TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No. FHWA/TX-89+457-5F	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle A SUMMARY OF STUDIES OF BONDED CONCRETE OVERLAYS		5. Report Date November 1988
		6. Performing Organization Code
7. Author(s) Young-Chan Suh, James R. Lundy, B. Frank McCullough, and D. W. Fowler		8. Performing Organization Report No. Research Report 457-5F
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 3-8-86-457
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: "Thin-Bonded Overlay Implementation"

16. Abstract

This report summarizes major findings of Research Project 457, "Thin-Bonded Concrete Overlay Implementation."

The performance of Bonded Concrete Overlays (BCO) in terms of pavement condition, deflection, fatigue life, and load transfer after overlay is described along with the warrants of BCO.

A field experimental program, performed on a stubout of State Highway 225, at IH-610 in Houston, is summarized. The objectives of the experimental program are to identify significant construction variables and to evaluate their effects on the bond strength between a CRCP overlay and an existing CRCP. Variables considered in the investigation were surface preparation, moisture condition, use of grout, vibration level, location of core, and season.

Various BCO material types in terms of reinforcement types (fibrous concrete vs. steel-mat-reinforced concrete, and CRCP vs. JCP) and bonding agents (portland cement grout vs. epoxy resin) are evaluated. Problems associated with the use of silicious river gravel as aggregates of the concrete mix are presented.

A summary of recommendations for the BCO construction are also presented.

Several case studies conducted using Rigid Pavement Rehabilitation Design system (RPRDS) are described. They include comparison of BCO design lives (20 vs. 40-year design), effect of early construction of BCO, comparison of asphalt shoulder and PCC shoulder, importance of directional and lane distribution in design effect of construction time on the traffic delay cost, and the effect of selecting different surface preparation methods on the total cost.

17. Key Words bonded concrete overlay, performance, reinforcement, alkali-silica reaction, bonding agent, pavement condition, fatigue life, deflection	18. Distribution Statement 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	48	

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A SUMMARY OF STUDIES OF BONDED CONCRETE OVERLAYS

by

Young-Chan Suh
James R. Lundy
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D. W. Fowler

Research Report Number 457-5F

Research Project 3-8-86-457
Thin-Bonded Overlay Implementation

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

PREFACE

Research Report 457-5F, "A Summary of Studies in Bonded Concrete Overlay," is the fifth and final report for Research Project 3-8-86-457, which was conducted at the Center for Transportation Research (CTR), The University of Texas at Austin, as part of the cooperative highway research program sponsored by the Texas State Department of Highways and Public Transportation (SDHPT) and the Federal Highway Administration (FHWA).

Authors would like to thank all members of the CTR staff and graduate students who participated in the various activities of the project.

LIST OF REPORTS

Report 457-1, "Preliminary Design of a Testing Facility to Subject Full Scale Pavement Sections to Static and Cyclic Loading," by Mark D. Wickham, B. Frank McCullough and D. W. Fowler, defines the problems and presents possible solutions for the design of a testing facility to cyclicly load full scale pavement sections.

Report 457-2, "A Laboratory Study of the Fatigue of Bonded PCC overlays," by Karen Reilley, Chhote Saraf, B. Frank McCullough, and D. W. Fowler, presents the findings of laboratory fatigue experiments which simulate the field conditions of IH-610 in Houston, Texas.

Report 457-3, "A Mechanistic Design for Thin-Bonded Concrete Overlay Pavements," by Moussa Bagate, B. F. McCullough, and D. W. Fowler, Presents a detailed procedure which can be used by the Texas SDHPT to design bonded concrete overlays of original jointed concrete pavements or continuously reinforced concrete pavements. The procedure utilizes the finite element method and field data for the structural analysis.

Report 457-4, "A Study of the Construction Variables on the Bond Behavior of CRCP Overlays," by Abdulrahman Ismail Solanki, B. F. McCullough, and D. W. Fowler, presents a summary of field experimental program to evaluate the effect of construction variables on the development of bond between a CRCP overlay and an old CRCP.

Report 457-5F, "Bonded Concrete Overlay Implementation," by Young-Chan Suh, James R. Lundy, B. F. McCullough, and D. W. Fowler, summarizes the important findings

ABSTRACT

This report summarizes major findings of Research Project 457, "Thin-Bonded Concrete Overlay Implementation."

The performance of Bonded Concrete Overlays (BCO) in terms of pavement condition, deflection, fatigue life, and load transfer after overlay is described along with the warrants of BCO.

A field experimental program, performed on a stubout of SH-225 at IH-610 in Houston, is summarized. The objectives of the experimental program were to identify significant construction variables and to evaluate their effects on the bond strength between a CRCP overlay and an existing CRCP. Variables considered in the investigation were surface preparation, moisture condition, use of grout, vibration level, location of core, and season.

Various BCO material types in terms of reinforcement types (fibrous concrete vs. steel-mat-reinforced concrete, and CRCP vs. JCP) and bonding agents (portland cement grout vs. epoxy resin) were evaluated. Problems associated with the use of silicious river gravel as aggregates of the concrete mix are presented.

A summary of recommendations for the BCO construction are also presented.

Several case studies conducted using Rigid Pavement Rehabilitation Design system (RPRDS) are described. They include comparison of BCO design lives (20 vs. 40 year design), effect of early construction of BCO, comparison of asphalt shoulder and PCC shoulder, importance of directional and lane distribution in design effect of construction time on the traffic delay cost, and the effect of selecting different surface preparation methods on the total costs.

KEYWORDS: Bonded concrete overlay, performance, reinforcement, alkali-silica reaction, bonding agent, pavement condition.

SUMMARY

Major accomplishments of Research Project 457 are summarized in this final report. Findings from field and laboratory studies conducted under the project are organized based on the specific objectives of the study. The objectives are: (1) to determine warrants of using a BCO, (2) to provide recommendations for the construction of bonded overlays, (3) to evaluate the types of BCO materials, and (4) to evaluate the strength, durability and economics of adopting different thicknesses for the overlay.

For the first objective, the warrants of BCO are presented along with the performance of BCO. For the second objective, recommendations for BCO construction are given based on the findings from various field and laboratory studies. For the third objective, BCO reinforcement types, bonding agents, and aggregates are evaluated. Finally, the effects of different thicknesses of overlay are presented along with other case studies for the fourth objective.

IMPLEMENTATION STATEMENT

Based on this study, the following are recommended for implementation:

(1) Bonded concrete overlays (BCO) are a viable rehabilitation alternative. It is warranted on the basis of friction/ skid resistance, riding quality, bridge restoration, correction of under design, and so on.

(2) Overlay before the pavement condition deteriorates. Failures should be repaired, and cracks with high deflection should be repaired before overlay placement.

(3) Bond strength at the corner of a slab was much lower than that at the middle. Therefore, special care should be taken for the construction of the corner of the BCO.

(4) Until further information is known, portland cement grout should be applied on the scarified existing pavement surface as a bonding agent to avoid excessive delamination. The grout should be thoroughly applied and promptly covered with the overlay concrete mix.

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CHAPTER 1. INTRODUCTION

This report summarizes the findings from field and laboratory studies conducted under Research Project 457, "Bonded Concrete Overlay Implementation." This chapter presents the background, objectives of the study, and scope of the report.

BACKGROUND

As an increasing portion of the Interstate and primary highway system has required rehabilitation in recent years, maintenance and rehabilitation of existing pavement have become very important issues in the highway industry.

Due to the recent developments in surface preparation techniques, bonded concrete overlays (BCO) are rapidly emerging as a viable rehabilitation alternative for portland cement concrete (PCC) pavements . Several lane miles of IH610 in Houston were rehabilitated using BCO and many more miles of the Texas highway system will become candidates for rehabilitation using BCO during the coming years.

Since most information available for BCO construction is insufficient and scattered, a series of studies by the Center for Transportation Research at The University of Texas at Austin has been recently completed to provide proper guidelines for BCO construction. Research includes behavior of BCO under alternative combinations of materials and design and the failure mechanism of BCO on previously fatigued concrete slabs.

OBJECTIVES

The objectives of this study are

(1) to determine warrants of using a BCO;

(2) to provide recommendations for the construction to ensure good quality BCO;

(3) to evaluate the types of BCO materials—reinforcement, grouting agents, and aggregates—and determine their relative advantages and disadvantages; and

(4) to evaluate the strength, durability, and economics of adopting different thicknesses for the overlays.

SCOPE OF THE REPORT

Chapter 2 presents the performance of BCO based on the findings of laboratory and field tests. General warrants for implementing BCO are also presented. This chapter covers the first objective of the study given in the previous section.

Chapter 3 summarizes the field experimental program to find the relationship between construction variables and bond strength of the two slabs. The results from this experimental program are used to achieve part of the second objective of the study.

Chapter 4 deals with the evaluation of the various BCO reinforcement types, bonding agents, and aggregates. Field and laboratory experimental programs concerned with these subjects are presented. This chapter covers the third objective of the study.

Chapter 5 presents recommendations for BCO construction based on the findings from the field and laboratory tests conducted throughout the study. This chapter covers the second objective of the study.

Chapter 6 discusses design and construction considerations of BCO. This chapter covers the fourth objective of the study.

Finally, the conclusions of the study and recommendations for further studies are presented in Chapter 7.

CHAPTER 2. PERFORMANCE AND USE OF BCO

This chapter summarizes the performance and use of bonded concrete overlays (BCO) based on the findings of laboratory and field tests conducted by the Center for Transportation Research (CTR). The following items will be discussed in this chapter:

(1) pavement condition,
(2) deflection,
(3) fatigue life and load transfer,
(4) shear strength at the interface, and
(5) the use of BCO.

The reader is referred to CTR Research Reports 920-2, 357-1, 357-2, and 457-2 for more detail (Refs 1 to 4).

PAVEMENT CONDITION

Research Report 920-2 (Ref 1) describes condition surveys before and after the placement of a 4-inch bonded concrete overlay on ten test sections of IH610 North in Houston. Each test section was about 600 feet long on the outside lane in the east bound direction. Measured distress types were transverse and longitudinal cracks, spallings, punchouts, and patches. Using a profilometer, riding quality and changes in profile of the pavement were measured to calculate the present serviceability index (PSI) before and after overlay. Table 2.1 summarizes the results of the condition survey before and after the overlay placement.

As can be seen in the table, all types of distress were significantly decreased after the overlay placement. Increased PSI also indicated a substantial improvement in riding quality.

DEFLECTION

Deflections of pavements before and after overlay placement were measured on the same ten test sections described above using the Texas State Department of Highways and Public Transportation (SDHPT) Dynaflect (Ref 1). Measurements were performed every 50 feet in the test sections (approximately the same locations before and after overlay placement). The results showed a significant decrease in deflection after overlay. All five Dynaflect sensor readings decreased about 15 to 50 percent. This gives an indication of significant improvement in structural quality.

TABLE 2.1. SUMMARY OF CONDITION SURVEY RESULTS BEFORE AND AFTER OVERLAY, IH 610 NORTH IN HOUSTON (AVERAGE OF ALL TEN TEST SECTIONS)

Type of Condition Survey	May 1985 (Before Overlay)	January 1987 (After Overlay)
Average Transverse Crack Spacing (feet)	2.1 *(1.8 - 2.5)	7.2 (3.0 - 17.4)
Average Length of Longitudinal Crack per 100 feet Section (feet/100 feet)	43.3 (1.5 - 73.9)	0.9 (0 - 7.0)
Average Number of Spallings and Punchouts in a Test Section (Approximately 600 feet)		
Minor Spalling**	8.0 (1 - 26)	0
Severe Spalling	1.0 (0 - 3)	0
Minor Punchout	4.2 (0 - 17)	0
Severe Punchout	0.4 (0 - 3)	0
Average Present Serviceability Index (PSI)	2.95 (2.77-3.27)	3.88*** (3.03-4.20)

* Numbers within parentheses represent the minimum and maximum values in 10 test sections.
** Minor Spalling: less than half an inch of spalling
Severe Spalling: greater than half an inch of spalling
Minor Punchout: no movement of block
Severe Punchout: block movement
*** Measured in March 1987

FATIGUE LIFE AND LOAD TRANSFER

In order to estimate the effect of long-term repeated loadings on BCO, a fatigue life study, using accelerated repeated loadings, was performed in the laboratory (Ref 4). Four base slabs, consisting of two continuously reinforced concrete pavements (CRCP) and two jointed concrete (JC) pavements were constructed. Test specimens were half-scale models of the IH610 pavement. Thicknesses of base slabs and overlays were 4 and 1-1/2 inches, respectively. The size of the slabs was 3 feet wide and 6 feet long. In order to simulate thermal cracking, slabs were cracked at mid-span and loaded in fatigue to various distress levels before the overlays were placed. Following overlay placement, specimens were again loaded in fatigue to determine the remaining lives of the pavement structures. Cracking of 1,400 feet per 1,000 square feet was used to define failure in the remaining life study. This cracking included all the longitudinal and transverse cracks excluding the simulated thermal cracking. Load transfer across the transverse cracks was also checked before and after overlays were placed.

It was found from the fatigue study that the overlay placement increased the fatigue life even when an overlay was placed on a failed base slab. If an overlay was placed on a base slab with some remaining life, a substantially longer fatigue life was obtained than when one was placed on a severely damaged base slab, and the two slabs acted as an integral unit. It was also found that the placement of an overlay improved the load transfer across the transverse cracks.

SHEAR STRENGTH AT THE INTERFACE

Theoretical Shear Stresses at the Interface by Traffic Loadings

A computer analysis using ELSYM 5 was performed to determine theoretical shear stresses at the interface between the overlay and the old pavement (Ref 2). Two and 4-inch-thick overlays on various existing pavement structures were analyzed. Figure 2.1 shows the pavement structures used in this analysis. The interfaces between the two layers were assumed to be fully bonded. The only cause of stress considered was loading (18-kip single axle load); temperature and moisture differentials were not taken into account.

The range of the shear stresses at the interface, from this linearly elastic analysis, was 16 to 24 psi, with a mean of 19 psi and a standard deviation of 3 psi.

Shear Strength at the Interface (A Laboratory Test; Ref 2)

In the laboratory four 6-foot by 3-foot slabs with a few hairline cracks on the surface were selected. Surfaces of the slabs were prepared by sand blasting. Cement grout was applied before overlay placement. The cement grout had a water-cement ratio of 0.62 (seven gallons of water per bag of cement).

The shear strength at the interface was to be determined on the first, seventh, and twenty-eighth day; however, attempts to take cores on the first and seventh days failed. Cores were broken at the interface due to the vibration of the coring machine. On the twenty-eighth day after overlay placement, 16 cores were obtained successfully. Shear strength at the interface of each core was measured using the direct shear test.

The mean shear strength at the interface was 204 psi. The mean strength for the cores obtained from the corner locations was 180 psi, for those from the edge 167 psi, and for those from the interior 271 psi. The lowest shear strength was 115 psi.

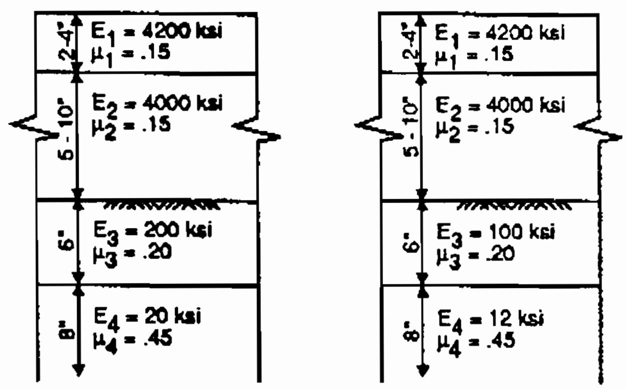
Since the shear stress for the worst condition obtained from the computer analysis was 24 psi, it can be said that the shear strength at the interface of BCO is adequate for the traffic loadings under the assumptions inherent in linear elastic analyses. Further study is recommended for the effects of temperature differential, moisture, and fatigue on the shear stress at the interface.

THE USE OF BCO

It is known that the placement of BCO improves the structural capacity and, given adequate construction controls, the riding quality of the pavement. With current surface preparation equipment and material the BCO became a viable rehabilitation alternative. The following are general warrants for implementing BCO presented at a symposium held at the Balcones Research Center of The University of Texas at Austin:

(1) faster and cheaper construction than complete reconstruction (the money saved can be used elsewhere);
(2) restore friction, skid resistance, and riding quality;
(3) bridge restoration (control excessive increase in dead weight of the bridge by resurfacing with a thin overlay);
(4) grade control (reduce problems that complete reconstruction can cause by raising the surface grade such as altering the height of guard rail or reducing the space between the bottom of the overriding bridge and the surface of the pavement after overlay);
(5) correction of under design (strengthen the pavement structure to meet unexpected increase in traffic volume or load limits); and
(6) lower user costs (reduce long delay time and high operating costs caused by bad road conditions).

A field experiment was performed to evaluate various reinforcement types of the overlay. Considered reinforcements were steel fibers, steel mats, and plain concrete. Thicknesses of the overlays were 2 to 3 inches. Condition surveys and measurements of Dynaflect deflection were conducted before and after the overlay placement. Chapter 4 of this report has more details of the experiment. The



(a) Strong support. **(b) Weak support.**

Fig 2.1. Pavement structures analyzed in the computer study (Ref 2).

findings of the experiment include the following warrants of BCO:

(1) The use of fibrous concrete overlay is warranted when the cracking is the prime concern since it was far superior to other sections in controlling longitudinal and transverse cracking.

(2) The use of steel-mat-reinforced BCO is warranted when the existing pavement has large deflections since the reduction in Dynaflect deflection was highest in steel-mat-reinforced sections.

SUMMARY

As a viable rehabilitation alternative, bonded concrete overlays have the following benefits:

(1) substantial reductions in all types of pavement distresses,

(2) improvement in riding quality (increased PSI),

(3) improvement in the structural quality (15 to 50 percent reductions in Dynaflect deflection), and

(4) increased fatigue life.

The following are general warrants for implementing BCO:

(1) faster and cheaper construction than complete reconstruction;

(2) restoration of friction, skid resistance, and riding quality of the existing pavement;

(3) bridge restoration, grade control, and correction of under design; and

(4) lower user costs by improving riding quality and reducing construction time.

From a field experiment, the following types of BCO are warranted for the specific existing pavement conditions:

(1) The use of steel-mat-reinforced BCO design is warranted when the existing pavement has excessive deflection.

(2) The use of fiber-reinforced BCO design is warranted when cracking of the existing pavement is the prime concern.

CHAPTER 3. EFFECT OF CONSTRUCTION VARIABLES ON BOND STRENGTH OF BCO

INTRODUCTION

Bonded concrete overlays are designed to act monolithically with the old concrete pavement so that the existing slab and overlay contribute to the maximum extent to the structural capacity of the pavement. Therefore, an important issue of BCO construction is assuring a sound bond between the overlay and the old concrete pavement. A clean and properly scarified surface of the old pavement should be provided to obtain an adequate bond between two slabs. Cement grout is sometimes applied to the scarified surface before overlay placement.

A field experiment (Ref 5) was conducted to find the relationship between construction variables and bond strength of the two slabs. The objective of the experimental program was to identify significant construction variables and to evaluate their effect on the bond strength between a CRCP overlay placed on an existing CRCP. For this purpose, 4-inch overlays were placed in winter and summer on an 8-inch existing pavement on SH-225 at IH-610 in Houston. A typical field layout for a given surface preparation is shown in Fig 3.1.

CONSTRUCTION VARIABLES

Variables considered in the investigation were:

(1) surface preparation,
(2) moisture condition,
(3) use of grout,
(4) vibration level,
(5) location, and
(6) season.

Each variable is described more thoroughly below.

Surface Preparation

The existing pavement needs to be cleaned and scarified before an overlay placement to ensure adequate bond between the old pavement and the overlay. Two types of surface preparation were evaluated:

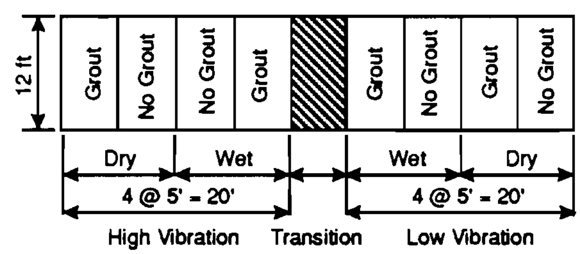


Fig 3.1. Typical field layout for a given surface preparation method (Ref 5).

(1) cold mill surface, and
(2) shot blast surface.

Textures of the two surfaces were measured using the sand patch method. The texture of the cold milled surface was 0.100 inch or more while the texture for the shot blasted surface was about 0.022 inch.

The sand patch method is a texture evaluation method selected as a best method from a pilot study (Ref 6) in which three texture evaluation devices (sand patch method, Text-Ur-Meter, and Texture Profile Recorder) were examined in terms of repeatability, time, and cost. It gives an average depth of the pavement surface macro-texture. It measures the average diameter of a known amount of fine sand particles spread on the scarified pavement surface. Thus, smaller sand patch diameters indicate greater average texture depth. The average depth of the surface texture can be calculated by dividing the volume of sand by the sand patch area.

Moisture Condition

The moisture condition was considered as a factor of the experiment to determine if an overlay can be successfully placed on a wet pavement surface. The wet surface condition for the experiment was achieved by sprinkling water on the pavement surface. Two levels of moisture conditions were evaluated in this experiment:

(1) wet: the condition of pavement just after rain, without standing water, and
(2) dry: completely dry surface condition.

Use of Grout

Previous research (Ref 2) performed on laboratory specimens and cores from overlaid slabs in the field showed that using a dry surface with portland cement grout gives lower bond than a dry surface without grout. This implied that grout does not always improve the bond between the old pavement and the overlay. Additional work was considered necessary to understand the interaction of grout with other variables. Two grout conditions were considered in this experiment:

(1) with grout and
(2) without grout.

Grout used in winter experiment had equal amounts of sand and cement mixed in a mortar mixer with enough water to form a stiff but workable mix that could be spread with a stiff broom. Grout was applied uniformly over the pavement surface with the help of stiff brooms. Grout used for the summer experiment had cement mixed with enough water to spread on the surface easily. Exact amounts of water used in mixing grouts were not measured.

Vibration Level

Selecting a proper vibration level was theorized to be very important to obtain good bond strength. Under-vibrating will lead to honeycombing, resulting in a bad bond at the interfaces; and over-vibrating will cause segregation of aggregate from the cement grout. A pilot study (Ref 5) was performed to select appropriate vibration levels to be tested in the field experiment. Different vibration levels were obtained by controlling the vibration time. Results of this pilot study showed that bond strength increased with an increase in vibration level. For the field experiment two vibration levels that showed higher bond strength in the pilot study were selected:

(1) high vibration level: 10 minute vibration per section, and
(2) low vibration level 2.5 minute vibration per section.

The dimension of each test section was 12 feet by 5 feet with thickness of 4 inches. The frequency of the vibrator was 8000 vibrations per minute. High and low levels of vibration were obtained by varying the time of vibration. In the winter condition, however, vibrators with frequency of 2,000 vibrations per minute were used because the required vibrators were not available. Therefore the vibration times used for the winter condition were multiplied by four to get the equivalent vibration levels.

Location of Core

Cores were taken from following locations of each test section for comparison:

(1) corner,
(2) side, and
(3) middle.

Figure 3.2 shows typical locations of cores in a test section.

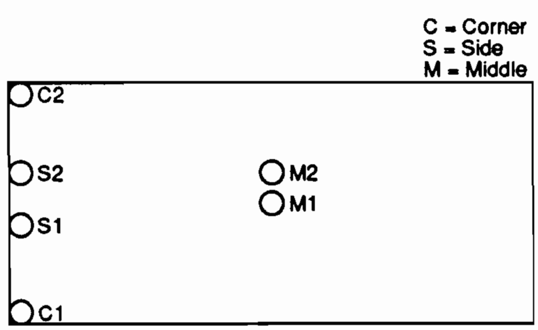


Fig 3.2. Typical test section with core locations (Ref 5).

Seasonal Effect

The experimental program was conducted at different times of the year to see if there were any seasonal effects. Two seasons were considered:

(1) winter condition (conducted in March 1987), and
(2) summer condition (conducted in August 1987).

MIX DESIGN

Mix design of the overlay is given in Table 3.1.

TABLE 3.1. MIX DESIGN OF OVERLAY

	Winter (March 1987)	Summer (August 1987)
Cement Content	7 sacks of cement/CY	7 sacks of cement/CY
Water/Cement Ratio	0.4	0.4
Maximum Aggregate Size	5/8 in.	1 in.
Design Slump	2 - 3 in.	2 - 3 in.
Actual Slump	1.5 in.	2 in.
Admixtures	None	Pozzolan

CURING

Winter: After initial set of the concrete, the surface was sprayed by water and covered with polyethylene sheets. The sheets were stapled to the sides to prevent moisture loss.

Summer: Curing compound was sprayed on the overlay.

PROBLEMS ENCOUNTERED DURING WINTER POUR

There were few problems in the summer pour, whereas many problems were encountered during the winter pour. Since most problems occurred during the winter pour, results of the winter experiment may not be acceptable. It would be also unreasonable to infer the seasonal effect of the winter and summer pour from the results. Problems of the winter pour were as follows:

(1) The surface cleaning compressor stopped functioning in the middle of the cleaning. Therefore, the surface was cleaned only using the brooms.
(2) Many times the slump of the concrete mix was less than the design slump of 2 to 3 inches. More water was added to meet the design slump.
(3) Since the vibrators with designed frequency (8000 vibrations per minute) were not available at the time of pouring, vibrators with a frequency of 2,000 vibrations per minute were used and the vibration time was quadrupled.
(4) Corners were hard to grout especially on the dry/grout sections. The grout would stick to the broom and not to the pavement. The sides also had a similar problem but to a lesser extent.

(5) After the no-grout/dry section was placed with the high vibration level, the side form gave away. The concrete was removed and the side reinforced. The form was filled again and vibrated to consolidate.

(6) On the second day of pouring, the truck brought in the wrong size of aggregate. The truck was sent back and the concrete had to be removed and dumped using wheel barrows. This section was designed as dry/no-grout section but then had to be redesigned as a wet/grout section because the surface had to be cleaned thoroughly using water. Since a completely cement-free surface was not obtainable, it was decided to grout the section.

(7) The actual vibration levels may not have been achieved. This was mainly because of lack of personnel on the site. There were not enough people to work the vibrators and move them around constantly. The vibrators were kept on one location. Therefore the effect of different vibration levels may not have been adequately determined.

RESULTS OF THE EXPERIMENTAL PROGRAM

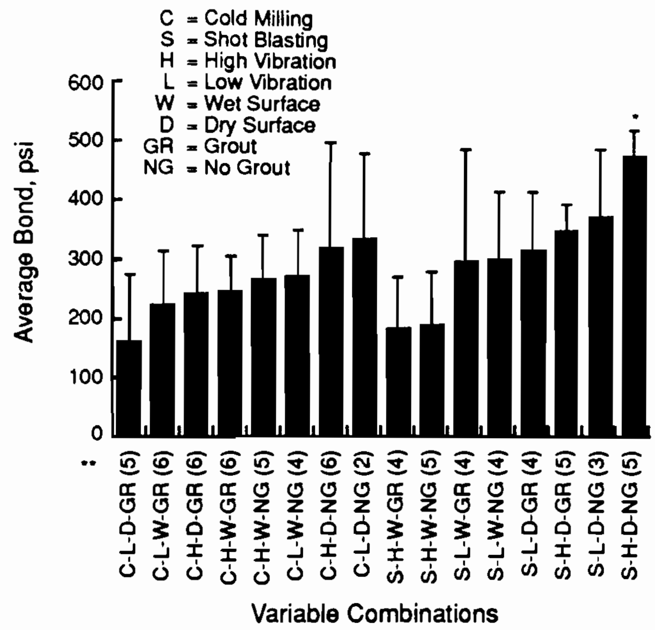
After the test slab was allowed to cure for seven days, six cores were taken from each test section: two at the corners, two at the side, and two from the middle. Direct shear tests were performed on these cores in the laboratory. The bond strength data from the test are given in Appendix A.

Figures 3.3 and 3.4 show the average bond strength and standard deviation of each variable combination for winter and summer experiment, respectively. It is seen from the figures that the variable combination showing the highest bond strength for winter was shot blast/high vibration/dry surface/no grout. For the summer condition, shot blast/low vibration/wet surface/grout had the highest strength.

Next, a General Linear Model (GLM) in SAS (Ref 7) was performed to find factors and interactions that significantly affected bond strength. Three or more factor interactions were neglected and included in the error term in the model. The following analyses were separately performed using GLM:

(1) winter experiment,
(2) summer experiment, and
(3) full factorial (winter and summer combined).

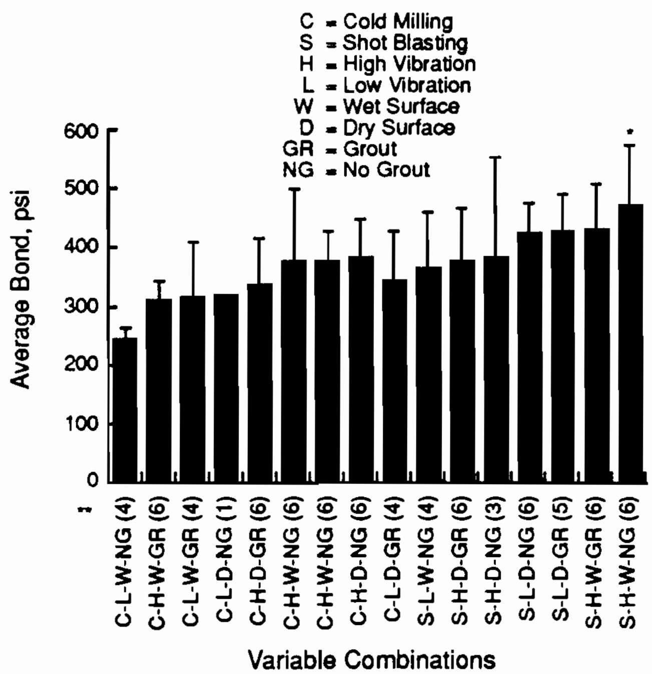
Tables 3.2 and 3.3 summarize the results of GLM analysis for the winter and summer experiment. The last columns in these tables indicate the significance of the experimental factors and interactions at the 0.05 a level.



* "T" bar on each column represents the standard deviation of the bond strength.

** Each number within parenthesis represents the number of samples averaged.

Fig 3.3. Average bond strength and standard deviation of each treatment combination (winter).



* "T" bar on each column represents the standard deviation of the bond strength.

** Each number within parenthesis represents the number of samples averaged.

Fig 3.4. Average bond strength and standard deviation of each treatment combination (summer).

Winter Condition

It is seen from Table 3.2 that all main variables except vibration are significant. Significant interactions are surface preparation/vibration, surface preparation/moisture, vibration/moisture, and moisture/grout. Main effects of surface preparation, moisture, and grout should be interpreted with their interactions since their interactions are also significant. Therefore interpretable significant effects are the location factor and all significant interactions.

Figures 3.5 to 3.9 show the effects of these factors and interactions for the winter condition. Following are findings from the figures:

(1) Bond strength at the interface was highest at the middle, and lowest at the corner of the slab (Fig 3.5).

(2) Low vibration on the cold milled surface gave slightly lower bond strength than the other vibration and surface preparation combinations (Fig 3.6).

(3) Shot blasting gave better bond than cold milling when the pavement surface was dry. No substantial difference was observed in wet conditions (Fig 3.7).

(4) High vibration gave higher bond only when the pavement surface was dry (Fig 3.8).

(5) No grout on the dry surface gave higher bond strength than the other moisture.

This analysis showed that the moisture condition plays a very important role in the decision whether or not to use grout and in the selection of the surface preparation method and vibration level.

As mentioned earlier in this chapter, however, these results from the winter experiment may not be meaningful due to many problems encountered during the pouring. Further studies are recommended for the verification of the results.

Summer Condition

Table 3.3 summarizes the GLM analysis for the summer experiment. The only significant effects are the surface preparation and the interaction of vibration and grout.

Figures 3.10 and 3.11 show these effects. It is seen that shot blasting performed better for bond than cold milling (Fig 3.10). Figure 3.11 shows that low vibration gave higher bond strength than high vibration when the surface was grouted, and high vibration gave higher bond strength when the surface was grouted, and high vibration gave higher bond strength when the surface was ungrouted.

Full Factorial

An analysis of the full factorial was also performed to obtain the overall effect of all factors including season. Table 3.4 shows the summary of the GLM analysis for the full factorial. Significant main effects and interactions are location, season, surface preparation, moisture, location/season, location/vibration, season/moisture, vibration/grout, and moisture/grout. Main effects of location, season, and moisture should be interpreted together with their inter-

TABLE 3.2. SUMMARY OF GLM ANALYSIS FOR THE WINTER FACTORIAL

Variable	F-value	Probability > F	Significance (α = 0.05)
Location	9.23	0.0004	Yes
Surface preparation	8.16	0.0061	Yes
Vibration	0.07	0.7874	--
Moisture	12.82	0.0007	Yes
Grout	4.72	0.0343	Yes
Location/Surface preparation	2.55	0.0879	--
Location/Vibration	1.22	0.3030	--
Location/Moisture	0.97	0.3854	--
Location/Grout	0.28	0.7567	--
Surface preparation/Vibration	4.49	0.0388	Yes
Surface preparation/Moisture	11.63	0.0012	Yes
Surface preparation/Grout	0.24	0.6262	--
Vibration/Moisture	6.51	0.0136	Yes
Vibration/Grout	0.13	0.7215	--
Moisture/Grout	4.84	0.0322	Yes

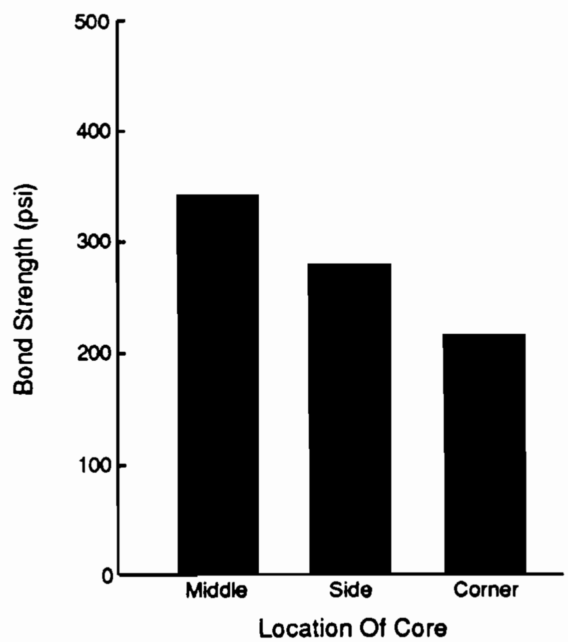


Fig 3.5. Main effect of location for bond at the interface for winter condition.

actions because their interactions are also significant. Therefore, interpretable effects are the main effect of surface preparation, and interactions of location/season, location/vibration, season/moisture, vibration/grout, and moisture/grout. Figures 3.12 to 3.17 show the effect of these factors and interactions. Findings from the figures can be summarized as follows:

(1) Shot blasting showed better performance for the bond strength than cold milling (Fig 3.12).

(2) Cores taken at the corner showed lowest bond. Higher

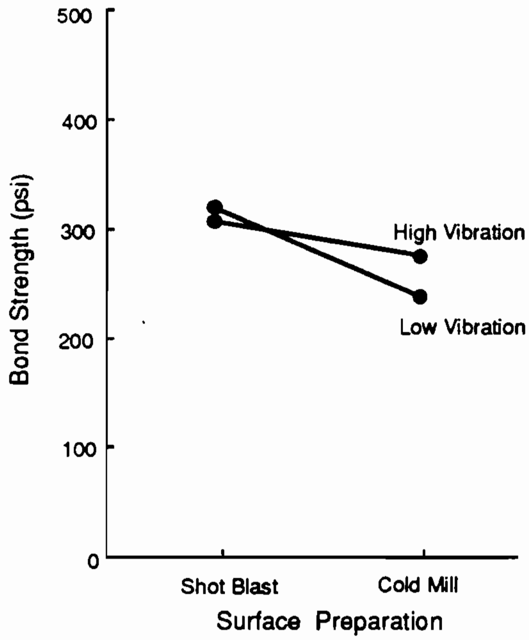


Fig 3.6. Interaction of surface preparation method and vibration level for bond at the interface for winter conditions.

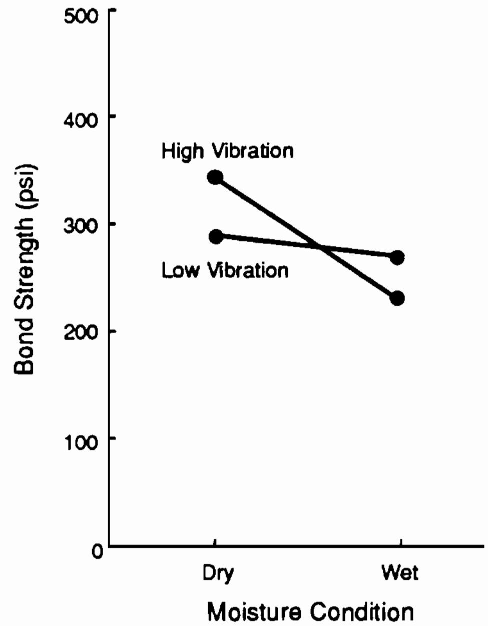


Fig 3.8. Interaction of vibration and moisture condition for bond at the interface for winter condition.

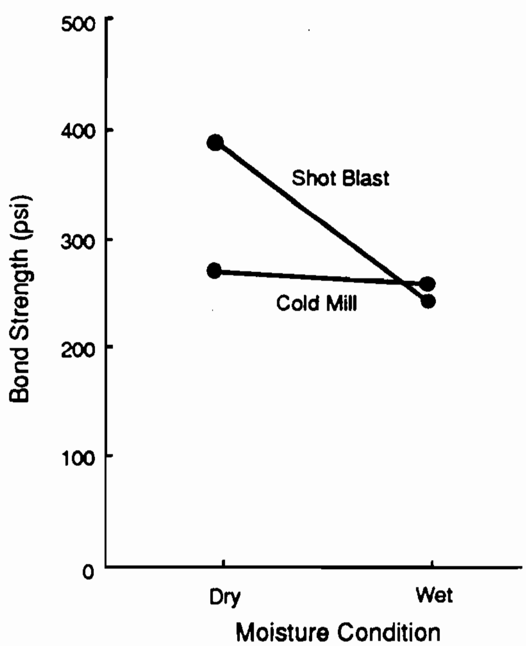


Fig 3.7. Interaction of surface preparation method and moisture condition for bond at the interface for winter condition.

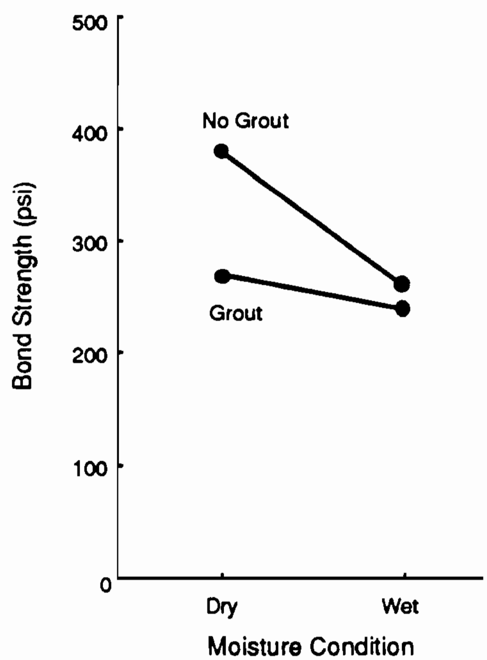


Fig 3.9 Interaction of grout and moisture condition for bond at the interface for winter condition.

bond strength was obtained in the summer condition than in winter (Fig 3.13). But care should be taken in the interpretation of this results since lower bond strength in winter may be due to the problems associated with the winter placement.

(3) Low vibration resulted in better bond than high vibration at the middle of the slab. At the side and corner of the slab, however, high vibration gave better bond (Fig 3.14). Therefore, higher vibration may be more important in obtaining good bond strength at the side and corner than at the middle of the slab.

(4) Dry surfaces showed better bond than wet surfaces in winter. For the summer condition, the moisture effect was negligible (Fig 3.15).

(5) When the surface was ungrouted, high vibration was better for bond (Fig 3.16).

(6) No grout resulted in better bond when the surface was dry (Fig 3.17).

(7) Due to the different pouring conditions in winter and summer, it is not reasonable to make a conclusion from this experimental program about the seasonal effect on the bond capacity.

TABLE 3.3. SUMMARY OF GLM ANALYSIS FOR THE SUMMER FACTORIAL

Variable	F-value	Probability > F	Significance (α = 0.05)
Location	2.08	0.1338	--
Surface preparation	14.94	0.0003	Yes
Vibration	1.33	0.2534	--
Moisture	0.44	0.5097	--
Grout	1.42	0.2381	--
Location/Surface preparation	0.45	0.6405	--
Location/Vibration	2.91	0.0623	--
Location/Moisture	0.24	0.7880	--
Location/Grout	1.35	0.2676	--
Surface preparation/Vibration	0.84	0.3631	--
Surface preparation/Moisture	2.02	0.1607	--
Surface preparation/Grout	0.29	0.5916	--
Vibration/Moisture	1.85	0.1788	--
Vibration/Grout	8.59	0.0048	Yes
Moisture/Grout	0.52	0.4734	--

SUMMARY AND DISCUSSION

This section presented a summary of experimental program to identify significant construction variables and to evaluate their effects on the bond strength between a CRCP overlay and an existing CRCP. The purpose of this experimental program was to provide helpful information for a quality bonded concrete overlay construction. Variables considered in this experiment were surface preparation, moisture condition, use of grout, vibration level, location, and season.

Findings of this experimental program can be summarized as follows:

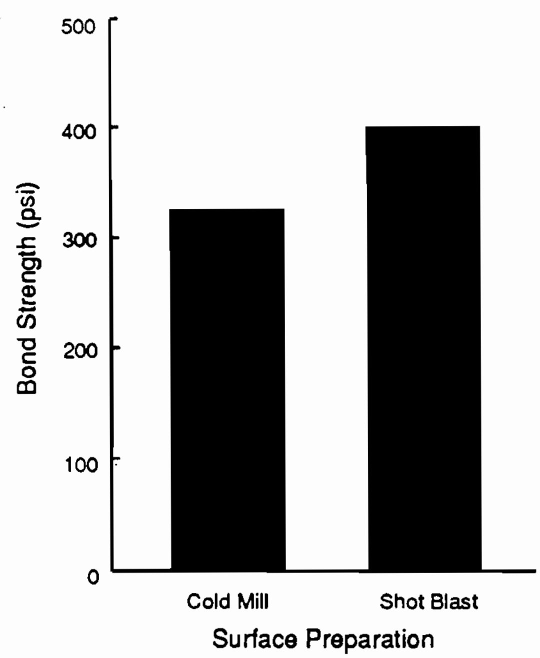


Fig 3.10. Main effect of surface preparation for bond at the interface for summer condition.

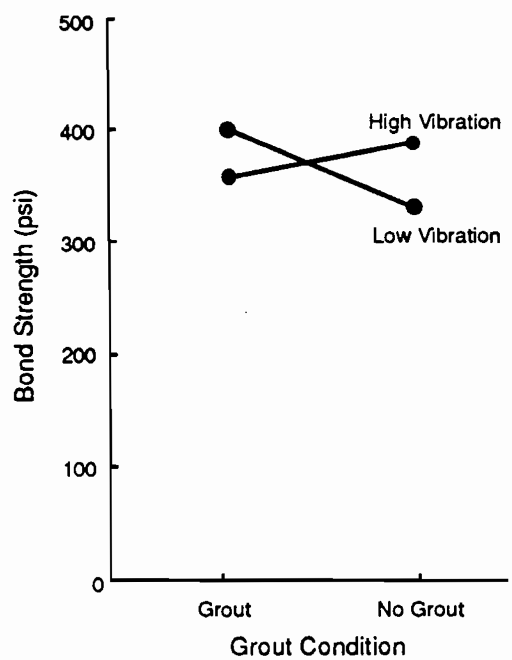


Fig 3.11. Interaction of vibration and grout condition for bond at the interface for summer condition.

(1) Generally shot blasting showed better performance for bond than cold milling in this experiment (Figs 3.10 and 3.12). However, since more delamination problems occurred with shot blasting in the field, further studies are needed for verification of the result.

(2) Bond strength at the corner of a slab was much lower than that at the middle (Figs 3.5, 3.13, and 3.14). Therefore care should be taken in the overlay construction to ensure sound bond especially at the corner, or the design should be modified to take this into account.

TABLE 3.4. SUMMARY OF GLM ANALYSIS FOR THE FULL FACTORIAL

Variable	F-value	Probability > F	Significance (α = 0.05)
Location	10.75	0.0001	Yes
Season	36.89	0.0001	Yes
Surface preparation	21.14	0.0001	Yes
Vibration	1.85	0.1762	--
Moisture	7.40	0.0074	Yes
Grout	0.42	0.5175	--
Location/Season	3.35	0.0381	Yes
Location/Surface preparation	2.01	0.1382	--
Location/Vibration	4.34	0.0150	Yes
Location/Moisture	0.60	0.5522	--
Location/Grout	0.65	0.5252	--
Season/Surface preparation	0.42	0.5178	--
Season/Vibration	0.13	0.7167	--
Season/Moisture	7.75	0.0062	Yes
Season/Grout	3.30	0.0716	--
Surface preparation/Vibration	3.77	0.0546	--
Surface preparation/Moisture	2.02	0.1579	--
Surface preparation/Grout	0.29	0.5904	--
Vibration/Moisture	0.85	0.3579	--
Vibration/Grout	6.41	0.0126	Yes
Moisture/Grout	5.38	0.0220	Yes

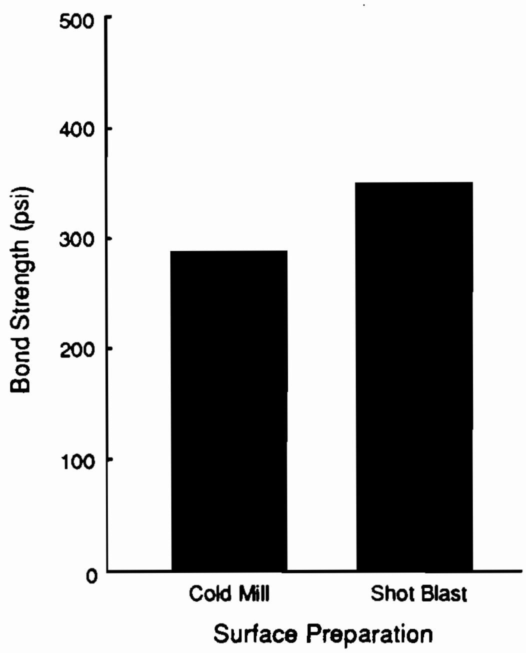


Fig 3.12. Main effect of surface preparation for bond at the interface (full factorial).

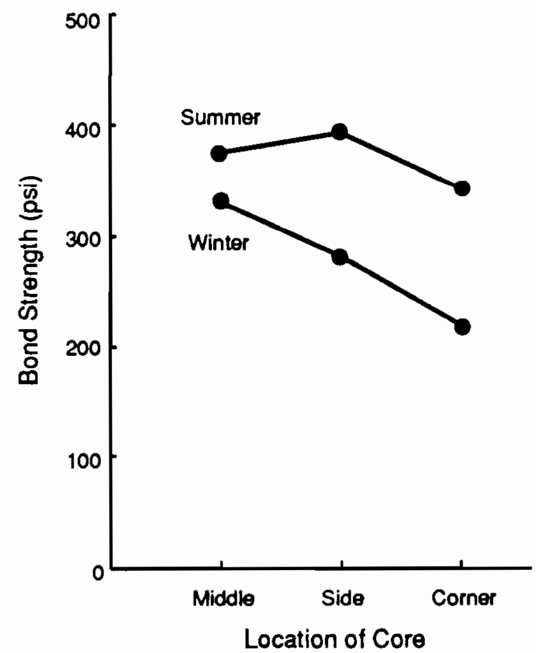


Fig 3.13. Interaction of season and location for bond at the interface (full factorial).

(3) Higher vibration is recommended when grout is not used (Figs 3.11 and 3.16). Even on the grouted surface, a fairly high level of vibration is required, since both levels (high and low) of the vibration tested in this experiment were fairly high levels selected from a pilot study (Ref 5).

(4) Higher vibration is recommended at the corner than at the middle of the slab. Too high vibration at the middle of the slab may cause lower bond strength (Fig 3.14).

(5) Ungrouted sections gave higher bond strength when the surface is in dry condition (Fig 3.17). However, the use of grout is still warranted since delamination was observed in the ungrouted sections in the condition survey of IH610 North Loop (Ref 8).

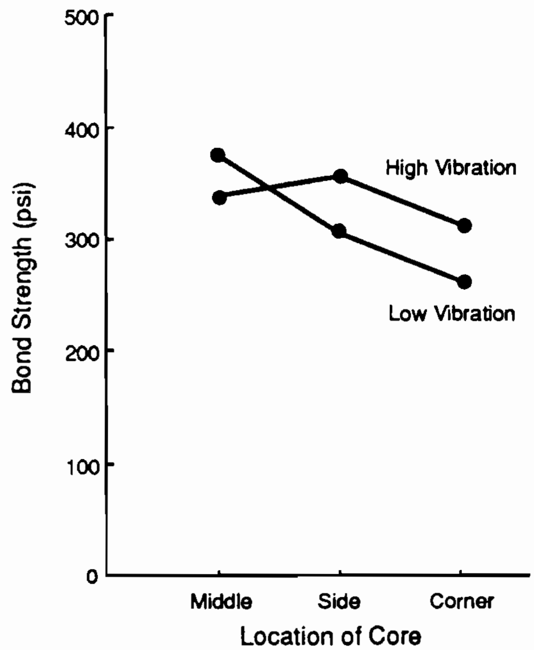


Fig 3.14. Interaction of vibration and location for bond at the interface (full factorial).

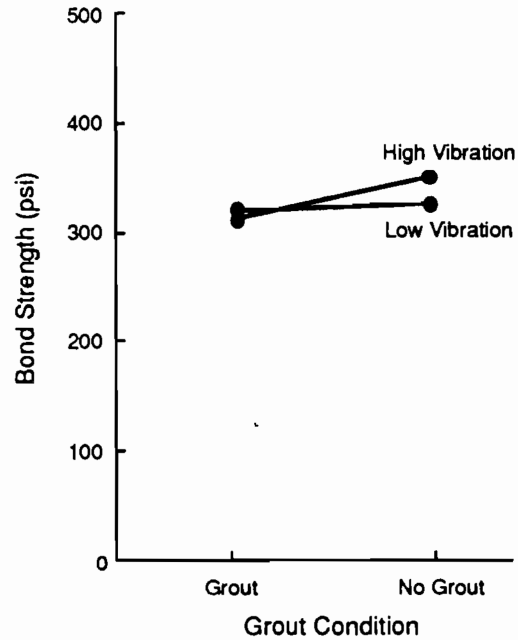


Fig 3.16. Interaction of vibration and grout condition for bond at the interface (full factorial).

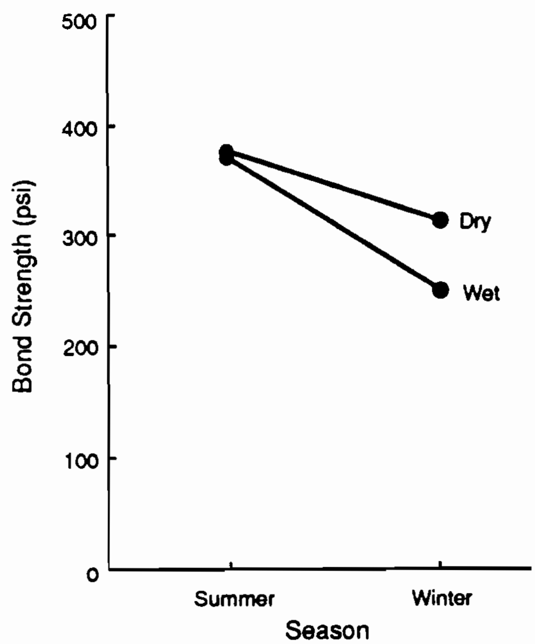


Fig 3.15. Interaction of season and moisture condition for bond at the interface (full factorial).

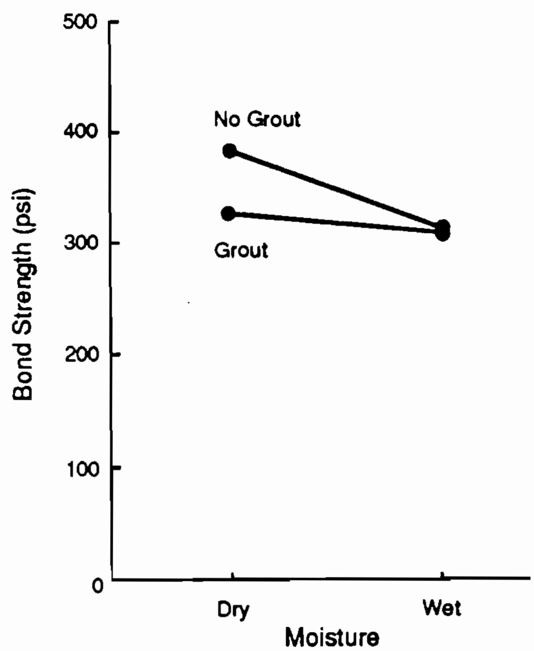


Fig 3.17. Interaction of grout and moisture condition for bond at the interface (full factorial).

CHAPTER 4. EVALUATION OF THE BCO MATERIAL

This chapter deals with the evaluation of the various BCO reinforcement types, bonding agents, and aggregates. Summaries of the field and laboratory experimental programs concerned with these subjects are presented. Problems associated with the use of siliceous aggregate are also presented.

REINFORCEMENT TYPES

Although there are various types of concrete resurfacings in terms of the reinforcement type, there have been few, if any, guidelines available to aid in the selection of the most appropriate resurfacing type for a certain existing pavement condition. In order to give information helpful in the selection of the reinforcement type, experimental programs comparing various reinforcement types were conducted.

South Loop 610 Project (Field Test in Houston)

An experimental section of BCO was placed on the South Loop 610 in Houston (Ref 3). The original pavement structure was an 8-inch-thick continuously reinforced concrete pavement on 6 inches of cement-treated base.

Two main factors including reinforcement type and overlay thickness were evaluated in this experimental program. The levels of the factors include three types of overlay reinforcement (fibrous, steel-mat-reinforced, and plain concrete overlay) and two overlay thicknesses (2 and 3 inches).

After field surveys and tests, following conclusions were made:

(1) Pavement conditions of all test sections after overlay were far superior to those before overlay. Most of the cracks after overlay were hairline cracks.

(2) The fibrous concrete overlay sections were far superior to other sections in controlling longitudinal and transverse cracking. Therefore the use of fibrous concrete overlay is warranted when cracking is the prime concern.

(3) No microcracking along the longitudinal joints was found in the fibrous concrete sections but was observed in the steel-mat-reinforced sections. Therefore, when spalling does occur, it would be expected to occur earlier on the steel-mat-reinforcement sections than on the fibrous concrete sections.

(4) Deflections of the old pavement varied with the lanes of the pavement. Lane 3 (third lane from the median) showed the highest surface deflections before overlay. The thickness effect of 2 and 3 inches BCO on reducing surface deflections was significant only for lane 3. This implies that the thickness effect is significant only when the deflection of the old pavement is high.

(5) Steel-mat-reinforced concrete sections showed the largest reduction in Dynaflect deflections. Therefore the use of steel-mat-reinforced BCO is warranted when the existing pavement has large deflections.

Fatigue Test for CRCP and JCP (Laboratory Test)

Another experimental program comparing fatigue lives of CRC and JC pavement with overlays was conducted in the laboratory (Ref 4). As described in the section of "Fatigue Life and Load Transfer" in Chapter 2, four model pavement slabs, consisting of two CRC and two JC pavements, were constructed to predict the effect of long-term repeated loadings. Each slab consisted of a base slab and a bonded PCC overlay. Base slabs were repetitively loaded to a certain distress condition before overlay placement. The slabs were loaded in the same manner after overlaying.

Results from the study showed that CRCP had longer fatigue lives and less deflection than JCP both in base slabs and overlays. It was also found that there were differences in the distress manifestations of CRCP and JCP. The CRCP slabs failed by cracking with no other signs of distress while the JCP slabs experienced a more severe type of failure; punchout, following loss of shear strength and delamination.

BONDING AGENTS

The purpose of applying bonding agents on the existing PCC pavement before overlay placement is to ensure sound bond at the interface of the two slabs. To meet this objective, various bonding agents have been being tried. Currently, the most widely used bonding agent throughout the United States is cement grout (water-cement or water-cement-sand grout). The cement grout is applied as a thin coating on the scarified pavement to eliminate any dry voids on the surface and to ensure that the old dry concrete slab will not absorb any water from the fresh concrete. An experimental program (Ref 2) revealed that if the mean strengths were nearly the same, an overlay with cement grout gave a reduced possibility of bond failure due to a smaller coefficient of variation of the shear strength at the interface than that of an overlay without grout.

Epoxy resin as a bonding media of BCO was compared with cement grout in a laboratory experimental program (Ref 2). The epoxy consisted of resin and hardener mixed together. The cement grout had a water-cement ratio of 0.62. The size of the test slabs was 3 feet by 3 feet.

In this experiment, debonding between the overlay and the original slab were experienced with epoxy resin, while sound bond was obtained on those slabs with cement grout at the interface. It was also found from this experiment that among the slabs exposed to temperature cycles, the one with grout at the interface had better bond than the one with epoxy, which separated from the existing surface.

More research on the effects of other bonding agents on the bond strength at the interface are now in progress through the Center for Transportation Research.

AGGREGATES AND ALKALI-SILICA REACTION

Many times the aggregate used in the pavement construction is siliceous gravel and siliceous sand, which are reactive to alkalis contained in the cement. In order to understand the alkali-silica reaction and evaluate the effect on the bonding condition of the overlay, the basic concept of the reaction and results of a petrographic study is discussed in this section.

Alkali-Silica Reaction

Most chemical durability problems result from a reaction between reactive silica in aggregates and alkalis contained in the cement. In the United States there were many reported failures of concrete structures built between the late 1920's to the early 1940's. These failures were the result of overall cracking throughout the concrete structure manifested at the surface as extensive map cracking and pattern cracking, frequently accompanied by gel exuding from the cracks, or surface popouts and spalling. It is known that high temperature accelerates the reaction, at least in the range of 50 to 100°F (Refs 9 and 10).

Four basic steps of the reaction (Ref 11) are:

(1) Initial alkaline depolymerization and dissolution of reactive silica. This step depends on the alkalinity of the solution. Therefore, the high-alkali cement can increase the solubility of amorphous silica and also the rate at which it dissolves.
(2) Formation of hydrous alkali-silica gel. Hydrous alkali-silica gel is formed by the reaction of the reactive silica and alkalis.
(3) Attraction of water by the gel. The gel has the ability to imbibe considerable amount of water, which is accompanied by a volume expansion. If this expansion is sufficient, the resulting stress will crack the weakened aggregate and the surrounding cement paste.
(4) Formation of a fluid sol. The final step takes place after the critical expansion has occurred, when further ingestion of water turns the solid gel into a fluid sol which escapes into the surrounding cracks and voids.

Factors affecting the expansion of the concrete due to the reaction include nature and amount of the reactive silica, particle size of the reactive aggregate, and the amount of available alkali. The reaction can be controlled by the following:

(1) control of pH in the pore solution,
(2) control of alkali concentrations by using low-alkali cements,
(3) control of amount of reactive silica by avoidance of a susceptible aggregate or by controlling the amount and particle size of the reactive aggregate,
(4) control of moisture, and
(5) alteration of alkali-silica gel.

A review of laboratory test results from the cement used on the North Loop IH610 showed some to be in excess of the state specification of 0.6 percent. No constituent correlation could be found with delaminated regions.

Petrographic Study

A petrographic study (Ref 12) was conducted by Erlin, Hime Associates, material and concrete consultants, on the cores taken from the CRCP bonded overlay on North Loop 610 in Houston. Cores used for the study were taken from areas judged to have "fair" to "poor" bond between the overlay and the old pavement.

Results from the study can be summarized as follows:

(1) Old pavement sections of the cores exhibited numerous traces of alkali-silica gel and ettringite deposits. Ettringite is a calcium sulfoaluminate commonly found in concrete subjected to moist subgrade conditions.
(2) Most of the alkali-silica gel deposits were exhibited within a thin zone adjacent to the interface. These deposits were unusually "fresh" and may have an impact on the bonding of the two concrete systems.
(3) The air void system appears to be accommodating the gel deposits. It is uncertain if the gel deposits within the new overlay near the interface cause distress and related to the debonding. In some cores, however, alkali-silica gel was also found at the aggregate-paste boundaries. The expansive force of the gel deposits may cause a distress which results in loss of bond. Moisture entering through cracks or joints may accelerate the reaction and thus aggravate the bonding conditions.
(4) One of the cores studied was taken from the overlay that contained crushed limestone for the coarse aggregate. Since, however, the fine aggregate consisted of siliceous sand, gel deposits were also noted in the contact zone of the overlay section of the core.
(5) Changes of mix design is recommended to control the alkali-silica reaction. They include the use of low-alkali cements, non-alkali susceptible aggregates or the introduction of a pozzolan such as certain fly ashes.

SUMMARY

Various BCO material types in terms of reinforcement types and bonding agents were evaluated. Problems associated with the use of silicious river gravel as the aggregates in the concrete mix are also presented in this chapter. Findings can be summarized as follows:

(1) The fibrous concrete overlay was far superior to other reinforcement types in controlling cracks. No micro-cracking along the longitudinal joints was observed in the fibrous section, whereas some was observed in other sections.

(2) Steel-mat-reinforced concrete overlay sections showed the largest reduction in Dynaflect deflections after overlaying.

(3) Laboratory data indicates that CRCP has a longer fatigue life and less deflection than JCP, both in base slabs and overlays.

(4) The CRCP laboratory slabs failed by cracking with no other signs of distress while the JCP laboratory slabs experienced a more severe type of failure such as punchouts.

(5) Based on laboratory tests, cement grout performed better than epoxy resin as a bonding agent for BCO. Debonding was experienced on the slabs with epoxy resin, whereas sound bonds were obtained with cement grout.

(6) Laboratory slabs with cement grout had better bonding than those with epoxy resin when exposed to temperature cycles.

(7) In a petrographic study, traces of alkali-silica reaction were observed from the cores taken from the CRCP bonded overlay on North Loop 610 in Houston. Most of the alkali-silica gel deposits were exhibited within a thin zone adjacent to the interface between the two slabs. Some of the gel deposits were found at the aggregate-paste boundaries. The study indicated that expansive force of the gel deposits might cause debonding of the two slabs.

CHAPTER 5. RECOMMENDATIONS FOR BCO CONSTRUCTION

Based on the findings from the field and laboratory tests, helpful recommendations for BCO construction are presented in this chapter. The following items will be discussed:

(1) repair of existing pavement,
(2) surface preparation,
(3) moisture condition, grout condition, and vibration level, and
(4) location of steel bar.

REPAIR OF EXISTING PAVEMENT

Since the existing pavement also contributes to the structural capacity of the BCO, the structural condition of the existing pavement at the time of overlay is very important.

The results of the fatigue test (Ref 4) described in Chapters 2 and 4 of this report indicate that overlaying an existing pavement with a higher remaining life yields a pavement structure with a much higher interface shear strength, longer fatigue life, and less variation in the shear strength by position. It was also found from this laboratory test that repairing the failures of the existing pavement before overlay placement adds life to the pavement structure.

Therefore, it is recommended that the overlay be placed before the existing pavement has failed. Cracks with low load transfer, based on field deflection measurements, should be repaired. Full-depth PCC patches may be required if total failure has been experienced.

SURFACE PREPARATION

Surface preparation is the process of scarifying and cleaning the old pavement to ensure sound bond between the old pavement and the overlay so that the two slabs act as a monolithic slab. Before an overlay is placed, all the loose materials and contaminants (such as debris, oil, and road markings) should be removed from the existing pavement surface. Roughening the surface results in better bond at the interface. The success of BCO may depend on the success of the surface preparation of the existing pavement.

There are many types of surface preparation techniques available. Table 5.1 gives a comparison of various surface preparation methods. In order to select effective and economical method, the pavement condition and the funds available should be considered. The use of a combination of two or more of these methods may result in a more reliable surface preparation.

Shot blasting and cold milling are the two most widely used surface preparation methods. Shot blasting uses high pressure air to force tiny steel balls at an angle to scarify the surface. The level of scarification can be easily varied by changing the speed of the blaster; the lower the speed of the blaster, the more the scarification. A shot blasting operation removes the matrix around the aggregates, thus exposing them for efficient interlocking bond at the interface.

It is recommended that the overlay placement be made at the same day or, at least, by the day after the shot blasting operation. Care should be taken to make sure that the corners and sides of the pavement are cleaned.

As one of the oldest methods of surface scarification, cold milling has been widely used on bridge decks, as well as surface scarification for overlay. The cold milling operation can take away up to 5 inches of the top layer of the pavement in one pass. The level of scarification can be varied depending on the requirement of the operation. After cold milling the surface needs to be vacuum cleaned again before overlay placement to remove all the loose and fractured concrete remaining on the surface. Light sand blasting of the cold milled section helps to remove these loose materials.

Shot blasting gave better performance for bond than cold milling in the experimental program presented in Chapter 3 of this report. Lower bond in cold milled sections might be due to the loose and fractured concrete remaining after cold milling. In the experiment, surfaces were cleaned using brooms and an air compressor but it was difficult to keep the surface clean. Further studies are recommended for the verification of the recommendations made.

MOISTURE CONDITION, GROUT CONDITION, AND VIBRATION LEVEL

The surface should be properly prepared to obtain better bond between the old pavement and the overlay. The surface condition includes moisture condition, grout condition, and vibration level.

A recent study (Ref 2) has shown that the beneficial effect of using a grouting agent was greater when the pavement was wet than when it was dry. Since, however, the highest delamination has been observed in non grouted sections on IH 610 North Loop in Houston (Ref 8), the use of grout is still recommended regardless of moisture condition.

There are two types of cement grout; one is obtained by mixing water with portland cement and the other by mixing water with equal amounts of cement and sand by weight. The first type of grout is easier to mix and faster to apply than the second. There is no previous study comparing the performance of these two types of grout.

The overlay should be placed before the grout dries. If the grout is allowed to dry before overlay placement, the bonding capacity of the overlay will be considerably reduced.

Proper vibration is required to get proper consolidation of the concrete. If a pavement is not properly vibrated, honeycombing (under-vibrated) or segregation (over-vibrated) will be result. Vibrators should be used only for consolidation of concrete and not for spreading or leveling. It is also important that the concrete be uniformly vibrated.

POSITION OF STEEL BAR

A laboratory test (Ref 2) was conducted to find whether or not the position of steel in BCO affects on the bonding capacity at the interface between the old pavement and the overlay.

TABLE 5.1. COMPARISON OF VARIOUS SURFACE PREPARATION METHODS

Method	Description and Advantages	Limitation or Disadvantages
Acid Etching	- Uses strong acid (HCL or muriatic acid is commonly used.) - Uniformly applied to the pavement - Helps to clean off paint, road markings, organic materials etc. - Clean with water after acid etching - Inexpensive, fast, and reliable in cleaning	- Leaves a defective coat on the old pavement - Leads to corrosion and accelerated deterioration of the steel reinforcement of the old pavement by acid penetration
Water Blasting	- Uses high pressure water to clean loose dirt or remove debris from cracks and joints - Inexpensive	- Unable to remove oil, paint, grease from the pavement - Carries contaminants to the lower level of the pavement and they adhere to the pavement when the water evaporates.
Air Blasting	- Removes loose material from the surface - Usually used with other surface preparation methods - Usually the last operation before overlay placement - Simple, fast, and inexpensive	- Unable to remove oil, paint, and grease from the pavement
Sand Blasting	- Uses high pressure air to force sand particles against the pavement surface - Loosens the oil, paint, grease, and grout matrix around the aggregate - Loose debris and sand left can be removed by air blasting.	- Difficult to get a uniformly scarified surface due to concentration of the blasting particles - Generates a lot of airborne dust
Shot Blasting	- Operation is basically the same as sand blasting except that it uses tiny steel balls instead of sand particles. - Used steel balls and dust are collected and separated; the steel balls are reused in circulation. - Minimizes dust and air pollution. - Can get a highly scarified, clean, and uniform surface. - No air blasting required - Can control the level of scarification by varying the operation speed. - Removes grout matrix around the aggregate. - Very practical and efficient - Uniform scarification, speed, and quality	- Generally does not provide as rough a surface as does milling
Cold milling	- One of the oldest methods of surface scarification - Can be also used to increase the skid resistance of old pavement - Level of scarification can be varied. - Can take away up to 5 inches of the top layer of the pavement in one pass. - One of the fastest and most effective methods for surface preparation	- Generates considerable dust and air pollution. Can cause fracture planes below surface. More expensive than other methods.

Two types of concrete slabs were cast. The first type of slab was cast with the steel bars at the interface between the base slab and the overlay. The surfaces of the base slabs were scarified before the final set of concrete. After four days of curing, the surfaces were air blasted to remove all loose particles. A grout with Daraweld-C was applied with the help of bristle brush. Steel bars were placed directly on the surface of the base slabs before overlay placement. The other type of the slabs was cast with the steel bars at mid-depth of the concrete slabs. The length of the steel bars was cut in such a manner that it provided an adequate grip for pulling the bars out. The slabs were cured under normal laboratory conditions.

Bond pull-out testing was performed on the fourth day and twenty-eighth day after the overlay was placed. During the test, all bars of both types of concrete slabs failed in tension before they could be pulled out. This implies that the bars will not lose bond with concrete even though placed directly on the surface of the existing pavement. In other words, position of steel bar does not affect the bond capacity of the reinforcing steel. Therefore the steel can be placed directly on the surface of the existing pavement, rather than at the mid-depth of the overlay, saving construction time and cost.

SUMMARY

The summary of recommendations for the BCO construction is given in this section.

(1) Overlays should be placed before the existing pavement has failed. Cracks with low load transfer, based on field deflection measurements, should be repaired before overlay placement.

(2) The surface of the existing pavement should be rough and clean before an overlay is placed. Special care should be taken to make sure that the corners and sides of the pavement are cleaned.

(3) The overlay placement should be made soon after surface preparation to avoid depositing loose materials on the surface again.

(4) The use of grout is recommended in any moisture condition, and overlays should be placed before the grout goes dry.

(5) Steel bars can be placed directly on the surface of the existing pavement, rather than at the mid-depth of the overlay, thus saving construction time and cost.

CHAPTER 6. SENSITIVITY ANALYSIS OF BCO DESIGN AND CONSTRUCTION USING THE COMPUTER PROGRAM, RPRDS

Rigid Pavement Rehabilitation Design System (RPRDS: Ref 13) is a computer program used to aid in the selection of an optimum pavement rehabilitation strategy at the project level which will provide a maximum service to the user over a given period of time at a minimum overall cost. It makes use of the systems approach to incorporate a number of pavement design and analytical models into a computer program for the generation, analysis, and comparison of numerous pavement design strategies.

Basically, RPRDS generates a number of feasible overlay design strategies based on user inputs such as pavement structural data, cost data, and constraints (i.e., pavement type, thicknesses, construction and maintenance methods, costs, analysis period, minimum time between overlays, etc.). The program performs a present value cost analysis on each strategy and presents the total cost for all alterations.

RPRDS also has a capability to predict the pavement life and the cost for construction, maintenance, and traffic delay for a given pavement and overlay. Using this capability, the following case studies were conducted:

(1) comparison of BCO design lives (20 vs. 40-year design),
(2) effect of timely construction of BCO,
(3) comparison of asphalt shoulder and PCC shoulder,
(4) importance of directional and lane distribution in design,
(5) effect of construction time on the traffic delay cost, and
(6) effect of selecting different surface preparation method on the total costs.

The case studies used to investigate bonded concrete overlays are intended to show the relative influence of various factors on the overall cost of pavement design strategies. The resulting life cycle costs reflect the estimated life of a given strategy based solely on the allowable repetitions of 18 kip ESAL. Regression equations used to predict the life of the pavement, after overlay, are fully described in Ref 13. These equations take into account only the maximum tensile stress in the pavement. Because many factors affect the performance of pavements, the results of this sensitivity analysis should not be directly used in design.

INPUT DATA USED AND OUTPUT

Pavement and traffic conditions of IH610 in Houston were used to prepare input data sets for the RPRDS program. Table 6.1 shows the basic input data used in the RPRDS program. More details, including cost data, are given in Appendix C. Table 6.2 summarizes the output of the program for the case studies. The results are analyzed in the next five sections.

CASE STUDY 1: COMPARISON OF BCO DESIGN LIVES (20 VS. 40-YEAR DESIGN)

In the past, a pavement design life of 20 years was usually used for the pavement design. It is now recom-

TABLE 6.1. SUMMARY OF BASIC INPUT DATA USED IN RPRDS (SIMULATING IH 610 IN HOUSTON)

Original Pavement	
Pavement Type	CRCP
Thickness	8 in.
Shoulder Type	Asphalt Shoulder
Number of Lanes (one direction)	4
Number of Layers (including roadbed)	3

Layer	Elastic Modulus (psi)	Thickness (in.)	Poisson's Ratio
PCC	5,000,000	8.0	0.15
Subbase	200,000	6.0	0.30
Roadbed	16,000	Semi-infinite	0.30

Project Length	4 miles
Lane width	12 ft
Total Shoulder Width	16 ft
Concrete Flexural Strength	650 psi
Critical Stress Factor	1.25*
Remaining Life at Time of Overlay	30 percent
Overlay	
Overlay Type	Bonded CRCP
Thickness	4 in.
Design Stiffness	5,000,000 psi
Poisson's Ratio	0.15
Flexural Strength	650 psi
Traffic Information	
Average Daily Traffic (ADT)	132,000
ADT Growth Rate	3.3 percent
Initial Yearly 18-kip ESAL	1.2 million
18-kip ESAL Growth Rate	3.7 percent
Directional Distribution Factor	50 percent
Lane Distribution Factor	60 percent
Traffic Blocking Time for BCO Construction	120 days

*Critical Stress Factor = Edge Stress/ Interior Stress

TABLE 6.2. SUMMARY OF RPRDS RESULTS FOR THE CASE STUDIES

		Pavement Life		Existing Pavement Maintenance Cost ($/SY)	Construction Cost ($/SY)	Traffic Delay Cost ($/SY)	BCO Maintenance Cost ($/SY)	Total Cost ($/SY)	Cost Effectiveness
		(years)	(mil.18k ESAL)						
BCO Thickness (Case Study 1)	2 in.	14.90	7.00	0.36	13.71	10.44	0.24 (10)*	24.75	0.28
	3 in.	21.10	10.70	0.36	14.66	14.57	0.58 (20)	30.17	0.35
	4 in.	28.50	15.90	0.36	15.62	18.69	0.33 (20)	35.00	0.45
	5in.	37.40	23.00	0.36	16.58	22.82	0.18 (20)	39.94	0.58
	6in.	47.50	32.50	0.36	17.54	26.94	0.05 (20)	44.89	0.72
	7in.	59.10	45.00	0.36	18.49	31.07	0.00 (20)	49.92	0.90
Time of Overlay (Case Study 2)	60% RL **	38.80	24.30	0.36	15.62	18.69	0.15 (20)	34.82	0.70
	30% RL	33.90	18.70	0.86	13.14	52.21	0.22 (20)	66.43	0.28
	10% RL	29.70	14.90	1.08	11.83	381.25	0.26 (20)	394.42	0.04
Shoulder Type (Case Study 3)	PCC Shoulder	38.40	23.93	0.36	16.13	18.69	0.18 (20)	35.36	0.68
	AC Shoulder	28.50	15.90	0.36	15.62	18.69	0.33 (20)	35.00	0.45
Directional and Lane Distribution (Case Study 4)	50%/30%	46.80	15.90	0.36	15.62	18.69	0.00 (10)	34.67	0.46
	50%/60%	28.50	15.90	0.36	15.62	18.69	0.00 (10)	34.67	0.46
	50%/90%	20.90	15.90	0.36	15.62	18.69	0.13 (10)	34.80	0.46
	70%/30%	37.00	15.90	0.36	15.62	18.69	0.00 (10)	34.67	0.46
	70%/60%	22.10	15.90	0.36	15.62	18.69	0.09 (10)	34.76	0.46
	70%/90%	16.00	15.90	0.36	15.62	18.69	0.24 (10)	34.91	0.46
	90%/30%	30.90	15.90	0.36	15.62	18.69	0.00 (10)	34.67	0.46
	90%/60%	18.10	15.90	0.36	15.62	18.69	0.19 (10)	34.86	0.46
	90%/90%	13.00	15.90	0.36	15.62	18.69	0.29 (10)	34.96	0.45
Curing Time (Case Study 5)	1 Day	28.50	15.90	0.36	15.62	16.66	0.33 (20)	32.97	0.48
	7 Days	28.50	15.90	0.36	15.62	17.59	0.33 (20)	33.90	0.47
	14 Days	28.50	15.90	0.36	15.62	18.69	0.33 (20)	35.00	0.45
Surface Preparation (Case Study 6)	Cold Mill	28.50	15.90	0.36	15.62	18.69	0.33 (20)	35.00	0.45
	Shot Blast	28.50	15.90	0.36	14.12	18.69	0.33 (20)	33.50	0.47

* Numbers within parentheses represent the time periods during which maintenance costs are considered.

** RL = Remaining Life of the Existing Pavement mended that consideration be given to a longer analysis period, especially for the design of high-volume freeways. In this case study, 20-year and 40-year design lives for bonded overlays were compared in terms of the cost efficiency.

A relationship between the BCO thickness and life of the pavement (Fig 6.1) was obtained from RPRDS using the base input data described in the previous section with various BCO thicknesses. Required overlay thicknesses which gave the BCO lives of 20 and 40 years were determined from the figure. It is shown that the BCO thicknesses of 2.8 and 5.3 inches are obtained for 20 and 40 year design, respectively.

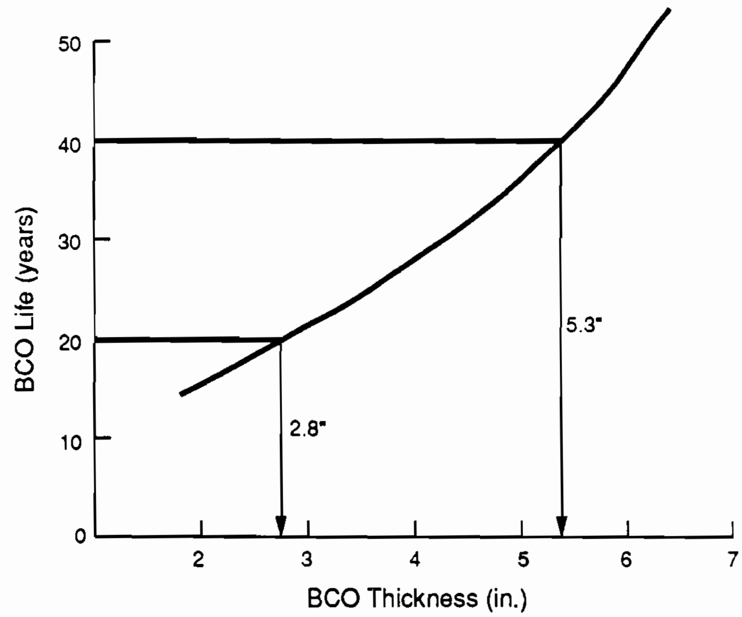


Fig 6.1. Relationship between BCO thickness and life.

Figure 6.2 shows the cost efficiency analysis for the 20 and 40 years of design. The black bars in the figure represent the BCO life in million 18-kip ESAL and various costs are shown. The cost efficiency factor (CEF) of each strategy can be calculated by using the following equation:

$$\text{CEF} = \frac{\text{Pavement life in millions of 18-kip ESAL}}{\text{Total Costs in dollars per square yard}} \quad (6.1)$$

The higher this factor, the better.

The total costs include the construction cost, traffic delay cost, and maintenance cost. The pavement life used in this equation represents the number of 18-kip ESAL that the pavement can carry until the overlay reaches zero remaining life. The reason for using pavement life in terms of 18-kip ESAL is that the cost efficiency should be calculated on the basis of load carrying capacity, not time, because traffic volume varies with time. It is seen from Fig 6.2 that the cost efficiency factor of 20 year design is only 0.34 while that of 40 year design is 0.62. In other words, the 40 year design is approximately twice as cost effective compared to the 20 year design.

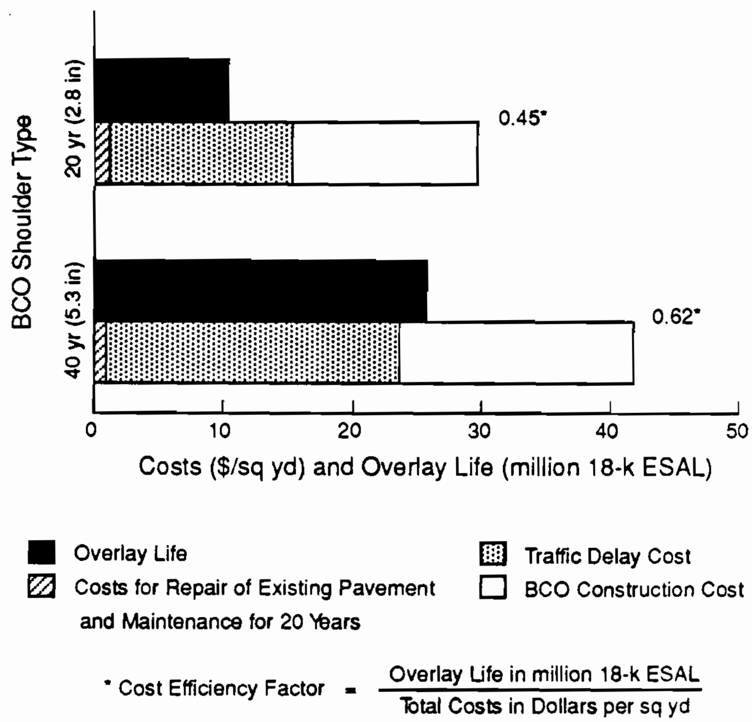


Fig 6.2. Cost efficiency analysis for 40 and 20-year design.

In addition to the comparison of design lives, the cost efficiency of selecting different BCO thicknesses was analyzed. It is seen from Fig 6.3 that the thicker the BCO, the better in terms of cost efficiency. This result is based only on an engineering analysis. Many other factors should be considered for the selection of proper BCO thickness. They may include funds available, tolerable traffic delay, and maximum overlay thickness.

The construction cost and traffic delay cost in Fig 6.3 are increasing as the thickness increases due to the amount of material needed and the longer construction time. Note that the maintenance cost is decreased slightly as the thickness increases. This is because the analysis period selected for the RPRDS input is 20 years regardless of BCO thickness. The thicker the BCO, the less maintenance required, due to the improved condition throughout 20 years.

CASE STUDY 2: EFFECT OF EARLY CONSTRUCTION OF BCO

It was found from the fatigue study described in the Chapter 2 of this report that the remaining life of the existing pavement at the time of BCO placement played an important role in determining the BCO life. An early overlay would take advantage of the remaining life of the existing pavement. Less maintenance would be required due to the better existing pavement condition; however, it requires a higher initial construction cost. It is not yet known how the overlay life would be affected nor how the cost benefit ratio would change. The purpose of this case study is to estimate the effect of early construction of BCO in terms of the cost efficiency.

Using RPRDS, three different overlay strategies (60, 30, and 10 percent remaining life of the existing pavement) were compared in terms of the cost efficiency. The results are summarized in Table 6.2 and analyzed in Fig 6.4. It was found that the time required for the existing pavement with 60 percent remaining life to reach 30 and 10 percent remaining life levels were 3.5 and 5.7 years, respectively. Each black bar in Fig 6.4 represents the pavement life from now (60 percent remaining life of the existing pavement) until the overlay reaches to the zero remaining life.

It is apparent in Fig 6.4 that an earlier overlay gives a longer life. The construction cost is highest in the earliest overlay construction due to the high present value of the cost. However, delayed construction requires much higher traffic delay cost due to the frequent maintenance before overlay. The cost efficiency analysis indicated that the earlier the BCO construction, the higher the cost efficiency. Therefore, earlier construction of BCO is recommended if funds are available.

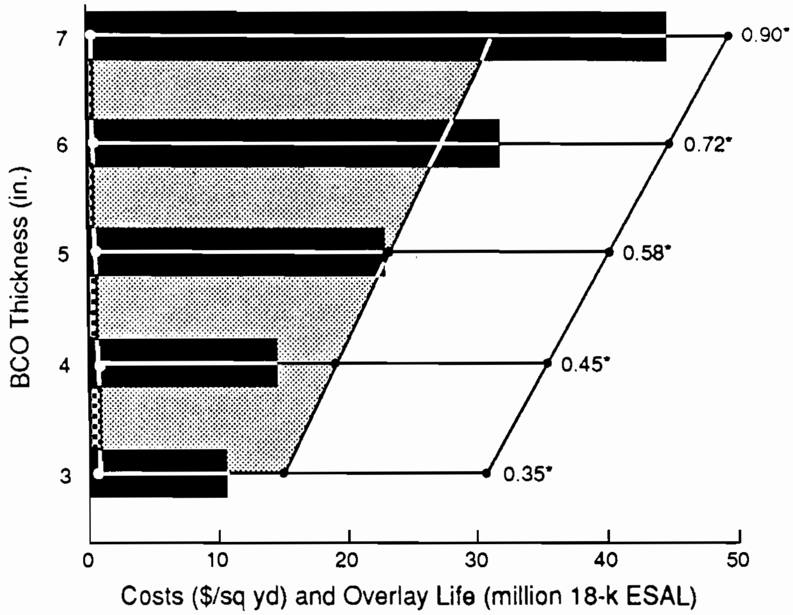


Fig 6.3. Cost efficiency analysis for different thicknesses in BCO.

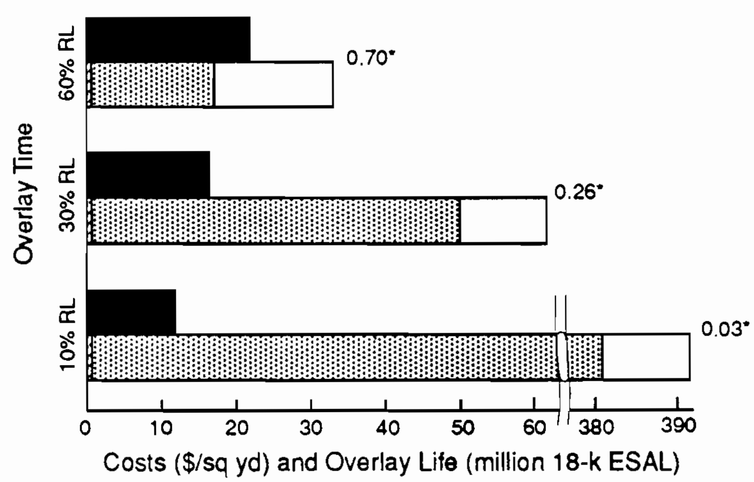


Fig 6.4. Cost efficiency analysis for early overlay placement.

CASE STUDY 3: COMPARISON OF ASPHALT SHOULDER AND PCC SHOULDER

Some of the shoulders of the concrete pavements in Houston are made of asphalt materials because of the lower cost. If PCC shoulders are used instead of asphalt shoulders, the pavements will have more traffic carrying capacity because of the lower critical stress at the edge of the pavements. This case study gives a comparison of these two types of shoulders.

Two different critical stress factors are recommended in the RPRDS user's manual, 1.10 for the pavement with PCC shoulder and 1.25 for the pavement with asphalt shoulders (Ref 13). These were used with the basic input data set to represent pavements with different shoulder types. The results of the RPRDS runs are summarized in Table 6.2. The cost efficiency analysis using the results is shown in Fig 6.5. It is seen from the figure that the overlay with PCC shoulders has a much longer life and only slightly higher total costs. Therefore it can be said that the use of PCC shoulder is better in terms of cost efficiency.

CASE STUDY 4: IMPORTANCE OF DIRECTIONAL AND LANE DISTRIBUTION

For design purposes, the most heavily loaded lane is selected as a design lane. Therefore, the pavement life of the design lane can vary with the amount of heavy truck traffic on the design lane, even though the total traffic volume and the thickness of the pavement are the same. If the heavy truck traffic is evenly distributed, the pavement life of the design lane would be longer than when the heavy truck traffic is concentrated in one lane for the same design thickness.

Using RPRDS, the BCO lives were estimated for various percents of total 18-kip Equivalent Single Axle Loads (ESAL) in the design lane. Percent of total 18-kip ESAL can be obtained by multiplying the directional distribution factor by the lane distribution factor.

The results are summarized in Table 6.2 and analyzed in Fig 6.6. It can be seen from the figure that the directional distribution and the lane distribution of heavy truck traffic are very important factors in determining the BCO lives. For the typical 8-lane highways, practical range of percent of total 18 kip ESAL on the design lane is 15 to 50 percent. The BCO lives in this range are 47 to 19 years.

CASE STUDY 5: EFFECT OF CONSTRUCTION TIME ON THE TRAFFIC DELAY COST

Traffic blocking during construction and curing is one of the major problems in concrete pavement construction. To solve this problem, new construction methods and fast curing concrete mixtures have been developed, reducing the total construction time.

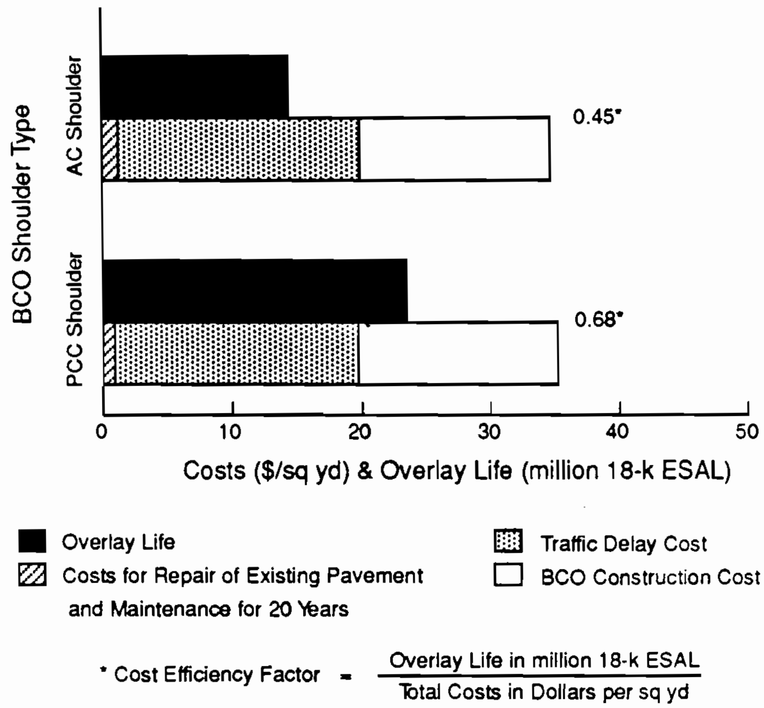


Fig 6.5. Cost efficiency analysis for different shoulder types.

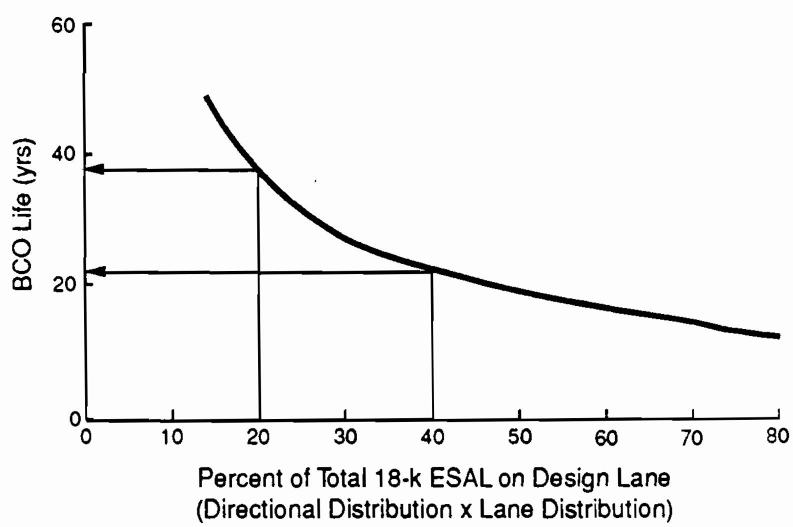


Fig 6.6. Importance of directional and lane distribution in pavement life.

The purpose of this case study is to analyze the sensitivity of construction time on the traffic delay cost. Traffic conditions during the overlay construction in IH610 in Houston were modeled. Input data used for the traffic delay cost calculation are included in Appendix C.

RPRDS calculates the traffic delay cost by multiplying the total construction time (construction time plus curing time) by the daily traffic delay cost (the slope of the traffic delay cost in Fig 6.7). If the total construction time is zero, the traffic delay cost would be zero (intercept of the traffic delay cost). Since the construction time is a fixed value for a given concrete production rate, curing time is the only variable for the calculation of total construction time. The slope of the traffic delay cost in Fig 6.7 is determined by giving several different curing times to the input data sets. From the intercept and the slope, a traffic delay cost model in terms of the total construction time in Fig 6.7 was determined.

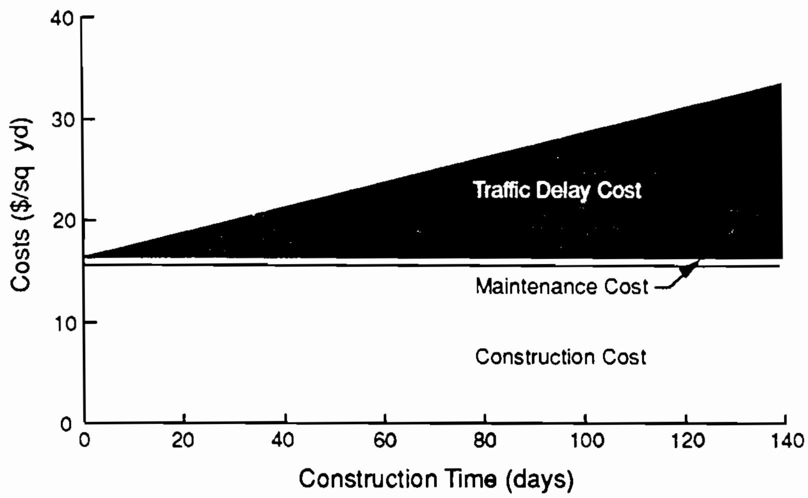


Fig 6.7. Traffic delay cost analysis.

Decisions whether or not to use various faster construction methods can be made by comparing the extra construction cost of each method and the benefit to be derived from reducing traffic delay cost.

CASE STUDY 6: EFFECT OF SELECTING DIFFERENT SURFACE PREPARATION METHODS ON THE TOTAL COSTS

In this case study, effect of using different surface preparation methods (cold milling and shot blasting) on the total costs in BCO construction is estimated. Surface preparation costs used in RPRDS were $3 per square yard for the cold milling and $1.50 per square yard for the shot blasting.

Total costs including construction, maintenance, and traffic delay were $35 per square yard for the BCO with cold milling and $33.50 per square yard for the shot blasting (Table 6.2). The difference in total costs was exactly the same as the difference in the surface preparation costs. Therefore, if shot blasting was used, instead of cold milling, the total cost could be reduced by $1.50 per square yard, which is approximately 4 percent of the total costs.

SUMMARY

Using the Rigid Pavement Rehabilitation Design System (RPRDS), several case studies were conducted. They include comparison of BCO design lives, effect of early construction of BCO, comparison of asphalt and PCC shoulders, importance of directional and lane distribution of heavy truck traffic in design, effect of construction time on the traffic delay cost, and the effect of selecting different surface preparation method on the total costs. Pavement and traffic conditions of IH610 in Houston were simulated for making the input data sets (see Table 6.1 and Appendix C). The findings from these case studies can be summarized as follows:

(1) A 40-year design is more cost efficient than 20-year design for the BCO construction (Fig 6.2).

(2) The thicker the BCO, the more cost efficient (Fig 6.3).

(3) The earlier the BCO construction, the more cost efficient (Fig 6.4).

(4) BCO with PCC shoulder is more cost efficient than that with asphalt shoulder (Fig 6.5).

(5) Directional and lane distribution is very important in design (Fig 6.6).

(6) A chart for deciding whether or not to use faster construction methods could be prepared using RPRDS (Fig 6.7).

(7) The difference of cold milling and shot blasting in cost may be about 4 percent of total costs.

CHAPTER 7. CONCLUSIONS AND RECOMMENDATIONS

The conclusions from the field and laboratory studies throughout the project along with the finding from case studies using Rigid Pavement Rehabilitation Design System (RPRDS) are presented in this chapter. These conclusions are based on limited tests and case studies and may not be applicable under other conditions. Recommendations for further studies are presented following the conclusions.

CONCLUSIONS

Conclusions from the field and laboratory studies are:

(1) Placement of a BCO improves the pavement condition significantly in terms of the structural capacity, load transfer, distress, and fatigue life.

(2) A BCO can be warranted on the basis of friction/skid resistance, riding quality, bridge restoration, grade control, correction of under design, and cheaper and faster construction than complete reconstruction.

(3) The use of a steel-mat-reinforced concrete overlay is warranted in pavements with high deflection.

(4) The use of fiber-reinforced concrete overlays is warranted when cracking is the prime concern.

(5) Overlays should be placed before the pavement condition deteriorates to an unacceptable level.

(6) Failures should be repaired before overlaying.

(7) The surface of the original pavement should be rough and clean when it is overlaid.

(8) The effect of the location of the steel bar was not significant. Therefore, the bar can be placed on the surface, thus saving time and cost.

(9) The bonding agent should be thoroughly applied and covered promptly with the overlay concrete mix.

(10) Bond strength at the corner or side of a slab was much lower than that at the middle.

(11) Vibration was not a significant factor in the experimental program. However, both levels of the vibration tested in this experiment were fairly high levels selected from a pilot study.

(12) Based on laboratory data, CRCP slabs and bonded overlays have a longer fatigue life than JCP and overlays.

(13) CRCP laboratory slabs failed by cracking with no other signs of distress while the JCP laboratory slabs failed by punchout-like cracking.

(14) From laboratory testing, cement grout proved to be a better bonding agent than epoxy resin.

Findings from the case studies using RPRDS are:

(1) A 40-year design is more cost efficient than 20-year design for the BCO construction.

(2) The thicker the BCO, the more cost efficient.

(3) The earlier the BCO construction, the more cost efficient.

(4) BCO with PCC shoulder is more cost efficient than that with asphalt shoulder.

(5) Directional and lane distribution is very important in design.

(6) A chart for deciding whether or not to use faster construction methods could be prepared (Fig 6.7) using RPRDS.

(7) The difference of cold milling and shot blasting in cost is about 4 percent to total costs.

RECOMMENDATIONS FOR FURTHER STUDIES

(1) The effects of fatigue on the shear stress between the overlay and the old pavement need to be investigated.

(2) There should be a study to determine the optimum time of overlay placement in terms of distress and remaining life of the existing pavement.

(3) The effects of different levels of scarification for the surface preparation need to be investigated.

(4) There should be more petrographic studies investigating the effect of alkali-silica reaction on the delamination of the overlay.

REFERENCES

1. Koesno, Koestomo, "Evaluation of the Performance of the Bonded Concrete Overlay on Interstate Highway 610 North, Houston,Texas," Master's Thesis, The University of Texas at Austin, December 1987.
2. 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.
3. Bagate, Moussa, B. Frank McCullough, D. W. Fowler, and M. Muthu, "An Experimental Thin-Bonded Concrete Overlay Pavement," Research Report 357-2F, Center for Transportation Research, The University of Texas at Austin, November 1985.
4. Reilley, Karen, Chhote Saraf, B. Frank McCullough, and D. W. Fowler, "A Laboratory Study of the Fatigue of Bonded PCC Overlays," Research Report 457-2, Center for Transportation Research, The University of Texas at Austin, September 1986.
5. Solanki, Abdulrahman, "A Study of the Effect of Construction Variables on the Bond Behavior of CRCP Overlays," Master's Thesis, The University of Texas at Austin, December 1987.
6. "Measurement of Texture Depth by the Sand-Patch Method," Texas State Department of Highways and Public Transportation (SDHPT), Materials and Tests Division, Test Method Tex-436-A, January 1983.
7. *SAS Language Guide for Personal Computers*, 6th Edition, SAS Institute, Cary, NC, 1985.
8. Lundy, Jim, "Condition Survey Summary-March and August Data," Tech Memo 920-27, Center for Transportation Research, October 30, 1987.
9. Stanton, T. E., et al., "California Experience with the Expansion of Concrete through Reaction between Concrete and Aggregate," ACI, January 1942.
10. Carlson, R. W., "Accelerated Tests of Concrete Expansion Due to Alkali- Aggregate Reaction," ACI, April 1946.
11. Sidney Mindess, and J. Francis Young, *Concrete*, Prentice-Hall, Inc., New Jersey,1981.
12. Patty, T. S., "Petrographic Studies of Loop 610 Houston, Dense Overlay Cores for Center for Transportation Research," Erlin, Hime Associates, October 16, 1987.
13. Seeds, Stephen B., B. Frank McCullough, and W. R. Hudson, "A Design System for Rigid Pavement Rehabilitation," Research Report 249-2, Center for Transportation Research, The University of Texas at Austin, January 1982.
14. American Concrete Institute, "Guide for Specifying, Mixing, Placing, and Finishing Steel Fiber Reinforced Concrete," ACI 544, 3R-84.
15. American Concrete Institute, "Measurement of Properties of Fiber Reinforced Concrete," ACI 544, 2R–78.

APPENDIX A. TABULATION OF THE DATA FOR BOND STRENGTH

BOND STRENGTH	LOCATION	SEASON	PREPARATION	VIBRATION	SURFACE MOISTURE	GROUT
253	C	W	R	H	D	N
228	C	W	R	H	D	N
475	S	W	R	H	D	N
480	S	W	R	H	D	N
119	M	W	R	H	D	N
457	M	W	R	H	D	N
110	C	W	R	H	D	Y
264	C	W	R	H	D	Y
192	S	W	R	H	D	Y
239	S	W	R	H	D	Y
336	M	W	R	H	D	Y
332	M	W	R	H	D	Y
230	C	W	R	H	W	N
—	C	W	R	H	W	N
184	S	W	R	H	W	N
252	S	W	R	H	W	N
368	M	W	R	H	W	N
322	M	W	R	H	W	N
208	C	W	R	H	W	Y
178	C	W	R	H	W	Y
312	S	W	R	H	W	Y
287	S	W	R	H	W	Y
230	M	W	R	H	W	Y
288	M	W	R	H	W	Y
205	C	W	R	L	W	Y
159	C	W	R	L	W	Y
181	S	W	R	L	W	Y
226	S	W	R	L	W	Y
159	M	W	R	L	W	Y
409	M	W	R	L	W	Y
—	C	W	R	L	W	N
—	C	W	R	L	W	N
262	S	W	R	L	W	N
381	S	W	R	L	W	N
195	M	W	R	L	W	N
275	M	W	R	L	W	N
51	C	W	R	L	D	Y
—	C	W	R	L	D	Y
299	S	W	R	L	D	Y
149	S	W	R	L	D	Y
196	M	W	R	L	D	Y
195	M	W	R	L	D	Y
—	C	W	R	L	D	N
—	C	W	R	L	D	N
—	S	W	R	L	D	N
262	S	W	R	L	D	N
—	M	W	R	L	D	N
431	M	W	R	L	D	N
427	C	W	S	L	D	N
—	C	W	S	L	D	N

BOND STRENGTH	LOCATION	SEASON	PREPARATION	VIBRATION	SURFACE MOISTURE	GROUT
—	S	W	S	L	D	N
245	S	W	S	L	D	N
—	M	W	S	L	D	N
443	M	W	S	L	D	N
206	C	W	S	L	D	Y
—	C	W	S	L	D	Y
298	S	W	S	L	D	Y
346	S	W	S	L	D	Y
—	M	W	S	L	D	Y
435	M	W	S	L	D	Y
178	C	W	S	L	W	Y
—	C	W	S	L	W	Y
169	S	W	S	L	W	Y
331	S	W	S	L	W	Y
—	M	W	S	L	W	Y
534	M	W	S	L	W	Y
—	C	W	S	L	W	N
—	C	W	S	L	W	N
215	S	W	S	L	W	N
206	S	W	S	L	W	N
412	M	W	S	L	W	N
391	M	W	S	L	W	N
103	C	W	S	H	W	Y
—	C	W	S	H	W	Y
156	S	W	S	H	W	Y
—	S	W	S	H	W	Y
280	M	W	S	H	W	Y
205	M	W	S	H	W	Y
—	C	W	S	H	W	N
146	C	W	S	H	W	N
147	S	W	S	H	W	N
148	S	W	S	H	W	N
187	M	W	S	H	W	N
339	M	W	S	H	W	N
351	C	W	S	H	D	Y
—	C	W	S	H	D	Y
338	S	W	S	H	D	Y
347	S	W	S	H	D	Y
316	M	W	S	H	D	Y
422	M	W	S	H	D	Y
—	C	W	S	H	D	N
402	C	W	S	H	D	N
543	S	W	S	H	D	N
475	S	W	S	H	D	N
447	M	W	S	H	D	N
462	M	W	S	H	D	N
310	C	SU	R	L	W	Y
191	C	SU	R	L	W	Y
400	S	SU	R	L	W	Y
—	S	SU	R	L	W	Y
355	M	SU	R	L	W	Y

BOND STRENGTH	LOCATION	SEASON	PREPARATION	VIBRATION	SURFACE MOISTURE	GROUT
—	M	SU	R	L	W	Y
240	C	SU	R	L	W	N
—	C	SU	R	L	W	N
240	S	SU	R	L	W	N
—	S	SU	R	L	W	N
271	M	SU	R	L	W	N
241	M	SU	R	L	W	N
361	C	SU	R	L	D	Y
—	C	SU	R	L	D	Y
—	S	SU	R	L	D	Y
389	S	SU	R	L	D	Y
316	M	SU	R	L	D	Y
470	M	SU	R	L	D	Y
—	C	SU	R	L	D	N
—	C	SU	R	L	D	N
—	S	SU	R	L	D	N
—	S	SU	R	L	D	N
—	M	SU	R	L	D	N
316	M	SU	R	L	D	N
320	C	SU	R	H	W	Y
343	C	SU	R	H	W	Y
315	S	SU	R	H	W	Y
307	S	SU	R	H	W	Y
264	M	SU	R	H	W	Y
301	M	SU	R	H	W	Y
320	C	SU	R	H	W	N
332	C	SU	R	H	W	N
469	S	SU	R	H	W	N
343	S	SU	R	H	W	N
226	M	SU	R	H	W	N
568	M	SU	R	H	W	N
292	C	SU	R	H	D	Y
229	C	SU	R	H	D	Y
412	S	SU	R	H	D	Y
417	S	SU	R	H	D	Y
286	M	SU	R	H	D	Y
366	M	SU	R	H	D	Y
417	C	SU	R	H	D	N
320	C	SU	R	H	D	N
412	S	SU	R	H	D	N
362	S	SU	R	H	D	N
406	M	SU	R	H	D	N
343	M	SU	R	H	D	N
—	C	SU	S	L	W	Y
—	C	SU	S	L	W	Y
480	S	SU	S	L	W	Y
364	S	SU	S	L	W	Y
549	M	SU	S	L	W	Y
492	M	SU	S	L	W	Y
—	C	SU	S	L	W	N
240	C	SU	S	L	W	N

BOND STRENGTH	LOCATION	SEASON	PREPARATION	VIBRATION	SURFACE MOISTURE	GROUT
—	S	SU	S	L	W	N
341	S	SU	S	L	W	N
389	M	SU	S	L	W	N
421	M	SU	S	L	W	N
400	C	SU	S	L	D	Y
—	C	SU	S	L	D	Y
387	S	SU	S	L	D	Y
400	S	SU	S	L	D	Y
515	M	SU	S	L	D	Y
398	M	SU	S	L	D	Y
182	C	SU	S	L	D	N
489	C	SU	S	L	D	N
257	S	SU	S	L	D	N
515	S	SU	S	L	D	N
381	M	SU	S	L	D	N
529	M	SU	S	L	D	N
387	C	SU	S	H	W	Y
512	C	SU	S	H	W	Y
409	S	SU	S	H	W	Y
489	S	SU	S	H	W	Y
353	M	SU	S	H	W	Y
398	M	SU	S	H	W	Y
364	C	SU	S	H	W	N
377	C	SU	S	H	W	N
478	S	SU	S	H	W	N
421	S	SU	S	H	W	N
560	M	SU	S	H	W	N
355	M	SU	S	H	W	N
406	C	SU	S	H	D	Y
523	C	SU	S	H	D	Y
381	S	SU	S	H	D	Y
351	S	SU	S	H	D	Y
296	M	SU	S	H	D	Y
290	M	SU	S	H	D	Y
432	C	SU	S	H	D	N
296	C	SU	S	H	D	N
432	S	SU	S	H	D	N
444	S	SU	S	H	D	Y
269	M	SU	S	H	D	Y
332	M	SU	S	H	D	Y

APPENDIX B. CONSTRUCTION CONSIDERATIONS AND IMPACT STRENGTH TEST FOR STEEL FIBROUS REINFORCED CONCRETE PAVEMENT

An outline of the construction considerations for the steel fibrous reinforced concrete is presented in this Appendix. Procedures of impact strength test, developed to determine the properties of steel fiber reinforced concrete, is also introduced. This Appendix is only a summary of two ACI reports, "Guide for Specifying, Mixing, Placing, and Finishing Steel Fiber Reinforced Concrete" (Ref 14), and "Measurement of Properties of Fiber Reinforced Concrete" (Ref 15). Readers are recommended to refer these reports for more detail.

CONSTRUCTION CONSIDERATIONS

Batching and Mixing

It is very important to obtain a good dispersion of the fibers and to prevent fiber clumping in the mix. Suitable equipment and technique for dispersing the fibers should be used for this purpose. The following are the possible causes of fiber clumping:

(1) adding the fibers too fast at some point in the mixing procedure,
(2) hanging up on a rough loading chute at the back of a mixer truck (fibers should not be allowed to pile up or slide down the vanes of a partially filled drum; this will form clumps),
(3) adding too many fibers to a mixture,
(4) adding fibers too fast to a harsh mixture (mixture is not fluid enough or workable enough and the fibers do not get mixed in fast enough; therefore, they pile up on each other in the mixer),
(5) adding fibers first to the mixer (fibers have nothing to keep them apart; they fall on each other and form clumps),
(6) using equipment with worn out mixing blades, and
(7) over mixing and using a mixture with too much coarse aggregate (more than about 50 percent).

The mixing time should be sufficient to uniformly distribute the fibers in the mixture. Any fibrous reinforced concrete which is not properly batched and which develops dry clumps of fibers or a significant number of wet fiber balls (which include fibers and matrix) should be discarded and removed from the site.

Placing and Curing

Conventional concrete equipment is adequate for the placing and finishing of nearly all steel fiber reinforced concrete. Internal or external vibrators should always be used to avoid excessive pockets of entrapped air voids. Even if a superplasticizer has been used, some vibration is needed around reinforcing steel to avoid reduction of bond to the bars. Acceptable workability should be determined by the inverted slump core test (ASTM 995) or slump test (preferably, by the inverted slump core test).

Because of fibers, a mix with the proper water-cement ratio appears very stiff and unworkable until subjected to vibration. Batch plant operators and truck drivers must be instructed not to add additional water to the mixture based on its appearance and their experience with conventional concrete. Tests have shown that further addition of water causes an increase in slump without a change in workability under vibration. This water addition reduces the quality of the mixture without improving the placability.

If a texture is required, a broom or roller can be used prior to initial set. Burlap drags should not be used because they will lift up the fibers and tear up the surface.

When the fibrous reinforced concrete is placed in thin sections like overlays, it is particularly vulnerable to plastic shrinkage cracking. This will occur on warm days where it is exposed to direct sun or breeze. Such placements must be shaded from the sun and sheltered from the wind to prevent this type of damage.

IMPACT STRENGTH TEST

Equipment

(1) a 10-lb compaction hammer with an 18-inch drop (ASTM D 1557-70);
(2) a 2.5-inch-diameter, hardened steel ball;
(3) a flat base plate with positioning bracket (see Fig B.1); and
(4) a mold to cast 6-inch-diameter by 2.5-inch-thick concrete specimens.

Specimen Preparation

The 2.5-inch-thick by 6-inch-diameter concrete samples are made in molds according to the procedures outlined in ASTM C 31 and C192. The molds can be partially filled to the 2.5-inch depth and float finished or they can be cut from full-sized cylinders to yield the proper thickness. The thickness of the specimens shall be recorded to the nearest 1/16 inch. Internal vibration or rodding should not be used in casting the specimens; external vibration only can be used to avoid fiber orientation and nonuniform samples. Specimens should be tested at 7, 28, and (if desired) 90 days of age.

Test Procedure

The samples are placed on the base plate within the positioning lugs with the finished face up and the hardened steel ball is placed on the top of specimen (see Fig B.1). The drop hammer is placed on the steel ball and dropped consecutively. The number of blows required to cause the first visible crack on the top and ultimate failure are recorded. Ultimate failure is defined as the number of blows required to open the cracks in the specimen sufficiently so that the pieces of concrete are touching three of the four positioning lugs on the base plate.

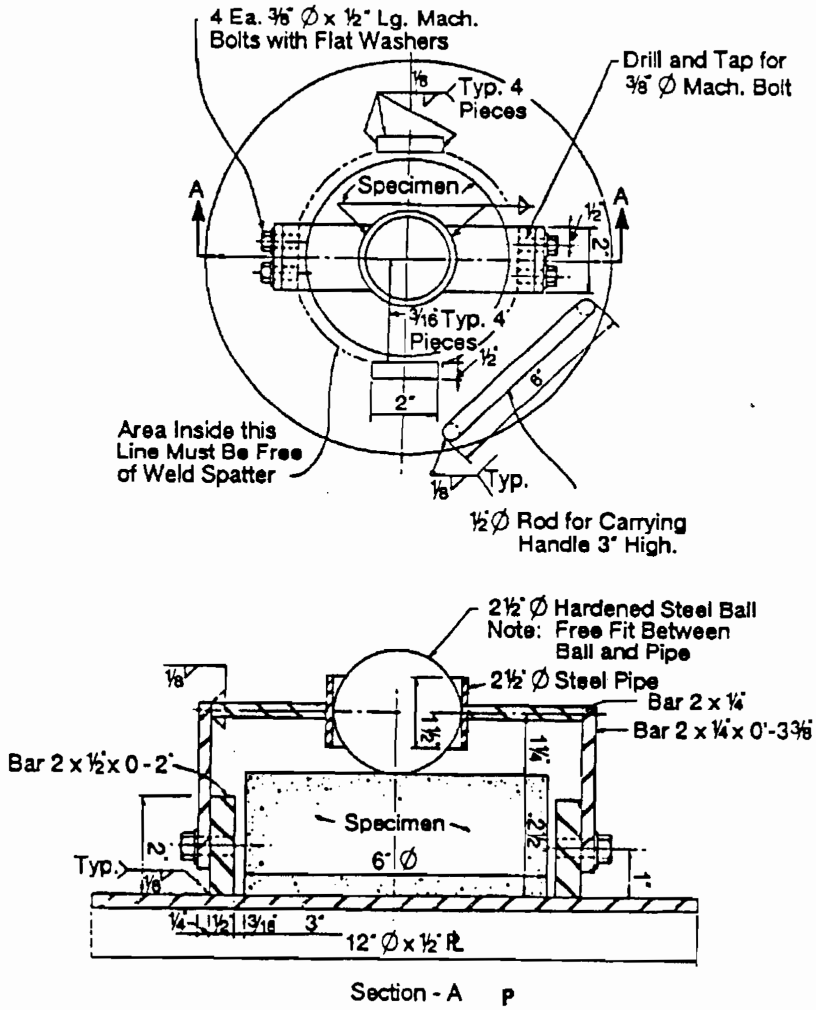


Fig B.1. Test equipment for impact strength (Ref 15).

APPENDIX C. BASIC INPUT DATA (RPRDS)

RPRDS1—RIGID PAVEMENT REHABILITATION DESIGN SYSTEM—VERSION 1, NOV 1980
CENTER FOR TRANSPORTATION RESEARCH
UNIVERSITY OF TEXAS AT AUSTIN

****
R P R D S   I N P U T   S U M M A R Y
****

NOTE - VARIABLE NUMBERS CORRESPOND TO THOSE IN RPRDS USERS MANUAL

PROJECT DESCRIPTION
****

1.1 TITLE
BASE CASE

ORIGINAL PAVEMENT
****

2.1	SURFACE TYPE	CRCP
2.2	CONCRETE SHOULDER	NO
2.3	NO. OF LANES (ONE DIRECTION)	4
2.4	NO. OF PAVEMENT LAYERS	3
3.1	PROJECT LENGTH, MILES	4.00
3.2	LANE WIDTH, FEET	12.00
3.3	TOTAL SHOULDER WIDTH, FEET	16.00

PAVEMENT STRUCTURE

LAYER NO.	4.0 THICKNESS (IN)	5.0 ELASTIC MODULUS (PSI)	6.0 POISSONS RATIO
1	8.0	5000000.	.15
2	6.0	200000.	.30
3	SEMI-INFINITE	16000.	.30

7.1	CONCRETE FLEXURAL STRENGTH, PSI	650.
7.2	CRITICAL STRESS FACTOR	1.25
7.3	CONCRETE STIFFNESS AFTER CRACKING, PSI	800000.
8.1	NO. OF EXISTING DEFECTS PER MILE	5.
8.2	COST OF REPAIRING A DEFECT, DOL	2000.
8.3	RATE OF DEFECT DEVELOPMENT, NO./YR/MILE	2.

TRAFFIC VARIABLES
****

9.1	AVERAGE DAILY TRAFFIC (ADT)	132000.
9.2	ADT GROWTH RATE, PERCENT	3.30
9.3	INITIAL YEARLY 18-KIP ESAL, MILLIONS	1.200
9.4	18-KIP ESAL GROWTH RATE, PERCENT	3.70
9.5	DIRECTIONAL DISTRIBUTION FACTOR, PERCENT	50.0
9.6	LANE DISTRIBUTION FACTOR, PERCENT	60.0

TIME CONSTRAINTS
****

10.1	ANALYSIS PERIOD, YEARS	20.0
10.2	MINIMUM TIME BETWEEN OVERLAYS, YEARS	20.0
10.3	MAXIMUM ALLOWABLE YEARS OF HEAVY MAINTENANCE AFTER LOSS OF STRUCTURAL LOAD-CARRYING CAPACITY	0

REMAINING LIFE VARIABLES
****

11.1	NO. OF ORIGINAL PAVEMENT REMAINING LIFE VALUES TO CONSIDER	1
11.2	MINIMUM EXISTING PAVEMENT REMAINING LIFE BELOW WHICH A BONDED PCC OVERLAY MAY NOT BE PLACED	10.
11.3	VALUES OF ORIGINAL PAVEMENT REMAINING LIFE AT WHICH FIRST OVERLAY MAY BE PLACED	

NO.	REMAINING LIFE (PERCENT)
1	30.

12.1	NO. OF FIRST OVERLAY REMAINING LIFE VALUES TO CONSIDER	0
12.2	VALUES OF FIRST OVERLAY REMAINING LIFE AT WHICH SECOND OVERLAY MAY BE PLACED (NONE)	

OVERLAY CHARACTERISTICS
****

13.0 TYPES OF FIRST OVERLAY TO CONSIDER
.1 ACP - NO
.2 BONDED CRCP - YES
.3 UNBONDED CRCP - NO
.4 BONDED JCP - NO
.5 UNBONDED JCP - NO

14.0 TYPES OF SECOND OVERLAY TO CONSIDER
.1 ACP - NO
.2 CRCP - YES
.3 JCP - NO

15.0 NO. OF DIFFERENT OVERLAY THICKNESS TO CONSIDER
.1 ACP FIRST OVERLAY - 0
.2 ACP SECOND OVERLAY - 0
.3 PCC OVERLAY - 1

16.0 ACP FIRST OVERLAY THICKNESSES, INCHES
(NONE)

17.0 ACP SECOND OVERLAY THICKNESSES, INCHES
(NONE)

18.0 PCC OVERLAY THICKNESSES, INCHES
.1 4.0

19.1	ALLOWABLE TOTAL OVERLAY THICKNESS, INCHES	10.0
19.2	AVERAGE LEVEL-UP THICKNESS, INCHES	1.0
19.3	BOND BREAKER THICKNESS, INCHES	0
20.1	ACP OVERLAY DESIGN STIFFNESS, PSI	0
20.2	POISSONS RATIO, ACP OVERLAY	0
20.3	PCC OVERLAY DESIGN STIFFNESS, PSI	5000000.
20.4	POISSONS RATIO, PCC OVERLAY	.15
20.5	BOND BREAKER STIFFNESS, PSI	0
20.6	POISSONS RATIO, BOND BREAKER	0
21.1	NO. OF OVERLAY FLEXURAL STRENGTHS TO CONSIDER	1
21.2	NO. WHICH IDENTIFIES WHICH FLEXURAL STRENGTH IN THE LIST TO USE FOR A BONDED PCC OVERLAY	1
22.0	PCC OVERLAY FLEXURAL STRENGTH(S), PSI	
	.1 650.	

*** PAVEMENT STRESS FACTORS AFTER OVERLAY ***

	FIRST OVERLAY TYPE	SECOND OVERLAY TYPE	CRITICAL STRESS LOCATION	OVERLAY SHOULDER TYPE	CRIT./INTER. STRESS FACTOR
23.1	ACP	(NONE)	EX PAVT	ACP	0
24.1	ACP	ACP	EX PAVT	ACP	0
25.1	ACP	CRCP	EX PAVT	ACP	0
25.2	ACP	CRCP	EX PAVT	CRCP	0
26.1	ACP	CRCP	CRCP O/L	ACP	0
26.2	ACP	CRCP	CRCP O/L	CRCP	0
27.1	ACP	JCP	EX PAVT	ACP	0
27.2	ACP	JCP	EX PAVT	JCP	0
28.1	ACP	JCP	JCP O/L	ACP	0
28.2	ACP	JCP	JCP O/L	JCP	0
29.1	BOND CRC	(NONE)	EX PAVT	ACP	1.25
29.2	BOND CRC	(NONE)	EX PAVT	CRCP	0
30.1	BOND CRC	ACP	EX PAVT	ACP	0
30.2	BOND CRC	ACP	EX PAVT	CRCP	0
31.1	BOND JCP	(NONE)	EX PAVT	ACP	0
31.2	BOND JCP	(NONE)	EX PAVT	JCP	0
32.1	BOND JCP	ACP	EX PAVT	ACP	0
32.2	BOND JCP	ACP	EX PAVT	JCP	0
33.1	UNBD CRC	(NONE)	EX PAVT	ACP	0
33.2	UNBD CRC	(NONE)	EX PAVT	CRCP	0
34.1	UNBD CRC	(NONE)	CRCP O/L	ACP	0
34.2	UNBD CRC	(NONE)	CRCP O/L	CRCP	0
35.1	UNBD CRC	ACP	EX PAVT	ACP	0
35.2	UNBD CRC	ACP	EX PAVT	CRCP	0
36.1	UNBD CRC	ACP	CRCP O/L	ACP	0
36.2	UNBD CRC	ACP	CRCP O/L	CRCP	0
37.1	UNBD JCP	(NONE)	EX PAVT	ACP	0
37.2	UNBD JCP	(NONE)	EX PAVT	JCP	0
38.1	UNBD JCP	(NONE)	JCP O/L	ACP	0
38.2	UNBD JCP	(NONE)	JCP O/L	JCP	0
39.1	UNBD JCP	ACP	EX PAVT	ACP	0
39.2	UNBD JCP	ACP	EX PAVT	JCP	0
40.1	UNBD JCP	ACP	JCP O/L	ACP	0
40.2	UNBD JCP	ACP	JCP O/L	JCP	0

NOTE - STRATEGIES WITH A ZERO VALUE FOR THE CRITICAL TO INTERIOR STRESS FACTOR WILL NOT BE CONSIDERED.

41.1 1 - LAYER PACKAGE USED TO PREDICT RESPONSE.

OVERLAY CONSTRUCTION COST VARIABLES
****

42.0 SITE ESTABLISHMENT COST, DOL

.1	ACP EQUIPMENT	0
.2	CRCP EQUIPMENT	20000.
.3	JCP EQUIPMENT	0
.4	ACP AND CRCP EQUIPMENT	25000.
.5	ACP AND JCP EQUIPMENT	

43.0 PAVEMENT SURFACE PREPARATION COSTS, DOL/SY

.1	EXISTING PAVEMENT	3.00
.2	ACP OVERLAY	0
.3	CRCP OVERLAY	0
.4	JCP OVERLAY	0

44.1	FIXED COST OF ACP OVERLAY CONSTRUCTION, DOL/SY	0
44.2	VARIABLE COST OF ACP OVERLAY CONSTR., DOL/SY/IN	0
44.3	FIXED COST OF FLEXIBLE SHOULDER CONSTR., DOL/SY	6.67
44.4	VARIABLE COST OF FLEX. SHOULDER CONSTR., DOL/SY/IN	.83
44.5	COST OF BOND BREAKER CONSTRUCTION, DOL/SY	0

45.0 CRCP FIXED COST FOR EACH FLEXURAL STRENGTH

	FLEXURAL STRENGTH (PSI)	FIXED COST (DOL/SY)
.1	650.	8.00

46.0 CRCP VARIABLE COST FOR EACH FLEXURAL STRENGTH

	FLEXURAL STRENGTH (PSI)	VARIABLE COST (DOL/SY/IN)
.1	650.	1.00

47.0 JCP FIXED COST FOR EACH FLEXURAL STRENGTH

	FLEXURAL STRENGTH (PSI)	FIXED COST (DOL/SY)
.1	650.	0

48.0 JCP VARIABLE COST FOR EACH FLEXURAL STRENGTH

	FLEXURAL STRENGTH (PSI)	VARIABLE COST (DOL/SY/IN)
.1	650.	0

49.1	TOTAL STEEL PERCENTAGE REQUIRED IN CRCP OVERLAYS	.60
49.2	TOTAL STEEL PERCENTAGE REQUIRED IN JCP OVERLAYS	0
49.3	COST OF STEEL REINFORCEMENT, DOL/LB	.50

TRAFFIC DELAY COST VARIABLES
****

50.1	LOCATION OF PROJECT (1=RURAL,2=URBAN)	2
50.2	MODEL NO. FOR HANDLING TRAFFIC	3

50.3	NO. OF OPEN LANES, OVERLAY DIRECTION	3
50.4	NO. OF OPEN LANES, NON-OVERLAY DIRECTION	4
51.1	MILITARY TIME OVERLAY CONSTRUCTION BEGINS	0
51.2	MILITARY TIME OVERLAY CONSTRUCTION ENDS	2400.
51.3	HOURS PER DAY OVERLAY CONSTRUCTION OCCURS	8.0
51.4	NO. OF DAYS CONCRETE IS ALLOWED TO CURE	14.
51.5	DETOUR DISTANCE TO USE IN MODEL 5, MILES	0
52.1	AVERAGE APPROACH SPEED, MPH	55.
52.2	AVERAGE SPEED, OVERLAY DIRECTION, MPH	30.
52.3	AVERAGE SPEED, NON-OVERLAY DIRECTION, MPH	50.
53.1	DISTANCE TRAFFIC IS SLOWED, OVERLAY DIRECTION, MILES	2.5
53.2	DISTANCE TRAFFIC IS SLOWED, NON-OVERLAY DIR., MILES	.1
53.3	PERCENT OF VEHICLES STOPPED, OVERLAY DIRECTION	10.0
53.4	PERCENT OF VEHICLES STOPPED, NON-OVERLAY DIRECTION	0
53.5	AVERAGE VEHICLE DELAY, OVERLAY DIRECTION, HRS	.08333
53.6	AVERAGE VEHICLE DELAY, NON-OVERLAY DIRECTION, HRS	0
54.1	ACP PRODUCTION RATE, CY/HR	0
54.2	CRCP PRODUCTION RATE, CY/HR	70.
54.3	JCP PRODUCTION RATE, CY/HR	0
54.4	BOND BREAKER PRODUCTION RATE, CY/HR	0

DISTRESS/MAINTENANCE COST VARIABLES
****

55.1	DISTRESS REPAIR COST, CRCP OVERLAY, DOL	2000.00
55.2	INITIAL CRCP OVERLAY DISTRESS RATE, NO./MI/YR	1.0
55.3	SECONDARY CRCP OVERLAY DISTRESS RATE, NO./MI/YR	2.0
55.4	CRCP OVERLAY DISTRESS RATE FOR EACH YEAR AFTER LOSS OF PAVEMENT LOAD-CARRYING CAPACITY (NONE)	
56.1	DISTRESS REPAIR COST, JCP OVERLAY, DOL	0
56.2	INITIAL JCP OVERLAY DISTRESS RATE, NO./MI/YR	0
56.3	SECONDARY JCP OVERLAY DISTRESS RATE, NO./MI/YR	0
56.4	JCP OVERLAY DISTRESS RATE FOR EACH YEAR AFTER LOSS OF PAVEMENT LOAD CARRYING CAPACITY (NONE)	
57.1	DISTRESS REPAIR COST, ACP OVERLAY ON CRCP, DOL	500.00
57.2	INITIAL ACP/CRCP DISTRESS RATE, NO./MI/YR	1.0
57.3	SECONDARY ACP/CRCP DISTRESS RATE, NO./MI/YR	2.0
57.4	ACP/CRCP DISTRESS RATE FOR EACH YEAR AFTER LOSS OF PAVEMENT LOAD-CARRYING CAPACITY (NONE)	
58.1	DISTRESS REPAIR COST, ACP OVERLAY ON JCP, DOL	100.00
58.2	INITIAL ACP/JCP DISTRESS RATE, NO./MI/YR	5.0
58.3	SECONDARY ACP/JCP DISTRESS RATE, NO./MI/YR	10.0
58.4	ACP/JCP DISTRESS RATE FOR EACH YEAR AFTER LOSS OF PAVEMENT LOAD CARRYING CAPACITY (NONE)	

COST RETURNS
****

59.1	SALVAGE VALUE, PERCENT OF OVERLAY CONSTRUCTION COST	0
59.2	VALUE OF EACH YEAR OF EXTENDED LIFE, DOL/SY/YR	0

COMBINED INTEREST AND INFLATION RATE
****

60.1	NTEREST RATE MINUS INFLATION RATE, PERCENT	5.0