TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
TX-93 1920-2		

4. Title and Subtitle Investigation of Parameters Affecting the Interface Bonding of Thin Concrete Overlays due to Vehicular Vibration	5. Report Date May, 1993 6. Performing Organization Code
7. Author(s) Makahaube, J.S., Nazarian, S. and Rozendal, D.B.	8. Performing Organization Report No. Research Report 1920-2
9. Performing Organization Name and Address Center for Geotechnical and Highway Materials Research The University of Texas at El Paso El Paso, Texas 79968-0516	10. Work Unit No. 11. Contract or Grant No. Study No. 10-24D-90/1-1920
12. Sponsoring Agency Name and Address Texas Department of Transportation P.O. Box 5051 Austin, Texas 78763	13. Type of Report and Period Covered Interim Report Sept. 1, 1991-Aug 31, 1992 14. Sponsoring Agency Code

15. Supplementary Notes

Research Performed in Cooperation with TxDOT
Research Study Title: Effects of Vehicular Vibration on Debonding and Delamination of Concrete Overlays

16. Abstract

This research is a further study of parameters affecting the interface bonding of thin concrete overlays. The specimens were tested in the flexural mode, while in the previous study, the direct shear test was applied to the specimens.

The parameters investigated were surface condition, surface texture, pre-vibration cure time, overlay thickness, and vibration amplitude. The parameters were combined in different sequences and their effects on the interface bonding of concrete overlays are reported. The effects of surface condition were studied by comparing the shear stress obtained with dry surfaces and wet surfaces. The intention of this investigation was to determine the optimal moisture condition at the interface immediately before the placement of the overlay. The effects of surface texture were investigated to determine if scarifying the interface would improve the bond between the overlay and the base concrete. The pre-vibration cure time which corresponds to the traffice closure after pouring was also studied. Finally, the effects of thickness of overlay were studied by comparing the effectiveness of interface bonding.

17. Key Words	18. Distribution Statement
Overlays, Interface Bonding, Vibration, Delamination, Pavement	No restrictions. This document is available to the public through the National Technical Information Service, 5285 Port Royal Road, Springfield, Virginia 22161

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	52	

Form DOT F 1700.7 (8-69)

INVESTIGATION OF PARAMETERS AFFECTING THE INTERFACE BONDING OF THIN CONCRETE OVERLAYS DUE TO VEHICULAR VIBRATION

by

Johanes S. Makahaube, BSCE

Soheil Nazarian, Ph.D., P.E.

and

David B. Rozendal, Ph.D., P.E.

Research Project 1920

EFFECTS OF VEHICULAR VIBRATION ON DEBONDING AND DELAMINATION OF CONCRETE OVERLAYS

Conducted for

Texas Department of Transportation

by

Center for Geotechnical and Highway Materials Research
The University of Texas at El Paso
Research Report 1920-2
May 1993

NOT INTENDED FOR CONSTRUCTION, BIDDING, OR PERMIT PURPOSES

NOT INTENDED FOR CONSTRUCTION, BIDDING, OR PERMIT PURPOSES

Johanes S. Makahaube, BSCE
Soheil Nazarian, Ph.D., P.E. (66495)
David B. Rozendal, Ph.D., P.E. (31887)

Acknowledgements

The authors would like to give their sincere appreciation to Mr. Joe M. Battle and Mr. William G. Burnett, District Engineers of the Texas Department of Transportation, District 24, for the financial support of this research project. Thanks are also due to Mr. Malcolm Steinberg and Mr. Richard R. Ellison of the Texas Department of Transportation, District 24, for their support as Project Coordinators. The authors would like to thank Jessica Rodriguez-Gomez of the Texas Department of Transportation and also Jamal Anwar and Mario Gomez, UTEP Graduate Students, their continuous help.

Implementation Statement

The implementation of this research's result is not recommended at this time. The research should be completed by August 1993 at which time implementation may begin.

Abstract

This research is a further study of parameters affecting the interface bonding of thin concrete overlays. The specimens were tested in the flexural mode, while in the previous study, the direct shear test was applied to the specimens.

The parameters investigated were surface condition, surface texture, pre-vibration cure time, overlay thickness, and vibration amplitude. The parameters were combined in different sequences and their effects on the interface bonding of concrete overlays are reported. The effects of surface condition were studied by comparing the shear stress obtained with dry surfaces and wet surfaces. The intention of this investigation was to determine the optimal moisture condition at the interface immediately before the placement of the overlay. The effects of surface texture were investigated to determine if scarifying the interface would improve the bond between the overlay and the base concrete. The pre-vibration cure time which corresponds to the traffic closure after pouring was also studied. Finally, the effects of thickness of overlay were studied by comparing the effectiveness of interface bonding.

Some conclusions have been drawn from this study. For 2 in. overlays with rough or smooth surfaces, the wet interfaces yield better or equal bond strengths as compared with dry surfaces. For thicker overlays (4 in.) with smooth surfaces, dry conditions are more desirable. However, on rough surfaces, the moisture condition does not contribute to the bond strength.

The results from comparison of smooth versus rough interfaces show that for 2 in. overlays, the texture of the interface does not seem to be a factor of significance for either wet or dry

surfaces. The surface texture is again of no consequence for 4 in. overlays placed on dry surfaces.

When the specimens are subjected to pre-vibration cure time, 2 in. overlays on smooth dry interfaces do not show any improvement on the bond strength. On roughened surfaces, both wet and dry, short periods of cure time is desirable before vibration.

For thicker overlays, the effectiveness of interface bonding is less than for thinner overlays. However, the shear stresses at failure are higher for thicker overlays.

Table of Contents

List of Figures

1

Introduction

1.1 Problem Statement

An investigation of the delamination and debonding of concrete overlays was conducted by Rodriguez-Gomez and Nazarian (1992) using small specimens. In that work, specimens 4-in. in diameter were prepared and were subjected to pure vertical and pure horizontal vibrations. The Guillotine Direct Shear Test was used to find the shear stress at the interface of the base concrete and the overlay. The results of that work show that the amplitude of vibration, curing time, thickness of concrete overlay, texture, and wetness of interface between the existing and freshly-poured concrete contribute to the shear stress at the interface of a concrete overlay.

That first-phase study significantly contributed to understanding and quantifying of the parameters which would influence the shear bond. However, a more realistic mode of vibration and larger specimens were needed to qualify the interface bond. To achieve these goals, the important parameters identified by Rodriguez-Gomez and Nazarian were used to test larger specimens. These specimens were 3 ft long, 6 in. wide and 2 in. thick. A 2 in. or 4 in. overlay was placed on top of the base concrete. The specimens were then tested by one-point line load flexural testing which were conducted in three different spans. These span are 30.5 in., 12 in. and 6 in.

1.2 Scope of Work

The main objective of this research is to continue the investigation of the effects of vibration on the initiation and propagation of debonding and delamination of concrete overlays. The parameters studied are the same as those studied by Rodriquez-Gomez and Nazarian.

1.3 Organization

This report consists of five chapters. Chapter 2 discusses the summary of the previous work and the background information of this research. The testing methodology including the testing matrix and the sample preparation is discussed in Chapter 3. The presentation of the results are discussed in Chapter 4. The closure of this study is found in Chapter 5. That chapter contains a summary, conclusions and recommendations for future work. The data that support this report are included in the appendices.

2

Background

2.1 Introduction

The delamination of thin-bonded overlays which occurred on the overpasses on IH-10 in El Paso, Texas was initially studied by Rodriguez-Gomez and Nazarian (1992). Thin-bond overlays were poured on the overpasses which were constructed in two phases. Phase I (outside lanes) was constructed with average depth of 3 1/2 inch during the summer of 1987. Phase II (inside lanes) was constructed during the Spring of 1988. The signs of distress (which lead to the delamination on the Phase II overlays) developed eight months after the overlays had been placed. All interior bent lines and transverse joints were severely cracked. Also, loss of material was common. Alligator cracks appeared throughout the overlays with no specific pattern from one overpass to the next.

Several possibilities for the overlay failure (including mix design variations, air-content, fly-ash content, and cement sources) were investigated. Also the weather conditions at the time of placement were taken into account. However, any changes in these conditions could not be correlated to the overlay failure. The possibility of improper construction procedures and inadequate inspection could have been a cause of failure (Manning, 1981). These procedures were checked and found to be according to the specifications. The case study is well described in Rodriguez-Gomez and Nazarian (1992) and is not repeated here for the sake brevity.

2.2 Discussion of Previous Work

In the previous work, Rodriguez-Gomez and Nazarian (1992) subjected 4-in. diameter specimens to two modes of vibrations, vertical and horizontal. In each mode of vibration, the effect of surface condition, pre-vibration cure time, and overlay thickness were experimentally investigated. Their results are summarized below.

2.2.1 Effect of Surface Condition. In the vertical vibration mode, the surface conditions (smooth vs rough, and wet vs dry) did not seem to consistently affect the shear strengths. Hence, no one combination of surface conditions, e.g. smooth-wet or rough-dry, gave consistent low or high shear strengths. On the other hand, the overlay thickness and the increasing of pre-vibration cure time seemed to be the more dominant parameters affecting the shear strength.

The direct shear test of the 2-in. and 4-in. overlays with no pre-vibration curing time exhibited variable results. A large variability existed between the shear strengths of specimen with specific conditions. The combination of surface conditions and vibration levels also did not produce consistent results. Variation in the results for the 0 hour pre-vibration cure time may reflect what occurred on the IH-10 widening project.

For the 6-in. overlay with longer pre-vibration cure times (4 and 12 hours), less variation in strength occurred between wet and dry surfaces. Shear strengths were more consistent. This seems to be caused by the increased overlay thickness and cure times but not the wet or dry surface conditions.

In the horizontal vibration mode, the shear strengths were found to be more consistent as compared to those in vertical vibration mode. Specimens with 2 in. overlay at any pre-vibration cure time with rough-dry surface were found to give higher results compared to other surface textures. The 4 in. overlay at zero hour pre-vibration cure time also gave higher results with rough surface conditions. However, by increasing the pre-vibration cure time the shear strength was found to be less affected by the surface condition, (whether rough or smooth and wet or dry). In general, horizontal vibration mode seemed to produce more consistent shear strengths, especially for specimens with 2 in. and 4 in. overlay at 0 hour pre-vibration cure time.

2.2.2 Effect of Pre-vibration Cure Time. For the specimens with 2-in. and 4-in. overlays subjected to vertical vibration, the increase in pre-vibration cure time resulted in a higher shear strength. The other significant results were that specimens with 4 or 12 hour pre-vibration cure time developed greater shear strengths than those which were never subjected to vibration regardless to the level of vibration.

The similar pattern was also found in 6 in. overlays. The variability of the shear strengths among the specimens which cured for 0, 4, and 12 hours were small.

In general, the best shear strengths could be achieved after the specimens were allowed to cure for 12 hours and then subjected to vibration for 12 hours. In this case, the average shear strength was approximately 150 psi.

The condition of the surface seemed to become less of a factor in the outcome of the shear strength as the overlay thickness increased. For a 6 in. overlay, the cure time also became less of a factor in determining the shear strengths.

The effects of the pre-vibration cure time on shear strength were less significant for the horizontal vibration mode as compared to vertical mode. This might indicate that the horizontal vibration mode is less of a concern to the bridge than the vertical vibration mode created by traffic.

2.2.3 Effect of Overlay Thickness. The combination of cure time and overlay thickness seemed to determine the outcome of the shear strengths of the overlays. The effect of overlay thickness was difficult to determine for specimens with 0 hour pre-vibration cure time. This means that for 0 hour pre-vibration cure time, the shear strength was not controlled by the thickness of the overlay. As the pre-vibration cure time increased (4 and 12 hour) more consistent results were obtained. The thicker overlays (4 in.) resulted in higher shear strengths. The tendency towards higher shear strengths due to the increase in thickness of the overlay was then obvious.

The shear strength of thin overlays could be improved by placing it on roughened surfaces. Regardless of the vibration level, 2 in. overlays on smooth surfaces produced lower shear strengths compared to the results from the 4 in. overlays. However, the shear strengths became less affected by the surface condition when the overlay thickness increased. The highest shear strengths were obtained on rough interface with 4 and 12 hour pre-vibration cure time.

2.2.4 Vertical Versus Horizontal Vibration Modes. For the short pre-vibration cure time zero to 4 hours, the shear strengths of 2 in. specimens were generally affected more by vertical vibration.

Regardless of the vibration level, the shear strengths of 2 in. overlays obtained after allowing the specimens to cure for 4 and 12 hours were similar when subjected to horizontal vibration mode. This indicated that pre-vibration cure time does not affect the shear strengths under the horizontal vibration mode. For specimens subjected to vertical vibration, the shear strength improved significantly for 4 to 12 hours pre-vibration cure time. A better bond at interface was created when the specimens were allowed to cure for 12 hours before being subjected to vertical vibration.

For the thicker specimens (4 in.) with zero hour pre-vibration cure time, inconsistent results were obtained. When the pre-vibration cure time increased (4 and 12 hours), horizontal vibration yielded higher shear strengths as compared to the vertical vibration. This indicated that vertical vibration affects the shear strength more than the horizontal vibration. High amplitude of vibration typically yielded higher shear strengths as compared to low amplitude.

2.2.5 General Recommendation. The thinner the overlay is the more the number of variables that would affect the shear strength. Higher shear strengths were generally produced by a rough surface. However, the highest shear strengths varied from one surface condition to another. It was then difficult to determine whether a wet or dry surface produced higher shear strengths.

The pre-vibration cure time definitely affected the shear strength of the specimens. The longer the pre-vibration cure time were, the less variable and the higher the shear strengths would be.

The amplitude of vibration obviously affected the shear strength. The high amplitudes of vibration created better bonding to the overlay as compared to those created by low amplitudes. Specimens not subjected to any vibration resulted lowest shear strengths.

The increase in thickness of overlay reduced the effect of surface condition on the outcome of the shear strengths. Overlays with 4 in. thickness were not as much affected by surface condition as the 2 in. overlays. However, a rough surface usually produced the highest shear strengths. The variability of shear strength due to surface condition was then obvious. This means that shear strengths at dry surfaces were not found to be consistently higher or lower than the shear strengths of wet surfaces. Specimens subjected to high vibration levels after pre-vibration cure time resulted in increased shear strengths. In this condition, the shear strengths were higher than those subjected to low vibration mode. Specimens subjected to no vibration yielded the lowest shear strengths.

The thickness of overlay affected the shear strengths. For the zero and 4 hours pre-vibration cure time, an increase in thickness of overlay improved the interface bonding. The thickest overlay tested (6 in.) was then the ideal thickness to use. However, the use of a 6 in. concrete overlay is very uncommon. The 4 in. and 2 in. concrete overlays are then the alternative thicknesses. Overlays with thickness of 4 in. could be expected to give higher shear strength with the least amount of variation after being allowed to cure for 12 hours before being subjected to the vibration of traffic. Allowing the 2 in. overlay thickness to cure for 12 hours before subjecting it to vibration could be also expected to give higher shear strengths. However, it has to be placed on a roughened surface.

3

Methodology

3.1 Introduction

Parameters investigated are the same as those in the previous work conducted by Rodriguez-Gomez and Nazarian (1992). These parameters are: amplitude of vibration, pre-vibration curing time, thickness of concrete overlay, interface texture and wetness of the interface. Since the previous study illustrated that for a 6 in. overlay thickness, the condition of the surface and the cure time are less of a factor in the outcome of the shear strengths, it was decided to eliminate this thickness. Therefore, overlay thicknesses of 2 in. and 4 in. were considered. Beams 3 ft x 6 in. x 2 in. were used as specimens. The concrete used for the base and overlay were the same as those of the small specimens. The base was poured using a class "H-H" concrete. This is the class of concrete used by the Texas Department of Transportation for the Precast Concrete Box beams used on the IH-10 project. The overlay concrete was class "CO" which is the overlay design mix of IH-10 project where the original thin-bonded overlay delamination occurred.

Each specimen was tested after reaching an age of 24 hours irrespective of the amplitude or duration of vibration. The specimen was subjected to a line load in order that the flexural failure would occur. Each overlay thickness was tested under different interface conditions and subjected to different vibration levels.

The overlay-base interface was either a smooth surface or a rough surface. The rough surface was created by a wood float finish. The smooth surface was the bottom of the beam on the side facing the forms. Before pouring the overlay, the base beam surface was kept dry or wet.

After the overlay was poured on the top of the base beam, the specimen was allowed to cure without being subjected to vibrations for 0, 4, 12 and 24 hours. A 0 hour pre-vibration cure time (i.e. vibrating the specimen immediately after preparation) would be similar to pouring a concrete overlay in the field while traffic is being allowed on the adjacent lanes and consequently subjected to traffic vibrations. A 12 hour pre-vibration cure time represents the field condition when an overlay is being poured and then allowed to cure without being subjected to vibration from the adjacent traffic for 12 hours. A 24 hour cure time represents the field condition when an overlay is allowed to cure for 24 hours without being subjected to vibration. The testing matrix showing all parameters tested is illustrated in Figure 3.1.

3.2 Vibration Measurement in the Field

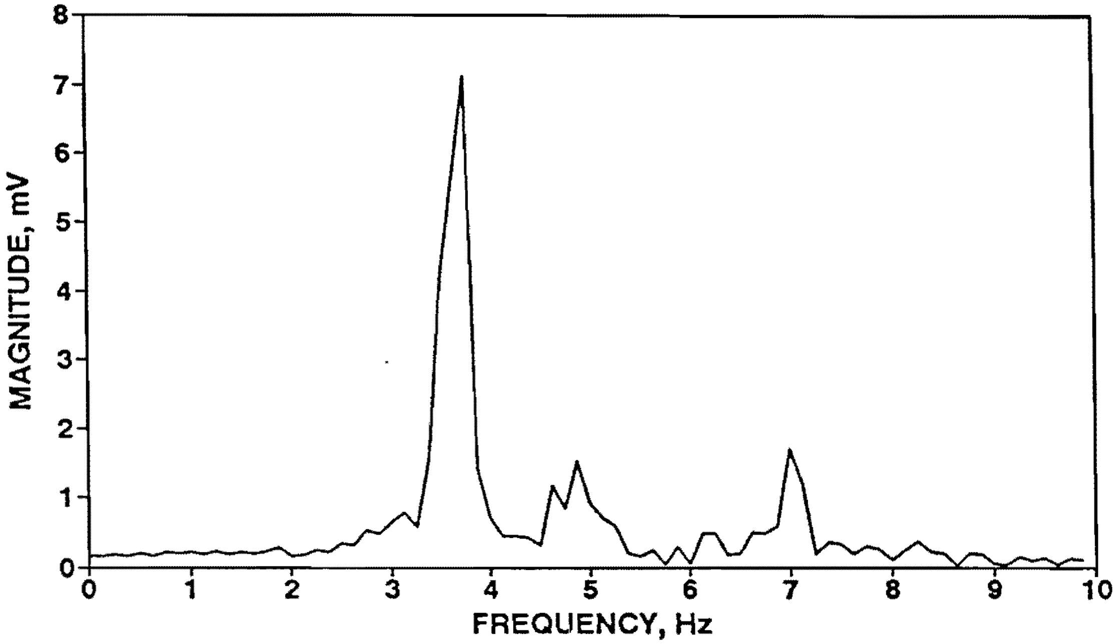
The vibration level used was measured on the IH-10 eastbound Hawkins Overpass in El Paso. This was one of the overpasses which had the overlay delamination problem. The procedure for measuring the vibration amplitude is described in Rodriguez-Gomez and Nazarian (1992). Amplitudes of 80 mils and 40 mils were determined as representative of the vibration of the long and the short span.

Two averaging techniques were used to characterize the volume of traffic. The first technique was "peak-hold" average and the second was the arithmetic average. In the first technique, the maximum amplitude which occurred at each frequency was saved. The record can be considered as the maximum envelope for 8 minutes of traffic. The result is shown in Figure 3.2a. The second technique, the arithmetic averaging was taken from all 8 minutes of traffic. Figure 3.2b shows the arithmetic average of all 50 records. The result varied substantially with the percentage of the trucks in the traffic flow. As the number of trucks increases, the arithmetic average would be closer to the "peak-hold" average.

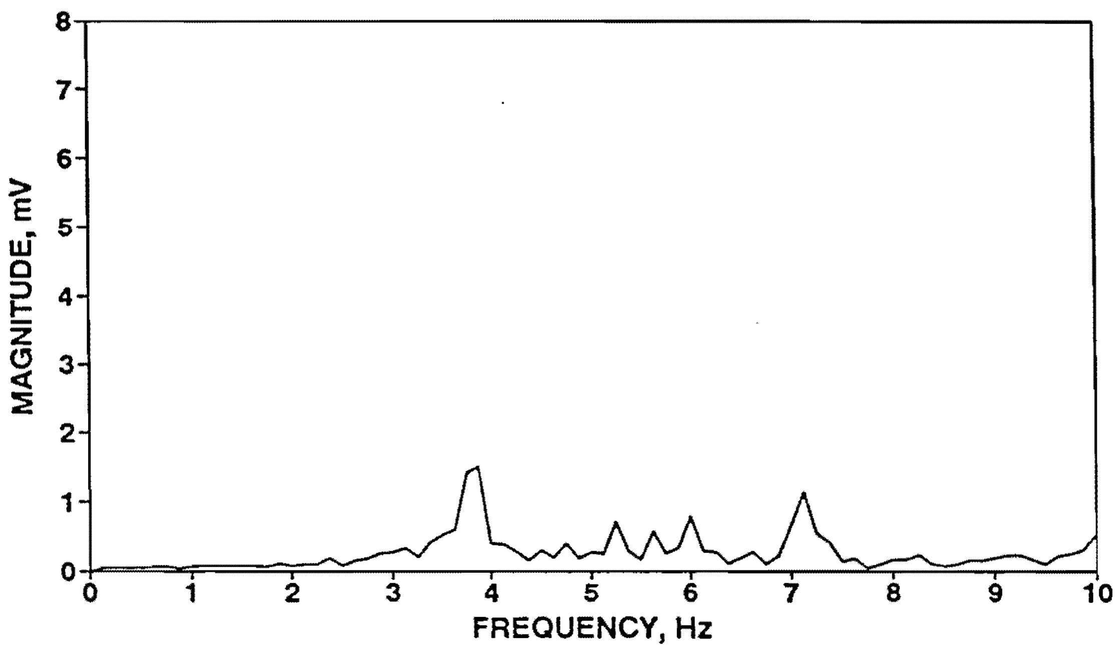
To better understand Figure 3.2a and Figure 3.2b, let us assume that the vibration produced by an automobile is negligible as compared to those of a heavy truck. These figures would be similar if all the traffic is purely heavy truck. The result of the arithmetic average would be smaller than those of the peak-hold average if most of the traffic is considered to be automobiles. Figure 3.2 showed that the peak-hold amplitude is 3 times larger than the arithmetic amplitude. Therefore, it can be approximated that for that time frame about 1/3 of the traffic was trucks.

SURFACE TEXTURE	SURFACE CONDITION														
	CURE TIME, Hours	0				4				12				24	
	AMPLITUDE	HIGH		LOW		HIGH		LOW		HIGH		LOW		NONE	
	THICKNESS	2	4	2	4	2	4	2	4	2	4	2	4	2	4
ROUGH	WET														
	DRY														
SMOOTH	WET														
	DRY														

Figure 3.1 Testing Matrix for Flexural Vibration Mode



a) "Peak-Hold" Average



b) Arithmetic Average

Figure 3.2 Typical Averaged Amplitude of Vibration of Hawkins Bridge

3.3 Sample Preparation

3.3.1 Base. The concrete used for the base was a class "H-H" concrete and was prepared on a 8 ft x 4 ft x 2in. piece of plywood which had been divided into twelve 6-in. width pieces.

The class "H-H" concrete design parameters are :

cement - 7 sacks/C.Y. concrete
coarse aggregate factor - 0.68
water - 5.25 gal/sack of cement
entrained air - 6.0 %
1/2" maximum aggregate size
high range water reducer - manufacture's recommendation.

The average 28-day compressive strength of this concrete was approximately 4800 psi.

Concrete was produced and brought to the field by ready-mix trucks. All forms had been oiled before the concrete was poured. In this manner, the beam could be easily separated from the form. Concrete was poured and spread evenly and then struck with tamping rods to consolidate the concrete beams. Finally, the concrete was finished with wooden floats. All the finishing work was done by hand. Concrete was covered by wet burlap sacks and plastic to maintain the humidity. Specimens were left curing for 28 days and every day the burlaps were checked and watered as necessary. After the 28 day cure time, the beams were separated from the mold and stored.

3.3.2 Overlay. Concrete with class "CO" was used for the overlay. This concrete was measured, mixed and placed by hand. The class "CO" concrete design parameters are:

cement - 8 sacks/C.Y.
fly-ash - 25 %
water - 4.5 gals/sacks of cement
coarse aggregate factor - 0.67
entrained air - 6.0 %
1/2" maximum aggregate size.

The average 28-day compressive strength was about 4750 psi.

The base beam was placed on the platform before pouring the overlay. The overlay was placed on the top of the base beam and consolidated with a tamping rod. The wet condition was prepared by applying water to the surface of base specimen before pouring the overlays on the top. For the dry condition, the surface of the base specimen was checked to be moisture free. The finishing process was done with a wooden float. The overlay was allowed to cure for 0 hour, 4 hours or 12 hours before being subjected to vibration.

3.4 Equipment

3.4.1 Platform. A platform was built in two parts. The steel frame held the base beam and the plexi-glass which was attached to the frames edges with bolts. The steel frame is then placed over the shaker and connected with bolts (see Figure 3.3). Plexi-glass was used to hold the fresh concrete in place. This plexi-glass was supported by five large bolts at both ends of the steel frame and was marked longitudinally at a point 4-in. from the bottom of the steel frame in order to mark the limits for a 2-in. overlay. The 4-in. overlay was constructed by placing concrete into the plexi-glass. A large C-clamp was placed in the middle of the span for extra support of the plexi-glass. This platform and its detail are shown in Figure 3.4.

3.4.2 Shaker. The 2000-lb. shaker, Ling Electronics Model B290, is controlled by several Ling Electronic components which consist of: Control Selector DA-10, Power Amplifier CP 5/6, Cycling Oscillators CO-10-A and CO-10-B, Preamplifier 111, Servo Control Amplifier S-10, and Amplifier S-12-D and G. All these components allow the control of the necessary amplitudes and frequencies are shown in Figure 3.5 and Figure 3.6.

3.4.3 Testing Machine. A 120,000-lb tension/compression testing machine was used to break the specimens (see Figure 3.7). The LT-40-D series Universal Testing Machine was made by Forney with the Forney Auto-Ranging Digital System and operated by the electric pump (see Figure 3.6). This machine had been calibrated based on the ASTM E-4.

3.5 Testing Procedure.

As mentioned before, all the specimens were tested by one point line load until they reached its flexural strength. Each specimen was tested in three different spans which were 30.5 in., 12 in. and 6 in.

The specimen was ready to be tested after it reached the age of 24 hours (cure time plus vibration time). In each test, the specimen was marked in the middle of each span to be tested. This is needed to make sure that the load was on the right line of loading.

The specimen was first tested with a span of 30.5 in. Load was applied with a constant speed until the beam failed. The load at failure was recorded. The two broken parts of the specimen were again tested, each of them with a 12 in. span. Finally, each half of these specimens was tested again with a 6 in. span. In every testing at a specific span, maximum load at failure and deflection of the beam were recorded. Based on the load at failure from each span tested, the shear stress and tensile stress were calculated. Due to limitation of testing instruments, deflections recorded did not represent the pure deflection of specimens but more of a combination of deflection and surface contact failure. Thus, in this study the deflections were neglected.

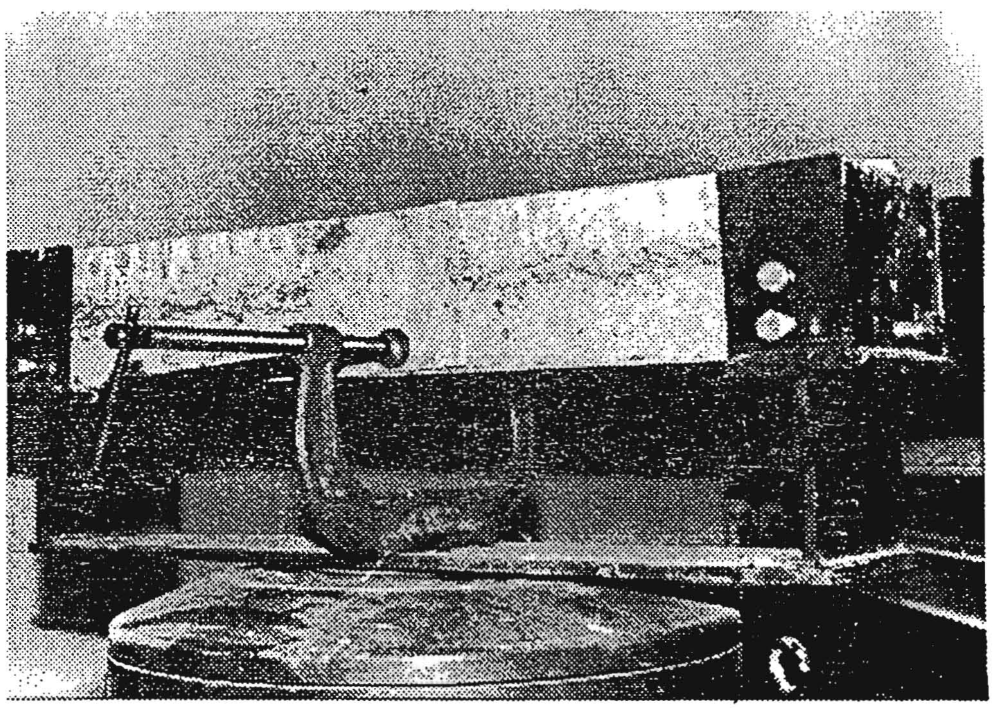


Figure 3.3 Platform Used to Place Beam Overlays Samples

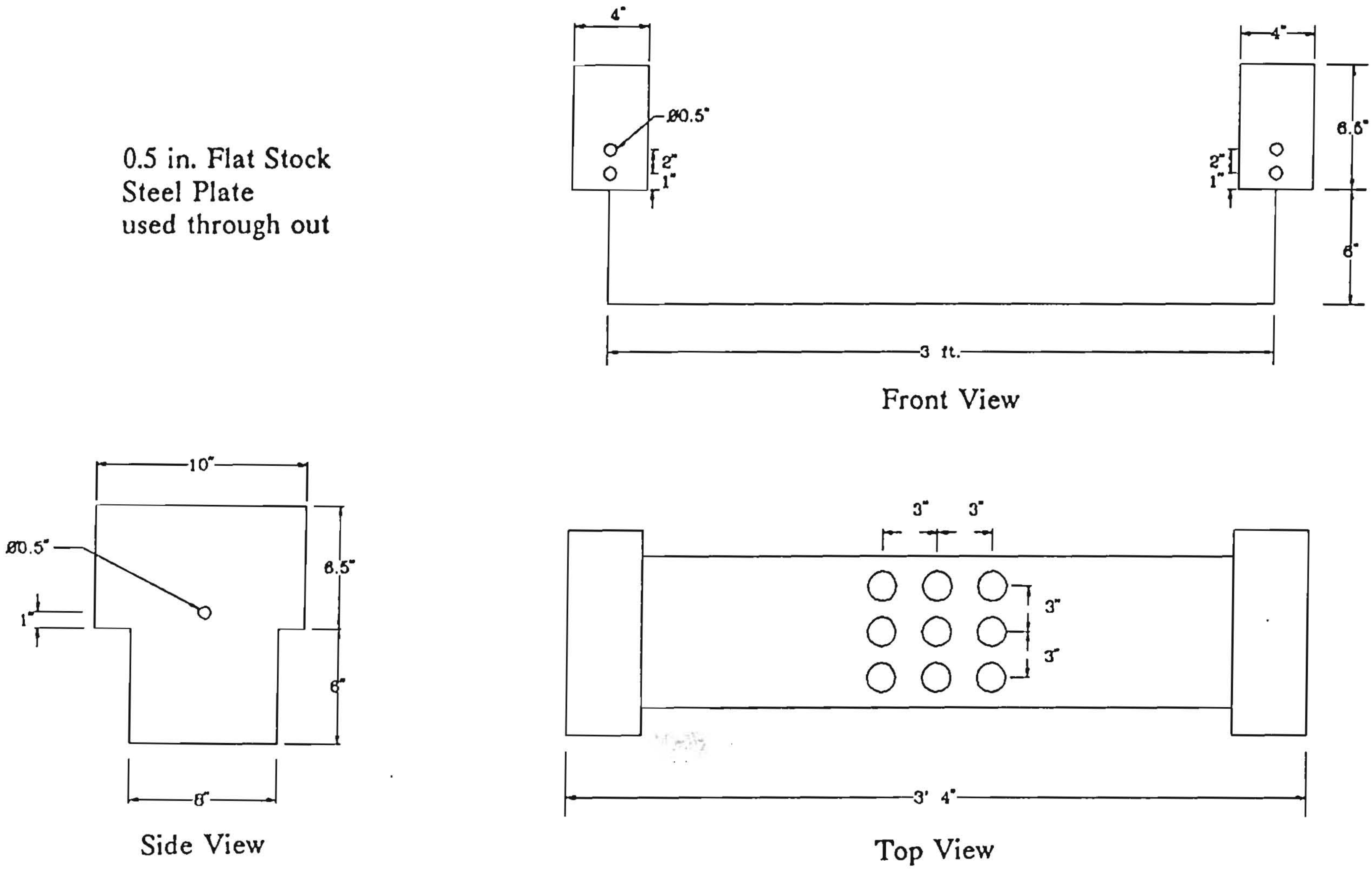


Figure 3.4 Detail of Platform

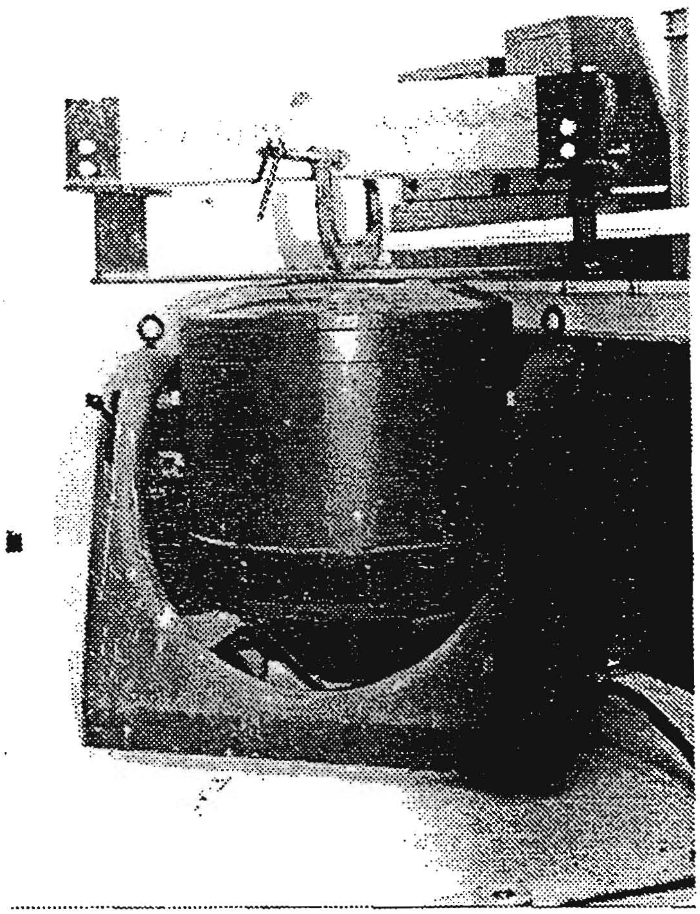


Figure 3.5 The 2000-lb. Shaker, Ling Electronics Model B-290 with Platform on the Top

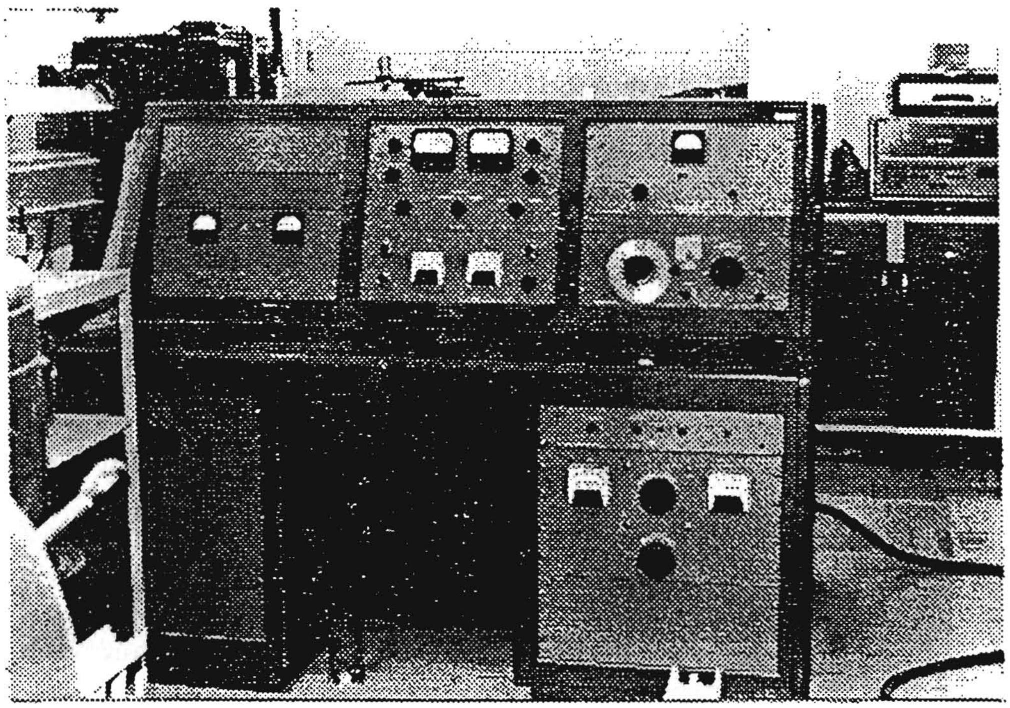


Figure 3.6 2000-lb. Shaker Control Components

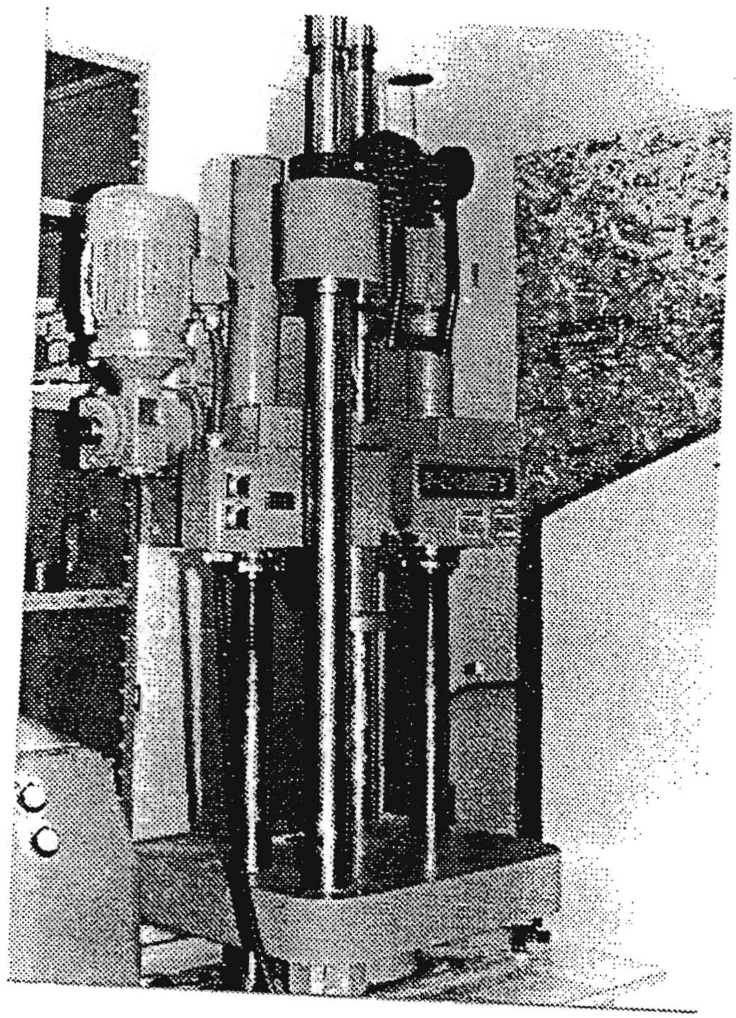


Figure 3.7 The 120-kip. Tension/Compression Forney Testing Machine

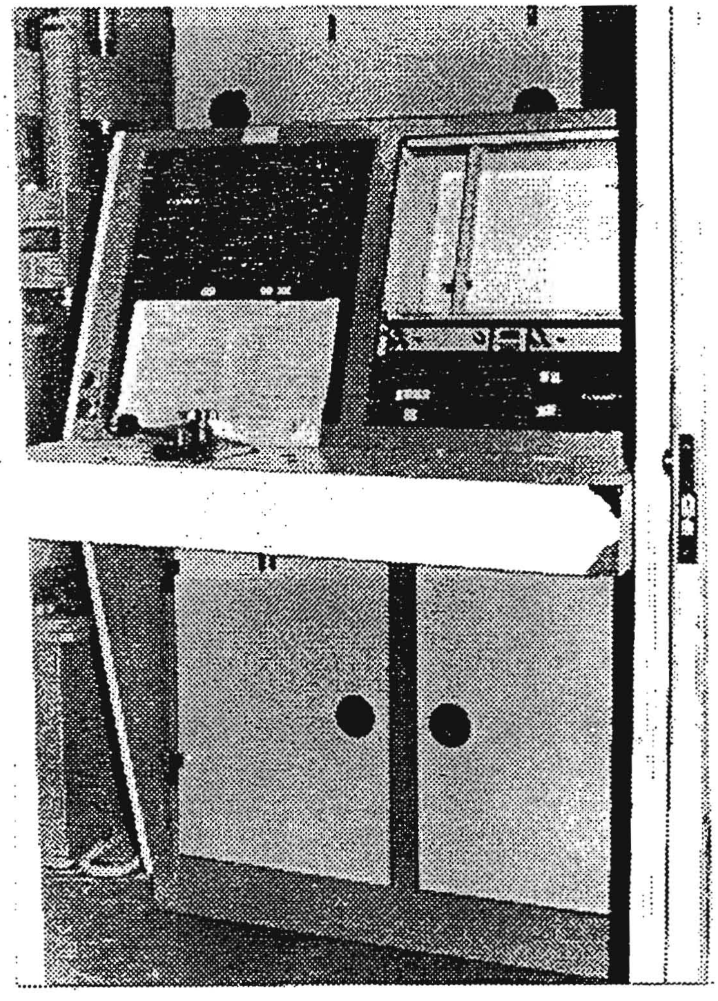


Figure 3.8 Forney Auto-Ranging Digital System

3.6 Data Reduction

As indicated before, each specimen was tested at three spans, 30.5 in., 12 in. (2 times) and 6 in. (4 times). The philosophy behind testing the specimens at such a wide range of spans follows. The 30.5 in. span is rather flexible. Therefore, the failure would occur in tension. The shear stress at the interface when tensile failure occurs is rather small. Typically, the shear stresses are on the order of 5 percent of tensile strengths.

For a 12 in. span the failure is again due to excessive tensile stresses. In this case, the tensile strengths are more or less the same as those from the 30.5 in. span; however, the shear stresses at failure are tripled. Typically, the shear stresses are 15 percent of the tensile strength. Tests with the 6 in. span were carried out to maximize the possibility of failure in shear (as apposed to tension). In this case, the shear stresses at failure are almost 1/3 of the tensile strengths. Unfortunately, no signs of failure in shear could be seen for this span either. Based upon the visual observation of the specimens all failures occurred in tension.

Given the fact that no shear stress failure could be achieved, it was decided to utilize the shear stress at tensile failure as a measure of bond at the interface of the overlay and the base concrete. This was based on the philosophy that the better the bond is, the more efficiently the overlay and the base concrete would react to the load; and therefore, the higher the tensile strength would be.

The shear strengths were calculated using equation below.

$$\tau = \frac{VQ}{Ib} \tag{3.1}$$

where:
- V = the shear at failure,
- Q = the first moment of the area above the overlay/base concrete interface,
- I = the moment of inertia, and
- b = the width of the beam

The specimens tested consisted of two different materials which would mean two different modulus of elasticity. The first layer, which was the base beam, had the age of at least 28 days and the second layer had the age of 1 day. The base specimen represented the old layer of pavement and the second layer represented the new overlay.

The modulus of elasticity of the base specimen was about 3900 ksi based upon compression tests. To obtain the modulus of elasticity of the concrete a series of tests were carried out on concrete cylinders using an ultrasonic device. The modulus of elasticity of the material was determined from 1 hour to 28 days after pouring for several specimens. The details of this study can be found in Zamora (1991). The best fit curve to the normalized modulus versus

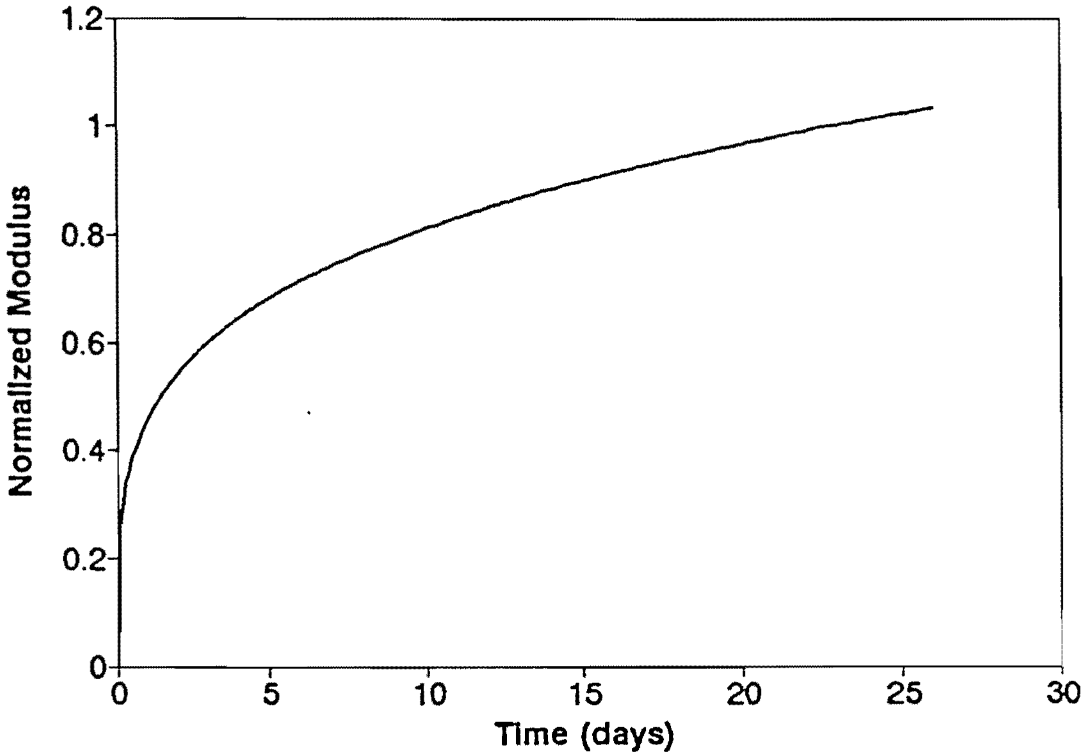


Figure 3.9 The Normalized Modulus versus Time

time for the overlay concrete is shown in Figure 3.9. The normalized modulus is defined as the ratio of modulus at a given time and modulus after 21 days. Based upon this study, the modulus of the overlay after one day was estimated as 1800 ksi.

The tensile stresses were calculated by using:

$$\sigma = \frac{MC}{I} \tag{3.2}$$

Where M = the moment at failure caused by the point load,
C = the distance from the neutral axis to the bottom extreme fiber, and
I = the moment of inertia of the transformed section.

The tensile strengths and shear stresses at failure are summarized in Appendix A. The tensile strengths were not directly utilized in this study, but are presented for completeness. Also shown in this appendix are the standard deviations associated with the average of the several tests conducted for spans of 6 in. and 12 in. The standard deviation should be a good indication of the repeatability of the results. In general, the results are quite repeatable with a typical coefficient of variation of less than 5 percent and a maximum of less than 10 percent. The same trend occurred for the shear stresses.

In the following chapter only the results from the 6 in. span are discussed. The reasons for this being that the result from the 6 in. span is the most critical in terms of shear and also because the results from the other spans are quite similar. For completeness, the results from 12 in. and 30.5 in. spans are summarized in Appendix A and are graphically shown in Appendix B.

To ensure the repeatability of results one other exercise was carried out. About 10 specimens were prepared under the same conditions and were tested. The results from this exercise, although not shown here, revealed an overall coefficient of variation of about 5 percent. Therefore, the results can be considered precise.

Typical results to be discussed in the next chapter are shown in Figure 3.10 as an example. The average shear stresses at failure at the interface of the overlay and base concrete are shown on the ordinate. Only results from the 6 in. span were utilized. Also shown on the figure is the highest theoretical shear stress at failure that one can expect should the whole cross-section has been constructed from the base material and cured for at least 28 days. The most desirable condition is of course when the shear stresses are close to this value.

The abscissa varies with the condition under study. For each case, the parameter of interest is selected for this axis. Typically, the results from several vibration levels are shown on the same graph.

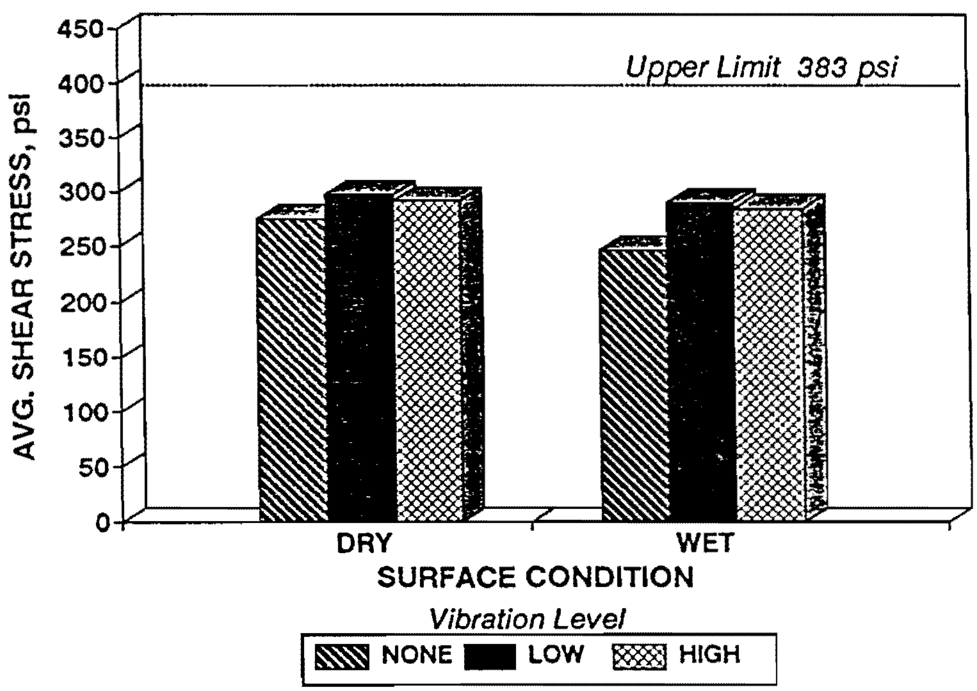


Figure 3.10 Typical Results Obtained from this Study

4

Presentation of Results

4.1 Introduction

In this chapter the results from tests discussed in the previous chapter are presented. Shear stresses at the interfaces of the base and the overlay at failure obtained from tests on all specimens are presented in Appendix B for completeness. In that appendix, the results from spans of 30.5 in., 12 in., and 6 in. are presented. However, as indicated before, only the results from the 6 in. span are discussed.

The effects of the surface condition at interface on the shear stresses were investigated by comparing results from the specimens with dry interfaces to those with wet interfaces. The effects of texture (smooth vs rough) at the interface were also studied. The results from the 2 in. overlays were compared to those of the 4 in. to determine the effects of increasing the thickness of the overlay on the interface bonding. The influence of the pre-vibration cure time is also investigated by comparing the results from three different pre-vibration cure times, 0, 4, and 12 hours.

4.2 Surface Condition

The shear stresses for dry surfaces and wet surfaces before pouring the overlay are compared in this section. The intention of this investigation was to determine the optimal moisture condition at the interface immediately before the placement of the overlay.

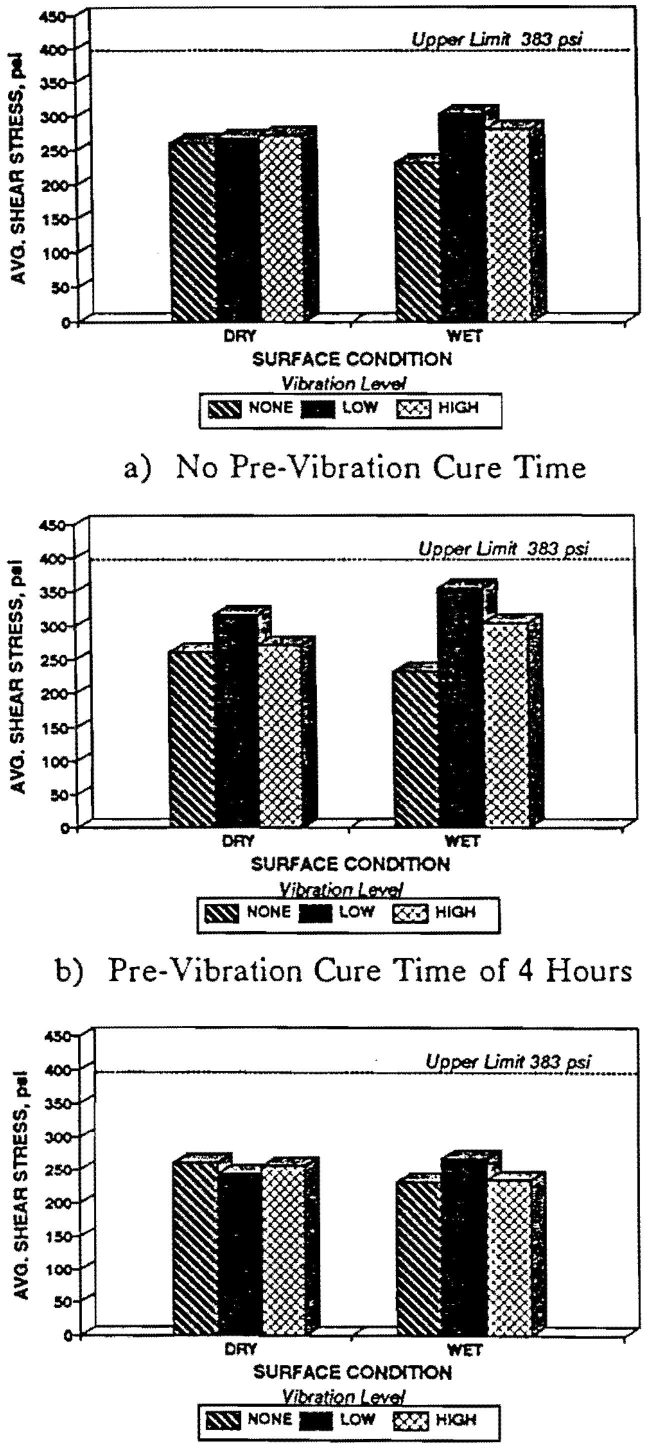
The shear stresses obtained from the smooth interfaces for 2 in. overlays are compared in Figure 4.1. When the specimens were not subjected to vibration, the dry conditions produced marginally better bonds. On the other hand, for the specimens vibrated at low levels, the wet surfaces resulted in higher shear stresses at failure. When the specimens were subjected to high vibration levels, the shear stresses measured exhibited a random pattern (depending on the pre-vibration cure time) and were more or less independent of the surface condition.

The shear stresses at failure at the interface of a 2 in. overlay for the rough surfaces and a span of 6 in. are presented in Figure 4.2. The results measured for the rough surfaces more or less confirm the results from the smooth surfaces. Once again, for specimens not subjected to vibration, the dry surfaces are desirable in terms of stronger bonds. For low levels of vibration, the wet surfaces may be slightly more appropriate. The only differences between the rough and smooth results may be for the case of high vibration levels. It seems that for this case, the wet surface may be slightly more appropriate.

The results from the smooth surfaces, when a 4 in. thick overlay was used are shown in Figure 4.3. In this case, the dry surfaces yielded more or less a constant shear stress at the interface, irrespective of the pre-vibration cure time or the level of vibration. The wet surface resulted in variable strengths. Under the wet surface condition, and no vibration, the highest stress at failure was achieved. The stresses were about 1.5 times of those obtained under dry condition.

For the low vibration levels, the stresses under wet surface condition widely varied with the pre-vibration cure time. Generally, as the pre-vibration cure time increased the stresses decreased. For no pre-vibration cure time, the wet condition yielded higher stresses as compared to the dry condition. When the specimens were cured for 4 hours before vibration, the wet and dry conditions yield similar stresses. Finally, the stresses at failure for the specimens with the wet surface were substantially lower (as compared to those under dry condition). When a pre-vibration cure time of 12 hours was permitted, the same trend was observed for high vibration levels, that is, the longer the pre-vibration cure times were permitted, the lower the stresses at failure for the wet surface became.

The results from experiments carried out on specimens with 4 in. overlays on rough interface are described in Figure 4.4. For pre-vibration cure times of zero and 4 hours, the stresses at failure are not affected by the level of vibration or the surface condition. In all these cases, the average shear stresses at failure are about 500 psi. However, when these specimens were

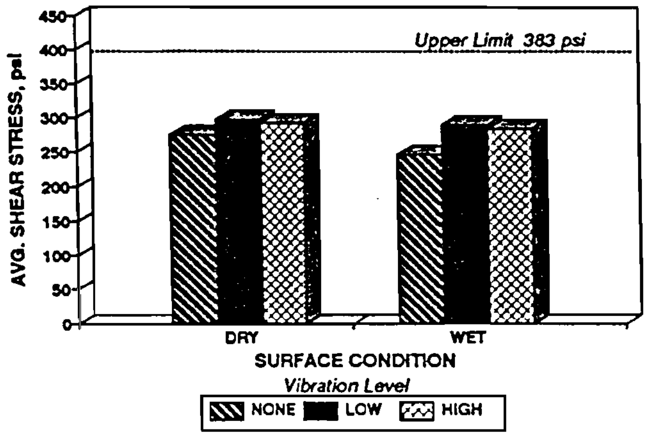


a) No Pre-Vibration Cure Time

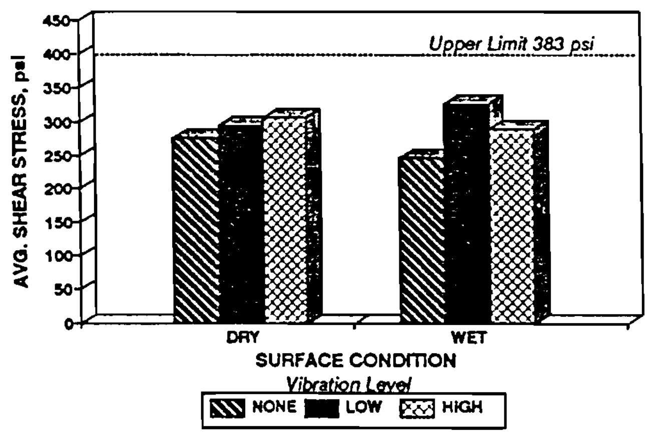
b) Pre-Vibration Cure Time of 4 Hours

c) Pre-Vibration Cure Time of 12 Hours

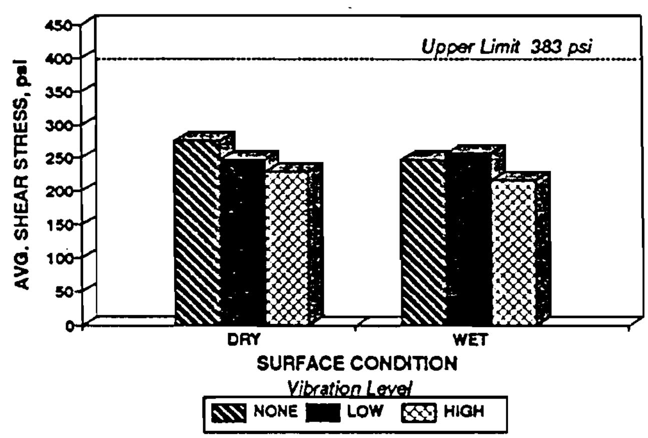
Figure 4.1 Comparison of Average Shear Stresses at Failure for 2 in. Overlays (Smooth Surface)



a) No Pre-Vibration Cure Time

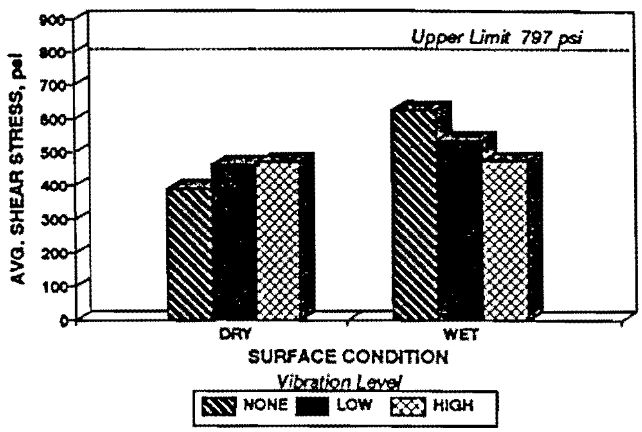


b) Pre-Vibration Cure Time of 4 Hours

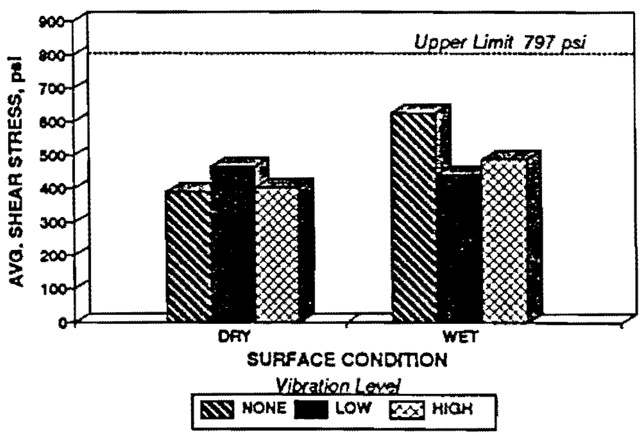


c) Pre-Vibration Cure Time of 12 Hours

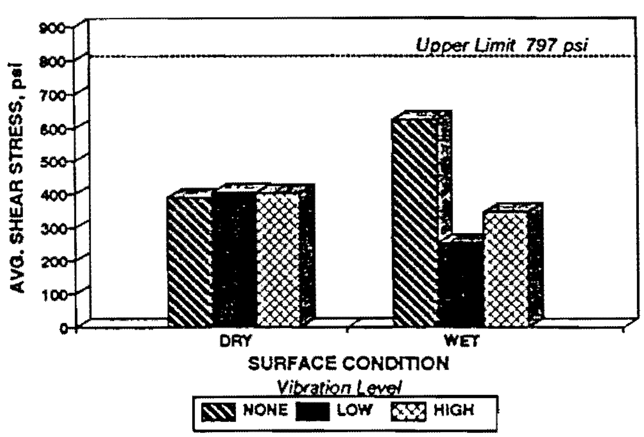
Figure 4.2 Comparison of Average Shear Stresses at Failure for 2 in. Overlays (Rough Surface)



a) No Pre-Vibration Cure Time

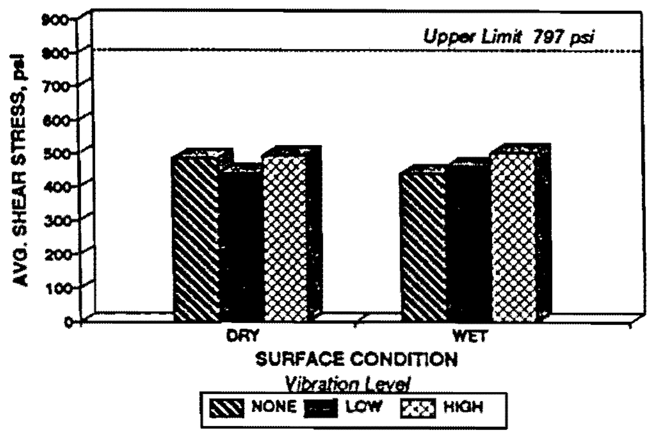


b) Pre-Vibration Cure Time of 4 Hours

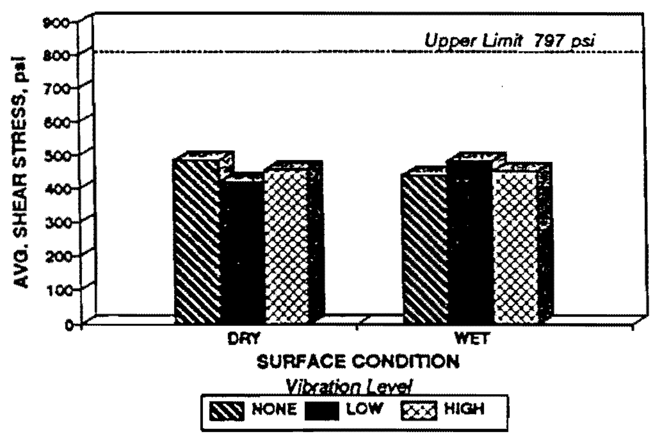


c) Pre-Vibration Cure Time of 12 Hours

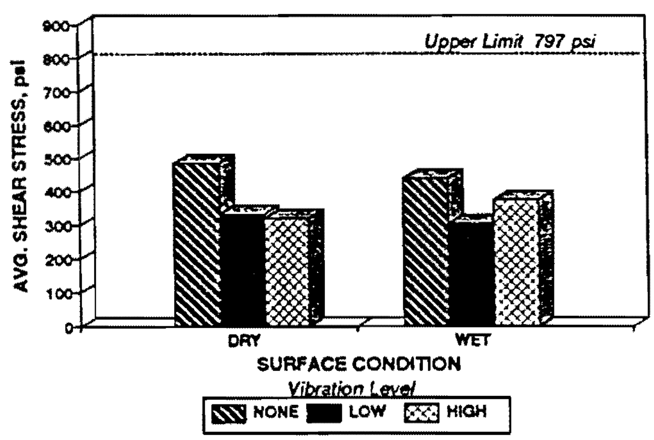
Figure 4.3 Comparison of Average Shear Stresses at Failure for 4 in. Overlays (Smooth Surface)



a) No Pre-Vibration Cure Time



b) Pre-Vibration Cure Time of 4 Hours



c) Pre-Vibration Cure Time of 12 Hours

Figure 4.4 Comparison of Average Shear Stresses at Failure for 4 in. Overlays (Rough Surface) cured for 12 hours, the shear stresses drastically decrease under low or high vibration levels. In these conditions the average shear stresses are closer to 320 psi.

4.3 Surface Texture

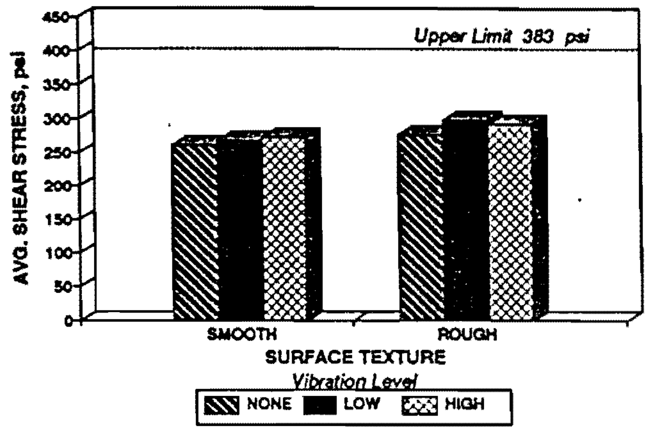
In this section, the focus of the study is on the effects of the surface texture (rough vs smooth) on the shear stresses measured at failure. The motivation behind this section is to determine if scarifying the interface would improve the bond between the overlay and the base concrete.

For 2 in. overlays and dry interfaces, the surface texture was not a factor in the measured shear stresses at failure. As shown in Figure 4.5, independent of the surface texture and the level of vibration, the average shear stresses are about 70 percent of those of a solid cross section made from the base concrete. Similar results were obtained when the interfaces were wetted before pouring the overlays (see Figure 4.6). However, more fluctuation in results for different levels of vibration could be observed. In general, for 2 in. overlays over the wet interfaces, the low levels of vibration resulted in slightly higher shear stresses at failure for the smooth surfaces. However, higher levels of vibrations may or may not improve the interface bonds for the rough or the smooth interfaces.

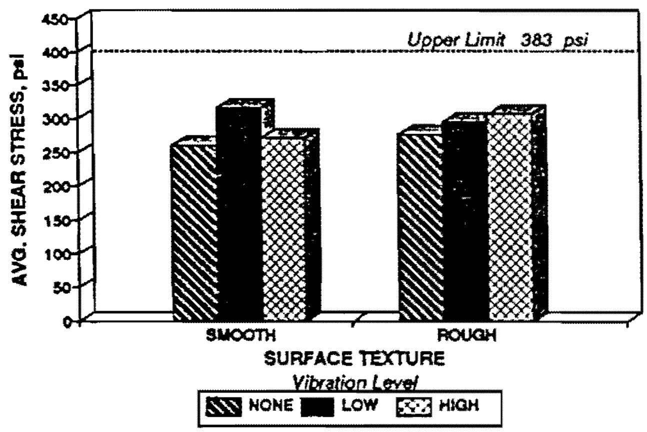
When specimens with 4 in. overlays were tested, the effects of surface texture were tied with the effects of pre-vibration cure time (see Figure 4.7). For no pre-vibration cure time, the specimens tested under the smooth or rough textures did not yield substantially different bonds, as shown in Figure 4.7a. This trend was more or less observed for the specimens cured for 4 hours. However, as shown in Figure 4.7c, for specimens which were allowed to cure for 12 hrs before vibration, specimens with the smooth textures yielded higher shear stresses at failure.

One point to discuss is that under static curing (i.e. when specimens were not subjected to vibration at all) the shear stresses at failure for the specimens with a rough texture were higher than those made with a smooth surface.

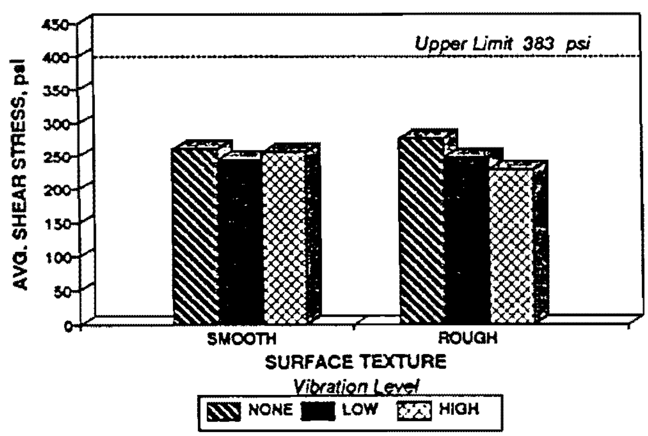
The most significant effects of the surface texture can be seen for the 4 in. overlays placed over a wet surface (Figure 4.8). In this case, under the static condition, the smooth texture yielded the highest interface bond. Under the static condition, the specimens tested with rough surfaces yielded 50 percent of the bond stress obtained from the smooth surface. Under the high and low vibration levels, the specimens tested with the rough and smooth textures yielded more of less the same results. The results from the two surface textures are in reasonable agreement.



a) No Pre-Vibration Cure Time

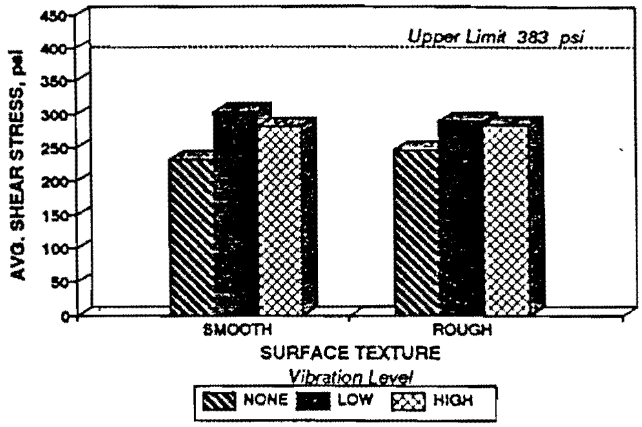


b) Pre-Vibration Cure Time of 4 Hours

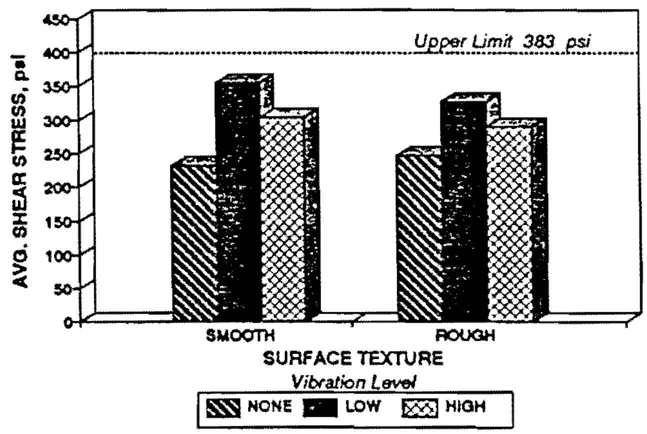


c) Pre-Vibration Cure Time of 12 Hours

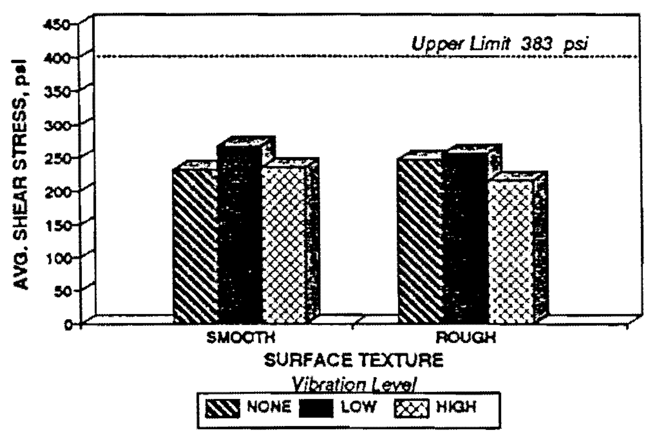
Figure 4.5 Comparison of Average Shear Stresses at Failure for 2 in. Overlays (Dry Interface)



a) No Pre-Vibration Cure Time

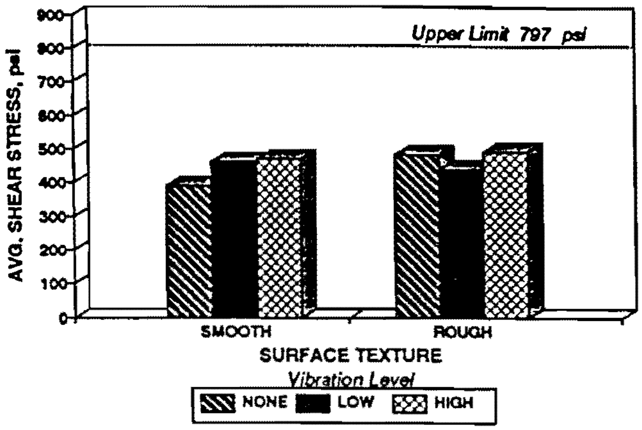


b) Pre-Vibration Cure Time of 4 Hours

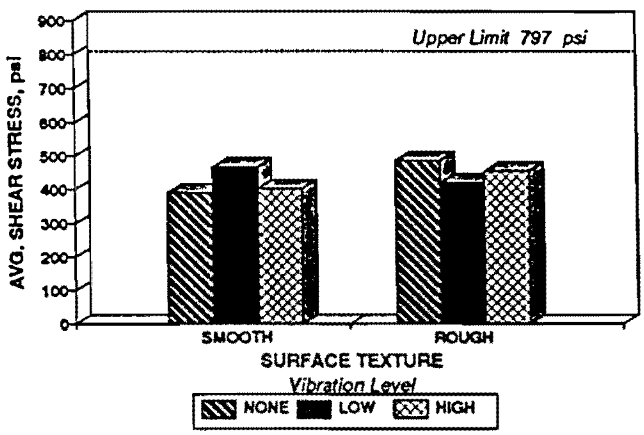


c) Pre-Vibration Cure Time of 12 Hours

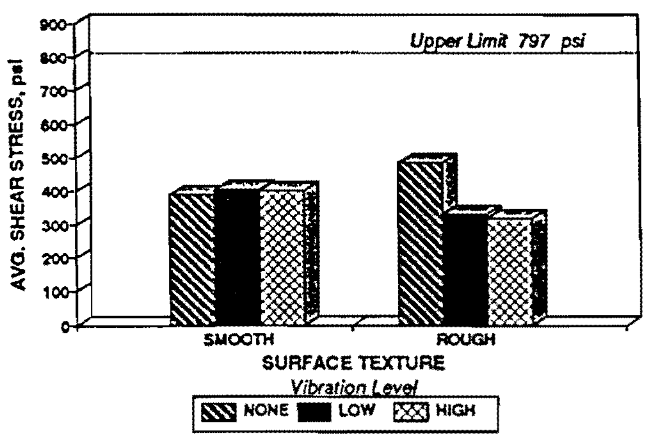
Figure 4.6 Comparison of Average Shear Stresses at Failure for 2 in. Overlays (Wet Interface)



a) No Pre-Vibration Cure Time

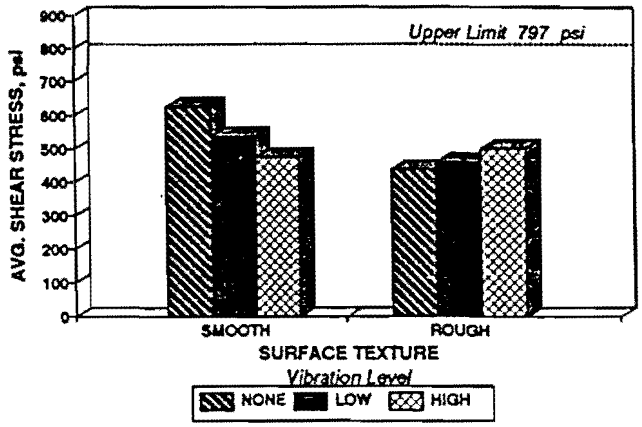


b) Pre-Vibration Cure Time of 4 Hours

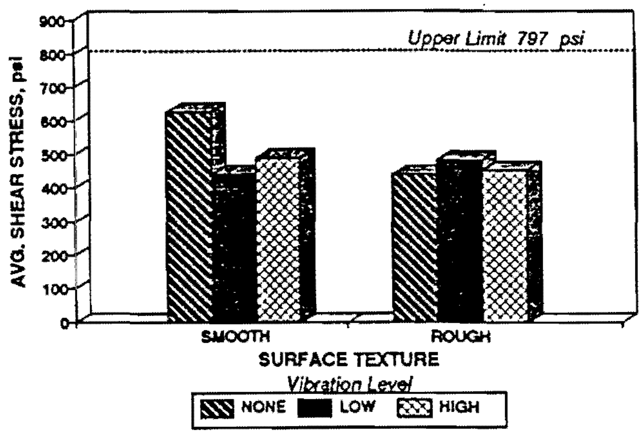


c) Pre-Vibration Cure Time of 12 Hours

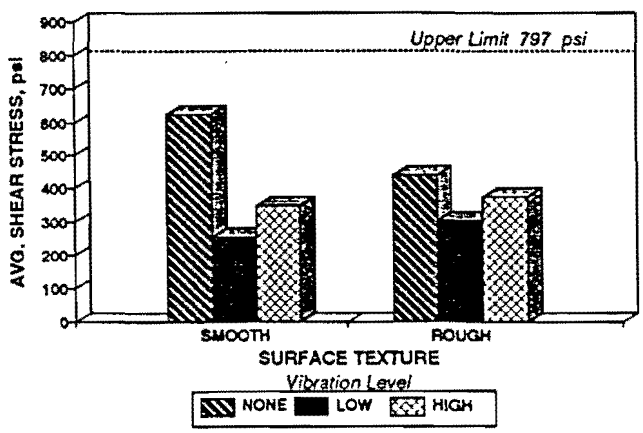
Figure 4.7 Comparison of Average Shear Stresses at Failure for 4 in. Overlays (Dry Interface)



a) No Pre-Vibration Cure Time



b) Pre-Vibration Cure Time of 4 Hours



c) Pre-Vibration Cure Time of 12 Hours

Figure 4.8 Comparison of Average Shear Stresses at Failure for 4 in. Overlays (Wet Interface)

4.4 Pre-vibration Cure Time

One major question is the effects of pre-vibration cure time on the bond strength. As discussed before, the pre-vibration cure time corresponds to the traffic closure after pouring the overlay.

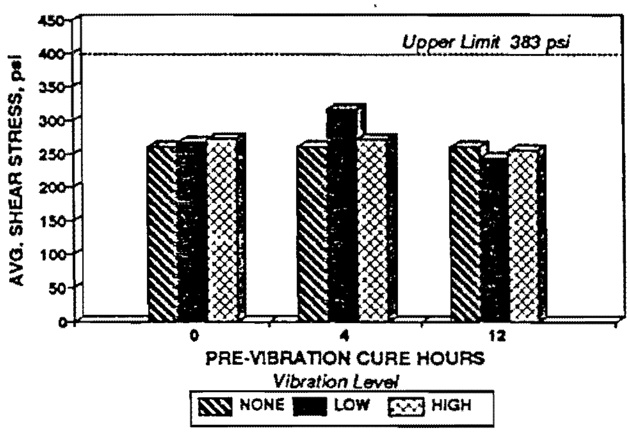
In Figure 4.9, the variation in shear stress at interface as a function of pre-vibration cure time for 2 in. thick overlays are shown. For a smooth dry surface, all experiments more or less yielded a constant stress. This stress is about 70 percent of the shear stress at failure of a solid beam with the same height at the same fiber as the interface of the base and overlay. This means that the effective stress at failure is about 70 percent of a solid beam made from the base concrete and cured for 28 days.

As shown in Figure 4.9b, for rough dry surfaces, the results are similar to those of smooth dry surface with one exception. It seems that rough dry surfaces are not suitable for cases when the bridge is closed for a period of time. The shear stresses at failure for specimens subjected to vibration (either high or low levels) after 12 hours of curing are lower. Ignoring this case, the average shear stress at failure for the rough dry surfaces is about 75 percent which is slightly above the stress at failure for the smooth dry surfaces (70 percent).

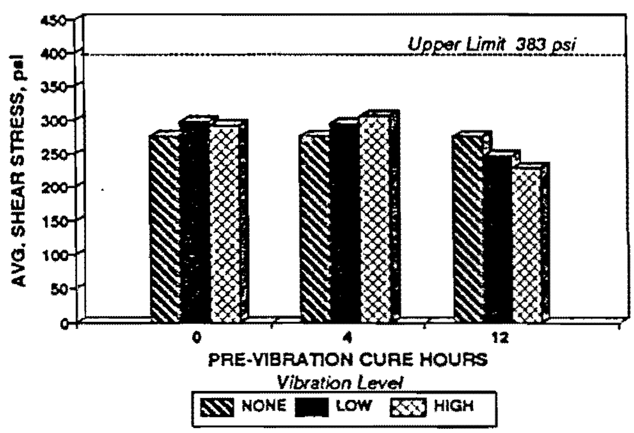
The results for the same 2 in. overlay, but for wet interfaces are presented in Figure 4.10. For wet interfaces, as for the dry rough case (shown in Figure 4.9b), extended cure time without vibration are nor recommended. The average shear stress at failure for wet interfaces (either rough or smooth) is about 60 percent of the intact specimens. For no or short pre-vibration cure times the shear stresses for specimens are higher then those subjected to 12 hrs of pre-vibration cure time. In general, the vibration improves the bond between the base and overlay layers. Especially, specimens subjected to lower levels of vibration exhibit the highest shear stress at failure. In addition, 4 hours of pre-vibration cure time improves the bond. The highest shear stresses obtained, which are about 90 percent of those of solid specimens, are for the cases when the specimens are cured for 4 hrs before vibration and then subjected to vibration. The lowest stresses are obtained when the specimens were allowed to cure for 12 hrs before being subjected to vibration.

The shear stresses at failure for the 4 in. overlays as a function of pre-vibration cure time are shown in Figures 4.11 and 4.12 for the dry and wet surfaces, respectively. The results are similar to those of the 2 in. overlay. Specimens subjected to 12 hrs of pre-vibration cure time and then subjected to traffic yielded much smaller shear stresses at failure except when the interface was smooth and dry.

For the smooth and dry interface, the shear stresses at failure were constant and equal to about 50 percent of the shear from a solid cross-section of the same height (Figure 4.11a). Ignoring the cases when the specimens were subjected to 12 hours of pre-vibration cure time, the specimens poured on rough dry bases resulted in slightly higher shear stresses at failure. As shown in Figure 4.11b, the shear stresses at failure average about 55 to 60 percent of

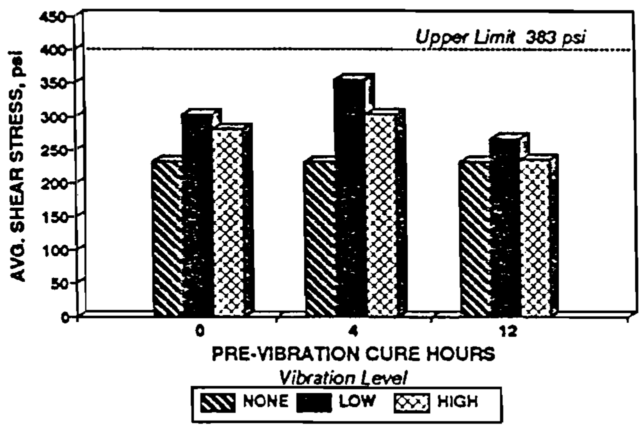


a) Smooth Surface

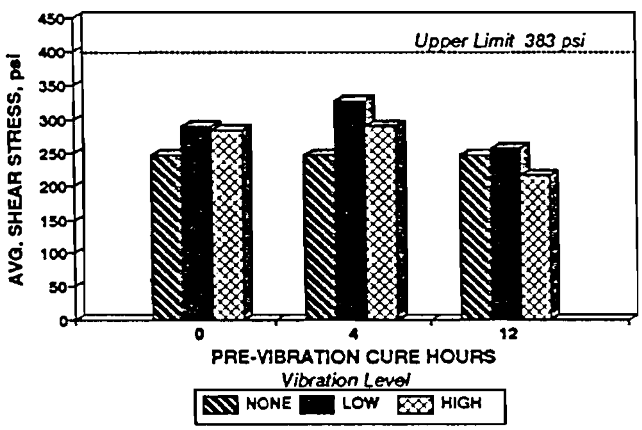


b) Rough Surface

Figure 4.9 Comparison of Average Shear Stresses at Failure for 2 in. Overlays after Pre-Vibration Cure Time (Dry Interface)

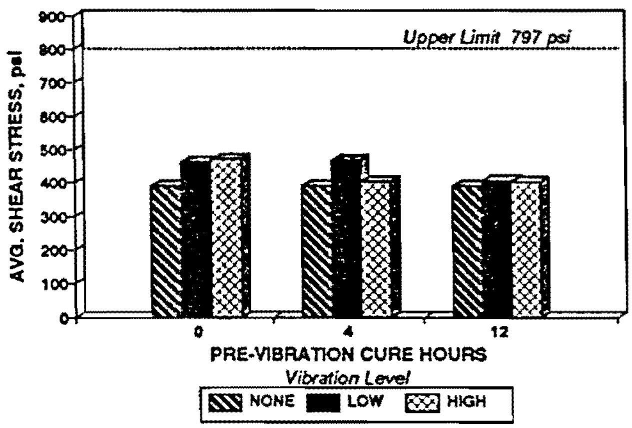


a) Smooth Surface

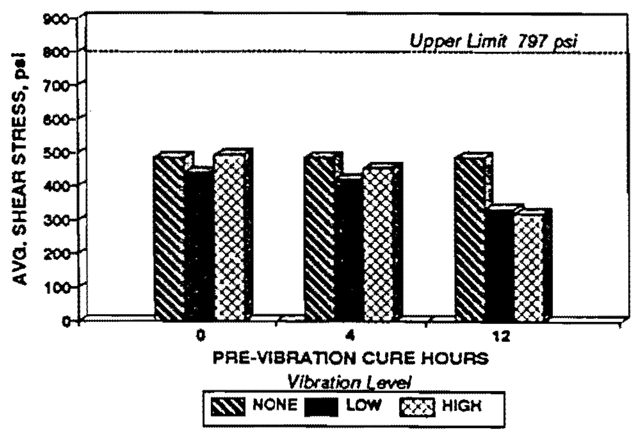


b) Rough Surface

Figure 4.10 Comparison of Average Shear Stresses at Failure for 2 in. Overlays after Pre-Vibration Cure Time (Wet Interface)

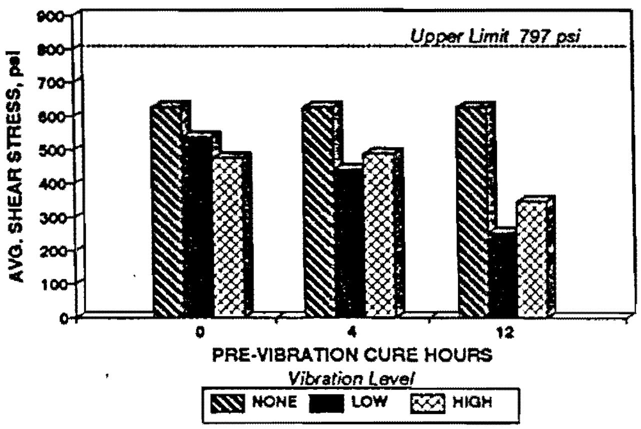


a) Smooth Surface

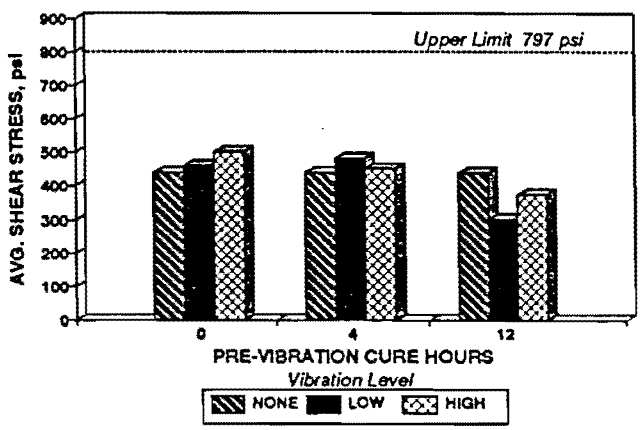


b) Rough Surface

Figure 4.11 Comparison of Average Shear Stresses at Failure for 4 in. Overlays after Pre-Vibration Cure Time (Dry Interface)



a) Smooth Surface



b) Rough Surface

Figure 4.12 Comparison of Average Shear Stresses at Failure for 4 in. Overlays after Pre-Vibration Cure Time (Wet Interface) those for the solid cross section. When the smooth wet interfaces are considered for 4 in. overlays the vibration resulted in reduced shear stresses as compared to the static conditions (Figure 4.12a). It seems that for the thicker overlays the best bonds are obtained when the specimens are not vibrated at all for 24 hours. The shear stress for the specimens subjected to low and high vibration levels after less than 4 hrs of pre-vibration cure are less than the corresponding static stresses; it is interesting to note that they are still larger than or close to those obtained from the dry surfaces.

In Figure 4.12b the results form tests performed on specimens poured on rough wet surfaces. The results are quite similar to those obtained from the rough dry surfaces. The average shear stresses at failure for all cases except those cured for 12 hrs are greater than 55 percent of the stresses obtained from the solid beam.

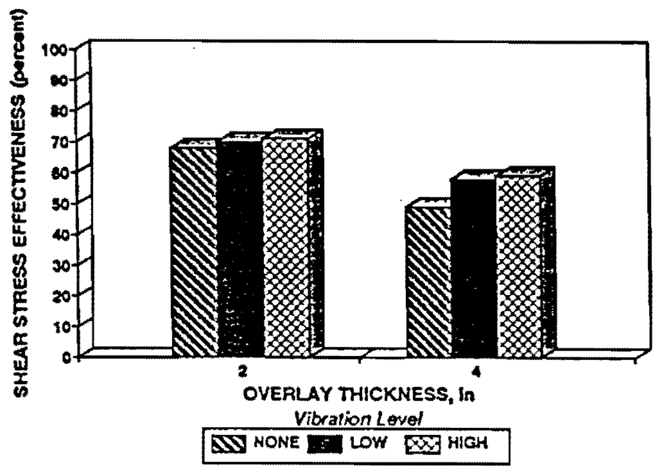
4.5 Thickness of Overlay

The impact of increasing the thickness of the overlays is demonstrated by comparing the effectiveness of the interface bonding between 2 in. and 4 in. thick overlays. The effectiveness of interface bonding is defined as the ratio of the average shear stress at failure of specimens to the shear stress at failure of a solid beam made from the base material with the same height and at the same fiber as the interface of the base and overlay. In general, the 4 in. overlays yielded lower effectiveness. In other words, the interface shear stresses at failure, was a lower percentage of the shear stress at the same fiber from a solid beam. However, as the shear stresses at failure for a solid beam was substantially higher for this case, the overall interface shear stresses are higher for the 4 in. overlays.

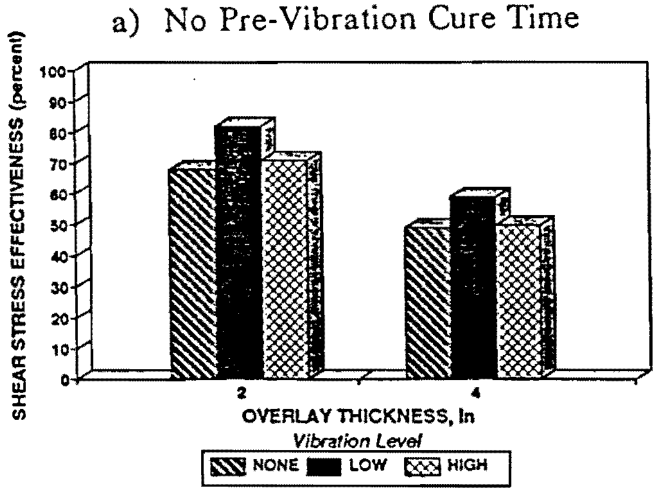
Shear stresses from 2 in. and 4 in. thick overlays with smooth-dry interfaces are compared in Figure 4.13. Typically, for the 2 in. overlays, the shear stress effectiveness was more or less constant and about 70 percent. The only exception may be the case when a pre-vibration cure time of 4 hours was allowed and then the specimen was subjected to medium levels of vibration. Similarly for the 4 in. overlays, the shear stress effectiveness was more or less constant and varied from 49 to 59 percent with an average of 55 percent.

The shear stress effectiveness as a function of overlay thickness for the smooth-wet interfaces are illustrated in Figure 4.14. Contrary to the smooth-dry condition, the effectiveness widely varies as a function of level of vibration as well as the pre-vibration cure time. For 2 in. overlays, the highest effectiveness is achieved when the specimens were subjected to low-levels of vibration. The lowest values were obtained from the specimens not subjected to vibration. Once again, the highest effectiveness was achieved when the specimen was cured for 4 hours and then subjected to vibration.

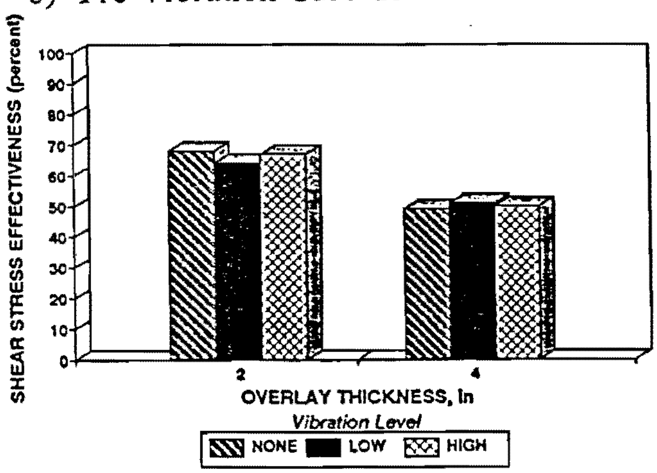
For the 4 in. thick overlays, the results were extremely dependent upon the level of vibration and the cure time. For the static condition, i.e. when specimens were not subjected to vibration, the highest effectiveness was achieved. This effectiveness is about 78 percent.



a) No Pre-Vibration Cure Time

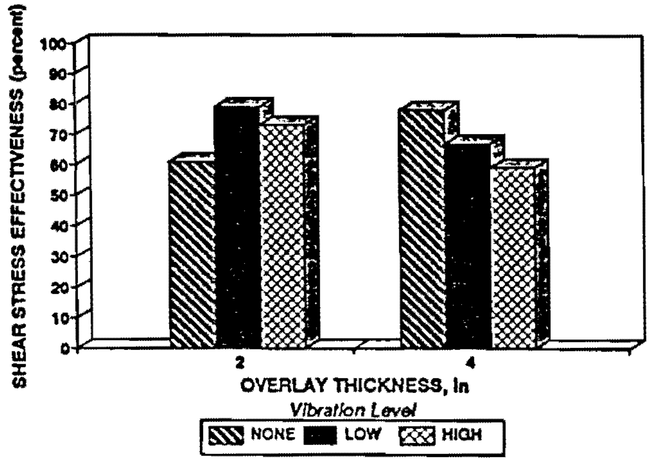


b) Pre-Vibration Cure Time of 4 Hours

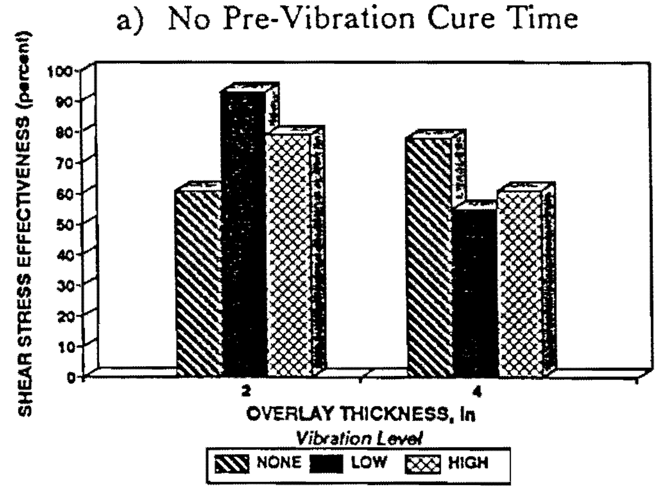


c) Pre-Vibration Cure Time of 12 Hours

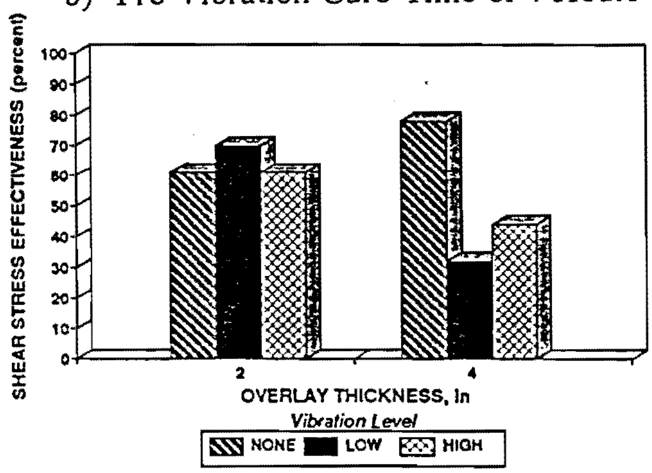
Figure 4.13 Comparison of Effectiveness of Interface Bonding of Specimens with Smooth-Dry Interface



a) No Pre-Vibration Cure Time



b) Pre-Vibration Cure Time of 4 Hours



c) Pre-Vibration Cure Time of 12 Hours

Figure 4.14 Comparison of Effectiveness of Interface Bonding of Specimens with Smooth-Wet Interface

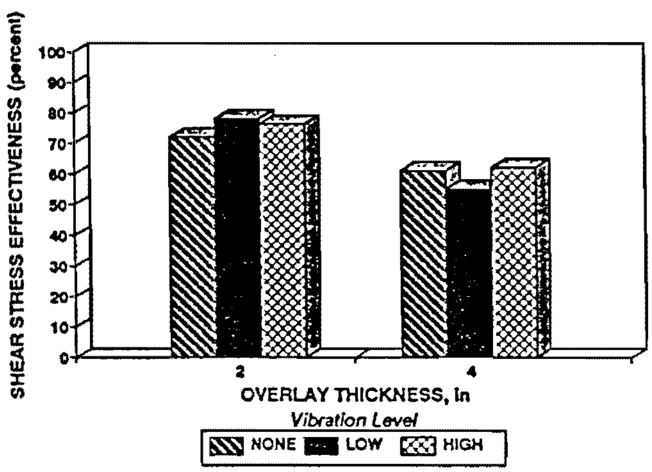
For low vibration levels, the effectiveness was related to the pre-vibration cure time. The effectiveness decreased from 67 percent for the no pre-vibration cure time case to 55 percent for 4 hrs of cure time to 32 percent for 12 hours of pre-vibration cure time.

For high vibration levels, trends similar to those of the low vibration levels were observed. However, the differences between the no-pre-vibration cure time and 4-hours pre-vibration cure time were small. The effectiveness values of bond as a function of overlay thickness for different pre-vibration cure time are shown in Figure 4.15 for the rough dry interface. For the 2 in. thick overlays, the level of vibration does not effect the effectiveness of bond for no or 4 hrs pre-vibration cure time. In all those cases, the effectiveness is about 70 to 80 percent. However, extended pre-vibration cure time (i.e. 12 hours) resulted in some reduction in effectiveness as the vibration levels increased.

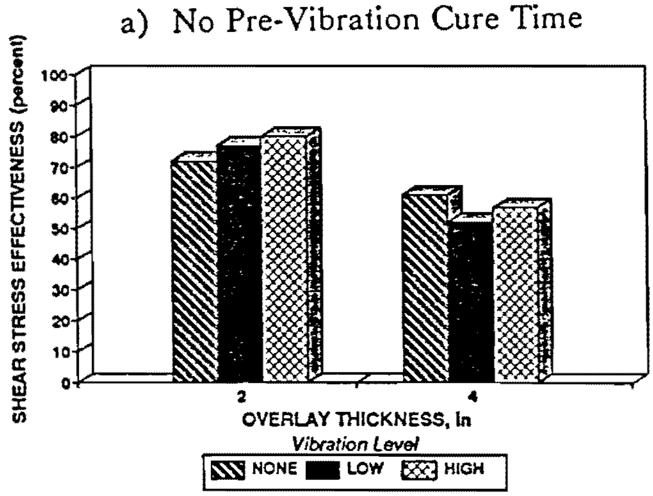
Results from the 4 in. overlays exhibited similar trends. For the zero and 4 hours pre-vibration cure times, the effectiveness is about 55 to 60 percent. However for the 12 hrs pre-vibration cure time the effectiveness is only about 40 percent.

The last parameter studied was the effect of thickness on the effectiveness for the rough-wet interfaces. The results are demonstrated in Figure 4.16. For the 2 in. overlays, the vibration level would result in an increase in effectiveness for almost all pre-vibration cure times. The only exception was for the case of 12 hours of pre-vibration cure time and high vibration levels where the effectiveness was reduced by about 10 percent. The highest bond was achieved when the specimens was cured for 4 hours and then subjected to low levels of vibration.

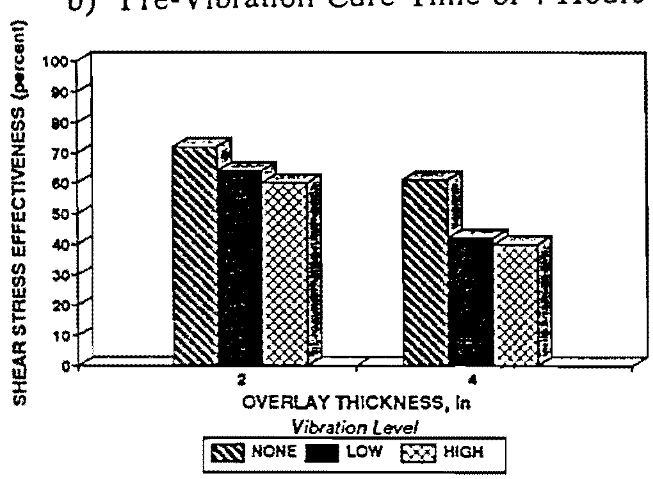
For the 4 in. overlays, the effect of vibration was small. The effectiveness either increased or decreased slightly in almost all cases. The exception was in the case when the specimens was subjected to 12 hours of pre-vibration cure time and then subjected to low levels of vibration.



a) No Pre-Vibration Cure Time

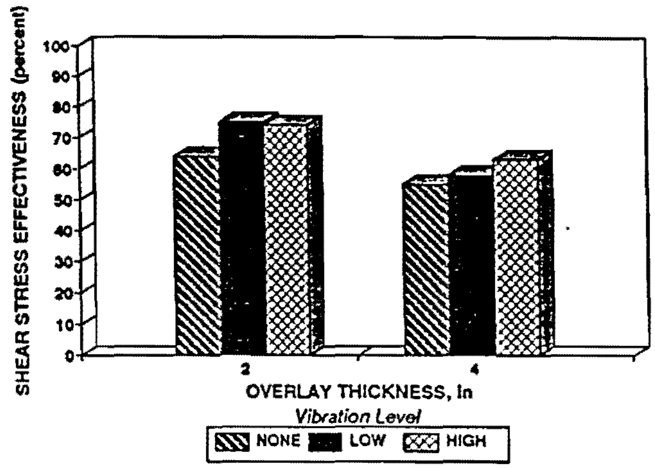


b) Pre-Vibration Cure Time of 4 Hours

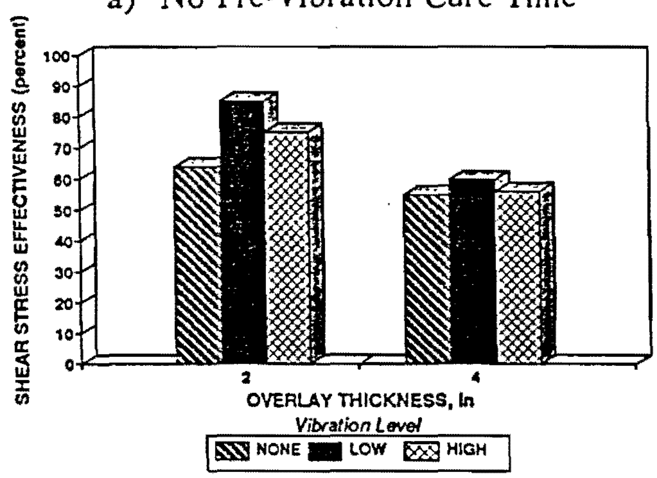


c) Pre-Vibration Cure Time of 12 Hours

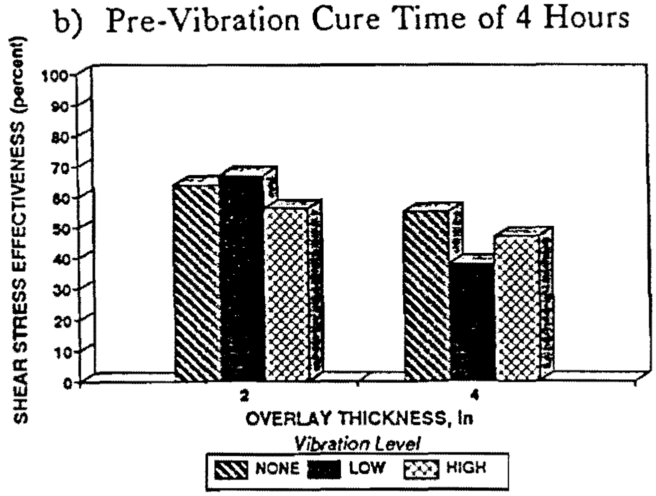
Figure 4.15 Comparison of Effectiveness of Interface Bonding of Specimens with Rough-Dry Interface



a) No Pre-Vibration Cure Time



b) Pre-Vibration Cure Time of 4 Hours



c) Pre-Vibration Cure Time of 12 Hours

Figure 4.16 Comparison of Effectiveness of Interface Bonding of Specimens with Rough-Wet Interface

5

Closure

5.1 Summary

Thin-bonded concrete overlays have been used by the Texas Department of Transportation for many years. These overlays have been used for different applications. Many existing pavement sections have been overlaid with concrete for rehabilitation purposes. Concrete overlays are also used on structures to provide for a durable riding surface. Several research projects have been conducted to determine the best construction process for concrete overlays on different types of pavements. However, little research has been conducted on concrete overlays placed on structures.

During the widening of Interstate 10, in El Paso, Texas, the thin-bonded concrete overlays began to show signs of distress only 8 months after their placement. The overlays had delaminated and debonded to an extent which required replacement. These concrete overlays were placed on new structures which were constructed in phases. This construction phasing subjected the thin-bonded overlays the vehicular vibrations from the adjacent lanes during the placement and curing of the concrete overlay. These vibrations were suspected as being partially responsible for causing the concrete overlays to delaminate and debond after an investigation of all construction records was conducted.

This research project was conducted in order to determine the effects of vehicular vibration on debonding and delamination of concrete overlay. Several parameters involved in concrete overlays were investigated. The effects of the overlay thickness, pre-vibration cure time, surface wetness, surface texture amplitude of vibration and vibration mode were studied. A laboratory experiment involving 3 ft long beams was developed. Several tests were conducted on these specimens. The results were recorded and then analyzed to determine the parameters which affected the bond strength of the concrete overlays the most and to determine under which conditions the best bonds were obtained.

5.2 Conclusions and Practical Considerations

The following conclusions can be drawn from the tests performed.

5.2.1 Wet versus Dry Interface. For rough or smooth interfaces, when 2 in. overlays are utilized, the wet interfaces yield better or equal bond strengths compared with dry surfaces. However, for thicker overlays generally wet smooth surfaces are not desirable. For thicker overlays on rough surfaces, the surface moisture condition (wet vs dry) does not contribute to the bond strength.

5.2.2 Smooth versus Rough Interface. For 2 in. overlays, the texture of the interface (i.e. rough vs smooth) does not seem to be a factor of significance for either wet or dry interfaces. For 4 in. overlays placed on dry interfaces, the surface texture is again of no consequence. However, for the same thickness of overlays but when the interface is wet, the bond strength is a function of pre-vibration cure time and vibration level. For static conditions, the smooth surface yields the strongest bond. As the level of vibration and pre-vibration cure time increase, the rough interfaces are more desirable for wet conditions.

5.2.3 Pre-Vibration Cure Time. For 2 in. overlays on smooth, dry interfaces, the pre-vibration cure time would not improve the bond strength. However, if wet, smooth interfaces are utilized, pre-vibration cure time may result in lower bond strength. It seems that the water acts as a lubricant interrupting the bond development.

On roughened surfaces, both wet and dry, short periods of cure time is desirable before vibration. However, the closure of the overlay to heavy traffic for 12 hrs seems to be detrimental. Either a longer closure period should be scheduled or the heavier vehicles should be rerouted. Results from thicker overlays support the conclusions for the 2 in. overlays.

5.2.4 Overlay Thickness. In general, 4 in. overlays are less effective in bond development than 2 in. overlays. The interface shear stresses at failure is a lower percentage of the shear stress at the same fiber from a solid beam. However, as the shear stresses at failure for the solid beams is substantially higher for the thicker overlay, the overall interface bond is higher for this case.

5.3 Direction for Future Work

In this work, the focus was on the bending mode of vibration using large laboratory specimens. However, as the base beams were not reinforced, all failures occurred due to excess tensile stresses at the bottom fiber of the beam, (instead of shear failure). In the next phase of this project, similar experiments will be followed but with reinforced base beams. In this manner, shear failure would occur.

Also the results from tests in bending on larger specimens will be combined with those reported by Rodriguez-Gomez and Nazarian (1992) to develop practical and implementable recommendations.

APPENDIX A

Table A.1 Average Shear Stresses and Tensile Strengths with 2 in. Overlays after 0 hrs. of Pre-vibration Cure Time (Smooth Surface)

a) Wet Interface

Span (in)	Vibration Level	Shear Stresses, psi		Tensile Strength, psi	
		Average	Std. Dev	Average	Std. Dev
30.5	None	34 *	-	675 *	-
	Low	48 *	-	943 *	-
	High	40 *	-	791 *	-
12	None	110	5	848	38
	Low	136	1	1056	4
	High	117	5	904	36
6	None	233	5	900	18
	Low	303	10	1171	39
	High	281	31	1086	119

b) Dry Interface

Span (in)	Vibration Level	Shear Stresses, psi		Tensile Strength, psi	
		Average	Std.Dev	Average	Std. Dev
30.5	None	37 *	-	737 *	-
	Low	40 *	-	787 *	-
	High	41 *	-	798 *	-
12	None	118	2	914	15
	Low	125	7	966	55
	High	115	3	890	24
6	None	261	13	1008	49
	Low	268	12	1036	48
	High	272	11	1053	43

* - Only one value is available

Table A.2 Average Shear Stresses and Tensile Strengths with 2 in. Overlays after 0 hrs. of Pre-vibration Cure Time (Rough Surface)

a) Wet Interface

Span (in)	Vibration Level	Shear Stresses, psi		Tensile Strength, psi	
		Average	Std. Dev	Average	Std. Dev
30.5	None	38 *	-	740 *	-
	Low	41 *	-	809 *	-
	High	33 *	-	643 *	-
12	None	112	8	866	60
	Low	134	5	1040	41
	High	126	8	977	63
6	None	247	14	955	56
	Low	290	12	1121	45
	High	284	23	1099	91

b) Dry Interface

Span (in)	Vibration Level	Shear Stresses, psi		Tensile Strength, psi	
		Average	Std.Dev	Average	Std. Dev
30.5	None	36 *	-	704 *	-
	Low	43 *	-	849 *	-
	High	43 *	-	852 *	-
12	None	121	10	935	81
	Low	131	3	1015	24
	High	141	1	1088	9
6	None	276	23	1067	89
	Low	297	24	1151	93
	High	291	6	1128	22

* - Only one value is available

Table A.3 Average Shear Stresses and Tensile Strengths with 2 in. Overlays after 4 hrs. of Pre-vibration Cure Time (Smooth Surface)

a) Wet Interface

Span (in)	Vibration Level	Shear Stresses, psi		Tensile Strength, psi	
		Average	Std. Dev	Average	Std. Dev
30.5	None	34 *	-	675 *	-
	Low	49 *	-	972 *	-
	High	46 *	-	899 *	-
12	None	110	5	848	38
	Low	137	2	1063	17
	High	145	9	1124	67
6	None	233	5	900	18
	Low	355	33	1373	126
	High	304	35	1175	134

b) Dry Interface

Span (in)	Vibration Level	Shear Stresses, psi		Tensile Strength, psi	
		Average	Std.Dev	Average	Std. Dev
30.5	None	37 *	-	737 *	-
	Low	52 *	-	1022 *	-
	High	42 *	-	834 *	-
12	None	118	2	914	15
	Low	144	3	1111	20
	High	119	7	920	54
6	None	261	13	1008	49
	Low	316	15	1222	59
	High	272	32	1051	122

* - Only one value is available

Table A.4 Average Shear Stresses and Tensile Strengths with 2 in. Overlays after 4 hrs. of Pre-vibration Cure Time (Rough Surface)

a) Wet Interface

Span (in)	Vibration Level	Shear Stresses, psi		Tensile Strength, psi	
		Average	Std. Dev	Average	Std. Dev
30.5	None	38 *	-	740 *	-
	Low	49 *	-	972 *	-
	High	49 *	-	968 *	-
12	None	112	8	866	60
	Low	140	14	1082	110
	High	136	6	1051	48
6	None	247	14	955	56
	Low	326	14	1263	54
	High	290	13	1120	50

b) Dry Interface

Span (in)	Vibration Level	Shear Stresses, psi		Tensile Strength, psi	
		Average	Std.Dev	Average	Std. Dev
30.5	None	36 *	-	704 *	-
	Low	46 *	-	896 *	-
	High	47 *	-	921 *	-
12	None	121	10	935	81
	Low	138	15	1065	113
	High	142	12	1095	90
6	None	276	23	1067	89
	Low	294	16	1137	61
	High	306	22	1184	87

* - Only one value is available

Table A.5 Average Shear Stresses and Tensile Strengths with 2 in. Overlays after 12 hrs. of Pre-vibration Cure Time (Smooth Surface)

a) Wet Interface

Span (in)	Vibration Level	Shear Stresses, psi		Tensile Strength, psi	
		Average	Std. Dev	Average	Std. Dev
30.5	None	34 *	-	675 *	-
	Low	39 *	-	776 *	-
	High	43 *	-	849 *	-
12	None	110	5	848	38
	Low	105	4	8166	31
	High	107	10	825	80
6	None	233	5	900	18
	Low	267	16	1034	64
	High	235	11	911	44

b) Dry Interface

Span (in)	Vibration Level	Shear Stresses, psi		Tensile Strength, psi	
		Average	Std.Dev	Average	Std. Dev
30.5	None	37 *	-	737 *	-
	Low	40 *	-	783 *	-
	High	40 *	-	791 *	-
12	None	118	2	914	15
	Low	105	9	813	68
	High	104	10	809	79
6	None	261	13	1008	49
	Low	244	18	9466	70
	High	256	22	991	86

* - Only one value is available

Table A.6 Average Shear Stresses and Tensile Strengths with 2 in. Overlays after 12 hrs. of Pre-vibration Cure Time (Rough Surface)

a) Wet Interface

Span (in)	Vibration Level	Shear Stresses, psi		Tensile Strength, psi	
		Average	Std. Dev	Average	Std. Dev
30.5	None	38 *	-	740 *	-
	Low	40 *	-	794 *	-
	High	31 *	-	617 *	-
12	None	110	5	848	38
	Low	12	3	977	25
	High	96	8	742	60
6	None	233	5	900	18
	Low	257	7	994	26
	High	216	14	837	56

b) Dry Interface

Span (in)	Vibration Level	Shear Stresses, psi		Tensile Strength, psi	
		Average	Std.Dev	Average	Std. Dev
30.5	None	36 *	-	704 *	-
	Low	33 *	-	653 *	-
	High	33 *	-	650 *	-
12	None	118	2	914	15
	Low	119	4	923	30
	High	99	1	764	11
6	None	261	13	1008	49
	Low	247	15	957	57
	High	228	18	883	68

* - Only one value is available

Table A.7 Average Shear Stresses and Tensile Strengths with 4 in. Overlays after 0 hrs. of Pre-vibration Cure Time (Smooth Surface)

a) Wet Interface

Span (in)	Vibration Level	Shear Stresses, psi		Tensile Strength, psi	
		Average	Std. Dev	Average	Std. Dev
30.5	None	67 *	-	869 *	-
	Low	79 *	-	1014 *	-
	High	66 *	-	856 *	-
12	None	203	6	1029	30
	Low	238	23	1208	115
	High	201	6	1021	30
6	None	424	37	1078	95
	Low	537	46	1364	116
	High	474	6	1204	16

b) Dry Interface

Span (in)	Vibration Level	Shear Stresses, psi		Tensile Strength, psi	
		Average	Std.Dev	Average	Std. Dev
30.5	None	79 *	-	1022 *	-
	Low	57 *	-	738 *	-
	High	65 *	-	836 *	-
12	None	211	5	1074	26
	Low	218	11	1108	57
	High	212	7	1079	37
6	None	391	17	993	42
	Low	462	21	1174	54
	High	471	32	1195	82

* - Only one value is available

Table A.8 Average Shear Stresses and Tensile Strengths with 4 in. Overlays after 0 hrs. of Pre-vibration Cure Time (Rough Surface)

a) Wet Interface

Span (in)	Vibration Level	Shear Stresses, psi		Tensile Strength, psi	
		Average	Std. Dev	Average	Std. Dev
30.5	None	60 *	-	776 *	-
	Low	59 *	-	766 *	-
	High	58 *	-	746 *	-
12	None	206	5	1045	27
	Low	195	5	992	26
	High	201	13	1023	64
6	None	426	29	1081	74
	Low	461	11	1170	29
	High	502	39	1275	100

b) Dry Interface

Span (in)	Vibration Level	Shear Stresses, psi		Tensile Strength, psi	
		Average	Std.Dev	Average	Std. Dev
30.5	None	77 *	-	999 *	-
	Low	58 *	-	750 *	-
	High	58 *	-	749 *	-
12	None	229	2	1166	12
	Low	206	17	1046	87
	High	192	2	976	9
6	None	447	70	1135	179
	Low	441	30	1120	76
	High	493	44	1252	113

* - Only one value is available

Table A.9 Average Shear Stresses and Tensile Strengths with 4 in. Overlays after 4 hrs. of Pre-vibration Cure Time (Smooth Surface)

a) Wet Interface

Span (in)	Vibration Level	Shear Stresses, psi		Tensile Strength, psi	
		Average	Std. Dev	Average	Std. Dev
30.5	None	67 *	-	869 *	-
	Low	59 *	-	762 *	-
	High	62 *	-	807 *	-
12	None	203	6	1029	30
	Low	203	18	1030	92
	High	216	9	1097	44
6	None	424	37	1078	95
	Low	441	42	1121	106
	High	487	27	1237	68

b) Dry Interface

Span (in)	Vibration Level	Shear Stresses, psi		Tensile Strength, psi	
		Average	Std.Dev	Average	Std. Dev
30.5	None	79 *	-	1022 *	-
	Low	65 *	-	845 *	-
	High	62 *	-	805 *	-
12	None	211	5	1074	26
	Low	213	10	1081	51
	High	188	12	956	62
6	None	391	17	993	42
	Low	467	33	1187	83
	High	403	34	1023	86

* - Only one value is available

Table A.10 Average Shear Stresses and Tensile Strengths with 4 in. Overlays after 4 hrs. of Pre-vibration Cure Time (Rough Surface)

a) Wet Interface

Span (in)	Vibration Level	Shear Stresses, psi		Tensile Strength, psi	
		Average	Std. Dev	Average	Std. Dev
30.5	None	60 *	-	776 *	-
	Low	68 *	-	872 *	-
	High	69 *	-	888 *	-
12	None	206	5	1045	27
	Low	209	9	1060	47
	High	205	0	1041	2
6	None	426	29	1081	74
	Low	482	27	1224	68
	High	450	33	1143	84

b) Dry Interface

Span (in)	Vibration Level	Shear Stresses, psi		Tensile Strength, psi	
		Average	Std.Dev	Average	Std. Dev
30.5	None	77 *	-	999 *	-
	Low	51 *	-	657 *	-
	High	64 *	-	827 *	-
12	None	229	2	1166	2
	Low	198	15	1008	74
	High	200	25	1016	127
6	None	447	70	1135	179
	Low	419	20	1064	51
	High	455	34	1157	87

* - Only one value is available

Table A.11 Average Shear Stresses and Tensile Strengths with 4 in. Overlays after 12 hrs. of Pre-vibration Cure Time (Smooth Surface)

a) Wet Interface

Span (in)	Vibration Level	Shear Stresses, psi		Tensile Strength, psi	
		Average	Std. Dev	Average	Std. Dev
30.5	None	67 *	-	869 *	-
	Low	52 *	-	672 *	-
	High	62 *	-	795 *	-
12	None	203	6	1029	30
	Low	170	6	862	29
	High	179	0	909	1
6	None	424	37	1078	95
	Low	253	9	642	23
	High	349	28	885	71

b) Dry Interface

Span (in)	Vibration Level	Shear Stresses, psi		Tensile Strength, psi	
		Average	Std.Dev	Average	Std. Dev
30.5	None	79 *	-	1022 *	-
	Low	61 *	-	786 *	-
	High	62 *	-	805 *	-
12	None	211	5	1074	26
	Low	180	2	914	8
	High	188	12	956	62
6	None	391	17	993	42
	Low	406	3	1032	9
	High	403	34	1023	86

* - Only one value is available

Table A.12 Average Shear Stresses and Tensile Strengths with 4 in. Overlays after 12 hrs. of Pre-vibration Cure Time (Rough Surface)

a) Wet Interface

Span (in)	Vibration Level	Shear Stresses, psi		Tensile Strength, psi	
		Average	Std. Dev	Average	Std. Dev
30.5	None	60 *	-	776 *	-
	Low	55 *	-	717 *	-
	High	50 *	-	643 *	-
12	None	2066	5	1045	27
	Low	162	4	825	22
	High	185	3	938	15
6	None	426	29	1081	74
	Low	303	8	769	21
	High	376	5	954	12

b) Dry Interface

Span (in)	Vibration Level	Shear Stresses, psi		Tensile Strength, psi	
		Average	Std.Dev	Average	Std. Dev
30.5	None	77 *	-	999 *	-
	Low	49 *	-	628 *	-
	High	55 *	-	704 *	-
12	None	229	2	1166	2
	Low	172	8	875	39
	High	162	3	825	13
6	None	447	70	1135	179
	Low	333	9	845	24
	High	318	12	808	31

* - Only one value is available

APPENDIX B

Vibration Level

NONE LOW HIGH

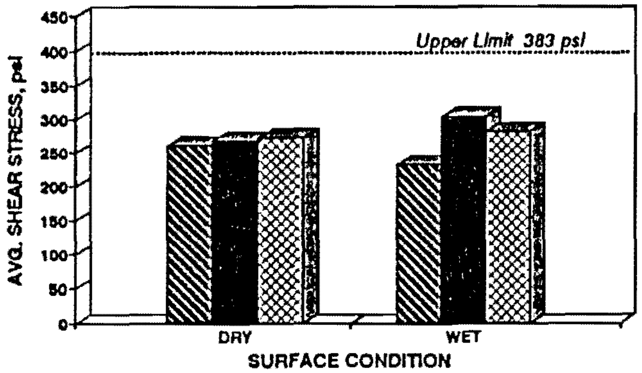


Figure B.1 Comparison of Avg. Shear Stresses for Dry and Wet condition for 2 in. Overlays after 0 Hrs. of Pre-Vibration Cure (Smooth Interface, 6 in. Span)

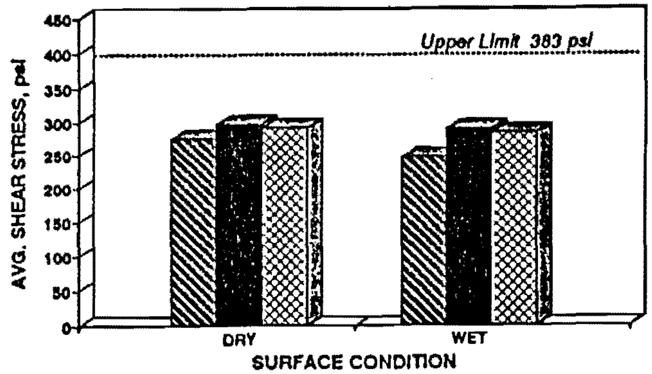


Figure B.2 Comparison of Avg. Shear Stresses for Dry and Wet Condition for 2 in. Overlay after 0 Hrs. of Pre-Vibration Cure (Rough Interface, 6 in. Span)

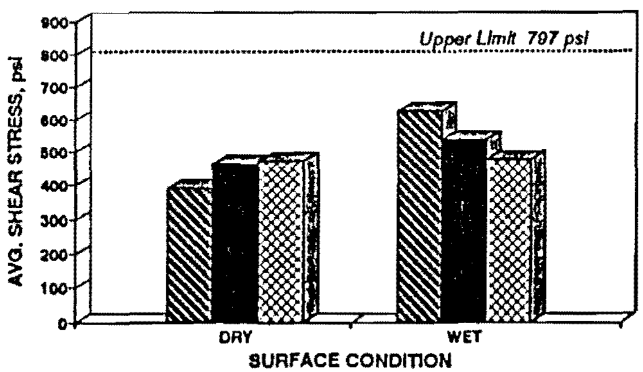


Figure B.3 Comparison of Avg. Shear Stresses for Dry and Wet Condition for 4 in. Overlay after 0 Hrs. of Pre-Vibration Cure (Smooth Interface, 6 in. Span)

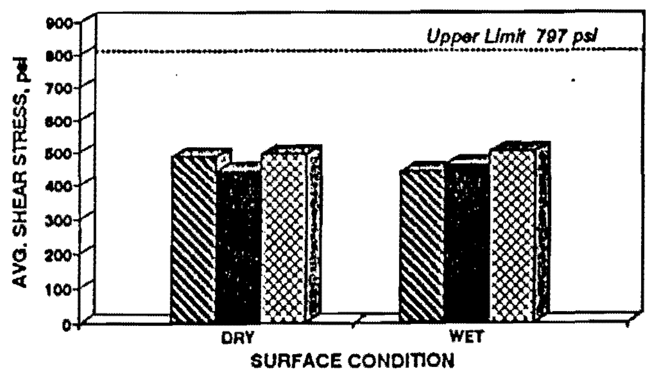
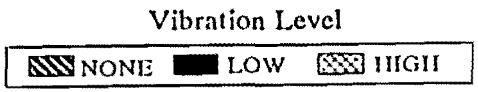


Figure B.4 Comparison of Avg. Shear Stresses for Dry and Wet Condition for 4 in. Overlay after 0 Hrs. of Pre-Vibration Cure (Rough Interface, 6 in. Span)



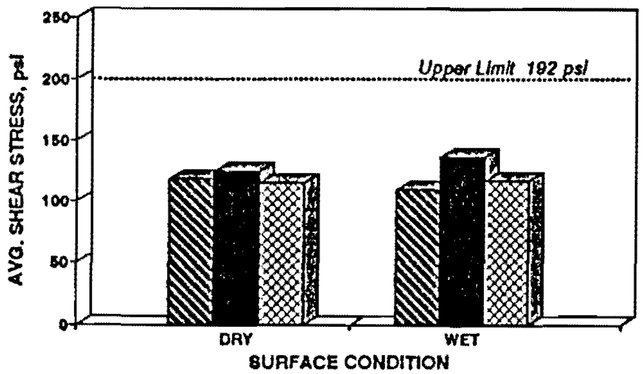


Figure B.5 Comparison of Avg. Shear Stresses for Dry and Wet Condition for 2 in. Overlay after 0 Hrs. of Pre-Vibration Cure (Smooth Interface, 12 in. Span)

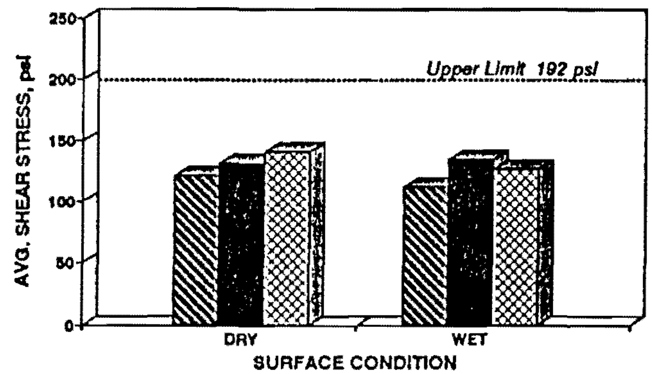


Figure B.6 Comparison of Avg. Shear Stresses for Dry and Wet condition for 2 in. Overlay after 0 Hrs. of Pre-Vibration Cure (Rough Interface, 12 in. Span)

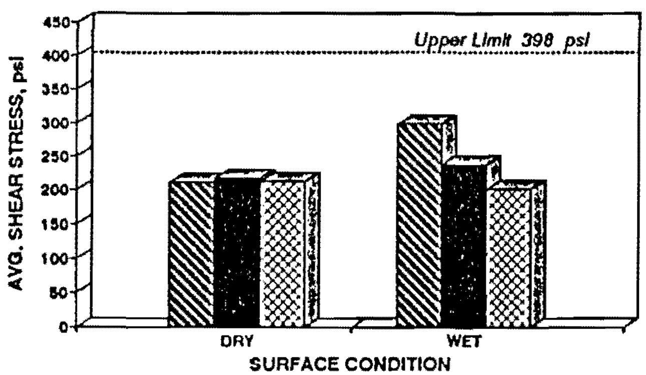


Figure B.7 Comparison of Avg. Shear Stresses for Dry and Wet Condition for 4 in. Overlay after 0 Hrs. of Pre-Vibration Cure (Smooth Interface, 12 in. Span)

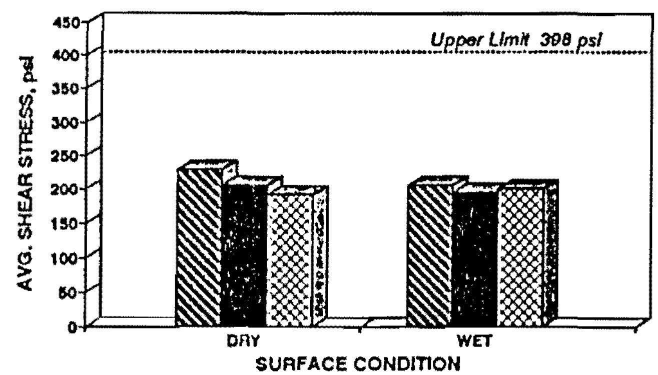


Figure B.8 Comparison of Avg. Shear Stresses for Dry and Wet Condition for a 4 in. Overlay after 0 Hrs. of Pre-Vibration Cure (Rough Interface, 12 in. Span)

Vibration Level

NONE LOW HIGH

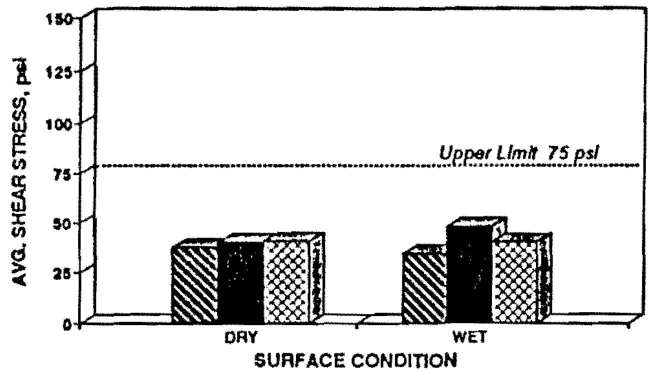


Figure B.9 Comparison of Avg. Shear Stresses for Dry and Wet Condition for 2 in. Overlay after 0 Hrs. of Pre-Vibration Cure (Smooth Interface, 30.5 in. Span)

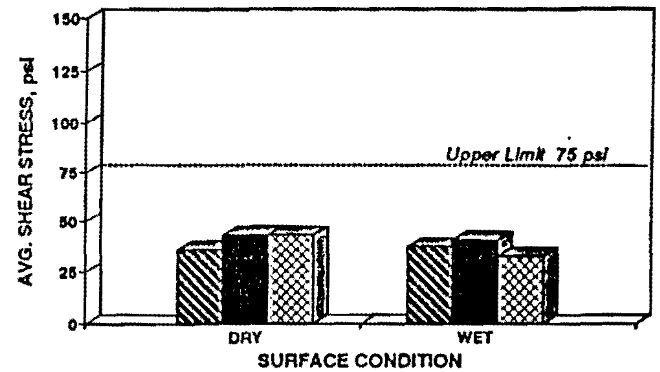


Figure B.10 Comparison of Avg. Shear Stresses for Dry and Wet Condition for 2 in. Overlay after 0 Hrs. of Pre-Vibration Cure (Rough Interface, 30.5 in. Span)

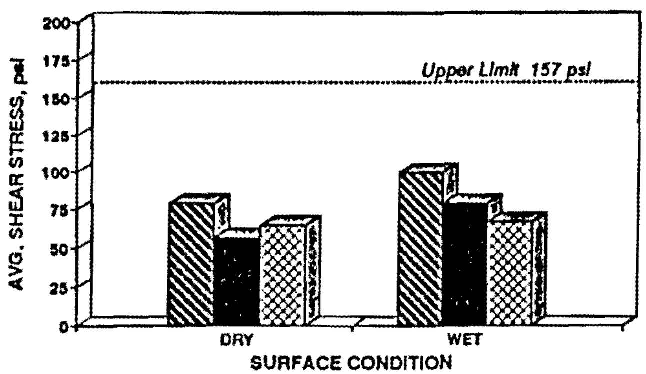


Figure B.11 Comparison of Avg. Shear Stresses for Dry and Wet Condition for 4 in. Overlay after 0 Hrs. of Pre-Vibration Cure (Smooth Interface, 30.5 in. Span)

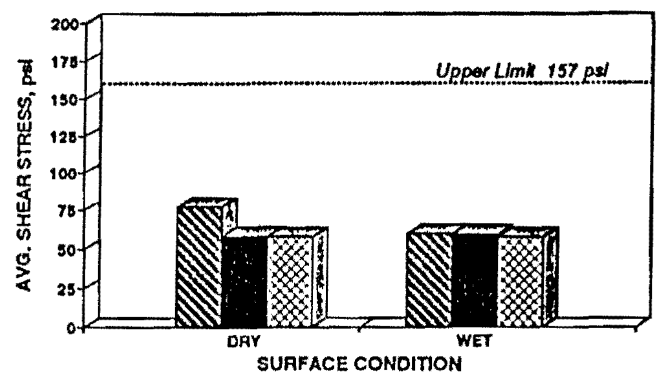
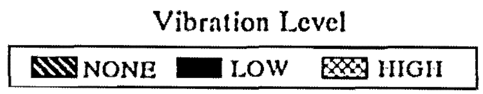


Figure B.12 Comparison of Avg. Shear Stresses for Dry and Wet Condition for 4 in. Overlay after 0 Hrs. of Pre-Vibration Cure (Rough Interface, 30.5 in. Span)



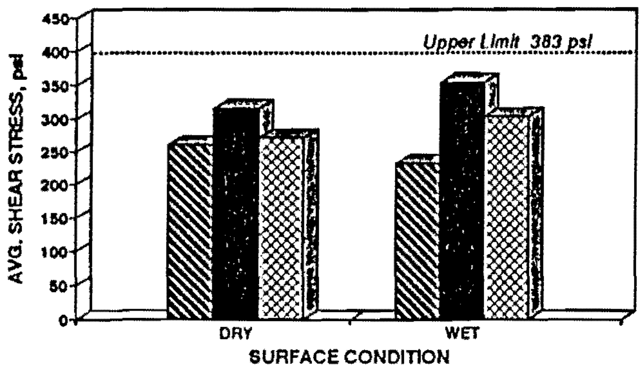


Figure B.13 Comparison of Avg. Shear Stresses for Dry and Wet Condition for 2 in. Overlay after 4 Hrs. of Pre-Vibration Cure (Smooth Interface, 6 in. Span)

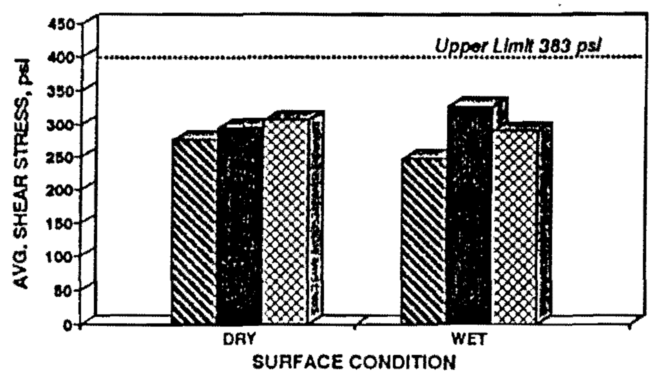


Figure B.14 Comparison of Avg. Shear Stresses for Dry and Wet Condition for 2 in. Overlay after 4 Hrs. of Pre-Vibration Cure (Rough Interface, 6 in. Span)

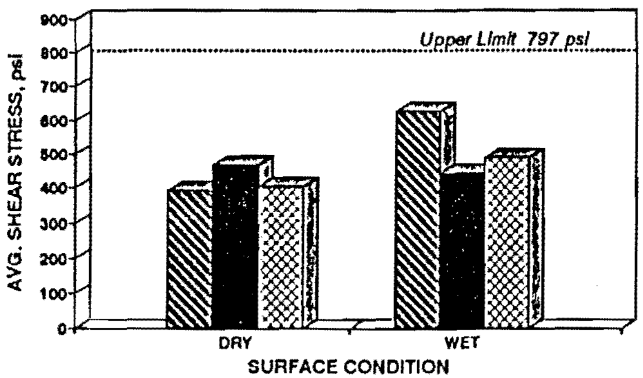


Figure B.15 Comparison of Avg. Shear Stresses for Dry and Wet Condition for 4 in. Overlay after 4 Hrs. of Pre-Vibration Cure (Smooth Interface, 6 in. Span)

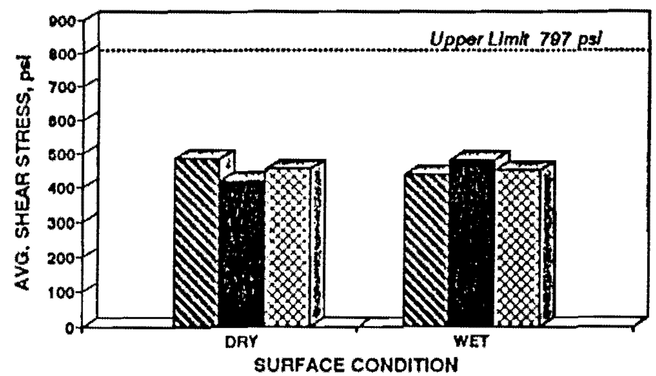
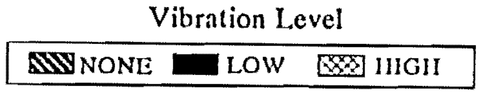


Figure B.16 Comparison of Avg. Shear Stresses for Dry and Wet Condition for 4 in. Overlay after 4 Hrs. of Pre-Vibration Cure (Rough Interface, 6 in. Span)



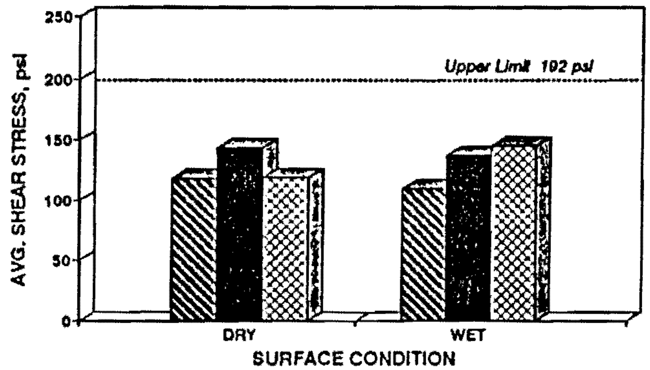


Figure B.17 Comparison of Avg. Shear Stresses for Dry and Wet Condition for 2 in. Overlay after 4 Hrs. of Pre-Vibration Cure (Smooth Interface, 12 in. Span)

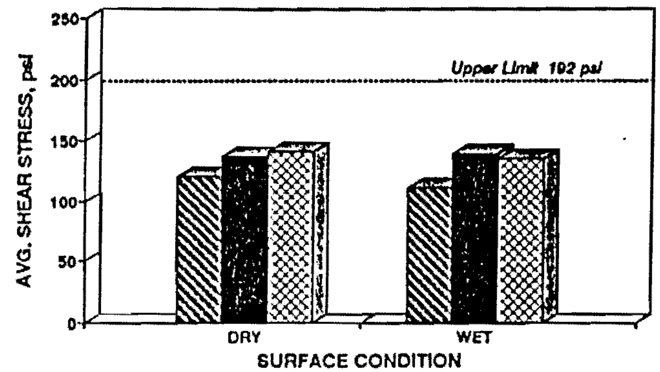


Figure B.18 Comparison of Avg. Shear Stresses for Dry and Wet Condition for 2 in. Overlay after 4 Hrs. of Pre-Vibration Cure (Rough Interface, 12 in. Span)

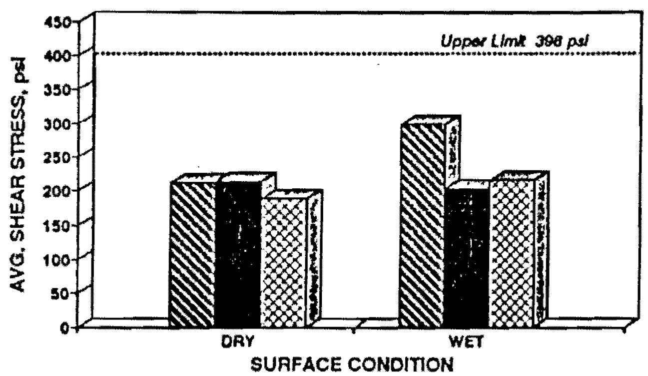


Figure B.19 Comparison of Avg. Shear Stresses for Dry and Wet Condition for 4 in. Overlay after 4 Hrs. of Pre-Vibration Cure (Smooth Interface, 12 in. Span)

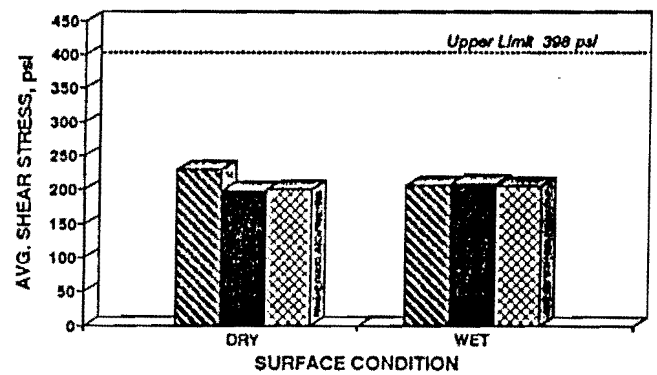


Figure B.20 Comparison of Avg. Shear Stresses for Dry and Wet Condition for 4 in. Overlay after 4 Hrs. of Pre-Vibration Cure (Rough Interface, 12 in. Span)

Vibration Level

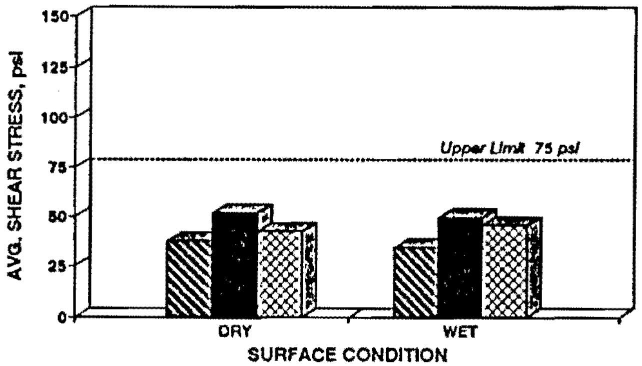


Figure B.21 Comparison of Avg. Shear Stresses for Dry and Wet Condition for 2 in. Overlay after 4 Hrs. of Pre-Vibration Cure (Smooth Interface, 30.5 in. Span)

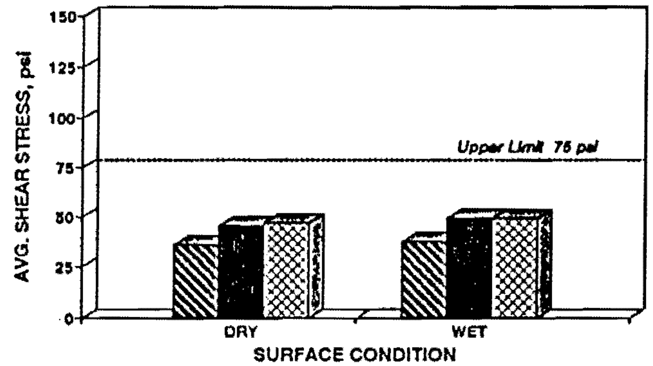


Figure B.22 Comparison of Avg. Shear Stresses for Dry and Wet Condition for 2 in. Overlay after 4 Hrs. of Pre-Vibration Cure (Rough Interface, 30.5 in. Span)

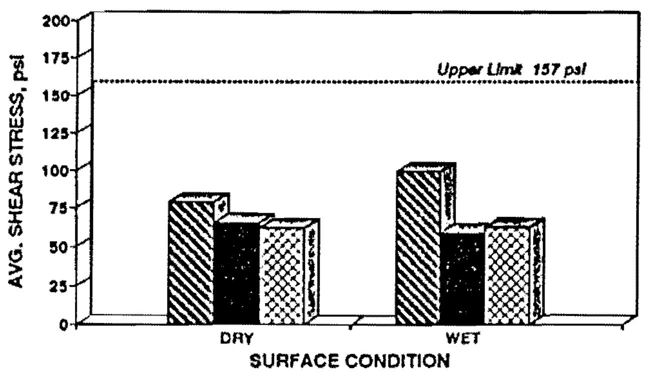


Figure B.23 Comparison of Avg. Shear Stresses for Dry and Wet Condition for 4 in. Overlay after 4 Hrs. of Pre-Vibration Cure (Smooth Interface, 30.5 in. Span)

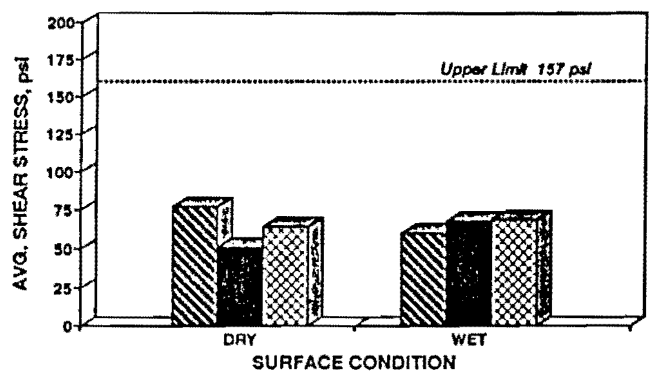


Figure B.24 Comparison of Avg. Shear Stresses for Dry and Wet Condition for 4 in. Overlay after 4 Hrs. of Pre-Vibration Cure (Rough Interface, 30.5 in. Span)

Vibration Level

NONE LOW HIGH

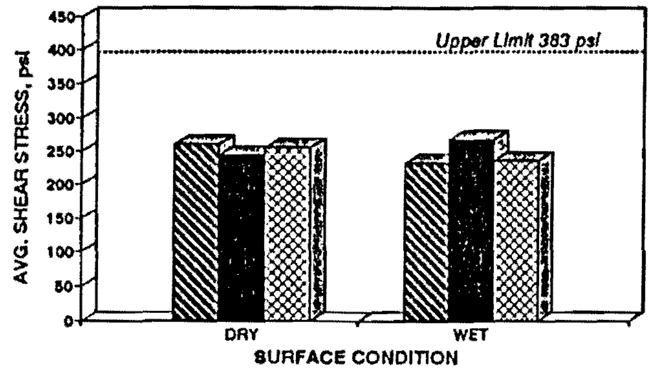


Figure B.25 Comparison of Avg. Shear Stresses for Dry and Wet Condition for 2 in. Overlay after 12 Hrs. of Pre-Vibration Cure (Smooth Interface, 6 in. Span)

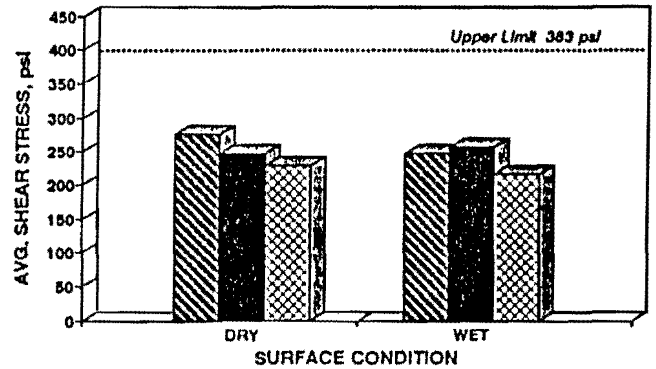


Figure B.26 Comparison of Avg. Shear Stresses for Dry and Wet Condition for 2 in. Overlay after 12 Hrs. of Pre-Vibration Cure (Rough Interface, 6in. Span)

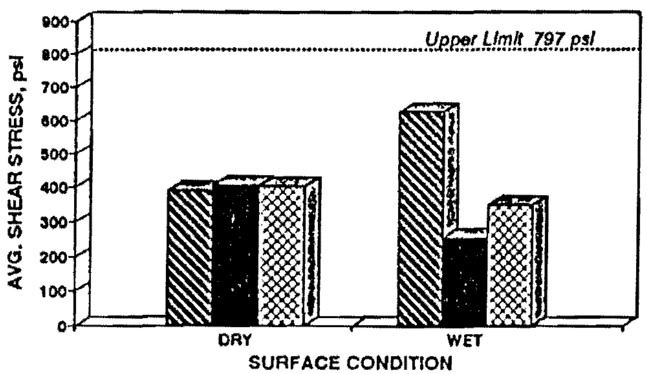


Figure B.27 Comparison of Avg. Shear Stresses for Dry and Wet Condition for 4 in. Overlay after 12 Hrs. of Pre-Vibration Cure (Smooth Interface, 6 in. Span)

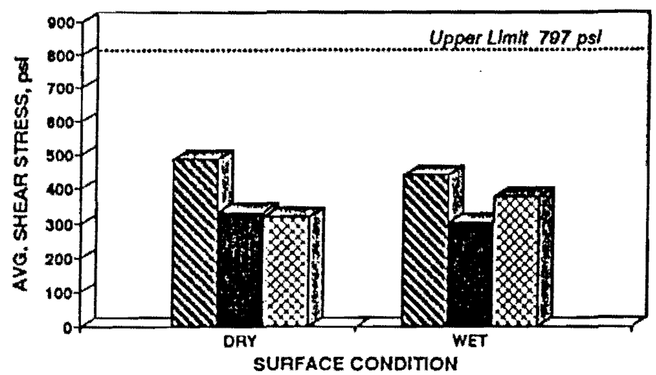
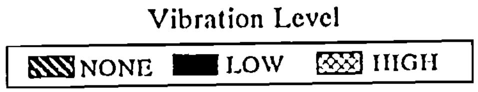


Figure B.28 Comparison of Avg. Shear Stresses for Dry and Wet Condition for 4 in. Overlay after 12 Hrs. of Pre-Vibration Cure (Rough Interface, 6 in. Span)



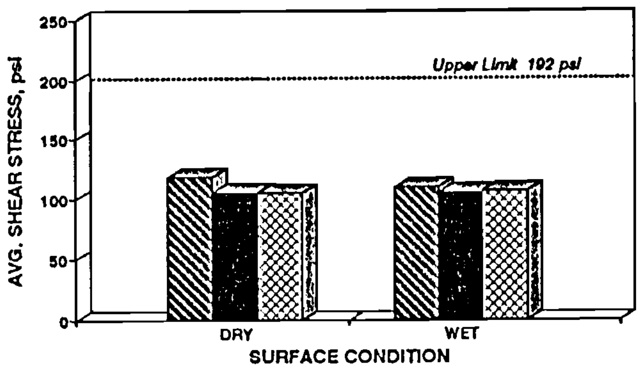


Figure B.29 Comparison of Avg. Shear Stresses for Dry and Wet Condition for 2 in. Overlay after 12 Hrs. of Pre-Vibration Cure (Smooth Interface, 12 in. Span)

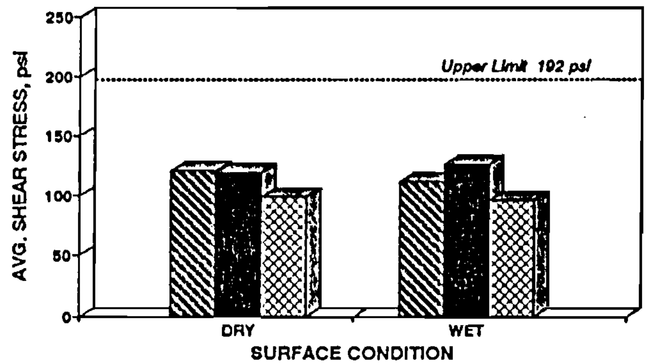


Figure B.30 Comparison of Avg. Shear Stresses for Dry and Wet Conditon for 2 in. Overlay after 12 Hrs. of Pre-Vibration Cure (Rough Interface, 12 in. Span)

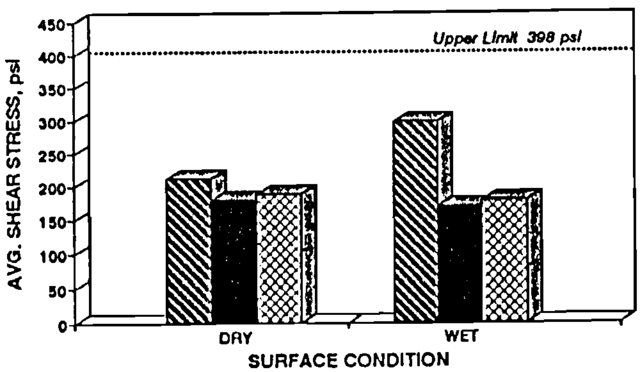


Figure B.31 Comparison of Avg. Shear Stresses for Dry and Wet Condition for 4 in. Overlay after 12 Hrs. of Pre-Vibration Cure (Smooth Interface, 12 in. Span)

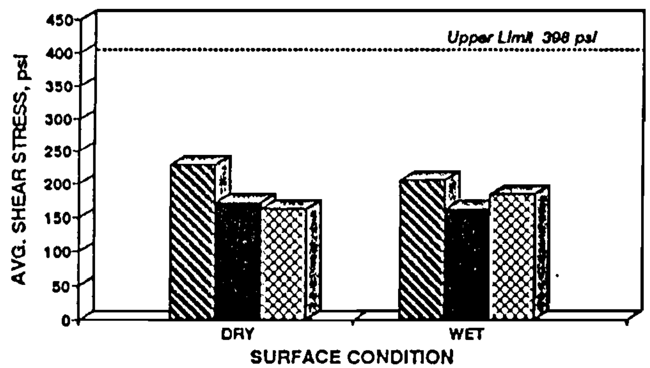
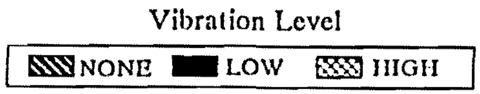


Figure B.32 Comparison of Avg. Shear Stresses for Dry and Wet Condition for 4 in. Overlay after 12 Hrs. of Pre-Vibration Cure (Rough Interface, 12 in. Span)



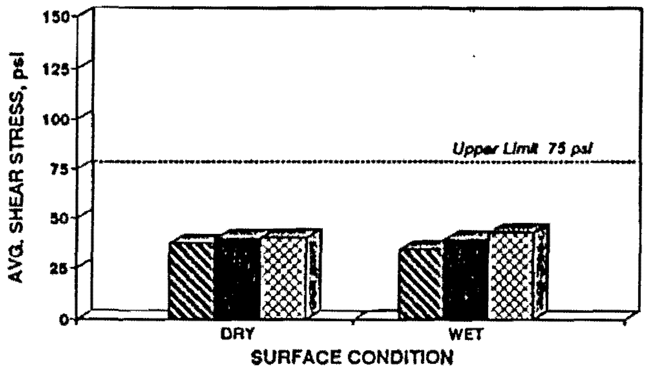


Figure B.33 Comparison of Avg. Shear Stresses for Dry and Wet Conditon for 2 in. Overlay after 12 Hrs. of Pre-Vibration Cure (Smooth Interface, 30.5 in. Span)

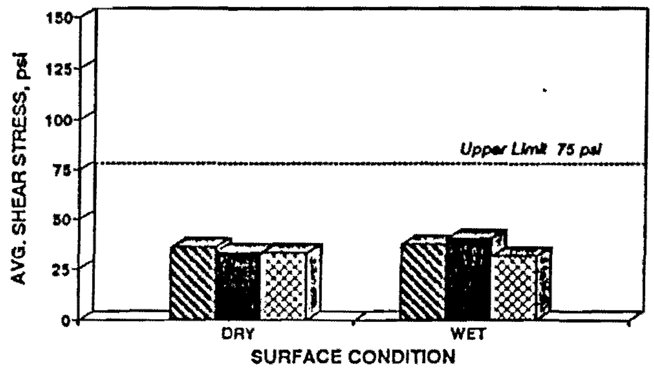


Figure B.34 Comparison of Avg. Shear Stresses for Dry and Wet Condition for 2 in. Overlay after 12 Hrs. of Pre-Vibration Cure (Rough Interface, 30.5 in. Span)

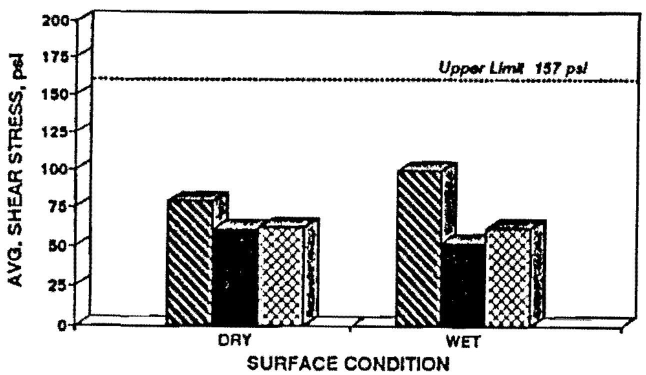


Figure B.35 Comparison of Avg. Shear Stresses for Dry and Wet Condition for 4 in. Overlay after 12 Hrs. of Pre-Vibration Cure (Smooth Interface, 30.5 in. Span)

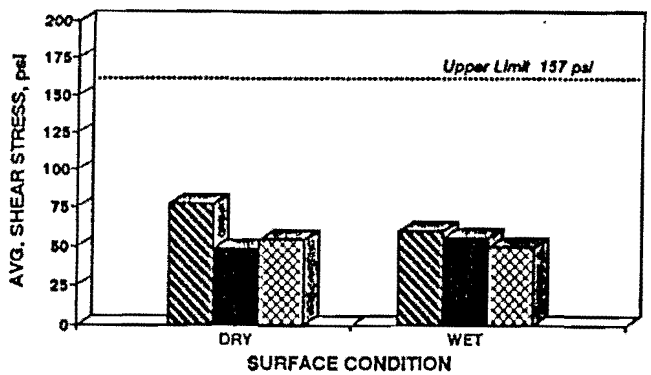


Figure B.36 Comparison of Avg. Shear Stresses for Dry and Wet Condition for 4 in. Overlay after 12 Hrs. of Pre-Vibration Cure (Rough Interface, 30.5 in. Span)

Vibration Level

NONE LOW HIGH

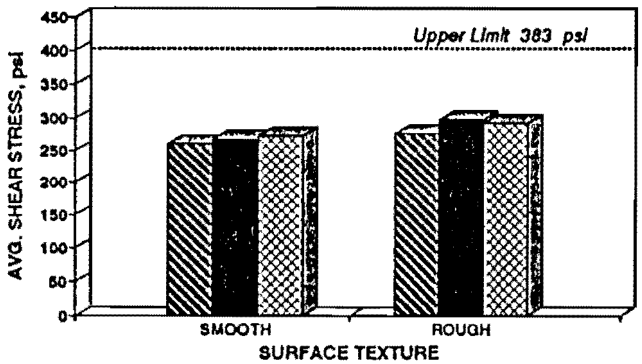


Figure B.37 Comparison of Avg. Shear Stresses for Smooth and Rough Interface for 2 in. Overlays after 0 Hrs. of Pre-Vibration Cure (Dry Condition, 6in. Span)

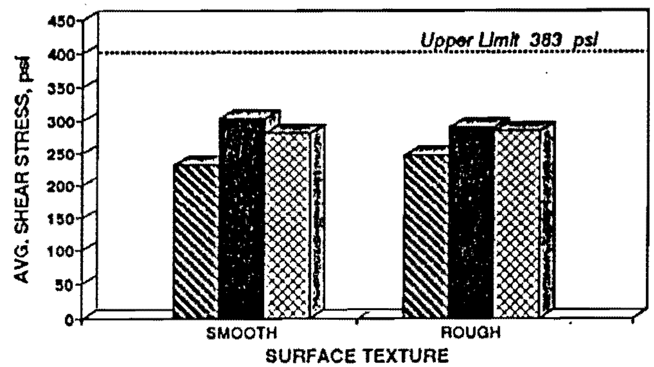


Figure B.38 Comparison of Avg. Shear Stresses for Smooth and Rough Interface for 2 in. Overlays after 0 Hrs. of Pre-Vibration Cure (Wet Condition, 6 in. Span)

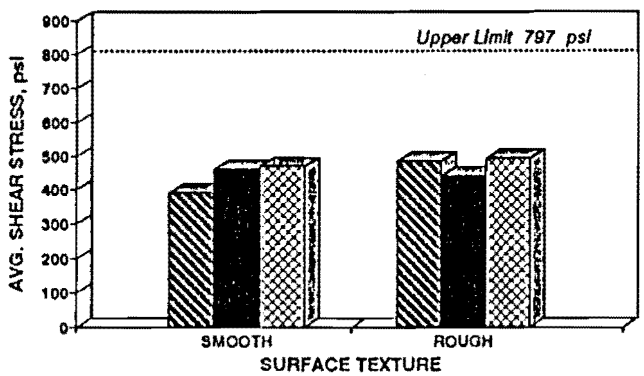


Figure B.39 Comparison of Avg. Shear Stresses for Smooth and Rough Interface for 4 in. Overlays after 0 Hrs. of Pre-Vibration Cure (Dry Condition, 6 in. Span)

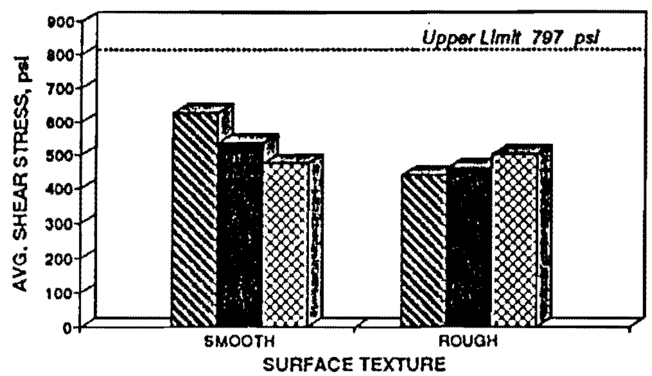


Figure B.40 Comparison of Avg. Shear Stresses for Smooth and Rough Interface for 4 in. Overlays after 0 Hrs. of Pre-Vibration Cure (Wet Condition, 6 in. Span)

Vibration Level

NONE LOW HIGH

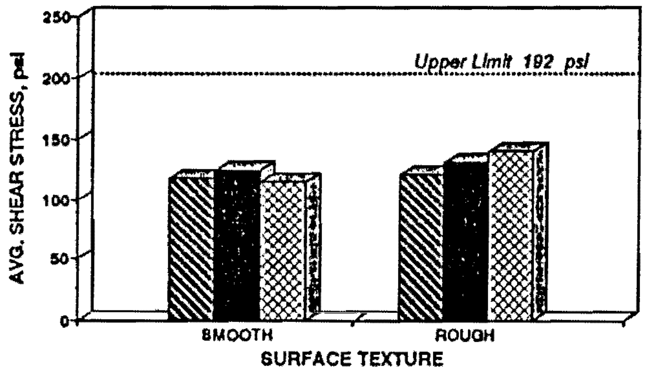


Figure B.41 Comparison of Avg. Shear Stresses for Smooth and Rough Interface for 2 in. Overlays after 0 Hrs. of Pre-Vibration Cure (Dry Condition, 12 in. Span)

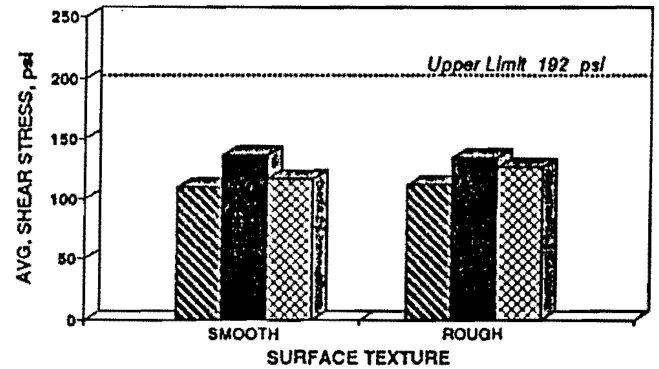


Figure B.42 Comparison of Avg. Shear Stresses for Smooth and Rough Interface for 2 in. Overlays after 0 Hrs. of Pre-Vibration Cure (Wet Condition, 12 in. Span)

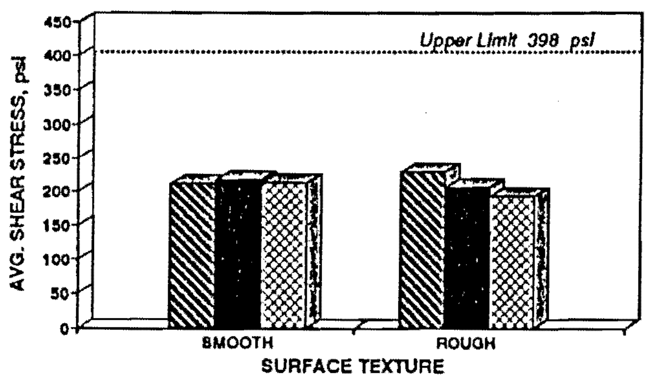


Figure B.43 Comparison of Avg. Shear Stresses for Smooth and Rough Interface for 4 in. Overlays after 0 Hrs. of Pre-Vibration Cure (Dry Condition, 12 in. Span)

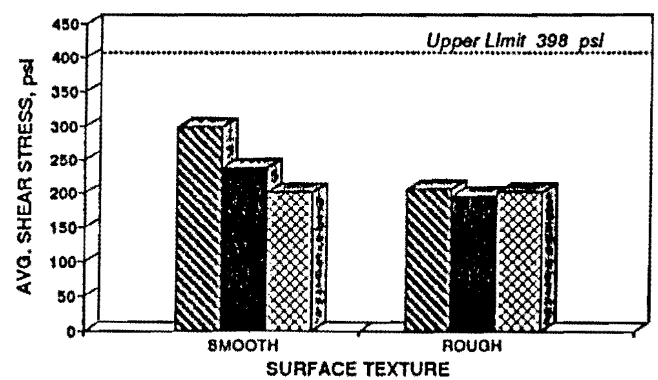
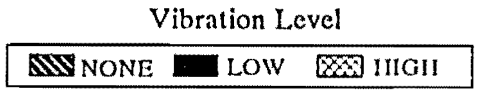


Figure B.44 Comparison of Avg. Shear Stresses for Smooth and Rough Interface for 4 in. Overlays after 0 Hrs. of Pre-Vibration Cure (Wet Condition, 12 in. Span)



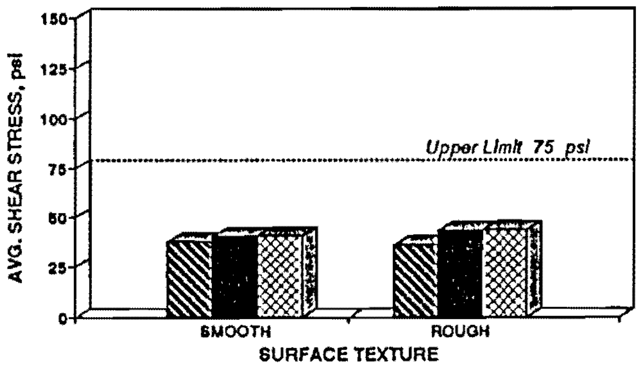


Figure B.45 Comparison of Avg. Shear Stresses for Smooth and Rough Interface for 2 in. Overlays after 0 Hrs. of Pre-Vibration Cure (Dry Condition, 30,5 in. Span)

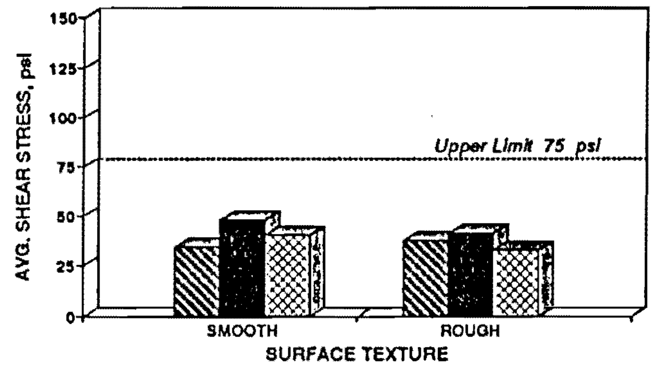


Figure B.46 Comparison of Avg. Shear Stresses for Smooth and Rough Interface for 2 in. Overlays after 0 Hrs. of Pre-Vibration Cure (Dry Condition, 30,5 in. Span)

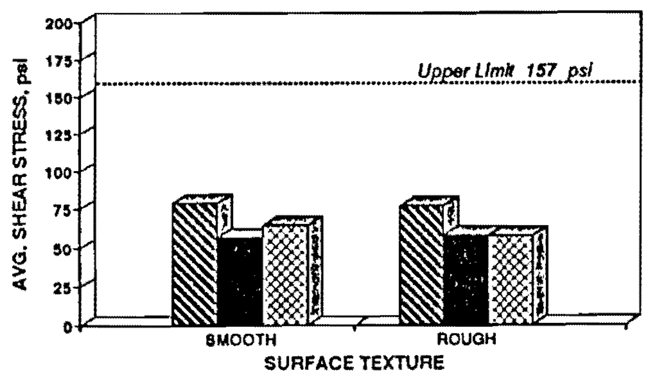


Figure B.47 Comparison of Avg. Shear Stresses for Smooth and Rough Interface for 4 in. Overlays after 0 Hrs. of Pre-Vibration Cure (Dry Condition, 30,5 in. Span)

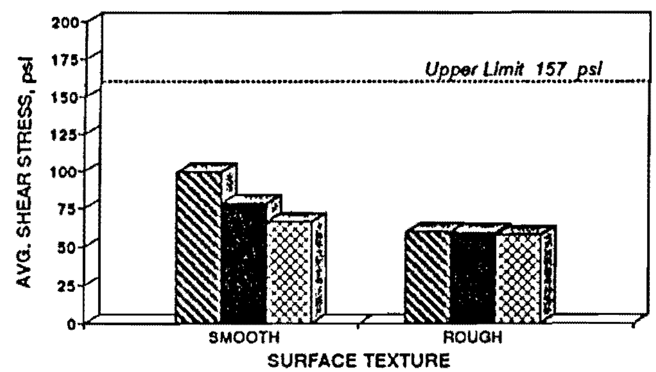


Figure B.48 Comparison of Avg. Shear Stresses for Smooth and Rough Interface for 4 in. Overlays after 0 Hrs. of Pre-Vibration Cure (Wet Condition, 30,5 in. Span)

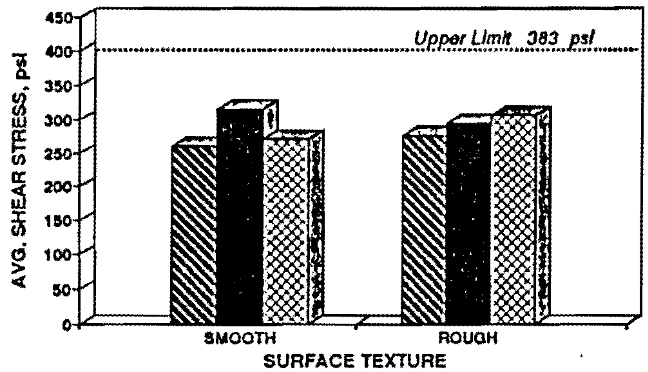


Figure B.49 Comparison of Avg. Shear Stresses for Smooth and Rough Interface for 2 in. Overlays after 4 Hrs. of Pre-Vibration Cure (Dry Condition, 6 in. Span)

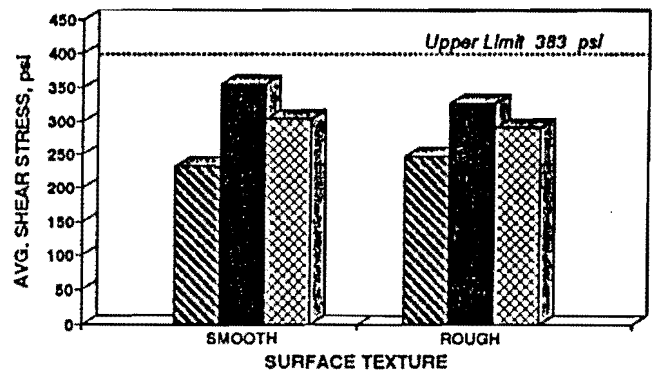


Figure B.50 Comparison of Avg. Shear Stresses for Smooth and Rough Interface for 2 in. Overlays after 4 Hrs. of Pre-Vibration Cure (Wet Condition, 6 in. Span)

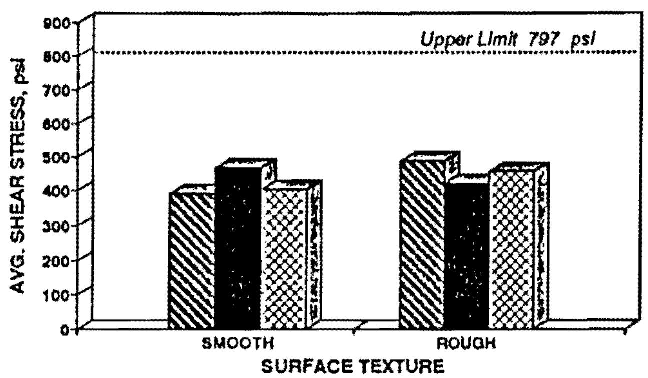


Figure B.51 Comparison of Avg. Shear Stresses for Smooth and Rough Interface for 4 in. Overlays after 4 Hrs. of Pre-Vibration Cure (Dry Condition, 6 in. Span)

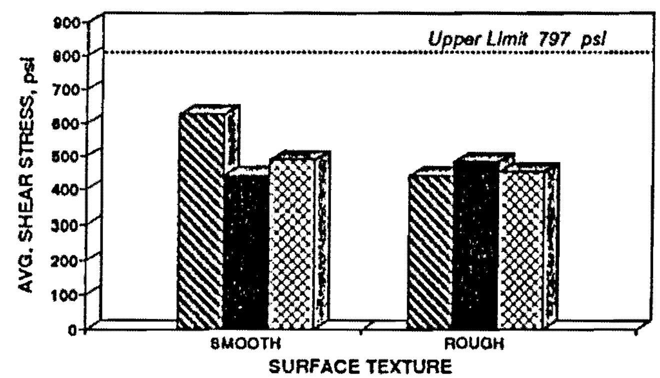


Figure B.52 Comparison of Avg. Shear Stresses for Smooth and Rough Interface for 4 in. Overlays after 4 Hrs. of Pre-Vibration Cure (Wet Condition, 6 in. Span)

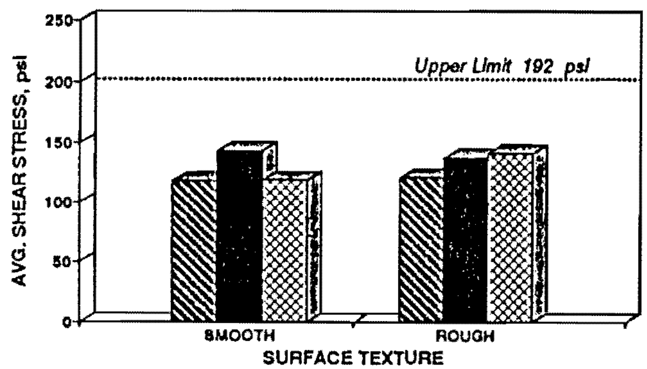


Figure B.53 Comparison of Avg. Shear Stresses for Smooth and Rough Interface for 2 in. Overlays after 4 Hrs. of Pre-Vibration Cure (Dry Condition, 12 in. Span)

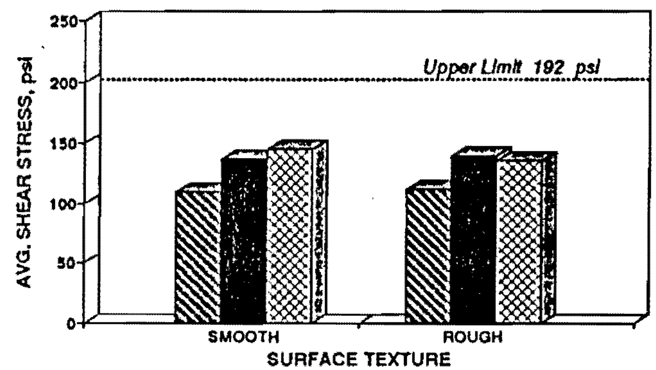


Figure B.54 Comparison of Avg. Shear Stresses for Smooth and Rough Interface for 2 in. Overlays after 4 Hrs. of Pre-Vibration Cure (Wet Condition, 12 in. Span)

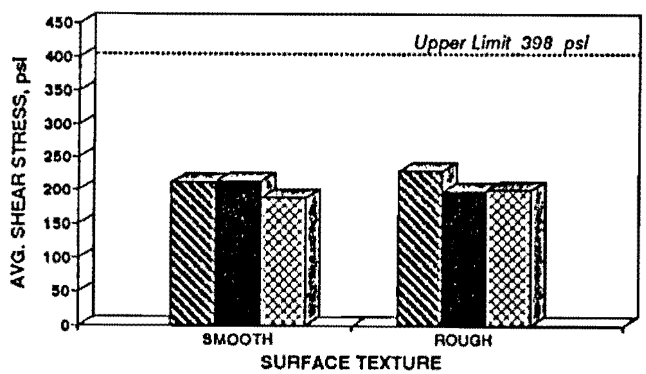


Figure B.55 Comparison of Avg. Shear Stresses for Smooth and Rough Interface for 4 in. Overlays after 4 Hrs. of Pre-Vibration Cure (Dry Condition, 12 in. Span)

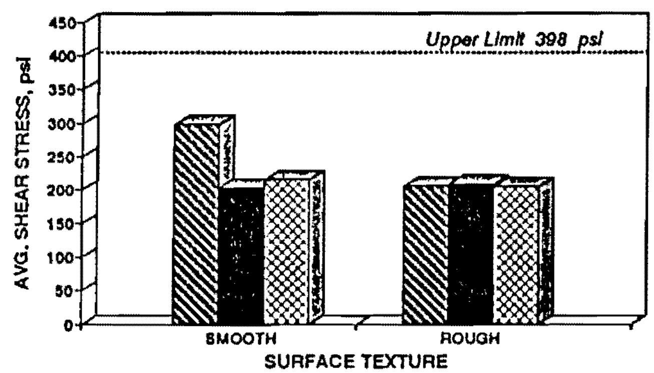
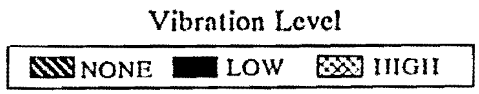


Figure B.56 Comparison of Avg. Shear Stresses for Smooth and Rough Interface for 4 in. Overlays after 4 Hrs. of Pre-Vibration Cure (Wet Condition, 12 in. Span)



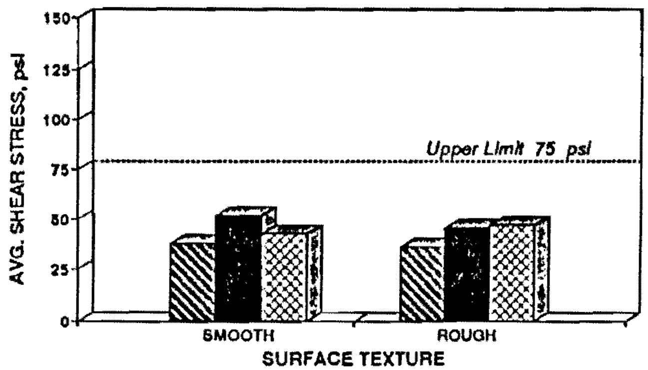


Figure B.57 Comparison of Avg. Shear Stresses for Smooth and Rough Interface for 2 in. Overlays after 4 Hrs. of Pre-Vibration Cure (Dry Condition, 30,5 in. Span)

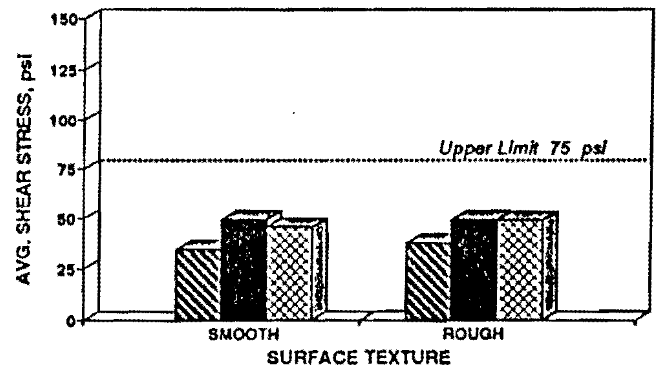


Figure B.58 Comparison of Avg. Shear Stresses for Smooth and Rough Interface for 2 in. Overlays after 4 Hrs. of Pre-Vibration Cure (Wet Condition, 30,5 in. Span)

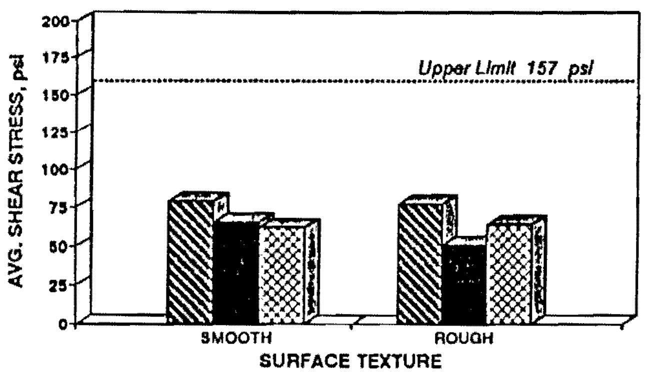


Figure B.59 Comparison of Avg. Shear Stresses for Smooth and Rough Interface for 4 in. Overlays after 4 Hrs. of Pre-Vibration Cure (Dry Condition, 30,5 in. Span)

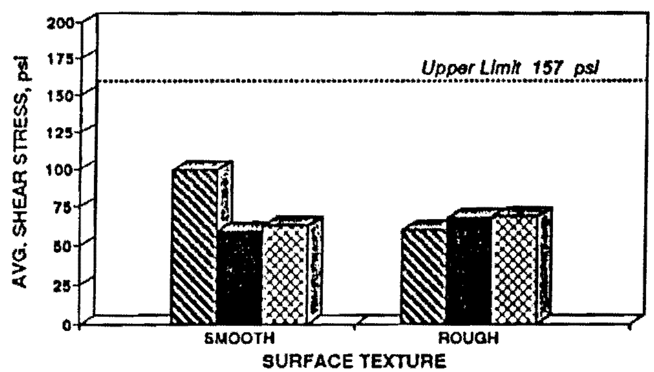
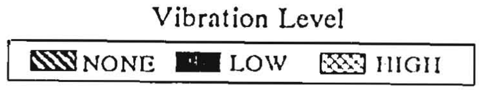


Figure B.60 Comparison of Avg. Shear Stresses for Smooth and Rough Interface for 4 in. Overlays after 4 Hrs. of Pre-Vibration Cure (Wet Condition, 30,5 in. Span)



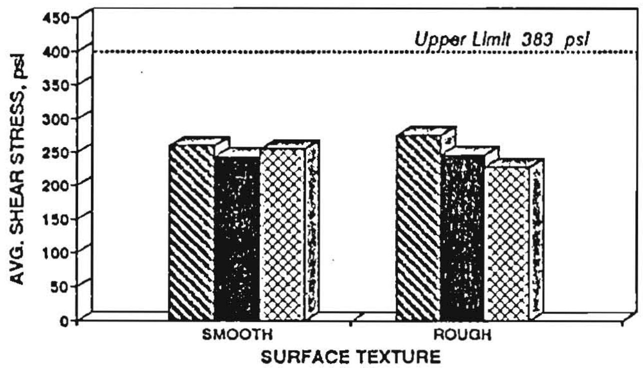


Figure B.61 Comparison of Avg. Shear Stresses for Smooth and Rough Interface for 2 in. Overlays after 12 Hrs. of Pre-Vibration Cure (Dry Condition, 6 in. Span)

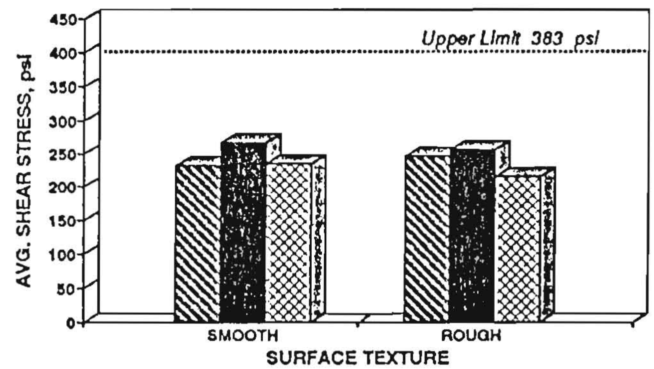


Figure B.62 Comparison of Avg. Shear Stresses for Smooth and Rough Interface for 2 in. Overlays after 12 Hrs. of Pre-Vibration Cure (Wet Condition, 6 in. Span)

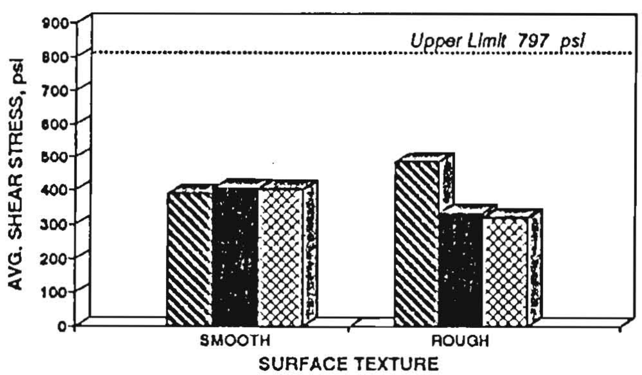


Figure B.63 Comparison of Avg. Shear Stresses for Smooth and Rough Interface for 4 in. Overlays after 12 Hrs. of Pre-Vibration Cure (Dry Condition, 6 in. Span)

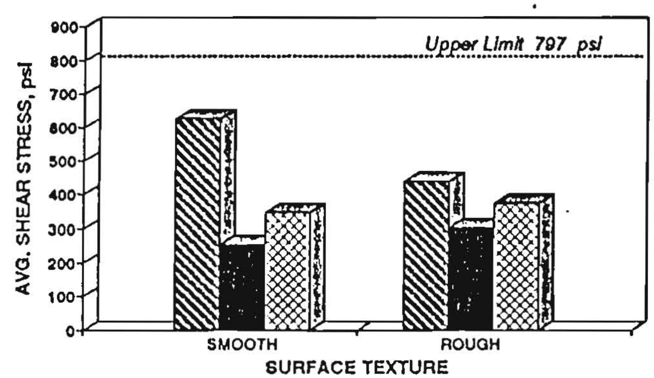
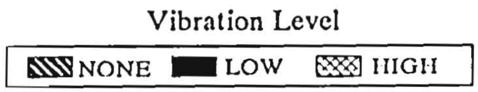


Figure B.64 Comparison of Avg. Shear Stresses for Smooth and Rough Interface for 4 in. Overlays after 12 Hrs. of Pre-Vibration Cure (Wet Condition, 6 in. Span)



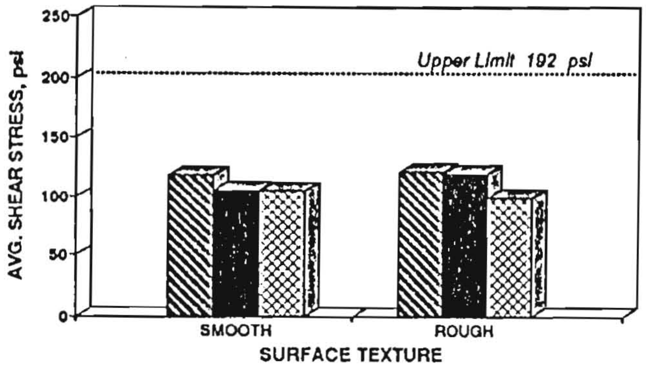


Figure B.65 Comparison of Avg. Shear Stresses for Smooth and Rough Interface for 2 in. Overlays after 12 Hrs. of Pre-Vibration Cure (Dry Condition, 12 in. Span)

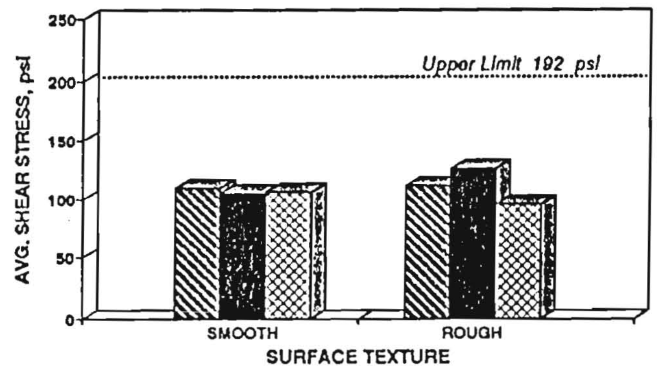


Figure B.66 Comparison of Avg. Shear Stresses for Smooth and Rough Interface for 2 in. Overlays after 12 Hrs. of Pre-Vibration Cure (Wet Condition, 12 in. Span)

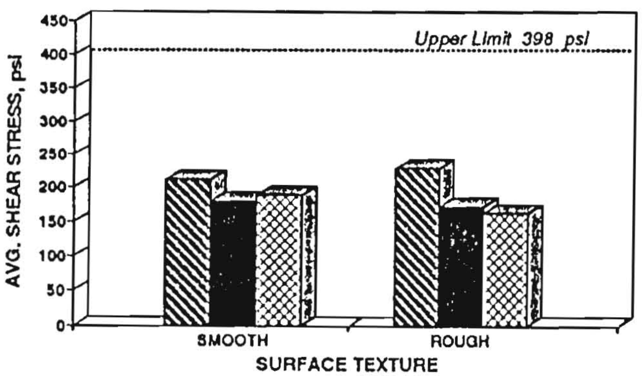


Figure B.67 Comparison of Avg. Shear Stresses for Smooth and Rough Interface for 4 in. Overlays after 12 Hrs. of Pre-Vibration Cure (Dry Condition, 12 in. Span)

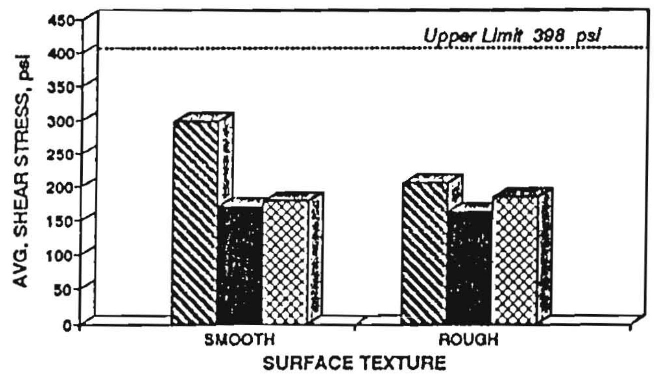
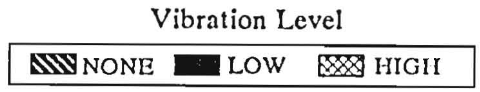


Figure B.68 Comparison of Avg. Shear Stresses for Smooth and Rough Interface for 4 in. Overlays after 12 Hrs. of Pre-Vibration Cure (Wet Condition, 12 in. Span)



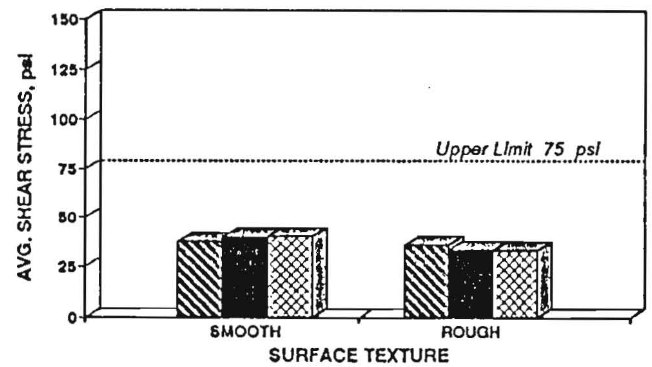


Figure B.69 Comparison of Avg. Shear Stresses for Smooth and Rough Interface for 2 in. Overlays after 12 Hrs. of Pre-Vibration Cure (Dry Condition, 30,5 in. Span)

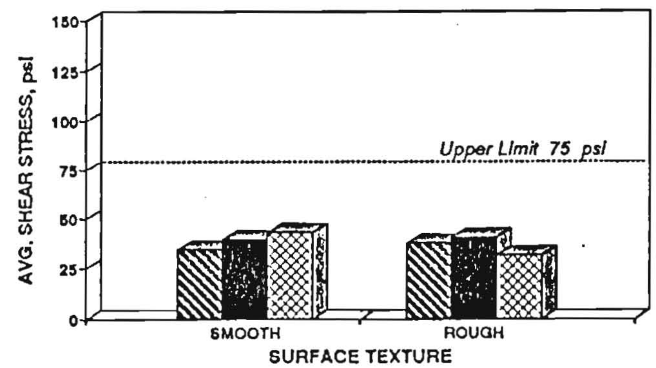


Figure B.70 Comparison of Avg. Shear Stresses for Smooth and Rough Interface for a 2 in. Overlays after 12 Hrs. of Pre-Vibration Cure (Wet Condition, 12 in. Span)

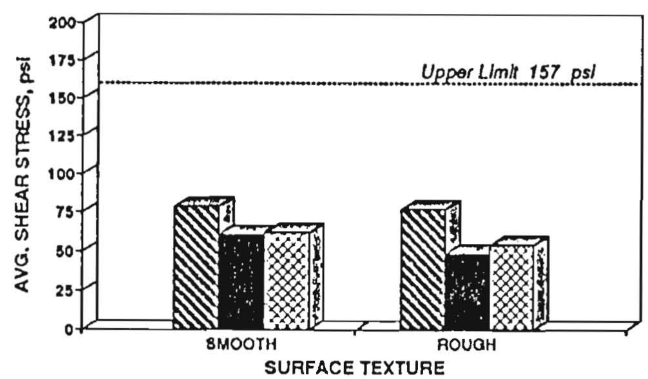


Figure B.71 Comparison of Avg. Shear Stresses for Smooth and Rough Interface for 4 in. Overlays after 12 Hrs. of Pre-Vibration Cure (Dry Condition, 30,5 in. Span)

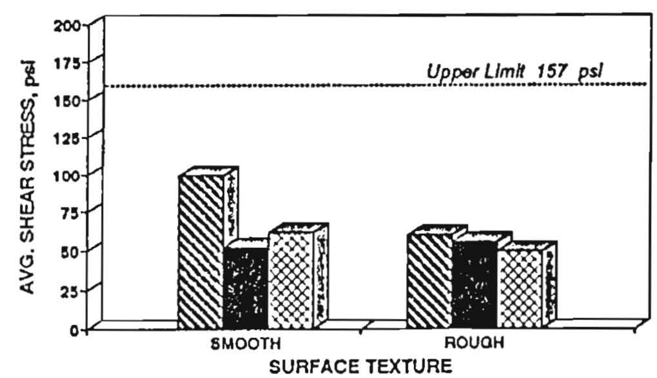


Figure B.72 Comparison of Avg. Shear Stresses for Smooth and Rough Interface for a 4 in. Overlays after 12 Hrs. of Pre-Vibration Cure (Wet Condition, 30,5 in. Span)

Vibration Level

NONE LOW HIGH

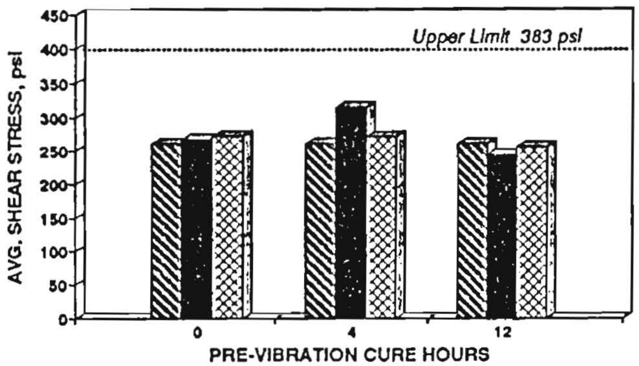


Figure B.73 Comparison of Avg. Shear Stresses After Pre-Vibration Cure Time for 2 in. Overlays with Smooth-Dry Interface (6 in. Span)

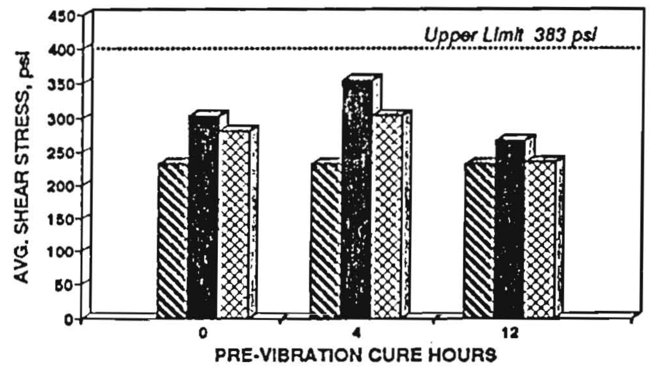


Figure B.74 Comparison of Avg. Shear Stresses After Pre-Vibration Cure Time for 2 in. Overlays with Smooth-Wet Interface (6 in. Span)

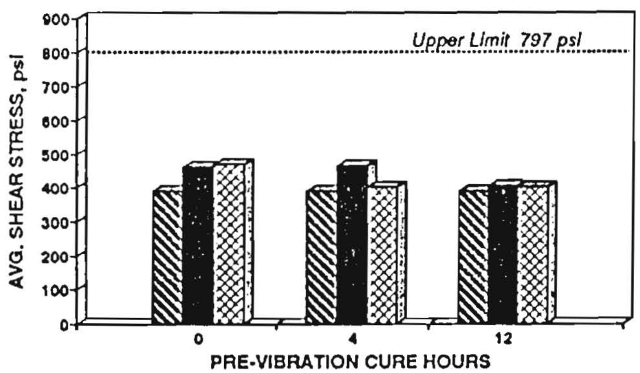


Figure B.75 Comparison of Avg. Shear Stresses After Pre-Vibration Cure Time for 4 in. Overlays with Smooth-Dry Interface (6 in. Span)

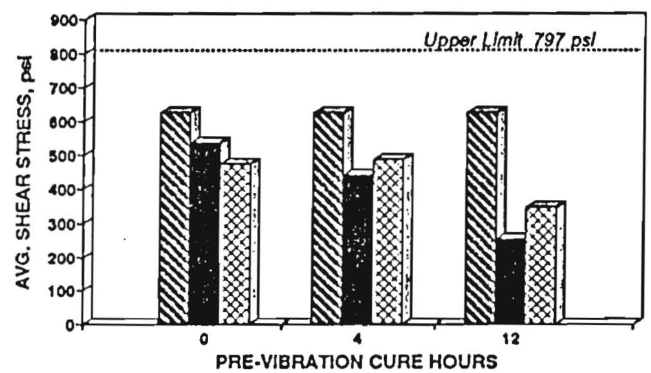
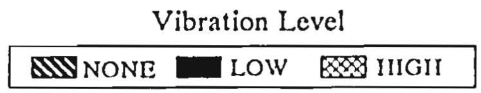


Figure B.76 Comparison of Avg. Shear Stresses After of Pre-Vibration Cure Time for 4 in. Overlays with Smooth-Wet Interface (6 in. Span)



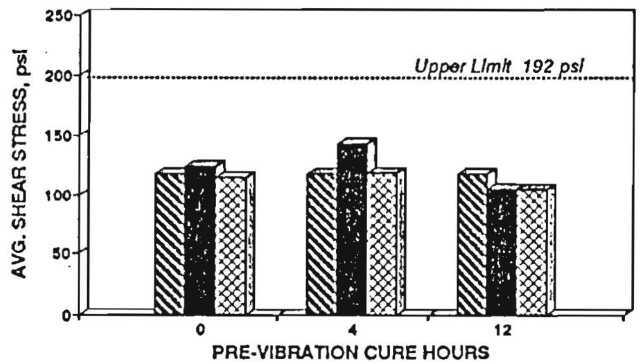


Figure B.77 Comparison of Avg. Shear Stresses After Pre-Vibration Cure Time for 2 in. Overlays with Smooth-Dry Interface (12 in. Span)

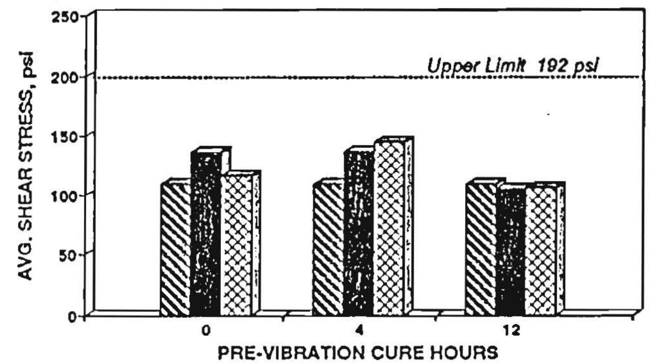


Figure B.78 Comparison of Avg. Shear Stresses After Pre-Vibration Cure Time for 2 in. Overlays with Smooth-Wet Interface (12 in. Span)

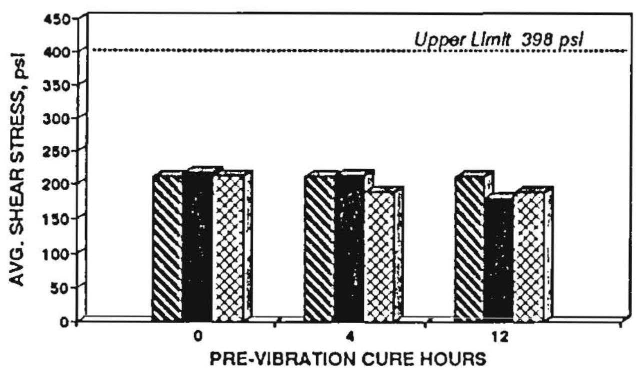


Figure B.79 Comparison of Avg. Shear Stresses After Pre-Vibration Cure Time for 4 in. Overlays with Smooth-Dry Interface (12 in. Span)

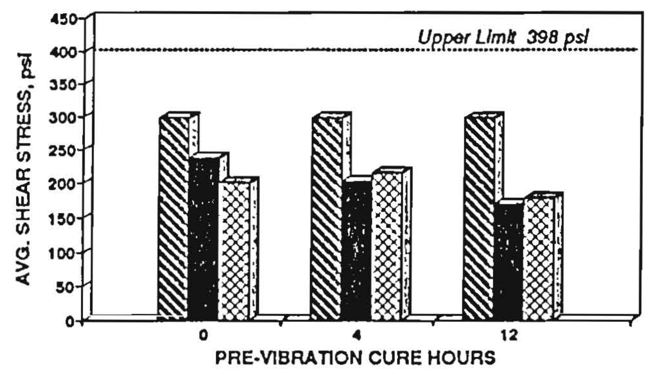
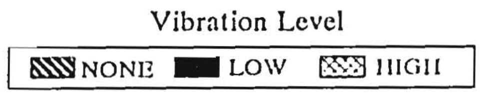


Figure B.80 Comparison of Avg. Shear Stresses After Pre-Vibration Cure Time for 4 in. Overlays with Smooth-Dry Interface (12 in. Span)



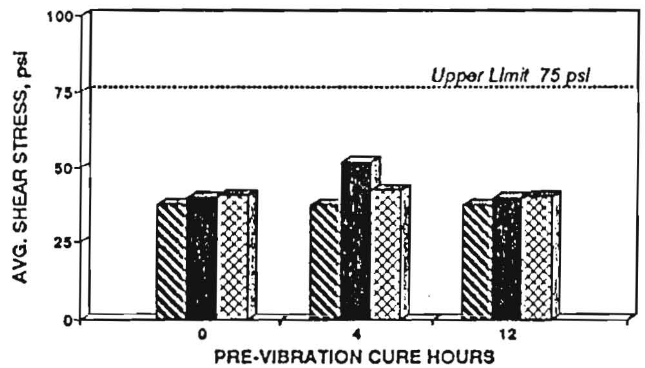


Figure B.81 Comparison of Avg. Shear Stresses After Pre-Vibration Cure Time for 2 in. Overlays with Smooth-Dry Interface (30.5 in. Span)

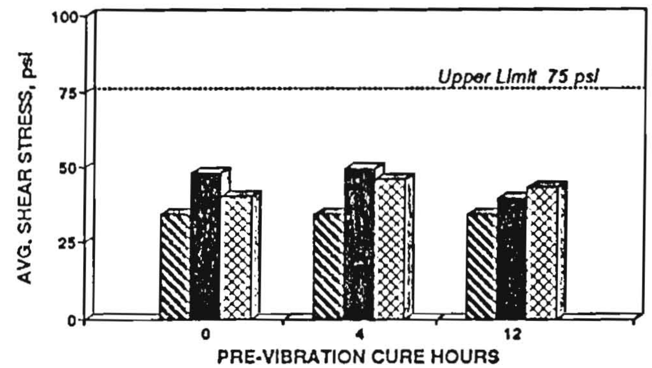


Figure B.82 Comparison of Avg. Shear Stresses After Pre-Vibration Cure Time for 2 in. Overlays with Smooth-Wet Interface (30.5 in. Span)

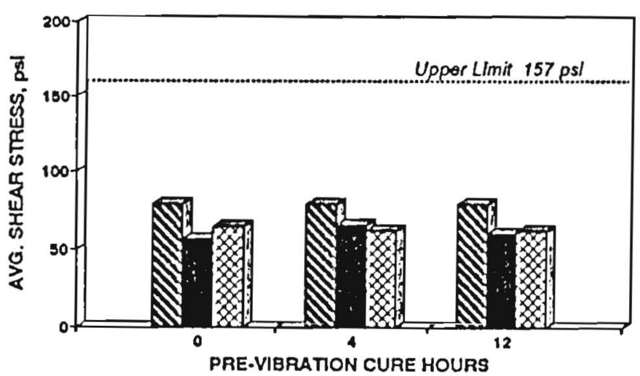


Figure B.83 Comparison of Avg. Shear Stresses After Pre-Vibration Cure Time for 4 in. Overlays with Smooth-Dry Interface (30.5 in. Span)

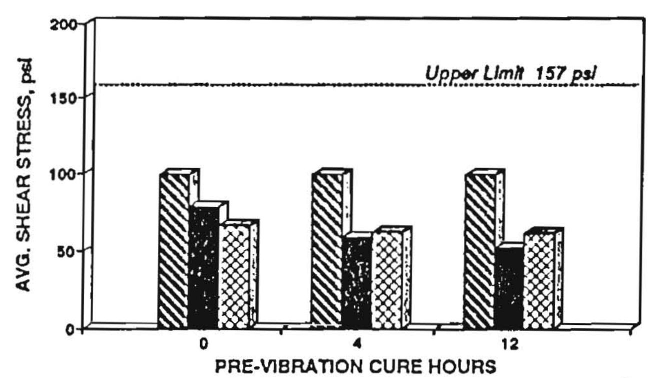
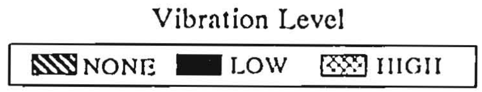


Figure B.84 Comparison of Avg. Shear Stresses After Pre-Vibration Cure Time for 4 in. Overlays with Smooth-Wet Interface (30.5 in. Span)



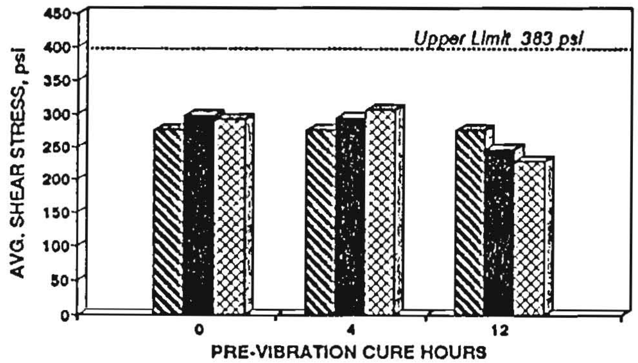


Figure B.85 Comparison of Avg. Shear Stresses After Pre-Vibration Cure Time for 2 in. Overlays with Rough-Dry Interface (6 in. Span)

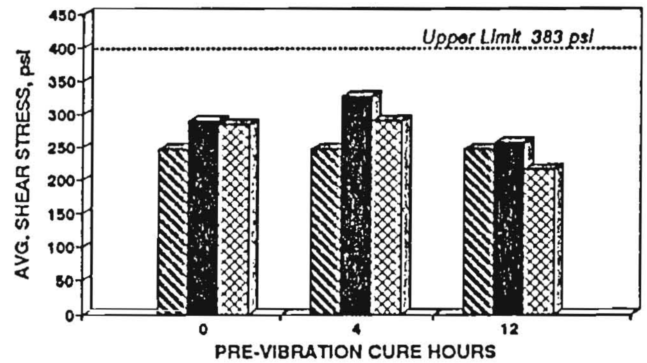


Figure B.86 Comparison of Avg. Shear Stresses After Pre-Vibration Cure Time for 2 in. Overlays with Rough-Wet Interface (6 in. Span)

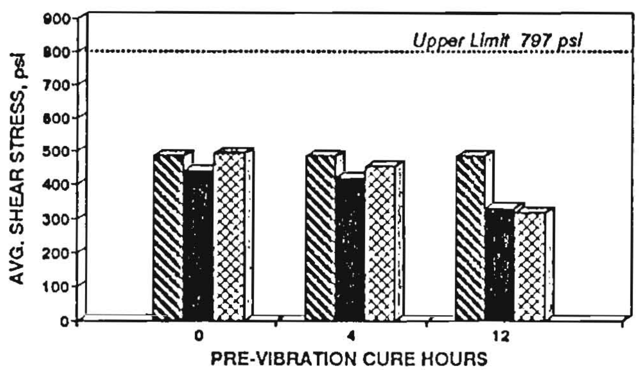


Figure B.87 Comparison of Avg. Shear Stresses After Pre-Vibration Cure Time for 4 in. Overlays with Rough-Dry Interface (6 in. Span)

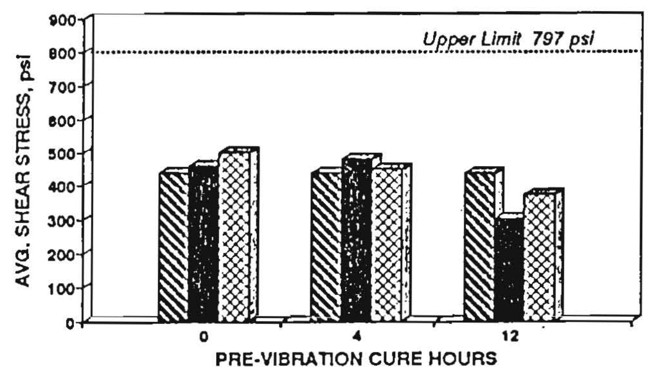
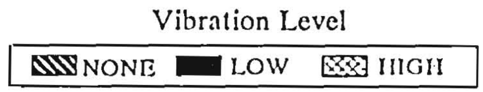


Figure B.88 Comparison of Avg. Shear Stresses After Pre-Vibration Cure Time for 4 in. Overlays with Rough-Wet Interface (6 in. Span)



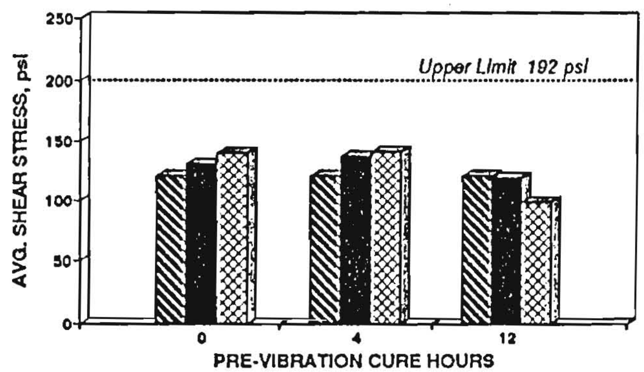


Figure B.89 Comparison of Avg. Shear Stresses After Pre-Vibration Cure Time for 2 in. Overlays with Rough-Dry Interface (12 in. Span)

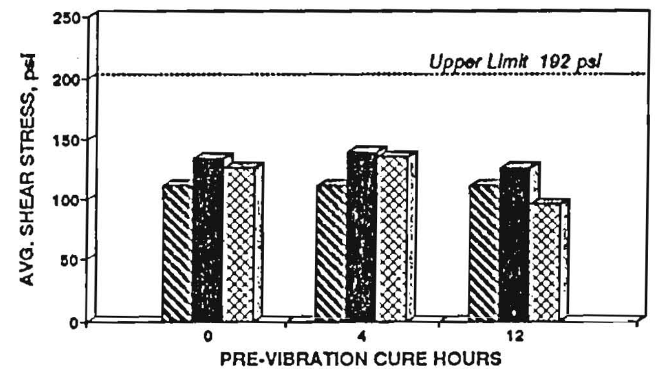


Figure B.90 Comparison of Avg. Shear Stresses After Pre-Vibration Cure Time for a 2 in. Overlay with Rough-Wet Interface (12 in. Span)

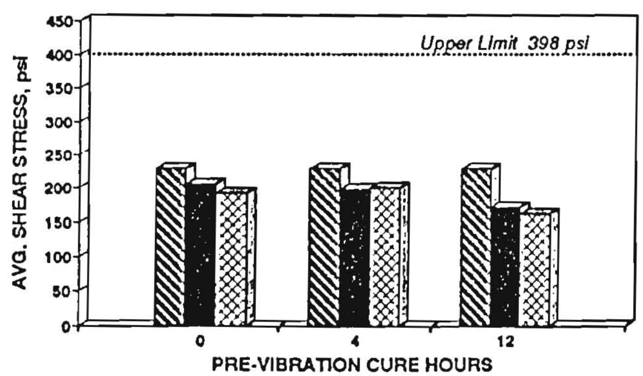


Figure B.91 Comparison of Avg. Shear Stresses After Pre-Vibration Cure Time for 4 in. Overlays with Rough-Dry Interface (12 in. Span)

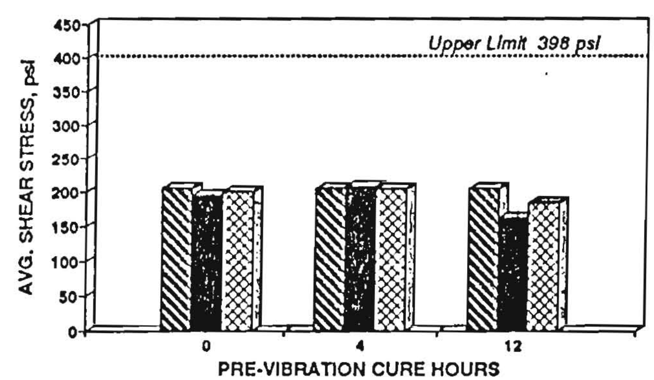


Figure B.92 Comparison of Avg. Shear Stresses After Pre-Vibration Cure Time for 4 in. Overlays with Rough-Wet Interface (12 in. Span)

Vibration Level

NONE LOW HIGH

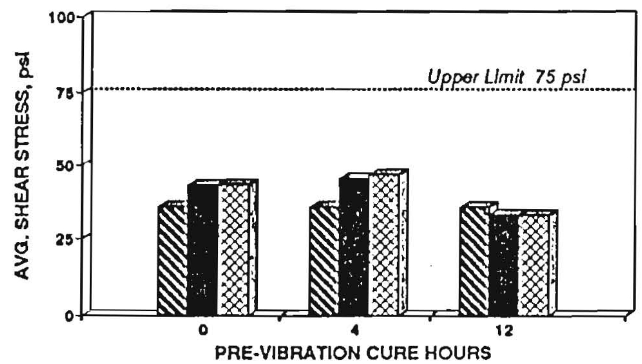


Figure B.93 Comparison of Avg. Shear Stresses After of Pre-Vibration Cure Time for 2 in. Overlays with Rough-Dry Interface (30.5 in. Span)

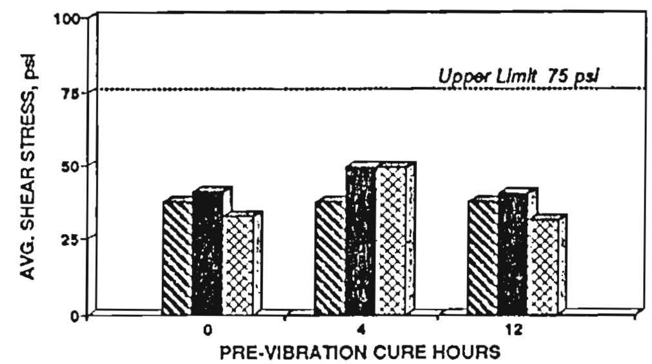


Figure B.94 Comparison of Avg. Shear Stresses After Pre-Vibration Cure Time for 2 in. Overlays with Rough-Wet Interface (30.5 in. Span)

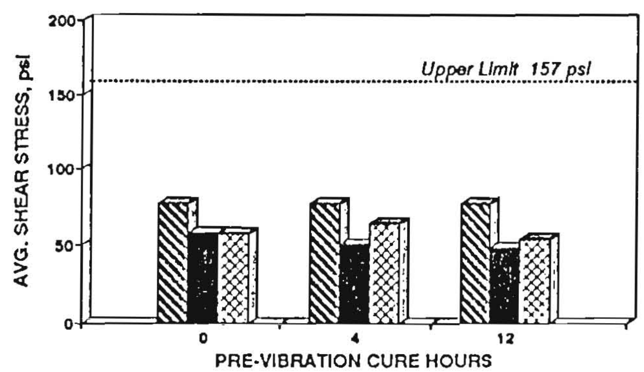


Figure B.95 Comparison of Avg. Shear Stresses After Pre-Vibration Cure Time for 4 in. Overlays with Rough-Dry Interface (30.5 in. Span)

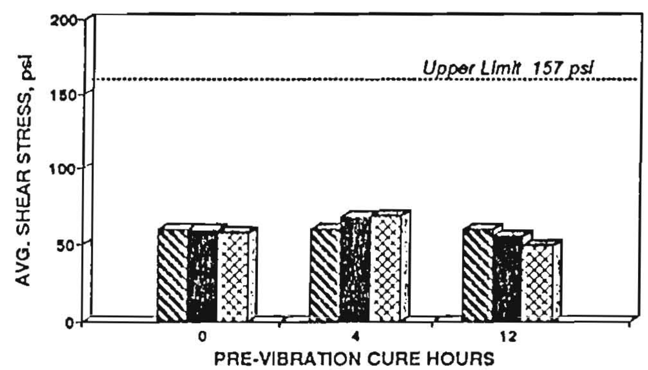
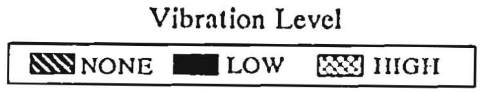


Figure B.96 Comparison of Avg. Shear Stresses After Pre-Vibration Cure Time for 4 in. Overlays with Rough-Wet Interface (30.5 in. Span)



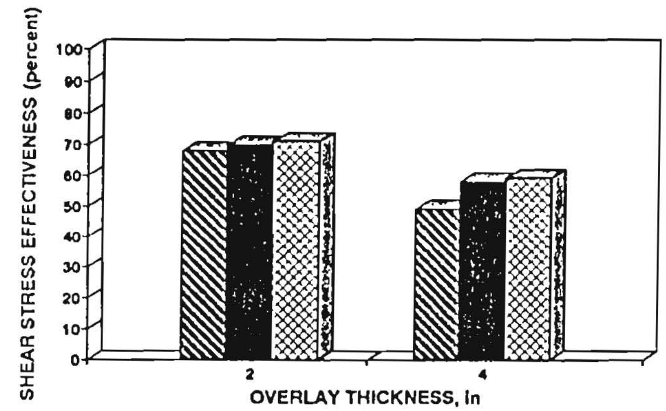


Figure B.97 Comparison of Effectiveness of Interface Bonding of Specimens with 2 in. and 4 in. Overlays After 0 Hrs of Pre-Vibration Cure with Smooth-Dry Interface (6 in. Span)

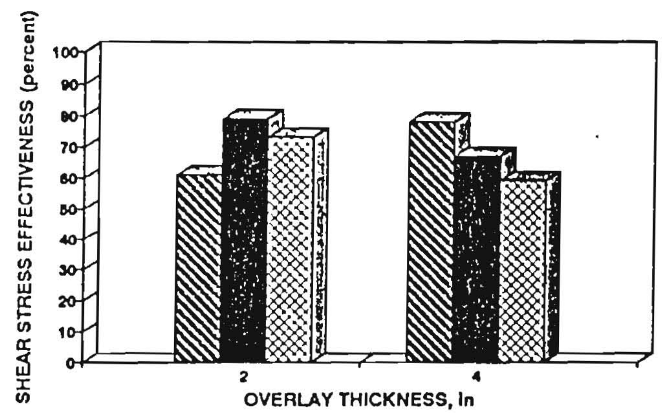


Figure B.98 Comparison of Effectiveness of Interface Bonding of Specimens with 2 in. and 4 in. Overlays After 0 Hrs of Pre-Vibration Cure with Smooth-Wet Interface (6 in. Span)

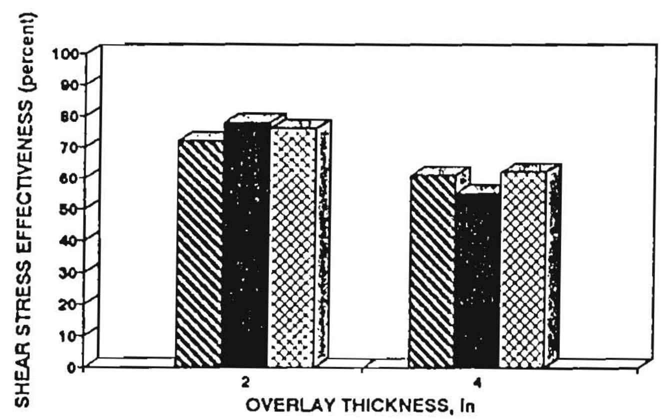


Figure B.99 Comparison of Effectiveness of Interface Bonding of Specimens with 2 in. and 4 in. Overlays After 0 Hrs of Pre-Vibration Cure with Rough-Dry Interface (6 in. Span)

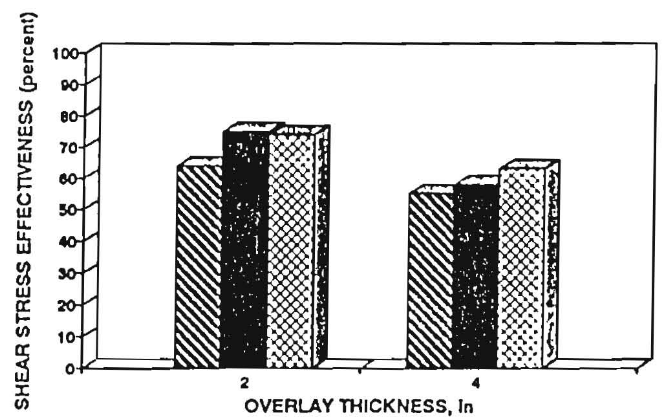


Figure B.100 Comparison of Effectiveness of Interface Bonding of Specimens with 2 in. and 4 in. Overlays After 0 Hrs of Pre-Vibration Cure with Rough-Wet Interface (6 in. Span)

Vibration Level

NONE LOW HIGH

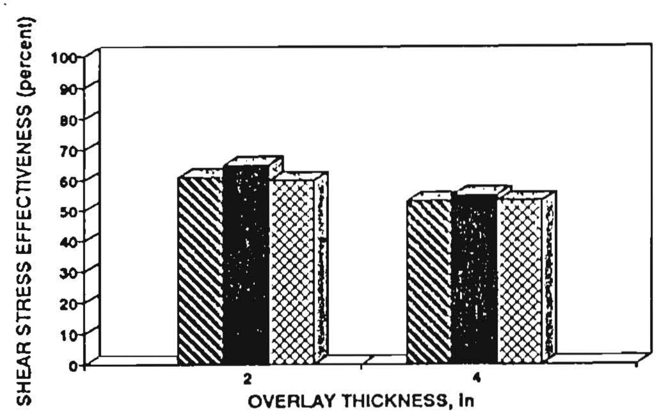


Figure B.101 Comparison of Effectiveness of Interface Bonding of Specimens with 2 in. and 4 in. Overlays After 0 Hrs of Pre-Vibration Cure with Smooth-Dry Interface (12 in. Span)

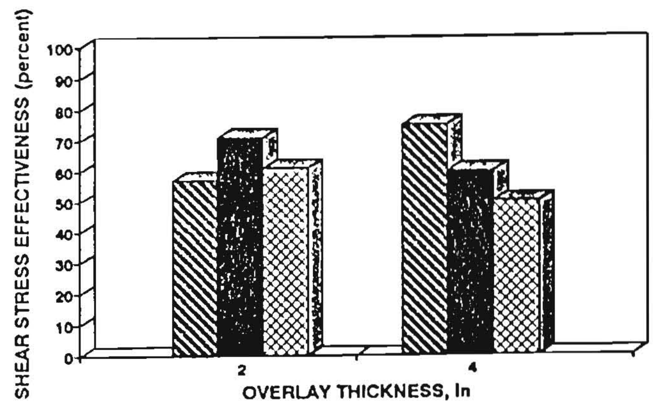


Figure B.102 Comparison of Effectiveness of Interface Bonding of Specimens with 2 in. and 4 in. Overlays After 0 Hrs of Pre-Vibration Cure with Smooth-Wet Interface (12 in. Span)

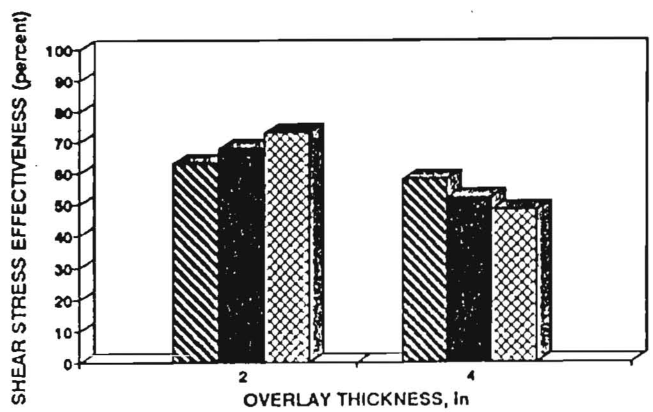


Figure B.103 Comparison of Effectiveness of Interface Bonding of Specimens with 2 in. and 4 in. Overlays After 0 Hrs of Pre-Vibration Cure with Rough-Dry Interface (12 in. Span)

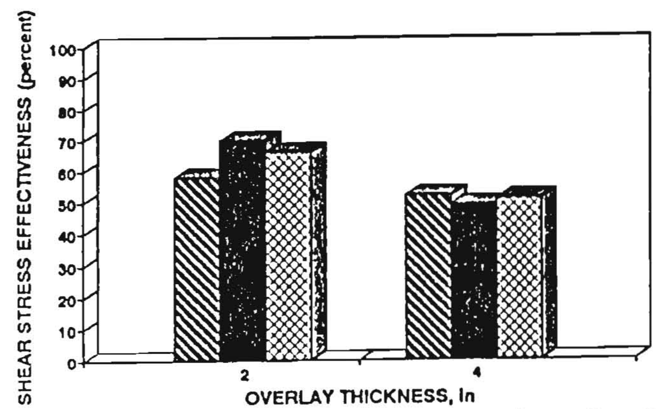


Figure B.104 Comparison of Effectiveness of Interface Bonding of Specimens with 2 in. and 4 in. Overlays After 0 Hrs of Pre-Vibration Cure with Rough-Wet Interface (12 in. Span)

Vibration Level

NONE LOW HIGH

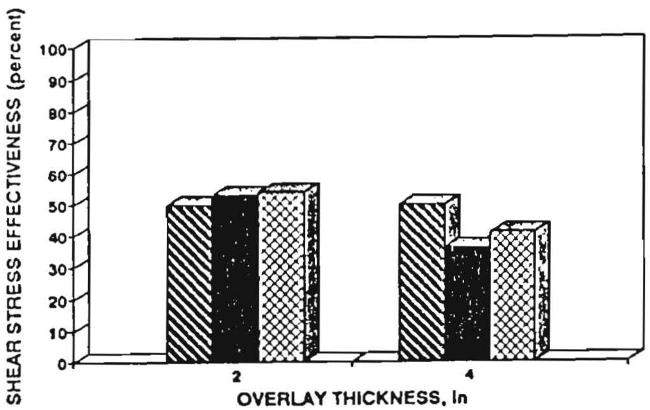


Figure B.105 Comparison of Effectiveness of Interface Bonding of Specimens with 2 in. and 4 in. Overlays After 0 Hrs of Pre-Vibration Cure with Smooth-Dry Interface (30.5 in. Span)

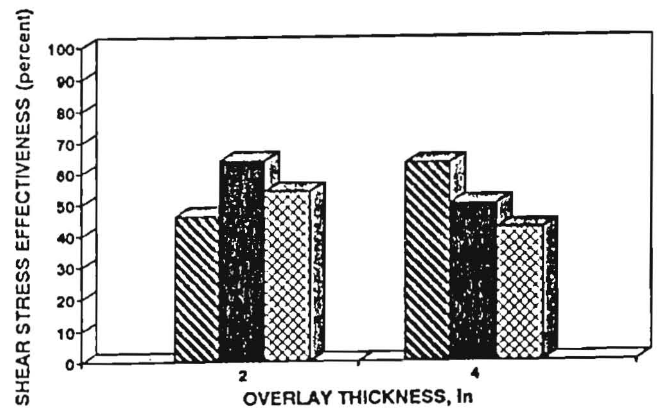


Figure B.106 Comparison of Effectiveness of Interface Bonding of Specimens with 2 in. and 4 in. Overlays After 0 Hrs of Pre-Vibration Cure with Smooth-Wet Interface (30.5 in. Span)

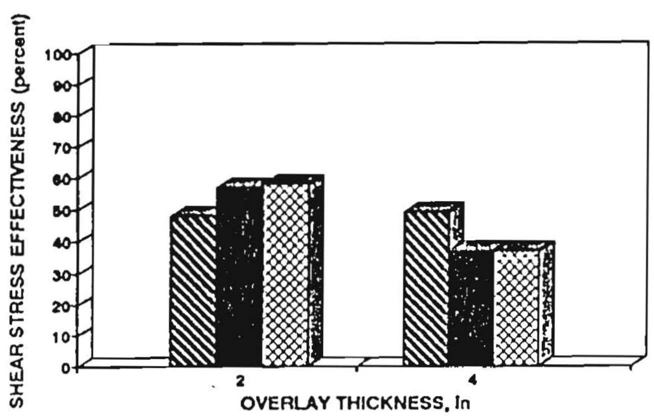


Figure B.107 Comparison of Effectiveness of Interface Bonding of Specimens with 2 in. and 4 in. Overlays After 0 Hrs of Pre-Vibration Cure with Rough-Dry Interface (30.5 in. Span)

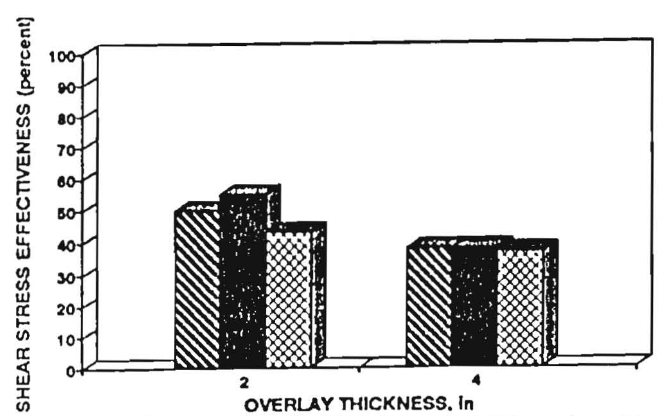


Figure B.108 Comparison of Effectiveness of Interface Bonding of Specimens with 2 in. and 4 in. Overlays After 0 Hrs of Pre-Vibration Cure with Rough-Wet Interface (30.5 in. Span)

Vibration Level

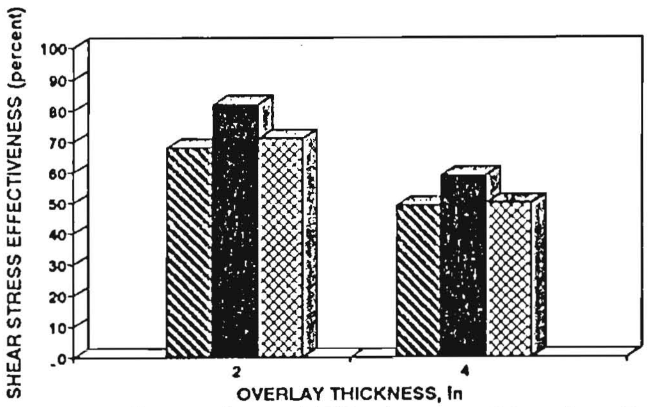


Figure B.109 Comparison of Effectiveness of Interface Bonding of Specimens with 2 in. and 4 in. Overlays After 4 Hrs of Pre-Vibration Cure with Smooth-Dry Interface (6 in. Span)

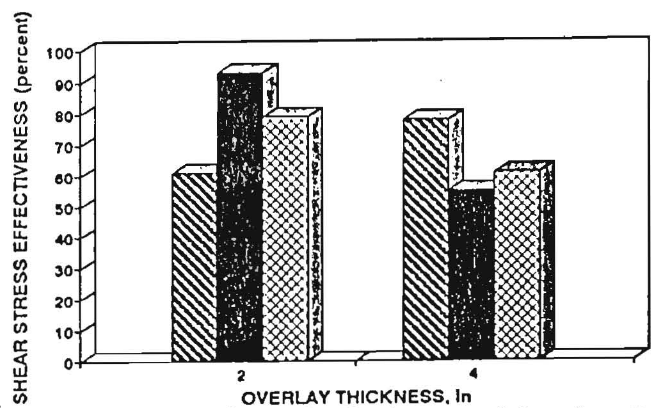


Figure B.110 Comparison of Effectiveness of Interface Bonding of Specimens with 2 in. and 4 in. Overlays After 4 Hrs of Pre-Vibration Cure with Smooth-Wet Interface (6 in. Span)

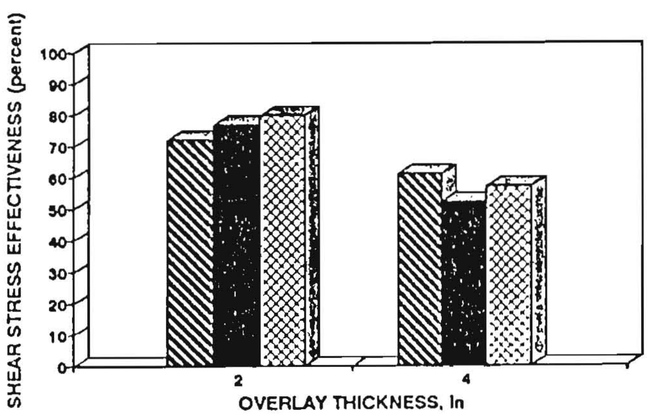


Figure B.111 Comparison of Effectiveness of Interface Bonding of Specimens with 2 in. and 4 in. Overlays After 4 Hrs of Pre-Vibration Cure with Rough-Dry Interface (6 in. Span)

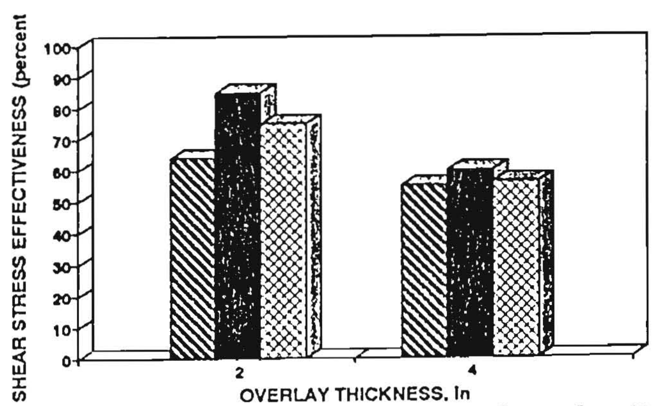


Figure B.112 Comparison of Effectiveness of Interface Bonding of Specimens with 2 in. and 4 in. Overlays After 4 Hrs of Pre-Vibration Cure with Rough-wet Interface (6 in. Span)

Vibration Level

NONE LOW HIGH

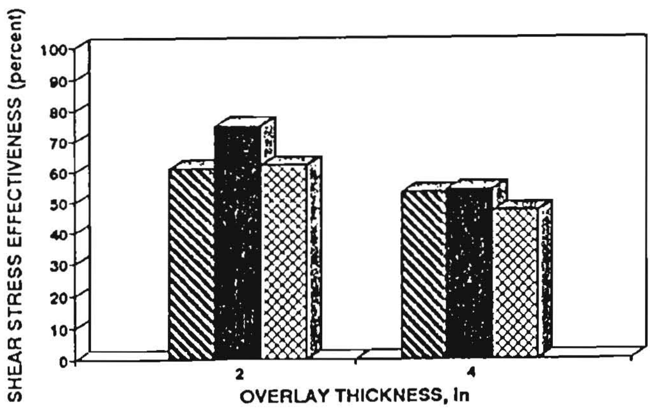


Figure B.113 Comparison of Effectiveness of Interface Bonding of Specimens with 2 in. and 4 in. Overlays After 4 Hrs of Pre-Vibration Cure with Smooth-Dry Interface (12 in. Span)

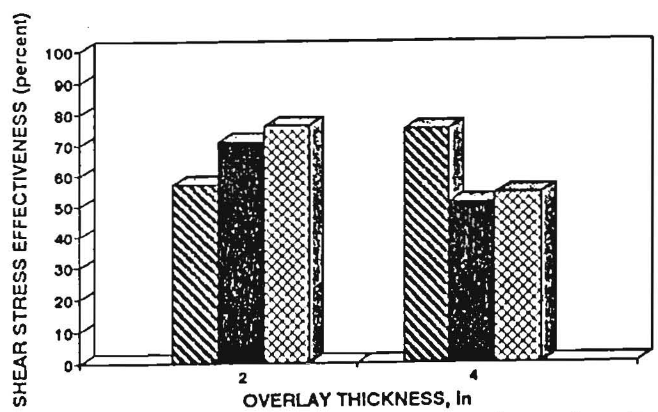


Figure B.114 Comparison of Effectiveness of Interface Bonding of Specimens with 2 in. and 4 in. Overlays After 4 Hrs of Pre-Vibration Cure with Smooth-Wet Interface (12 in. Span)

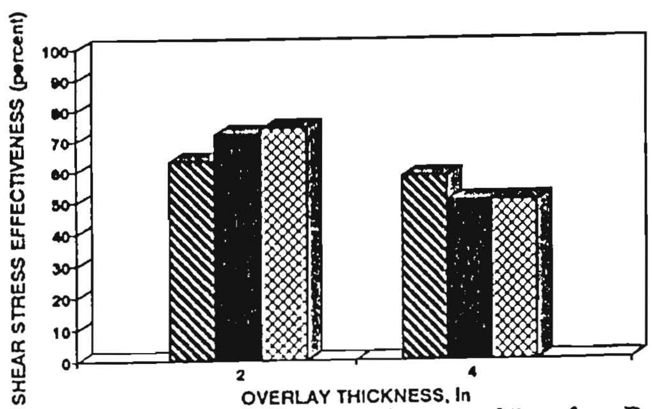


Figure B.115 Comparison of Effectiveness of Interface Bonding of Specimens with 2 in. and 4 in. Overlays After 4 Hrs of Pre-Vibration Cure with Rough-Dry Interface (12 in. Span)

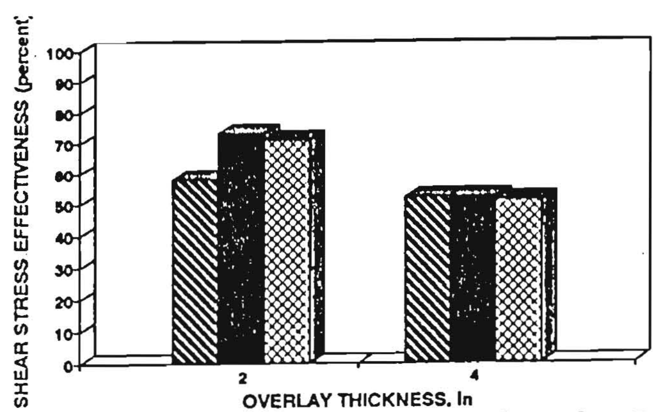


Figure B.116 Comparison of Effectiveness of Interface Bonding of Specimens with 2 in. and 4 in. Overlays After 4 Hrs of Pre-Vibration Cure with Rough-Wet Interface (12 in. Span)

Vibration Level

NONE LOW HIGH

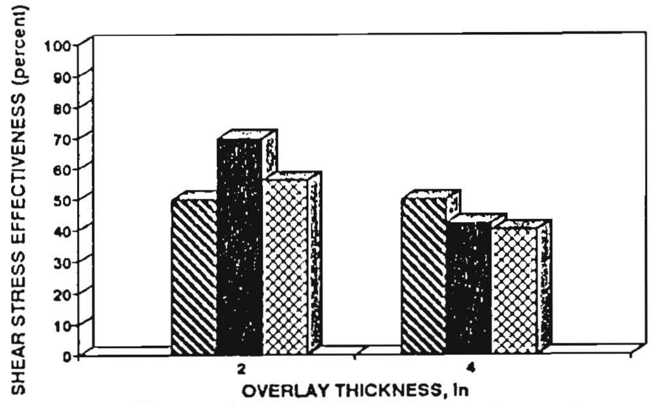


Figure B.117 Comparison of Effectiveness of Interface Bonding of Specimens with 2 in. and 4 in. Overlays After 4 Hrs of Pre-Vibration Cure with Smooth-Dry Interface (30.5 in. Span)

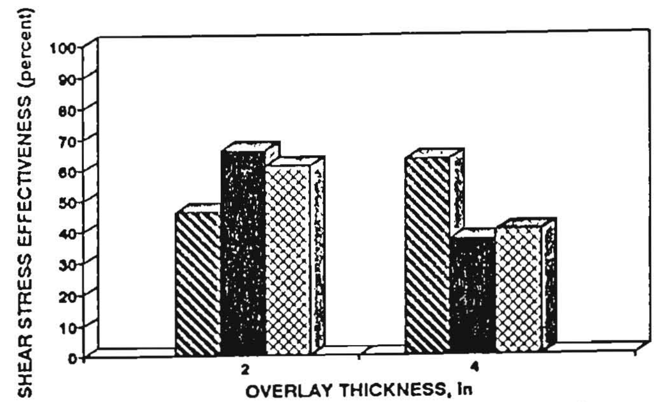


Figure B.118 Comparison of Effectiveness of Interface Bonding of Specimens with 2 in. and 4 in. Overlays After 4 Hrs of Pre-Vibration Cure with Smooth-Wet Interface (30.5 in. Span)

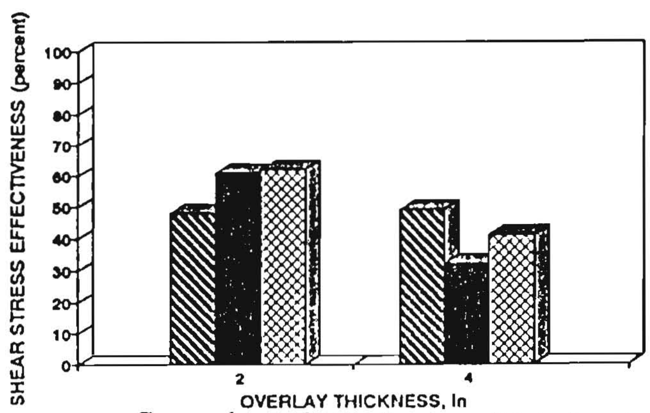


Figure B.119 Comparison of Effectiveness of Interface Bonding of Specimens with 2 in. and 4 in. Overlays After 4 Hrs of Pre-Vibration Cure with Rough-Dry Interface (30.5 in. Span)

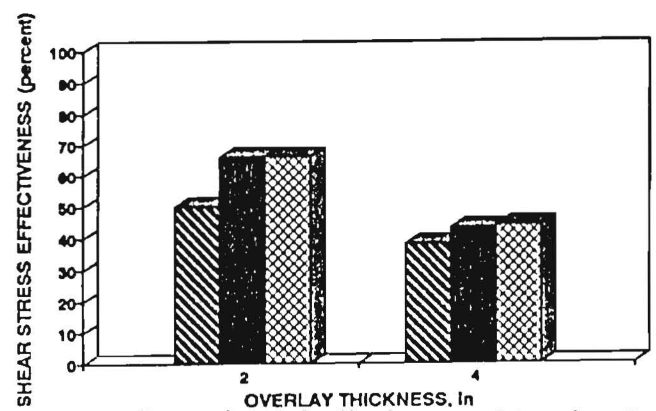


Figure B.120 Comparison of Effectiveness of Interface Bonding of Specimens with 2 in. and 4 in. Overlays After 4 Hrs of Pre-Vibration Cure with Rough-Wet Interface (30.5 in. Span)

Vibration Level

NONE LOW HIGH

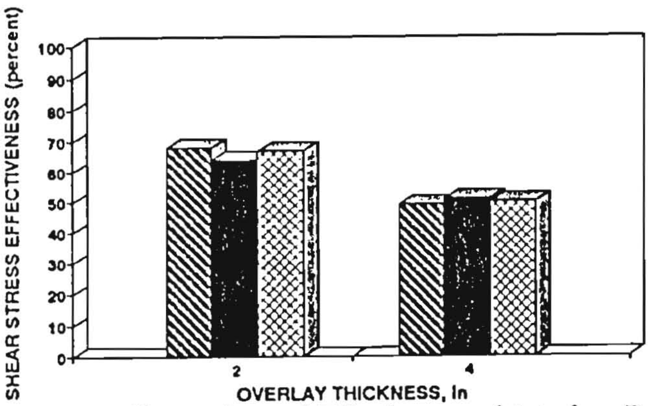


Figure B.121 Comparison of Effectiveness of Interface Bonding of Specimens with 2 in. and 4 in. Overlays After 12 Hrs of Pre-Vibration Cure with Smooth-Dry Interface (6 in. Span)

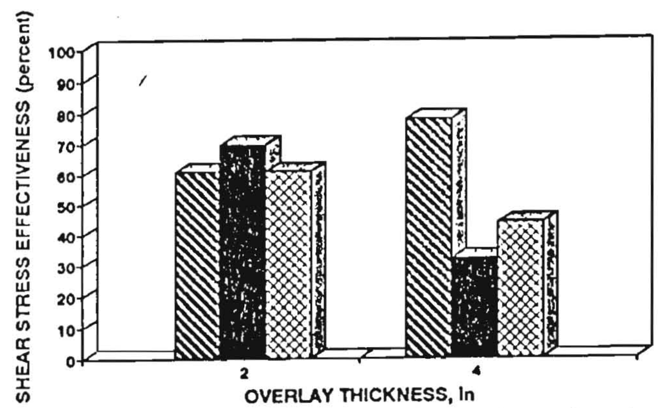


Figure B.122 Comparison of Effectiveness of Interface Bonding of Specimens with 2 in. and 4 in. Overlays After 12 Hrs of Pre-Vibration Cure with Smooth-Wet Interface (6 in. Span)

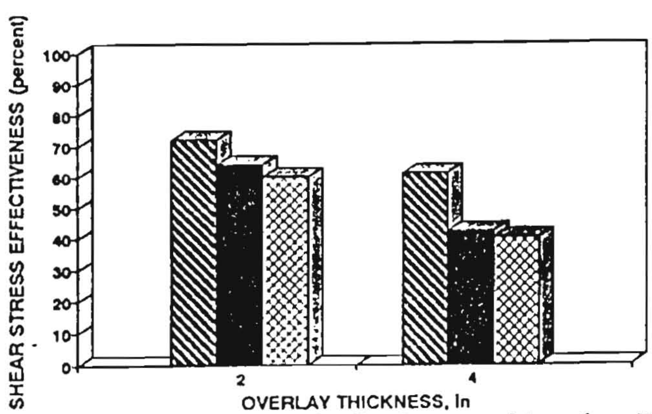


Figure B.123 Comparison of Effectiveness of Interface Bonding of Specimens with 2 in. and 4 in. Overlays After 12 Hrs of Pre-Vibration Cure with Rough-Dry Interface (6 in. Span)

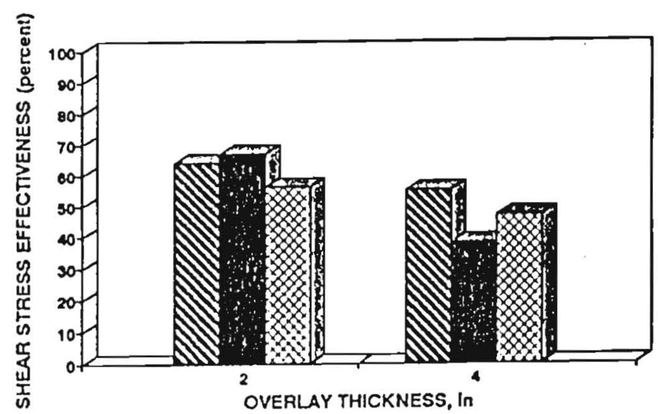


Figure B.124 Comparison of Effectiveness of Interface Bonding of Specimens with 2 in. and 4 in. Overlays After 12 Hrs of Pre-Vibration Cure with Rough-Wet Interface (6 in. Span)

Vibration Level

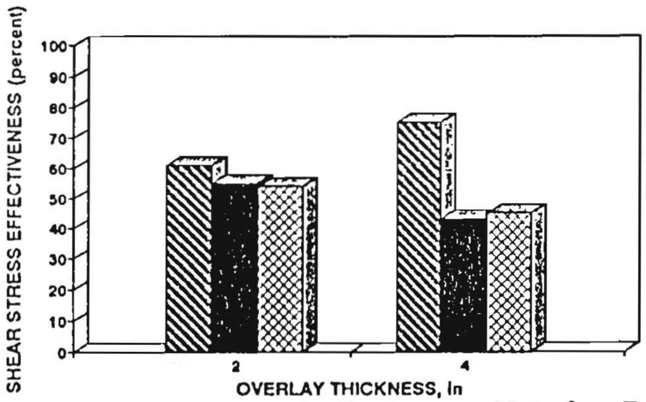


Figure B.125 Comparison of Effectiveness of Interface Bonding of Specimens with 2 in. and 4 in. Overlays After 12 Hrs of Pre-Vibration Cure with Smooth-Dry Interface (12 in. Span)

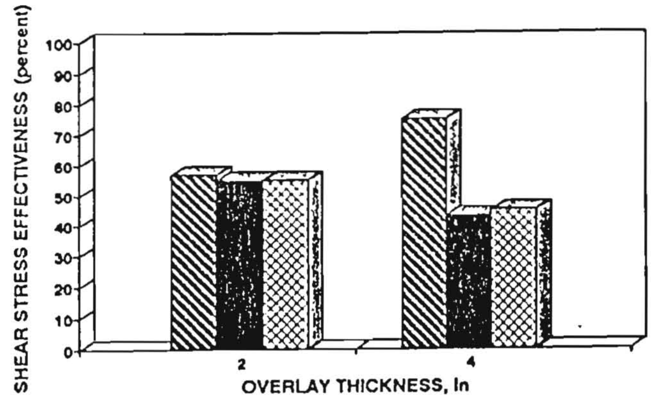


Figure B.126 Comparison of Effectiveness of Interface Bonding of Specimens with 2 in. and 4 in. Overlays After 12 Hrs of Pre-Vibration Cure with Smooth-Wet Interface (12 in. Span)

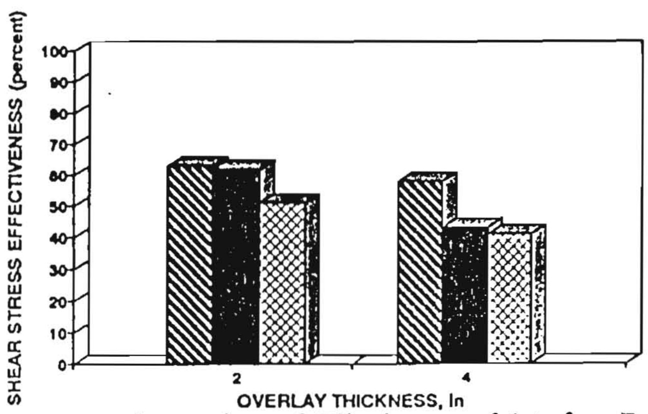


Figure B.127 Comparison of Effectiveness of Interface Bonding of Specimens with 2 in. and 4 in. Overlays After 12 Hrs of Pre-Vibration Cure with Rough-Dry Interface (12 in. Span)

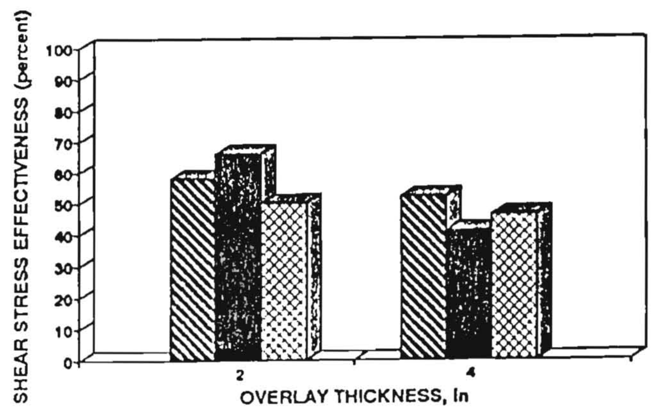


Figure B.128 Comparison of Effectiveness of Interface Bonding of Specimens with 2 in. and 4 in. Overlays After 12 Hrs of Pre-Vibration Cure with Rough-Wet Interface (12 in. Span)

Vibration Level

NONE LOW HIGH

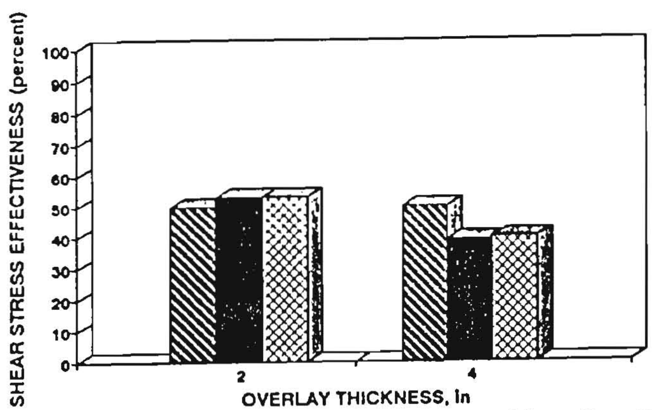


Figure B.129 Comparison of Effectiveness of Interface Bonding of Specimens with 2 in. and 4 in. Overlays After 12 Hrs of Pre-Vibration Cure with Smooth-Dry Interface (30.5 in. Span)

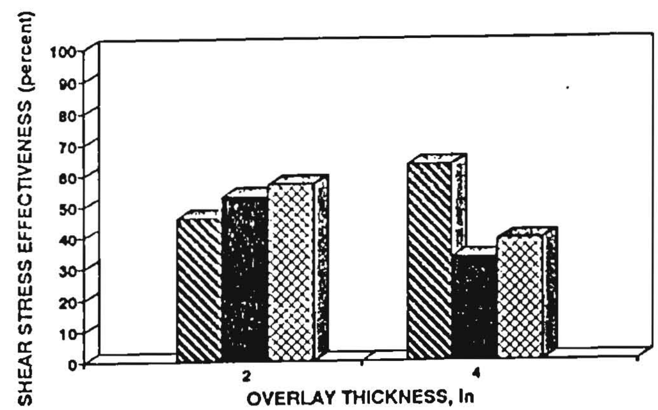


Figure B.130 Comparison of Effectiveness of Interface Bonding of Specimens with 2 in. and 4 in. Overlays After 12 Hrs of Pre-Vibration Cure with Smooth-Wet Interface (30.5 in. Span)

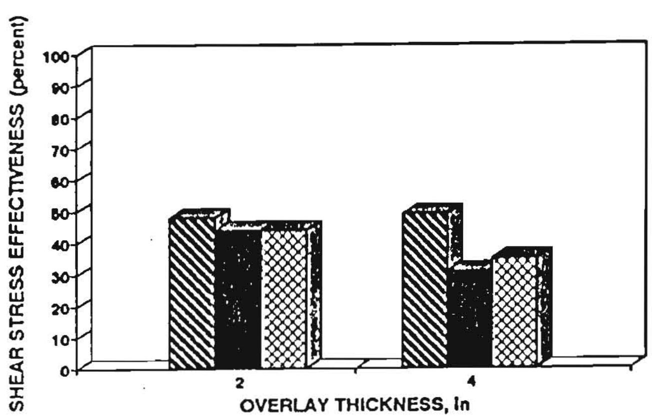


Figure B.131 Comparison of Effectiveness of Interface Bonding of Specimens with 2 in. and 4 in. Overlays After 12 Hrs of Pre-Vibration Cure with Rough-Dry Interface (30.5 in. Span)

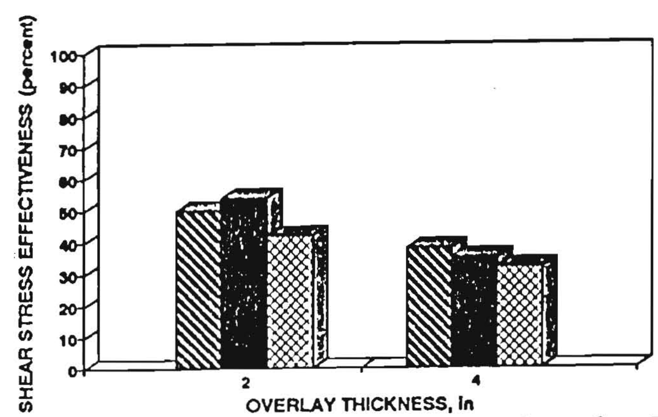


Figure B.132 Comparison of Effectiveness of Interface Bonding of Specimens with 2 in. and 4 in. Overlays After 12 Hrs of Pre-Vibration Cure with Rough-Wet Interface (30.5 in. Span)

References

1. AASHTO-AGC-ARTBA Joint Committee (1990), Subcommittee on New Highway Material Task Force 30 Report (in Two Parts) "Guide Specifications for Concrete Overlays of Pavements and Bridge Decks," Washington, D.C.

2. Furr, H. L. and H. Fouad (1981), "Bridge Slab Concrete Placed Adjacent to Moving Live Loads," Research Report No. 266-1F, Texas Transportation Institute, The Texas A&M University System.

3. Gausman, R. H. (1986), "Status of Thin-bonded Concrete Overlays," Report No. FHWA-EP-2-1, Federal Highway Administration Office of Highway Operations Demonstration Projects Division, Washington, D.C.

4. Kailasananthan, K., F. B. McCullough and D. W. Fowler, (1984), "A Study of the Effects of Interface condition on Thin Bonded PCC Overlays,"Research Report No. 357-1, Center for Transportation Research Bureau of Engineer Research, The University of Texas at Austin.

5. Manning, D. G. (1981), "Effects of Traffic-Induced Vibrations on Bridge-Deck Repairs," Synthesis of Highway Practice 86, National Cooperative Highway Research Program, Transportation Research Board, Washington, D.C.

6. Peshkin, D.G., A. L. Mueller, K. D. Smith, and M. I. Darter, (1989), "Performance Evaluation and Analysis of Thin Bonded Concrete Overlays," FHWA Contract No. DTFH61-86-C-00079, ERES Consultants, Inc., Savoy, Il.

7. Suh, Y.C., J.R. Lundy, F.B. McCullough and D. W. Fowler, (1988), "A Summary of Studies of Bonded Concrete Overlays, "Research Report No. 457-5F, Center for Transportation Research, The University of Texas at Austin.

8. Rodriguez-Gomez, J. and S. Nazarian, (1992), "Laboratory Investigation of Delamination and Debonding of Thin-Bonded Overlays Due to Vehicular Vibration,"Research Report 1920-1, Center for Geotechnical & Highway Materials Research, The University of Texas at El Paso.

9. Zamora R. (1991), "Comparison of Laboratory and In Situ Curing of Concrete", Proceedings, National Engineering Symposium of The Society of Mexican-American Engineers and Scientists, Houston, Texas.