
1:00	78	84	83	84	81	78
1:30	78	82	80	82	79	77
2:00	77	83	82	83	80	77
2:30	78	84	82	84	81	79
3:00	78	82	80	82	80	79
3:30	74	78	76	78	76	76
4:00	74	77	77	78	76	74
4:30	72	73	72	73	72	72
5:00	70	71	70	71	70	70

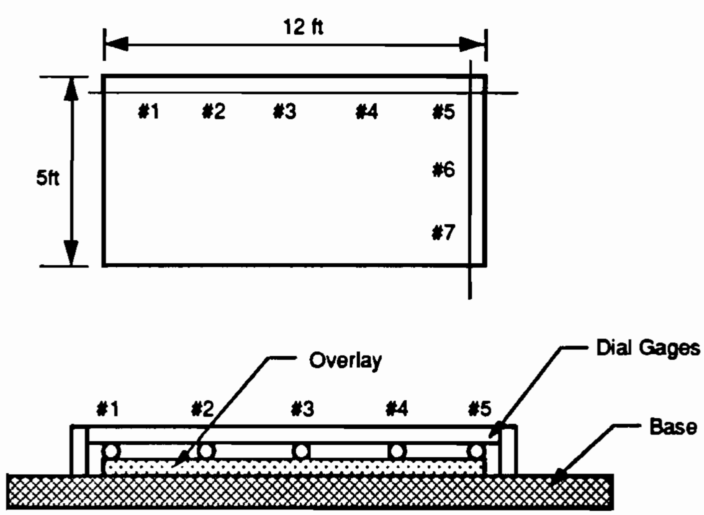


Fig A.1. Position of dial gages.

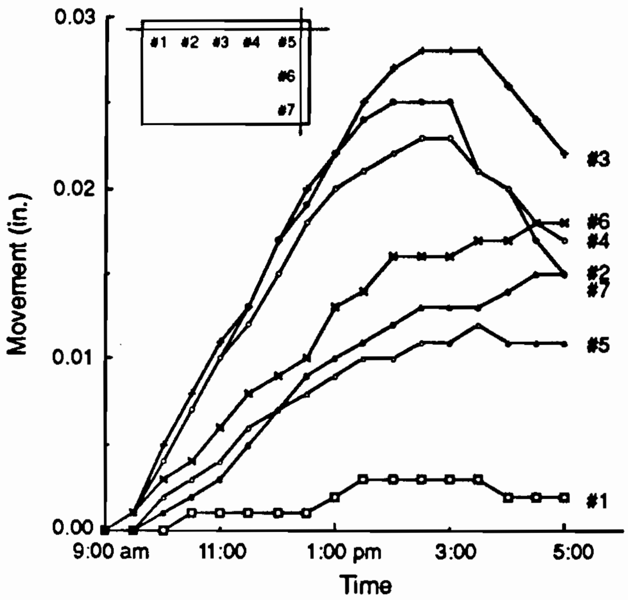


Fig A.2. Curling movement for dry test section, winter condition, March 12, 1987.

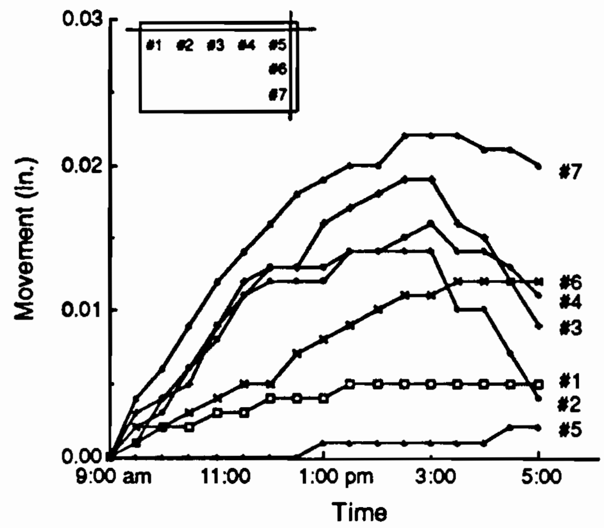


Fig A.3. Curling movement of wet test section, winter condition, March 12, 1987.

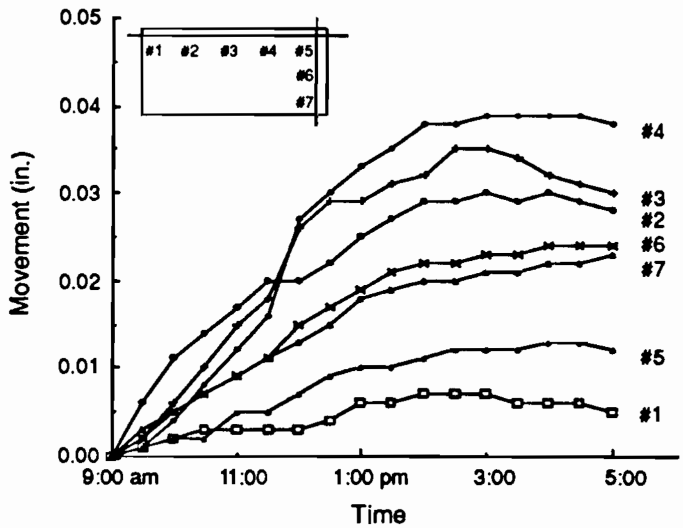


Fig A.4. Curling movement of dry test section, winter condition, April 26, 1987.

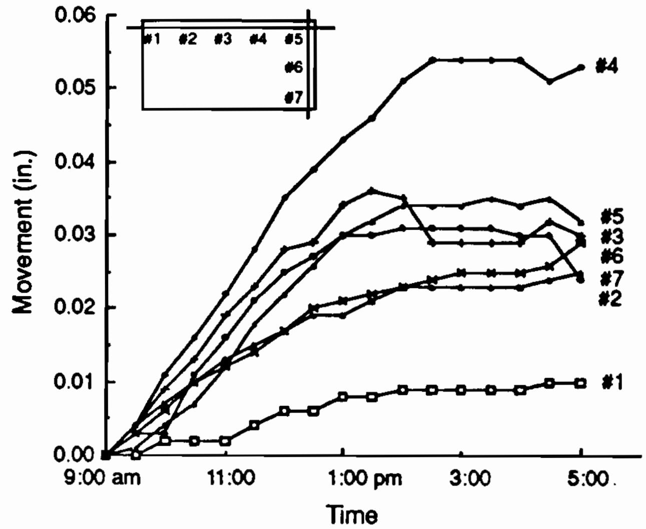


Fig A.5. Curling movement of wet test section, winter condition, April 26, 1987.

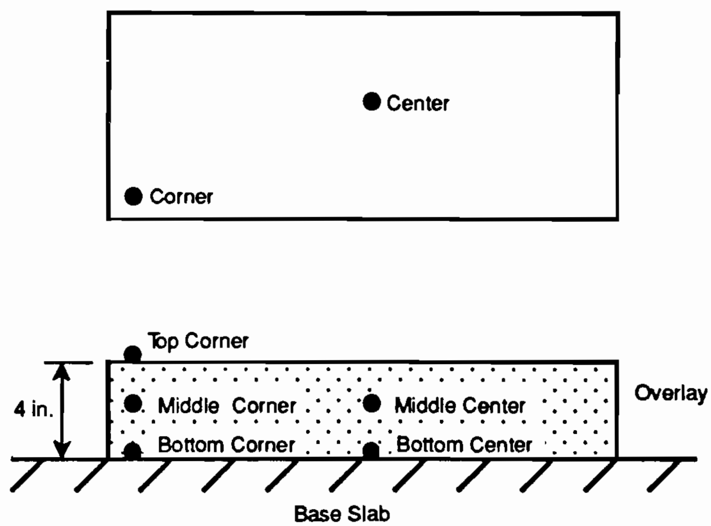


Fig A.6. Locations of thermocouples.

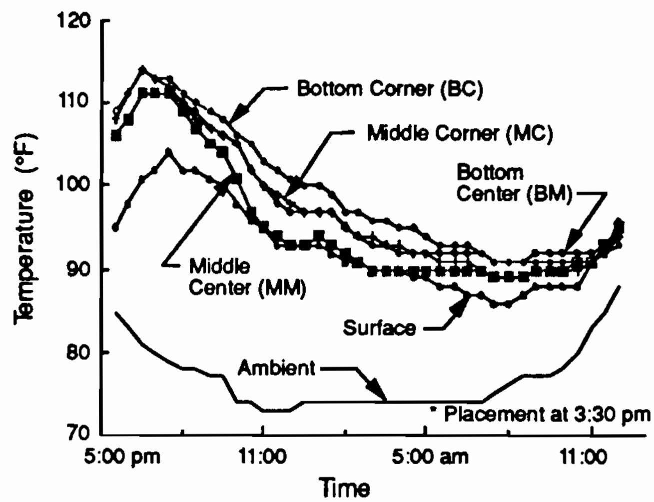


Fig A.7. Curling temperature of overlay for dry section, summer condition, August 29, 1987.

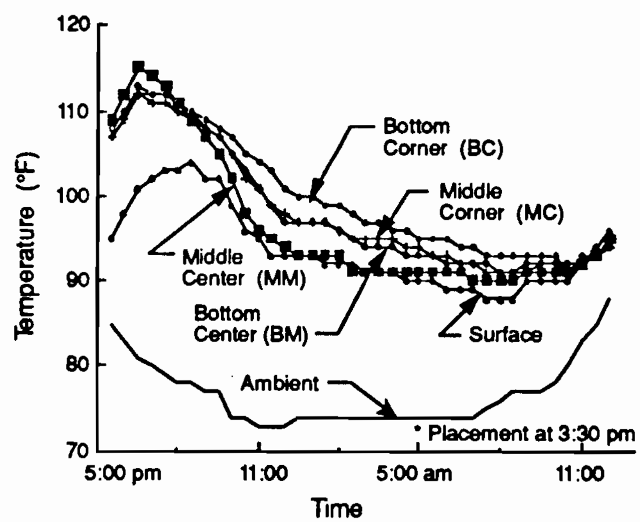


Fig A.8. Curling temperature of overlay for wet section, summer condition, August 29, 1987.

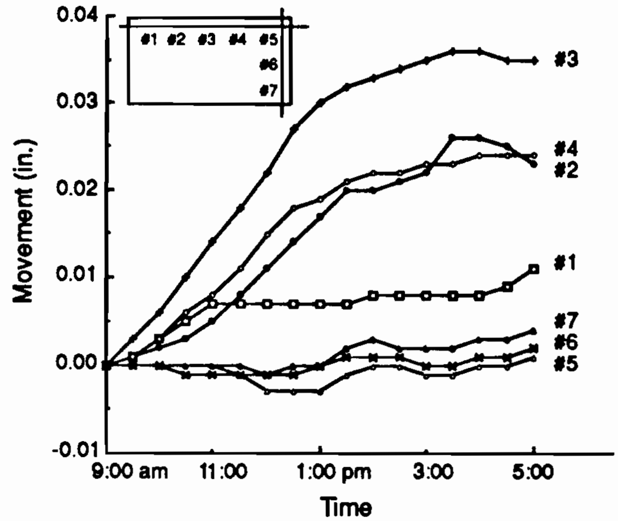


Fig A.9. Curling movement for dry test section, summer condition, September 5, 1987.

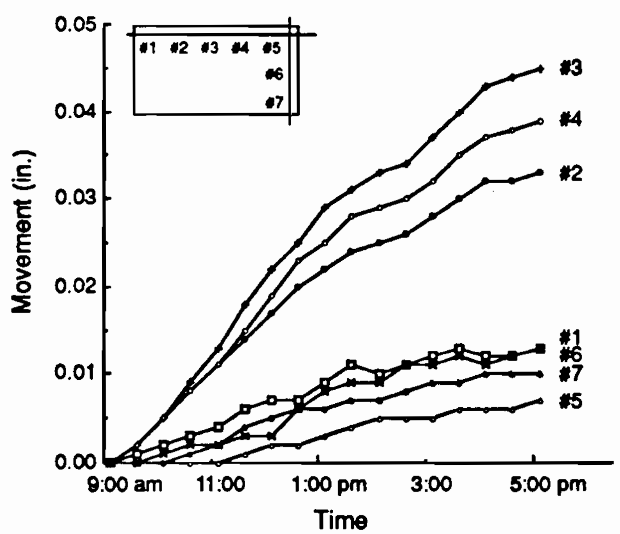


Fig A.10. Curling movement for wet test section, summer condition, September 5, 1987.

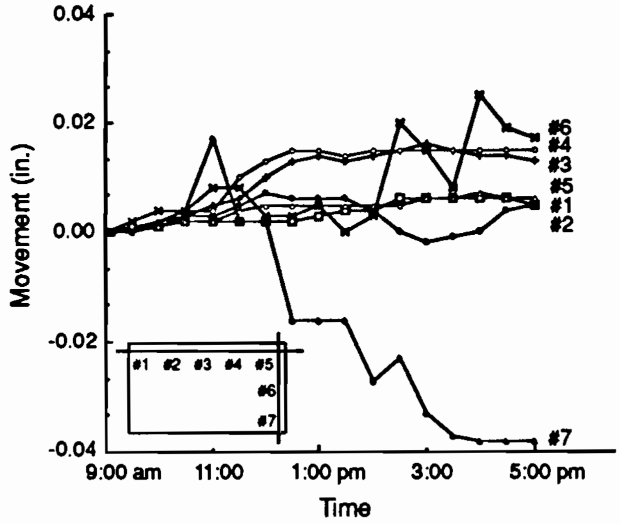


Fig A.11. Curling movement for dry test, summer condition, November 14, 1987.

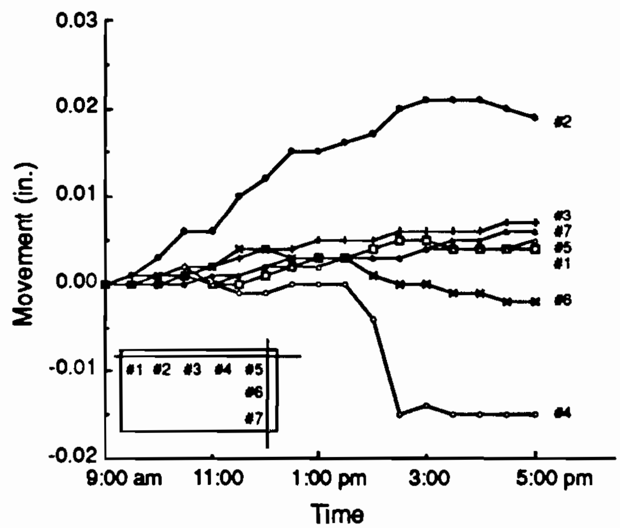


Fig A.12. Curling movement for wet test section, summer condition, November 14, 1987.

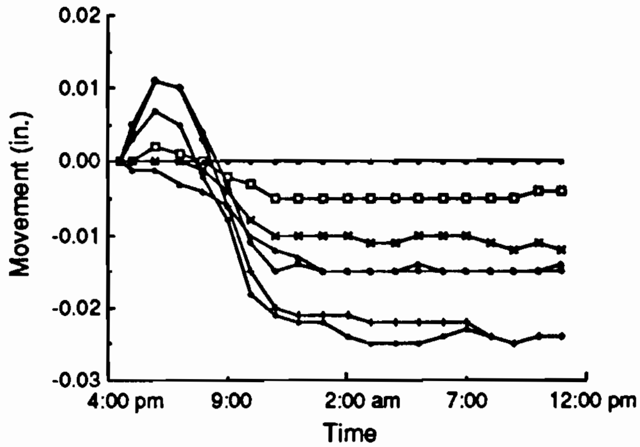


Fig A.13. Curling movement for dry test section, summer condition, August 29, 1987.

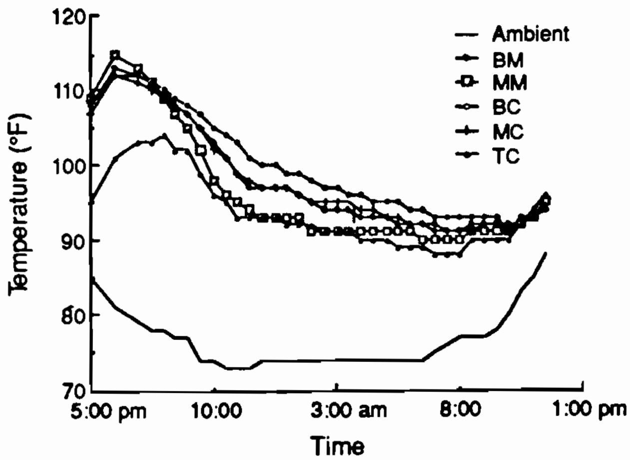


Fig A.14. Curling temperature for dry test section, summer conditions, August 29, 1987.

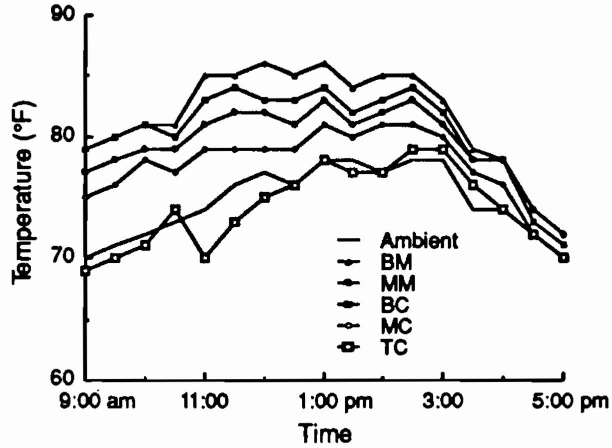


Fig A.15. Curling temperature for dry test section, summer condition, November 14, 1987.

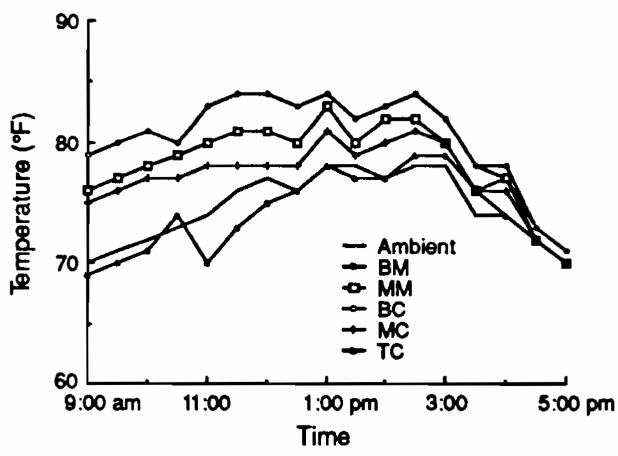


Fig A.16. Curling temperature of overlay for wet test section, summer condition, November 14, 1987.

APPENDIX B. LABORATORY RESULTS

TABLE B.1. TABULATION OF SHEAR STRENGTH AND TENSILE STRENGTH DATA FOR LABORATORY PHASE

Observations	Temperature of Placement (°F)	Shear Strength (psi)	Tensile Strength (psi)	Location	Moisture	Grout
1	60	302	88	CE	W	Y
2	60	525	239	CO	W	Y
3	60	557	395	CE	W	N
4	60	577	358	CO	W	N
5	60	496	191	CE	D	Y
6	60	473	175	CO	D	Y
7	60	462	215	CE	D	N
8	60	792	334	CO	D	N
9	78	318	215	CE	W	Y
10	78	334	199	CO	W	Y
11	78	374	207	CE	W	N
12	78	438	151	CO	W	N
13	78	497	72	CE	D	Y
14	78	358	581	CO	D	Y
15	78	338	96	CE	D	N
16	78	597	310	CO	D	N
17	85	501	167	CE	W	Y
18	85	227	151	CO	W	Y
19	85	505	191	CE	W	N
20	85	501	88	CO	W	N
21	85	418	199	CE	D	Y
22	85	589	96	CO	D	Y
23	85	513	159	CE	D	N
24	85	609	72	CO	D	N
25	96	414	111	CE	W	Y
26	96	509	111	CO	W	Y
27	96	398	119	CE	W	N
28	96	286	159	CO	W	N
29	96	613	135	CE	D	Y
30	96	318	154	CO	D	Y
31	96	601	154	CE	D	N
32	96	665	263	CO	D	N

CE = Center D = Dry Y = Grouted
CO = Corner W = Wet N = Not Grouted

TABLE B.2. TEMPERATURE GRADIENT OF SLAB DURING CURING PERIOD. TEMPERATURE OF PLACEMENT IS 60°F, DRY SECTION

	Temperature (°F)					
Time	Ambient	#1	#2	#3	#4	#5
5:00 pm	62	52	55	61	62	62
5:30	59	55	55	57	59	59
6:00	55	55	55	57	58	58
6:30	51	55	55	57	58	57
7:00	49	55	55	57	57	55
7:30	47	55	55	56	56	54
8:00	46	54	55	55	55	53
8:30	45	54	55	55	54	52
9:00	44	54	54	54	54	52
9:30	43	54	54	53	53	51
10:00	45	53	53	53	50	52
10:30	45	53	53	52	52	50
11:00	42	53	53	51	51	49
11:30	42	52	52	51	51	48
12:00 am	41	52	52	50	50	48
0:30	42	52	51	50	50	47
1:00	42	51	51	49	49	47
1:30	41	51	50	49	49	46
2:00	41	51	50	48	48	46
2:30	40	50	50	48	48	46
3:00	39	50	49	47	48	45
3:30	39	50	49	47	47	45
4:00	39	49	48	47	47	44
4:30	38	49	48	46	46	44
5:00	38	49	48	46	46	44
5:30	28	48	47	46	46	44
6:00	38	48	47	46	46	43
6:30	38	48	47	45	45	43
7:00	37	48	47	45	45	43
7:30	38	48	46	45	45	43
8:00	40	48	46	45	45	43
8:30	43	47	46	45	45	44
9:00	46	47	46	45	45	44
9:30	49	48	47	46	46	46
10:00	53	49	48	47	48	49
10:30	56	49	48	48	48	50
11:00	66	50	50	49	51	54
11:30	66	51	50	51	52	56
12:00 pm	71	51	51	52	54	57
12:30	72	51	51	53	56	60
1:00	75	51	52	54	57	61
1:30	74	52	52	55	58	62
2:00	73	52	53	56	59	63
2:30	75	53	54	57	61	64
3:00	75	53	55	59	62	66
3:30	76	54	56	60	63	66
4:00	78	55	57	60	63	67
4:30	76	56	57	61	63	67
5:00	75	56	58	61	64	66

TABLE B.3. TEMPERATURE GRADIENT OF SLAB DURING CURING PERIOD. TEMPERATURE OF PLACEMENT IS 60°F, WET SECTION

	Temperature (°F)					
Time	Ambient	#1	#2	#3	#4	#5
5:00 pm	62	51	54	59	62	62
5:30	59	55	56	58	59	59
6:00	55	55	57	58	58	58
6:30	51	55	56	57	58	57
7:00	49	55	56	57	57	55
7:30	47	55	56	56	56	54
8:00	46	55	55	55	55	53
8:30	45	55	55	55	54	52
9:00	44	54	54	54	54	52
9:30	43	54	54	54	53	51
10:00	45	54	54	53	50	52
10:30	45	54	53	53	52	50
11:00	42	53	53	52	51	49
11:30	42	53	53	52	51	48
12:00 am	41	53	52	51	50	48
0:30	42	53	52	51	50	47
1:00	42	52	52	50	49	47
1:30	41	52	51	50	49	46
2:00	41	52	51	50	48	46
2:30	40	51	51	49	48	46
3:00	39	51	50	49	48	45
3:30	39	51	50	48	47	45
4:00	39	50	49	48	47	44
4:30	38	50	49	48	46	44
5:00	38	50	49	47	46	44
5:30	28	50	48	47	46	44
6:00	38	49	48	47	46	43
6:30	38	49	48	46	45	43
7:00	37	49	48	46	45	43
7:30	38	49	47	46	45	43
8:00	40	49	47	46	45	43
8:30	43	49	47	46	45	44
9:00	46	49	48	46	45	44
9:30	49	49	48	47	46	46
10:00	53	50	49	48	48	49
10:30	56	50	49	48	48	50
11:00	66	51	50	50	51	54
11:30	66	51	51	52	52	56
12:00 pm	71	52	51	53	54	57
12:30	72	52	52	54	56	60
1:00	75	52	53	55	57	61
1:30	74	52	54	56	58	62
2:00	73	53	55	57	59	63
2:30	75	54	55	59	61	64
3:00	75	55	56	60	62	66
3:30	76	55	57	60	63	66
4:00	78	56	58	61	63	67
4:30	76	56	58	61	63	67
5:00	75	57	59	62	64	66

TABLE B.4. TEMPERATURE GRADIENT OF SLAB DURING CURING PERIOD. TEMPERATURE OF PLACEMENT IS 78°F, DRY SECTION

	Temperature (°F)					
Time	Ambient	#1	#2	#3	#4	#5
5:00 pm	79	69	72	75	75	77
5:30	79	70	73	75	76	77
6:00	78	71	73	75	75	76
6:30	75	71	73	75	75	75
7:00	73	71	73	74	74	74
7:30	71	71	72	73	73	73
8:00	68	71	72	73	72	71
8:30	67	70	71	72	71	70
9:00	67	70	71	71	71	70
9:30	66	70	71	71	70	69
10:00	66	69	70	70	69	69
10:30	66	69	70	70	69	69
11:00	66	69	69	69	69	68
11:30	64	69	69	69	69	68
12:00 am	65	68	69	69	68	67
0:30	64	68	68	68	68	67
1:00	63	68	68	68	67	67
1:30	64	68	68	68	67	66
2:00	62	67	68	67	67	66
2:30	61	67	67	67	66	65
3:00	61	67	67	67	66	64
3:30	59	67	67	66	65	64
4:00	57	66	66	66	64	63
4:30	55	66	66	65	64	62
5:00	53	66	65	64	63	61
5:30	52	65	65	64	62	60
6:00	51	65	64	63	62	59
6:30	51	64	64	63	61	59
7:00	51	64	63	62	60	58
7:30	52	64	63	62	60	58
8:00	54	64	63	62	60	58
8:30	56	63	63	62	60	58
9:00	57	64	63	62	60	59
9:30	61	64	63	62	61	60
10:00	64	64	64	63	62	60
10:30	66	64	64	63	62	61
11:00	69	64	63	64	62	61
11:30	71	64	64	64	62	62
12:00 pm	70	64	64	65	63	64
12:30	73	64	65	66	65	66
1:00	71	64	66	68	66	68
1:30	73	65	66	69	68	69
2:00	70	66	68	71	69	71
2:30	69	66	69	72	71	73
3:00	69	67	70	74	72	74
3:30	68	68	71	75	74	76
4:00	69	69	72	76	75	77
4:30	70	70	73	77	76	77
5:00	68	71	73	77	77	78

TABLE B.5. TEMPERATURE GRADIENT OF SLAB DURING CURING PERIOD. TEMPERATURE OF PLACEMENT IS 78°F, WET SECTION

	Temperature (°F)					
Time	Ambient	#1	#2	#3	#4	#5
5:00 pm	79	69	71	74	75	77
5:30	79	70	72	75	76	77
6:00	78	70	72	74	75	76
6:30	75	70	72	74	75	75
7:00	73	69	71	73	74	74
7:30	71	69	71	73	73	73
8:00	68	69	71	72	72	71
8:30	67	69	71	71	71	70
9:00	67	69	70	71	71	70
9:30	66	69	70	70	70	69
10:00	66	69	69	70	69	69
10:30	66	68	69	69	69	69
11:00	66	68	69	69	69	68
11:30	64	68	69	69	69	68
12:00 am	65	68	68	68	68	67
0:30	64	68	68	68	68	67
1:00	63	67	68	68	67	67
1:30	64	67	68	68	67	66
2:00	62	67	67	67	67	66
2:30	61	66	67	67	66	65
3:00	61	66	66	66	66	64
3:30	59	66	66	66	65	64
4:00	57	66	66	65	64	63
4:30	55	65	65	64	64	62
5:00	53	65	65	64	63	61
5:30	52	64	64	63	62	60
6:00	51	64	64	63	62	59
6:30	51	64	63	62	61	59
7:00	51	63	63	62	60	58
7:30	52	63	63	61	60	58
8:00	54	63	62	61	60	58
8:30	56	63	62	61	60	58
9:00	57	63	63	61	60	59
9:30	61	63	63	62	61	60
10:00	64	64	63	62	62	60
10:30	66	64	63	62	62	61
11:00	69	63	63	62	62	61
11:30	71	63	63	63	62	62
12:00 pm	70	63	63	63	63	64
12:30	73	63	63	64	65	66
1:00	71	63	63	65	66	68
1:30	73	63	64	66	68	69
2:00	70	64	65	67	69	71
2:30	69	64	66	69	71	73
3:00	69	65	67	70	72	74
3:30	68	66	68	71	74	76
4:00	69	67	69	73	75	77
4:30	70	67	70	74	76	77
5:00	68	68	71	75	77	78

TABLE B.6. TEMPERATURE GRADIENT OF SLAB DURING CURING PERIOD. TEMPERATURE OF PLACEMENT IS 96°F, DRY SECTION

	Temperature (°F)					
Time	Ambient	#1	#2	#3	#4	#5
7:00 pm	93	100	101	98	94	92
7:30	92	99	100	99	95	93
8:00	92	97	100	99	95	93
8:30	91	97	99	99	96	93
9:00	89	97	99	99	96	94
9:30	87	97	99	100	96	94
10:00	87	97	100	100	97	94
10:30	85	98	101	101	97	95
11:00	84	99	102	102	98	95
11:30	83	101	104	103	98	96
12:00 am	82	103	106	104	99	96
0:30	81	104	106	105	100	96
1:00	80	103	106	105	100	97
1:30	79	102	105	104	101	98
2:00	78	101	104	104	101	98
2:30	78	100	103	104	101	98
3:00	77	99	102	103	101	98
3:30	76	98	101	102	100	98
4:00	77	98	101	102	100	98
4:30	76	97	100	101	100	98
5:00	76	96	99	100	100	98
5:30	75	95	98	100	99	98
6:00	75	94	98	99	99	98
6:30	75	94	97	99	98	97
7:00	76	94	97	98	98	97
7:30	77	94	97	98	98	97
8:00	80	94	97	98	98	97
8:30	82	94	97	98	98	98
9:00	86	101	103	105	105	104
9:30	87	96	98	99	99	99
10:00	90	95	97	98	98	97
10:30	92	95	96	97	97	96
11:00	92	94	96	97	96	96
11:30	92	95	96	96	96	96
12:00pm	92	96	96	97	96	96
12:30	94	98	94	96	96	95
1:00	95	103	98	96	95	95
1:30	95	108	101	96	95	95
2:00	95	112	104	98	96	95
2:30	96	113	106	99	96	95
3:00	95	112	106	100	96	94
3:30	94	112	107	101	97	95
4:00	96	116	109	102	98	96
4:30	97	117	110	103	99	97
5:00	97	117	111	104	100	97
5:30	97	116	111	105	101	98
6:00	96	113	110	105	101	98
6:30	95	110	109	105	101	98
7:00	94	108	108	105	102	99

TABLE B.7. TEMPERATURE GRADIENT OF SLAB DURING CURING PERIOD. TEMPERATURE OF PLACEMENT IS 96°F, WET SECTION

	Temperature (°F)					
Time	Ambient	#1	#2	#3	#4	#5
7:00 pm	93	100	101	99	95	93
7:30	92	99	100	99	96	94
8:00	92	97	100	99	96	94
8:30	91	97	99	99	96	94
9:00	89	97	99	99	96	94
9:30	87	97	99	99	96	94
10:00	87	97	100	99	96	95
10:30	85	98	101	100	97	95
11:00	84	99	102	100	97	95
11:30	83	101	104	102	97	95
12:00 am	82	103	106	103	98	96
0:30	81	104	106	104	99	96
1:00	80	103	106	104	99	97
1:30	79	102	105	104	100	97
2:00	78	101	104	103	100	97
2:30	78	100	103	103	100	98
3:00	77	99	102	102	100	98
3:30	76	98	101	102	100	98
4:00	77	98	101	101	100	98
4:30	76	97	100	101	99	98
5:00	76	96	99	100	99	98
5:30	75	95	98	100	99	97
6:00	75	94	98	99	98	97
6:30	75	94	97	99	98	97
7:00	76	94	97	98	98	97
7:30	77	94	97	98	98	97
8:00	80	94	97	98	98	97
8:30	82	94	97	98	98	97
9:00	86	101	103	98	98	98
9:30	87	96	98	97	97	97
10:00	90	95	97	101	101	100
10:30	92	95	96	101	101	100
11:00	92	94	96	101	101	100
11:30	92	95	96	98	98	98
12:00 pm	92	96	96	97	96	96
12:30	94	98	94	96	96	95
1:00	95	103	98	96	95	95
1:30	95	108	101	97	95	94
2:00	95	112	104	99	96	95
2:30	96	113	106	100	96	95
3:00	95	112	106	101	96	94
3:30	94	112	107	102	97	95
4:00	96	116	109	103	98	96
4:30	97	117	110	104	99	97
5:00	97	117	111	105	100	97
5:30	97	116	111	106	100	98
6:00	96	113	110	106	101	98
6:30	95	110	109	106	101	98
7:00	94	108	108	106	101	99

TABLE B.8. CURLING MOVEMENT FOR DRY TEST SECTION. PLACEMENT TEMPERATURE IS 60°F

Time	#1	#2	#3	#4	#5
7:00pm	0	0	0	0	0
7:30	1	0	0	0	0
8:00	1	0	1	0	0
8:30	1	0	1	0	0
9:00	2	0	2	0	0
9:30	2	0	2	0	0
10:00	2	0	3	0	0
10:30	2	0	4	0	1
11:00	2	1	4	0	1
11:30	2	1	4	0	1
12:00am	2	1	4	0	1
0:30	2	1	4	0	1
1:00	3	1	5	0	1
1:30	3	1	5	0	1
2:00	3	1	5	0	1
2:30	3	1	5	0	1
3:00	3	1	5	0	2
3:30	3	1	5	0	2
4:00	3	1	6	0	2
4:30	3	1	6	0	2
5:00	3	1	6	0	2
5:30	3	1	6	0	2
6:00	3	1	7	0	3
6:30	3	1	8	0	3
7:00	3	1	9	0	3
7:30	3	1	10	1	3
8:00	3	1	12	1	4
8:30	3	1	13	1	4
9:00	2	1	14	1	5
9:30	2	1	15	1	5
10:00	2	1	17	1	6
10:30	2	0	18	1	7
11:00	1	1	21	0	7
11:30	0	1	22	0	7
12:00pm	1	1	23	0	7
12:30	1	1	24	0	7
1:00	1	1	23	0	7
1:30	1	1	23	0	6
2:00	1	1	23	0	5
2:30	1	1	24	0	5
3:00	1	1	25	0	5
3:30	1	1	25	0	4
4:00	1	1	25	0	3
4:30	1	1	24	0	3
5:00	1	1	24	0	3
5:30	0	1	23	0	3
6:00	0	1	23	0	3
6:30	1	0	22	0	3
7:00	1	0	22	0	3

Note: Values of curling movement are in 0.001 in.

TABLE B.9. CURLING MOVEMENT FOR WET TEST SECTION. PLACEMENT TEMPERATURE IS 60°F

Time	#1	#2	#3	#4	#5
7:00pm	0	0	0	0	0
7:30	1	0	0	0	0
8:00	1	0	1	1	1
8:30	1	1	1	1	2
9:00	1	1	2	2	4
9:30	1	2	2	2	4
10:00	1	2	3	3	5
10:30	1	2	3	3	5
11:00	1	3	4	4	6
11:30	1	3	4	4	6
12:00am	1	4	4	4	8
0:30	1	4	5	5	8
1:00	1	4	5	5	8
1:30	1	4	5	6	8
2:00	2	5	6	6	9
2:30	2	5	6	6	9
3:00	2	6	6	6	10
3:30	2	6	7	7	11
4:00	2	6	7	7	11
4:30	2	7	7	7	11
5:00	2	7	8	8	12
5:30	2	7	8	8	12
6:00	2	7	8	8	12
6:30	2	7	9	9	8
7:00	2	8	9	9	13
7:30	2	8	9	9	12
8:00	2	8	10	10	13
8:30	1	7	10	10	12
9:00	1	6	9	10	12
9:30	1	6	10	11	8
10:00	1	4	9	10	5
10:30	1	4	9	11	6
11:00	1	2	9	10	2
11:30	1	3	9	11	2
12:00pm	0	3	9	10	3
12:30	0	2	8	10	1
1:00	1	2	8	9	1
1:30	0	2	7	9	1
2:00	0	2	7	9	0
2:30	0	1	7	8	1
3:00	0	2	7	8	1
3:30	0	2	7	7	1
4:00	0	3	8	7	0
4:30	0	4	8	7	1
5:00	1	4	8	7	1
5:30	1	6	8	7	3
6:00	1	7	9	8	4
6:30	1	6	9	8	4
7:00	1	6	8	8	3

Note: Values of curling movement are in 0.001 in.

TABLE B.10. CURLING MOVEMENT FOR DRY TEST SECTION. PLACEMENT TEMPERATURE IS 78°F

Time	#1	#2	#3	#4	#5
7:00pm	0	0	0	0	0
7:30	0	1	1	1	1
8:00	0	2	1	1	1
8:30	0	2	1	2	2
9:00	0	3	2	2	2
9:30	0	4	2	3	3
10:00	1	4	2	3	3
10:30	1	5	3	4	4
11:00	1	5	3	4	4
11:30	1	6	3	4	4
12:00am	1	6	4	4	5
0:30	1	6	4	5	5
1:00	1	7	4	5	5
1:30	1	7	5	5	6
2:00	1	8	5	5	6
2:30	1	8	6	6	6
3:00	1	8	6	6	7
3:30	1	8	6	6	7
4:00	1	8	6	6	7
4:30	1	8	6	6	7
5:00	1	8	6	6	7
5:30	1	8	6	6	7
6:00	1	8	6	6	7
6:30	1	8	6	6	7
7:00	1	8	6	6	8
7:30	1	9	6	6	8
8:00	1	9	6	6	8
8:30	1	9	6	6	8
9:00	1	9	6	7	8
9:30	1	9	7	7	8
10:00	1	9	7	7	8
10:30	1	9	7	7	8
11:00	1	10	7	7	8
11:30	2	10	7	7	8
12:00pm	2	10	7	7	9
12:30	2	10	7	7	9
1:00	2	10	7	7	9
1:30	2	10	7	7	9
2:00	2	10	7	6	9
2:30	2	10	7	6	9
3:00	2	10	7	6	9
3:30	2	10	7	6	9
4:00	2	10	7	5	8
4:30	2	10	7	5	8
5:00	2	10	7	4	7
5:30	1	10	6	4	7
6:00	1	10	6	4	7
6:30	1	10	6	4	7
7:00	1	10	6	4	7

Note: Values of curling movement are in 0.001 in.

TABLE B.11. CURLING MOVEMENT FOR DRY TEST SECTION. PLACEMENT TEMPERATURE IS 78°F

Time	#1	#2	#3	#4	#5
7:00 pm	0	0	0	0	0
7:30	0	0	0	0	0
8:00	0	0	0	0	0
8:30	0	1	1	0	0
9:00	0	1	1	0	0
9:30	0	1	1	0	0
10:00	1	1	1	0	1
10:30	1	1	1	1	1
11:00	2	1	2	1	1
11:30	2	1	2	1	1
12:00 am	3	1	2	1	1
0:30	3	1	2	1	1
1:00	4	1	2	1	2
1:30	5	1	2	2	2
2:00	5	1	2	2	2
2:30	5	1	2	2	2
3:00	5	1	3	2	2
3:30	5	1	3	2	2
4:00	5	1	3	2	2
4:30	5	1	3	2	2
5:00	5	1	3	2	2
5:30	5	1	3	2	2
6:00	5	1	3	2	2
6:30	5	1	3	2	2
7:00	5	2	3	2	2
7:30	5	2	4	2	2
8:00	5	2	4	2	2
8:30	5	2	4	2	2
9:00	6	2	4	2	2
9:30	6	2	4	2	2
10:00	7	1	4	2	2
10:30	7	1	4	2	2
11:00	7	1	4	2	2
11:30	8	1	4	2	2
12:00 pm	8	1	3	3	2
12:30	10	1	3	4	2
1:00	11	1	3	4	2
1:30	12	1	3	4	2
2:00	12	1	3	4	2
2:30	12	1	3	4	2
3:00	12	1	3	4	1
3:30	11	0	3	4	1
4:00	12	0	3	4	1
4:30	11	0	2	4	1
5:00	11	0	3	4	1
5:30	11	0	3	4	1
6:00	11	1	3	3	1
6:30	11	1	4	1	0
7:00	10	1	4	1	0

Note: Values of curling movement are in 0.001 in.

TABLE B.12. CURLING MOVEMENT FOR DRY TEST SECTION. PLACEMENT TEMPERATURE IS 96°F.

Time	#1	#2	#3	#4	#5
7:00 pm	0	0	0	0	0
7:30	0	1	0	0	1
8:00	1	1	1	1	1
8:30	1	1	1	1	2
9:00	1	2	1	1	2
9:30	2	2	1	1	3
10:00	2	3	1	1	4
10:30	3	3	2	1	4
11:00	4	3	2	1	5
11:30	4	3	2	1	5
12:00 am	4	4	2	1	6
0:30	5	4	2	1	6
1:00	5	5	3	1	7
1:30	6	5	3	1	7
2:00	6	5	3	1	8
2:30	7	6	3	1	8
3:00	7	6	4	1	9
3:30	8	7	4	6	9
4:00	8	7	4	6	10
4:30	8	7	4	7	11
5:00	9	8	5	7	11
5:30	9	8	5	7	11
6:00	10	8	5	8	12
6:30	10	9	6	8	12
7:00	11	9	6	9	13
7:30	13	11	7	10	14
8:00	13	11	7	1	14
8:30	14	11	7	2	15
9:00	13	11	8	1	15
9:30	14	12	7	4	15
10:00	13	11	8	11	15
10:30	13	11	8	11	15
11:00	13	11	8	12	14
11:30	13	12	8	12	14
12:00 pm	14	13	9	12	15
12:30	15	13	9	14	15
1:00	15	12	9	14	17
1:30	15	12	9	13	16
2:00	14	11	8	12	15
2:30	12	10	7	10	13
3:00	13	11	7	7	13
3:30	12	11	7	6	13
4:00	12	10	7	4	12
4:30	10	9	6	1	12
5:00	9	9	6	1	10
5:30	8	9	5	7	10
6:00	8	9	5	1	10
6:30	8	9	5	6	9
7:00	8	8	5	6	9

Note: Values of curling movement are in 0.001 in.

TABLE B.13. CURLING MOVEMENT FOR WET TEST SECTION. PLACEMENT TEMPERATURE IS 96°F.

Time	#1	#2	#3	#4	#5
7:00 pm	0	0	0	0	0
7:30	0	0	0	0	0
8:00	0	0	0	0	0
8:30	1	0	1	0	0
9:00	1	1	1	1	0
9:30	1	1	1	1	1
10:00	2	2	2	2	1
10:30	3	2	3	3	2
11:00	3	2	3	3	2
11:30	3	3	4	3	2
12:00 am	4	3	4	4	3
0:30	4	4	5	4	3
1:00	5	4	5	5	4
1:30	5	5	6	6	4
2:00	6	5	6	6	4
2:30	6	6	6	7	5
3:00	7	6	7	7	5
3:30	7	7	7	8	6
4:00	8	8	8	9	6
4:30	8	8	8	9	7
5:00	8	8	8	9	7
5:30	14	9	9	10	7
6:00	9	9	9	11	8
6:30	10	10	9	11	8
7:00	10	10	10	11	8
7:30	12	12	10	13	10
8:00	12	12	11	13	10
8:30	8	13	11	13	10
9:00	12	12	11	13	10
9:30	12	12	11	13	10
10:00	12	12	11	13	10
10:30	12	12	11	13	10
11:00	11	12	11	13	11
11:30	11	12	11	13	11
12:00 pm	11	13	12	14	12
12:30	11	14	12	14	12
1:00	13	14	13	14	13
1:30	12	14	12	13	12
2:00	11	13	12	12	12
2:30	9	11	10	11	11
3:00	8	11	10	10	11
3:30	9	11	11	10	11
4:00	8	10	10	10	10
4:30	7	9	9	9	10
5:00	6	8	8	9	9
5:30	5	7	7	8	8
6:00	4	6	7	7	7
6:30	4	6	6	7	7
7:00	4	6	6	7	7

Note: Values of curling movement are in 0.001 in.

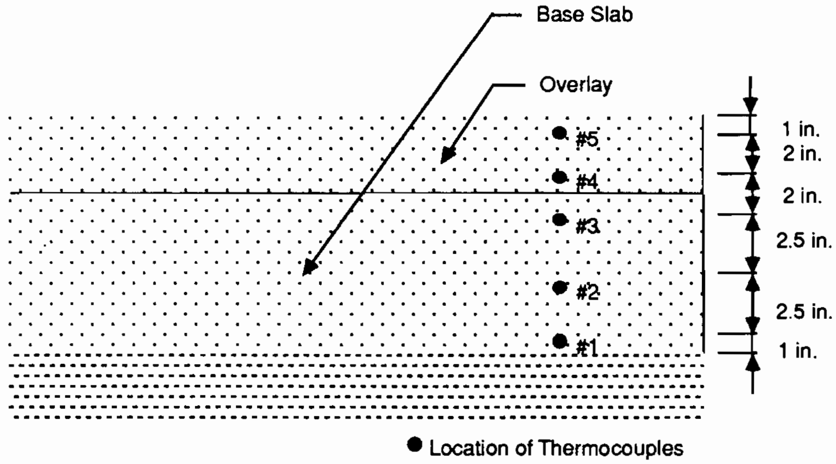


Fig B.1. Location of thermocouples.

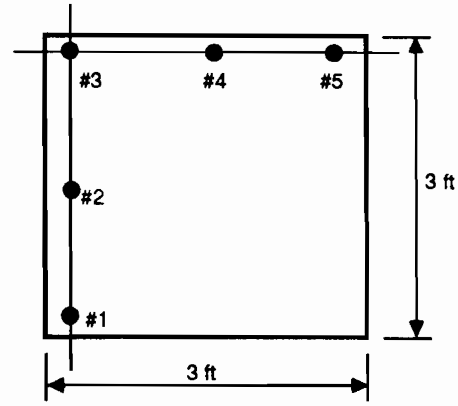


Fig B.2. Location of DCDTs.

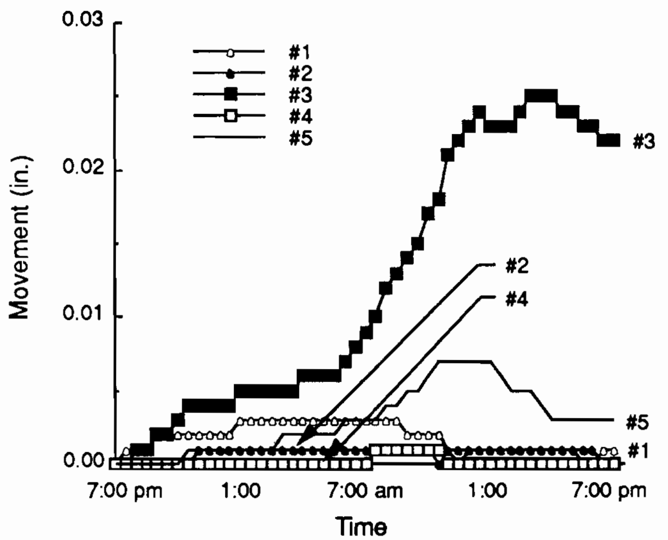


Fig B.3. Curling movement of slab during curing period. Temperature at placement is 60°F, dry section.

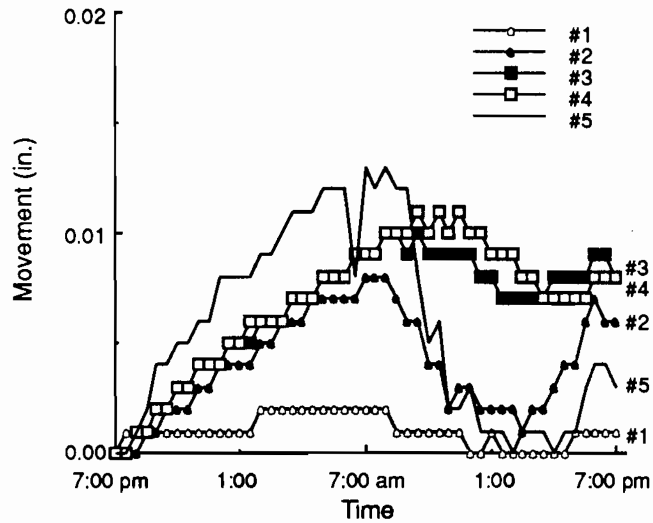


Fig B.4. Curling movement of slab during curing period. Temperature at placement is 60°F, wet section.

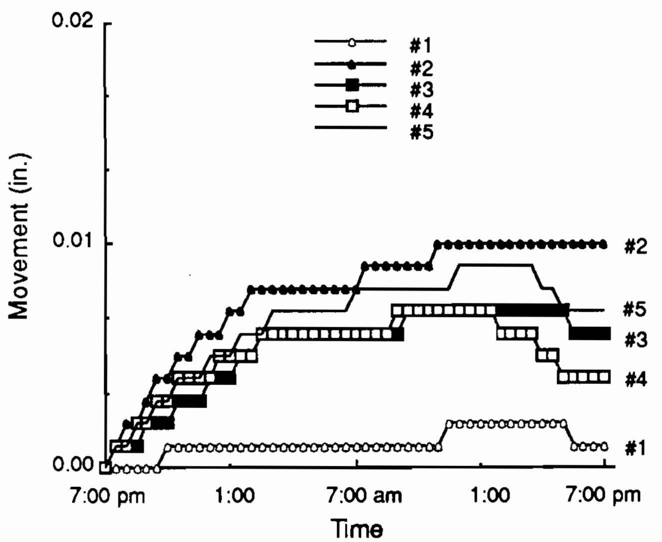


Fig B.5. Curling movement of slab during curing period. Temperature at placement is 78°F, dry section.

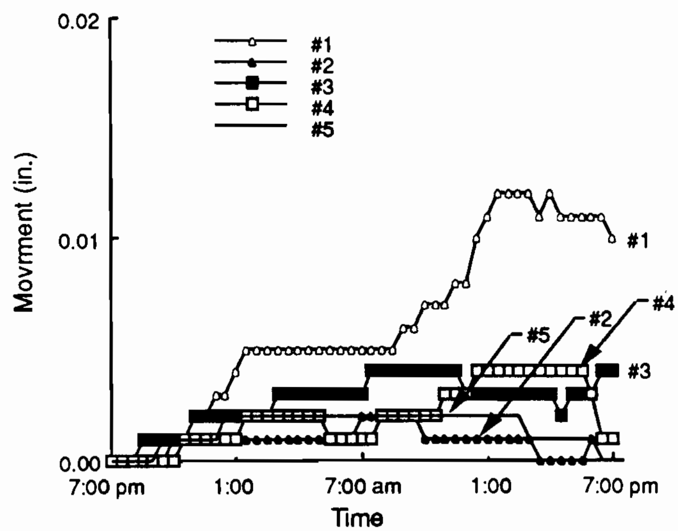


Fig B.6. Curling movement of slab during curing period. Temperature at placement is 78°F, wet section.

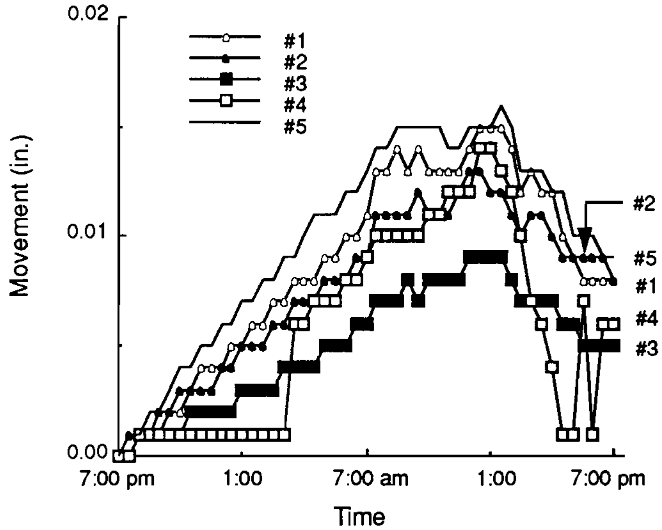


Fig B.7. Curling movement of slab during curing period. Temperature at placement is 96°F, dry section.

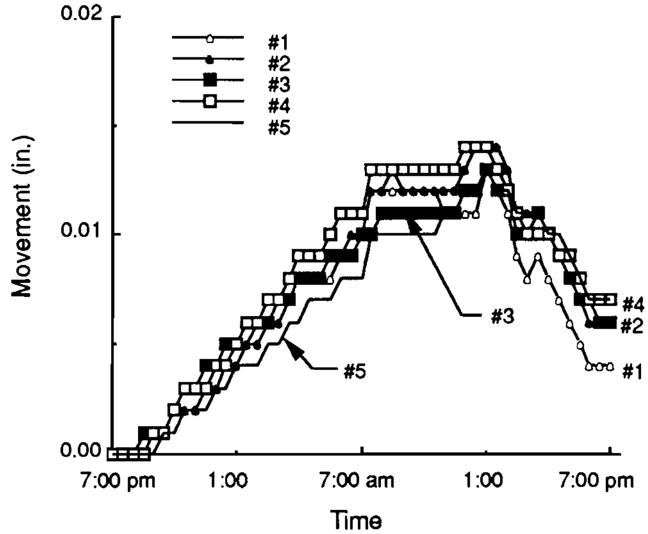


Fig B.8. Curling movement of slab during curing period. Temperature at placement is 96°F, wet section.

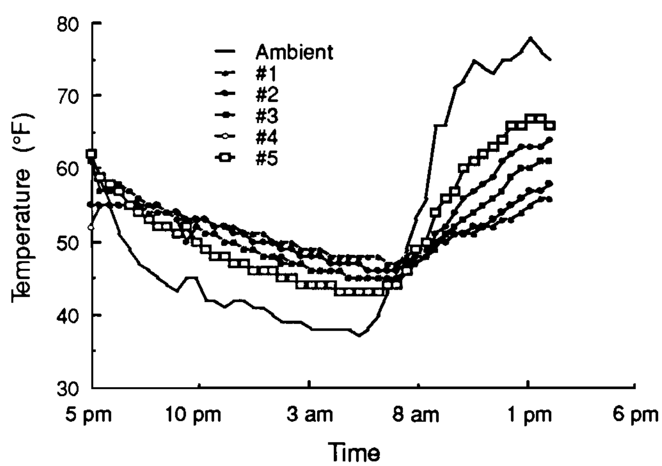


Fig B.9. Curling temperature of slab during curing period. Temperature of placement is 60°F, dry section.

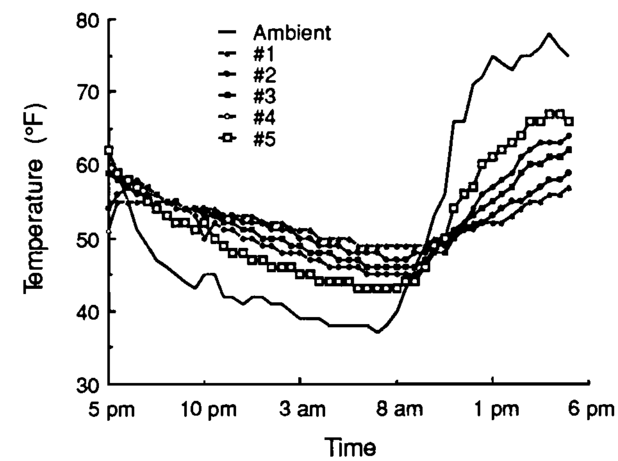


Fig B.10. Curling temperature of slab during curing period. Temperature of placement is 60°F, wet section.

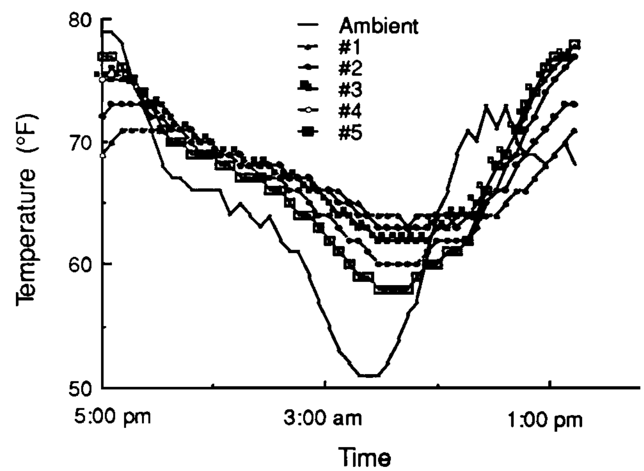


Fig B.11. Curling temperature of slab during curing period. Temperature of placement is 78°F, dry section.

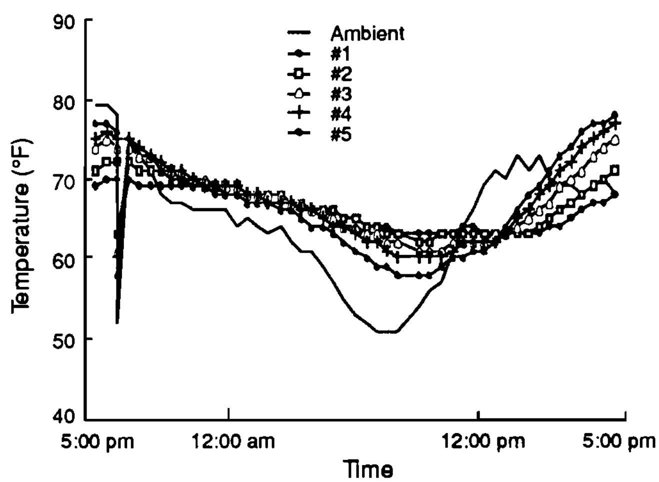


Fig B.12. Curling temperature of slab during curing period. Temperature of placement is 78°F, wet section.

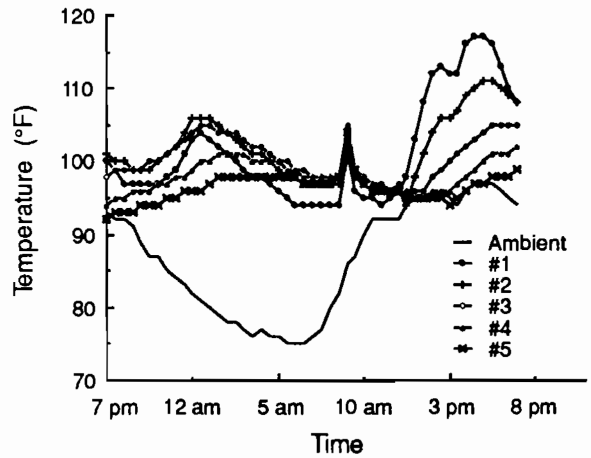


Fig B.13. Curling temperature of slab during curing period. Temperature of placement is 96°F, dry section.

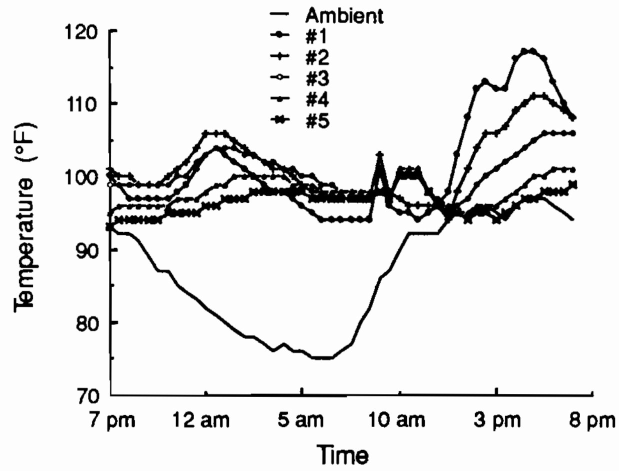


Fig B.14. Curling temperature of slab during curing period. Temperature of placement is 96 F, wet section.