ARIZONA DEPARTMENT OF TRANSPORTATION

REPORT NUMBER: FHWA/AZ-83/186

# LABORATORY EVALUATION OF ANTI-REFLECTION CRACKING MATERIALS

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**December 1983**

**Prepared for**
Arizona Department of Transportation
206 South 17th Avenue
Phoenix, Arizona 85007
and
The U.S. Department of Transportation
Federal Highway Administration
Arizona Division

**Technical Report Documentation Page**

| 1. Report No. | 2. Government Accession No. | 3. Recipient's Catalog No. |
|---|---|---|
| FHWA/AZ-83/186 | | |

| 4. Title and Subtitle | 5. Report Date / 6. Performing Organization Code / 8. Performing Organization Report No. |
|---|---|
| Laboratory Evaluation of Anti-Reflection Cracking Materials | 5. December 1983 |
| | 6. |
| 7. Author(s): R. A. Jimenez and W. R. Meier | 8. ATTI-83-4 |
| 9. Performing Organization Name and Address: Arizona Transportation and Traffic Institute, College of Engineering, University of Arizona, Tucson, Arizona 85721 | 10. Work Unit No. (TRAIS) |
| | 11. Contract or Grant No.: HPR-1-23(186) |
| 12. Sponsoring Agency Name and Address: Arizona Department of Transportation, 206 So. 17th Avenue, Phoenix, Arizona 85007 | 13. Type of Report and Period Covered: Final December 1983 |
| | 14. Sponsoring Agency Code |

15. Supplementary Notes Prepared in cooperation with the U.S. Department of Transportation, Federal Highway Administration, from a study of anti-reflection cracking materials. The opinions and conclusions are those of the authors and not necessarily of the Federal Highway Administration.

16. Abstract This report is concerned with the evaluation of four mixtures of asphalt-rubber to serve as a strain attenuating layer in asphaltic concrete overlays. The four mixtures consisted of two different blends of asphalt-rubber and the strain attenuating layer was made with and without stone chips. The tests used for the evaluation were developed to simulate certain pavement loadings, and they were classified as repeated vertical shear, horizontal shear, repeated horizontal shear, and flexure fatigue. Calculations were carried out to determine the effects of the strain attenuating layer on stress in the laboratory models and also in flexible layered pavement systems. The laboratory test results showed that the layers without the stone chips had the best performance. The calculations for the laboratory and pavement models indicated that the greatest effects brought about by the layer was in reduction of horizontal shear at the overlay-layer interface and that there must be a limiting thickness of the layer to prevent tensile overstress of the bottom surface of the asphaltic concrete overlay.

| 17. Key Words | 18. Distribution Statement |
|---|---|
| asphalt-rubber, asphalt testing, reflection cracking, strain attenuating material. | No restrictions. This document is available to the pbulic through the National Technical Information Service, Springfield, Virginia 22161 |

| 19. Security Classif. (of this report) | 20. Security Classif. (of this page) | 21. No. of Pages | 22. Price |
|---|---|---|---|
| Unclassified | Unclassified | 87 | |

**Form DOT F 1700.7** (8-72) **Reproduction of completed page authorized**

ACKNOWLEDGEMENT

The cooperation received from the Arizona Department of Transportation, Arizona Refining Company, and the Sahuaro Petroleum and Asphalt Company is greatly appreciated. Particular individuals to be recognized are Gene Morris, former Director of the Arizona Transportation Research Center of ADOT, Frank McCullagh of ADOT, and two University of Arizona civil engineering students: John Patterson and Steve Wilson.

We sincerely value the consideration given by ADOT and FHWA to the sponsorship of this investigation. We believe that the best use of asphalt-rubber in a strain attenuating layer has not been as yet employed.

LABORATORY EVALUATION OF ANTI-REFLECTION CRACKING MATERIALS

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## SYNOPSIS

This report is concerned with the evaluation of four mixtures of asphalt-rubber to serve as a strain attenuating layer in asphaltic concrete overlays. The four mixtures consisted of two different blends of asphalt-rubber and the strain attenuating layer was made with and without stone chips. The tests used for the evaluation were developed to simulate certain pavement loadings and they were classified as repeated vertical shear, static horizontal shear, repeated horizontal shear and flexure fatigue. Calculations were carried out to determine the effects of the strain attenuating layer on stresses in the laboratory models and also in flexible layered pavement systems. The laboratory test results showed that the layers without the stone chips had the best performance. The calculations for the laboratory and pavement models indicated that the greatest effects brought about by the attenuating layer was in reduction of horizontal shear at the overlay-asphalt-rubber layer interface and that there must be a limiting thickness of that layer to prevent tensile overstress of the bottom surface of the asphaltic concrete overlay.

## INTRODUCTION

A reflection crack is one that develops in an overlay and which is directly over a preexistent crack in its supporting layer. In asphaltic concrete overlays, the supporting layer may have cracked from (a) shrinkage stresses, (b) load stresses, or (c) from the reflection crack phenomenon. The supporting layer may be composed of portland cement concrete, asphaltic concrete, cement treated base or a clay bound soil course.

The design of overlays has included the concept of making the overlay thick enough to resist the stresses causing reflection cracking or by placing a layer of low deformation modulus between the old pavement surface and the new overlay. The first method was generally expensive in cost, especially if wire mesh was used, and also found not to be always successful; in the second method a layer of unbound granular base, or a large stone-open-asphalt-bound base, or a relatively thin asphalt-rubber chip seal has been found to minimize the incidence of reflection cracking. It is surmized the success of those materials was due to their low deformation modulus.

Asphalt-rubber (A-R) is a mixture of asphalt and fine grindings from rubber tires. Its properties and uses have been reported by McDonald (1), Morris and McDonald (2), Green and Tolonen (3) and Jimenez (4). The Arizona Department of Transportation (ADOT) has used the asphalt-rubber chip seal since the early 1970's as an anti-reflection cracking material (2).

In Reference 4, Jimenez suggests that reflection cracking is brought about by shear stresses rather than by tensile stresses. That statement was made on the basis of results from laboratory testing which attempted to simulate field loading conditions. In those tests, an asphaltic concrete beam was attached to aluminum plates with RC-250 or asphalt-rubber; however, the asphalt-rubber serving as the anti-reflection cracking material did not have the stone chips. Also in Reference 4 (as will be done in this report) the low deformation modulus material will be labeled a "strain attenuating layer" (SAL).

In Arizona, two types of asphalt-rubber are used for the construction of SALs. The rubber in one kind is synthetic and obtained from passenger tires; the other one is a combination of synthetic and natural rubber obtained from truck tires. The A-R made with the passenger tire grindings is mixed with a low viscosity asphalt and the other A-R is mixed with a high viscosity asphalt plus a small amount of an extender oil (an aromatic material). A limited investigation for comparing the viscosity of these two asphalt-rubber mixtures was reported by Jimenez (5).

The investigation being reported was concerned with determining differences between the two types of A-R and also those resulting for the use of stone chips in the SAL. The work plan included testing beams simulating an overlay situation under loadings of (a) repeated vertical shear, (b) static horizontal shear, (c) repeated horizontal shear, and (d) flexural fatigue. Additionally, calculations were performed for determining the effects of SALs on stresses for assumed flexible pavement layered systems and also for the laboratory models.

## MATERIALS USED

In the planning of the work program, it was the intention that there would not be a variation in materials other than the A-Rs. However, because of increasing the scope of work and the re-running of tests for checking purposes, the asphaltic concrete for making the beams was not held to a constant mixture. Nevertheless, for a particular group comparison, the asphaltic concrete mixture was not a variable.

### Materials

#### Asphalts

The two asphalt cements used were furnished by the respective suppliers which are also the producers of the two A-R systems used by ADOT. The low viscosity asphalt, AR-1000, was furnished by Sahuaro Petroleum and Asphalt Company of Phoenix for use with the synthetic rubber and the high-viscosity asphalt was given by Arizona Refining Company (ARCO) of Phoenix for A-R blends containing some natural rubber. The asphalts were assumed to meet ADOT's specification (6) as shown in Appendix A, Table 1.

#### Rubber

The rubber to be used with the Sahuaro asphalt was obtained from Atlos Rubber, Inc., of Los Angeles, California, and characterized as Overflex TP 044.

The rubber to be used with the high viscosity asphalt, AR-4000, was furnished by ARCO as was the extender oil. The ARCO rubber was identified as G-274.

No measurements were made on the two types of rubber; however, References 4 and 5 present particle size distributions for both the TP 044 and G-274.

## Asphalt Rubber

The two asphalt-rubber blends will be identified as Sahuaro A-R and ARCO A-R. The Sahuaro A-R was made with 78 percent of AR-1000 and 22 percent TP-044 by total weight. The ARCO blend was composed of 78.4 percent AR-4000; 20.0 percent G-274; and 1.6 percent extender oil.

The procedure for making and storing the A-R blends is given in Appendix C.

## Asphaltic Concrete

Asphaltic concrete mixtures came from The Tanner Company plant in Tucson. Large quantities were obtained and stored in 5-gallon (19 l.) metal cans. A proven satisfactory procedure for storing and sampling the asphaltic mixtures in the containers is discussed in Reference 4. The asphaltic concrete mixtures were from regular plant production. The aggregate gradation and asphalt content from laboratory extractions are shown in Table 2 of Appendix A.

## Stone Chips and Sand

The stone chips came from a stock pile used for chip sealing from The Tanner Company. The chips used with the A-R for the SAL were one size, 3/8" - #4.

A concrete sand was used to correspond to a blotting operation in field construction. It had been anticipated that if the stone chips were to be omitted in actual construction of a SAL, then a blotting sand would be required to carry construction traffic over the straight A-R. At the present, we believe the A-R only SAL can be constructed without having construction traffic coming in direct contact with the A-R. The gradation of the blotting sand is shown in Table 2 of Appendix A.

## TESTS AND PROCEDURES

Test procedures for characterizing A-R blends have not been standardized; however, an extensive amount of laboratory measurements and their results have been reported by Rosner and Chehovits (7).

Original work and tests on laboratory models to investigate the effects of SALs on the resistance to reflection cracking are reported in Reference 4 as well as by Jimenez, Morris, and DaDeppo (8). The test procedures developed in the laboratory of The University will be described in the appropriate Appendix and minimal discussion on details will be presented in this section. Standard tests or those developed elsewhere will be referenced to the related publication.

### Viscosity and Aging

A-R blends of Sahuaro and ARCO as well as the AR-1000 cement were measured for viscosity at temperatures of 15, 25, and 35°C (59, 77, 95°F) before and after aging with the Rolling Thin Film Oven Test (RTFOT) (9). Period of exposures were 0, 75, and 225 minutes. The viscosity measurements were made with the Schweyer Rheometer using the procedure described in Reference 5.

In the RTFOT exposure, the A-R mixtures agglomerated and thus did not form a film to coat the inside of the test bottle; additionally, a short metal tube had to be inserted and attached to the mouth of the bottle to prevent the A-R mixture from falling out. Because of this occurrence the standard Thin Film Oven Test (TFOT) was used to age the two A-R blends.

### Making Composite Beams

The laboratory pavement model was composed of two aluminum plates to serve as the cracked supporting layer to an overlay; a tack coat of asphalt cement or the SAL to tie the overlay to the supporting layer, and an asphaltic concrete to represent the overlay. Each aluminum plate was 6 x 20 x 1/2-inch (152 x 508 x 12.7mm) and the asphaltic concrete beam was 5 inches (127mm) wide and 24 inches (610mm) long. The height of beam was varied from 2 to 4 inches (51 to 102mm). The procedures for placing the tack coat (or SALs) and for the compaction of the asphaltic-aluminum beam is given in Appendices D and E, respectively. Photographs of the equipment are shown in those appendices.

## Repeated Vertical Shear Test

The repeated vertical shear test was developed, as mentioned in Reference 4, to simulate wheel loads being transmitted from one side of a crack to the other by the overlay. The set-up and testing procedures are described in Appendix F. It is noted that the placement of the load is not exactly as occurs in a pavement, but it is believed the test is appropriate for comparing the response of different SAL treatments to the test.

## Static Horizontal Shear Test

The effect of this test was thought to be comparable to that occurring at the interface of an overlay or SAL and at the crack of the old pavement surface as the system undergoes cooling. A reading of Appendix G will show that the load applied axially to one of the aluminum plates was transmitted to the asphaltic beam through the SAL.

## Repeated Horizontal Shear Test

The repetitive nature of this test was considered to represent a repeated shear stress caused by the passage of traffic loads over the crack; it is recognized that the maximum shear stress caused by traffic is not necessarily of a horizontal direction. The testing procedure is described in Appendix H.

## Flexural Fatigue

The flexural fatigue procedure was that called the "Deflectometer Test" in this laboratory. The making and testing of 18-inch (457mm) diameter specimens has been reported to ADOT (9) as well as to ASTM (10).

It was the purpose of this testing to establish if there was any difference in fatigue resistance of the overlay should the SAL contain stone chips or not. As a consequence, the only difference to the standard procedure of making a specimen was to first place the SAL on an 0.010 inch (0.25mm) thick by 18-inch (457mm) diameter aluminum sheet which had been diametrically slit at right angles -- a length of 16 inches (406mm). The asphaltic concrete mixture was placed and compacted over the aluminum-SAL system in the normal manner.

All specimens were stored for a period of seven days prior to testing. The first day of storage was at 77°F (25°C) and the remaining six days at those corresponding to the test temperatures.

## RESULTS AND DISCUSSIONS OF TESTS

The total evaluation program was developed to help establish differences in performance between the Sahuaro and the ARCO asphalt-rubbers, between SALs with or without stone chips, and to calculate the effects of a SAL on shear and tensile stresses in the overlay system. However, only the testing portion of the program will be discussed in this section.

The results of the laboratory testing are shown numerically in Appendix A and graphically in Appendix B.

### Viscosities of Asphalt Cement and Asphalt-Rubbers

Viscosity measurements were performed with the Schweyer Rheometer in which the viscosity has generally been reported at a shear rate of 1 reciprocal second. Tables A-3 to A-5 show viscosities obtained for the AC-1000 asphalt and the Sahuaro and ARCO A-Rs at three temperatures before and after aging. Additionally, and assuming a power equation expressing the relationship between shear stress and shear rate, the viscosity at a shear rate of 0.05 $sec^{-1}$ was calculated and shown on the respective tables.

Table A-5-a presents relative viscosity values for the asphalt and A-Rs after aging by RTFOT.

Although none of the asphalt blends were overly susceptible to an increase in viscosity due to the hot air exposure, the Sahuaro A-R had slightly higher relative viscosity values than did the ARCO A-R.

Table A-5-b and Figures B-1 and B-2 indicate effects of temperature on the asphalt blends' viscosity before and after aging. The table shows the statistics for a relationship between temperature and viscosity in the form of

$$\eta = a\, T_F^{-b} \tag{1}$$

where $\eta$ is viscosity in k Pa-sec

$T_F$ is temperature in $^oF$

a and b are material constants.

The exponent b in the above equation is the geometric slope of the linearized plot in log-log scales; additionally, it has been accepted as a measure of the viscosity-temperature susceptibility. The data show that the ARCO A-R had the least viscosity-temperature susceptibility, but after aging there was not much difference between Sahuaro and ARCO.

## Repeated Vertical Shear Test

The repeated vertical shear test was developed to simulate the passing of wheel loads from one side to the other side of a sublayer crack under an overlay. The relative performance of the SALs was established by comparing the effects of repeated vertical deflections on the number of their repetitions to cause failure. A plot of two typical curves showing this comparison is shown on Figure B-3. The results of the tests performed using AR-4000 as a standard tack coat and the Sahuaro and ARCO SALs are listed in Tables A-6, A-7, and A-8, respectively.

The data as plotted in Figure B-4 show quite clearly that the SAL without chips had a superior response over the tack coat or SAL with chips treatment. An examination of the average curves and their 95-percent confidence limits shows that for the SALs with no chips there was not much difference between Sahuaro and ARCO and that the variability in test results was not as great as the variability in the test results for the SALs containing chips.

For the SALs containing chips, the data indicate that at high values of vertical deflections, the Sahuaro and the AR-4000 performed better than the

ARCO; however, at low values of deflections, the ARCO SAL with chips had the best performance.

The much wider band of the 95-percent confidence limits for the SALs containing chips is attributed to the seemingly greater number and size of flaws or stress concentration points in the system. We would expect the same situation to occur in a field installation.

## Static Horizontal Shear Test

The static horizontal shear test was thought to produce effects comparable to those when the underlying course of an overlay is subjected to temperature shrinkage and thus causing a crack to widen. The tests were performed at three extension rates and various measurements were recorded as shown in Tables A-6 to A-8.

The most consistent measurement made for which to compare the response of the SALs was that of maximum load. Figure B-5 shows the effect of extension rate upon the maximum load carried or transfer by the different SALs. An interpretation of the data is that the SAL with the smallest maximum load would have the best performance since it would transfer the smallest load to the overlay. In this context, the Sahuaro performed better than the ARCO SALs. The distinction between chips and no chips is not seen to be clearly defined.

At this point it is felt necessary to remind the reader that the Sahuaro A-R was made with an AR-1000 asphalt and that the ARCO A-R was made with an AR-4000. Even though the ARCO A-R contained a small amount of an extender oil, we assume the oil's main purpose was to react with the rubber rather than to decrease the viscosity of the asphalt, thus the ARCO System should have the greater resistance to the test loads.

## Repeated Horizontal Shear Test

The repeated horizontal shear test was designed to represent some shear stress in the SAL-beam system caused by the passages of wheel loads. Appendix H presents a description of the test procedure and measurements to be recorded. Initial examination of the recorded data showed that interpretation was going to be difficult. For example, at the start of the test, the applied displacement caused a tensile load on the system; however, as the SAL elongated and the repeated cam displacement value was held constant, this effect caused a compressive load on the system. Additionally, at times it was impossible to determine whether failure had occurred in the SAL or the asphaltic beam.

Tables A-6, A-7 and A-8 have the data considered to best represent the responses to the test for the AR-4000 tack coat, the Sahuaro SAL and the ARCO SAL respectively. An examination of the tables show that for the AR-4000 tack coat system, all of the failures occurred within the beam; for the Sahuaro system, the SAL without chips was the layer that failed; and for the ARCO system the failure was always in the SAL but at the low stress levels.

In Figure B-6, curves are presented that show the effects of load on the number of repetitions to cause failure. The figure indicates as did the curves for the repeated vertical shear test of Figure B-4, that the SAL without chips performed better than the one with chips and that there was not much difference in performance between the Sahuaro and ARCO systems.

## Variable Beam-Size Tests

This part of the evaluation program was included to determine the effects of beam size on the results for the repeated vertical shear and the static horizontal shear tests. The data obtained are shown in Table A-9.

Repeated Vertical Shear Test

The data for this test on the 12-inch (305mm) long beams showed that failure on the 4-inch (102mm) thickness occurred by separation of the SAL from the beam which was considered to be not a normal field type of failure. Although the 2-inch (51mm) thick beam failed in a normal or expected fashion, it was considered that this thickness was not appropriate for the test nor the asphaltic concrete mixture which contained some plus 3/4-inch (19mm) aggregate.

The data for the 24-inch (610mm) long beams are shown plotted in Figure B-7. Also shown on the figure are regression analyses values. As can be seen, the measurements for the 2-inch (51mm) thick specimens had the greatest variability and those for the 3-inch (76mm) thick ones the least. It would seem that from a viewpoint of efficiency and economy, the 3-inch (76mm) thick and 24-inch (610mm) long specimen is to be preferred for the repeated vertical shear test. Note the SALs contained stone chips.

Static Horizontal Shear Test

Figure B-8 shows the effects of beam thickness and length on the response of the static horizontal shear test. As would be expected, the longer beams, therefore, the greater area of SAL did have the greater maximum loads with corresponding extension rates. However, if the loads for the 24-inch (610mm) long beams are divided by two, then there would not be much difference from the loads for the 12-inch (305mm) long beams.

The curves of Figure B-8 do show that the thickness of the asphaltic beam did influence the value of the maximum load transmitted by the SAL. Again, we note that the SALs had stone chips and suggest the preferred size of test specimen to be 3 inches (76mm) in thickness and 24 inches (610 mm) in length.

## Variable Temperature Testing

The repeated vertical and horizontal shear tests were performed on Sahuaro and ARCO SALs containing chips. The data for these tests are listed in Table A-10 and visual representation is given in Figures B-9 and B-10.

Figure B-9 shows that under the repeated vertical shear loading and at the 5°C (41°F) temperature, the performance of the Sahuaro SAL system was quite similar to that of the ARCO one. However, at the test temperature of -5°C (23°F), the performance of the ARCO SAL system was superior to that of the Sahuaro's SAL.

In Figure B-10 the data from Table A-10 for the repeated horizontal shear test are shown plotted to facilitate the comparison between the two A-R systems. An "eyeball" evaluation of the data points shown for the 5°C (41°F) test suggests that one line could represent both systems; however, we believe that the indication is due to the scale chosen to represent the load variable and also since the regression statistics do show a difference in slopes for the Sahuaro and ARCO data. The preferable system for responding to the load variable depends on the magnitude of the load at this test temperature.

The data obtained for tests performed at a temperature of 25°C (77°F) as shown plotted in Figure B-10 show that the ARCO SAL system performed better than the Sahuaro.

It is of interest to compare the load-repetition relationships for the repeated horizontal shear test for the two mixtures tested at 25°C (77°F) as shown on Figures B-6 and B-10. Note is made of the similar values for slope even though it is recognized that the variability of the data for the SALs containing chips was somewhat high.

## Deflectometer Fatigue Testing

The fatigue testing of the SAL system was added to the evaluation program after initial test results indicated that the SAL without chips performed better than the one with chips. There had been some concern that fatigue life would be reduced if the SAL were built without chips.

A limited amount of fatigue testing was performed following the procedure described earlier. The test results are shown in Table A-11. The data show that although the tensile stress at the bottom of the system was higher for specimens containing SAL without chips, the repetitions to cause failure were slightly greater than for the SAL system with chips. The data are limited in quantity and the difference in repetitions to cause failure was small; therefore, we assume there was no difference in fatigue life for the two sets of specimens. We would suspect that for the repeated shear tests, the fatigue life of the two systems would be different and in favor of the SAL without the chips.

## RESULTS AND DISCUSSIONS OF CALCULATIONS

Field experience and laboratory testing have shown the benefits of incorporating a SAL prior to an overlay to minimize reflection cracking. In planning the evaluation program, it was felt desirable to examine the influence of a SAL through the use of theoretical analysis of stresses.

The following sections are concerned with the stresses calculated for various five-layered pavement systems and also for the laboratory beam tests of vertical and horizontal shear.

### Calculated Stresses in Pavements With SALs

The CHEV5L computer program was used to calculate stresses in a five-layered pavement system. The new pavement was assumed to consist of an old three-layered system plus variable thicknesses of SAL and also of overlays. The load and pavement properties are shown in Tables I-1 and I-2 of Appendix I. Those tables also present the radial and shear stresses calculated for points on the bottom of the overlays.

Figures J-1 and J-2 show plots indicating the influence of various thicknesses of SAL on the radial and shear stresses at the bottom of the overlays. Both figures show quite clearly that the thickness of the SAL has a great effect on the radial and shear stresses for overlays of 2 or 4 inches (51 or 102mm) in thickness.

The thicker the SAL, the greater is the reduction on the shear stress. However, as the thickness of the SAL increases from a value of zero to 3/8 inch (0 to 9.5mm) the radial stress beneath the center of the load goes from compression to a tensile value of over 100 psi (690 kPa). This behavior points out a detrimental effect and we would suggest that a limiting value of tensile stress for fatigue considerations should be less than 100 psi (690 kPa). As a consequence, the spread rate of a SAL should not exceed about 0.7 gallon per square yard or a thickness of about 1/8 inch (3.2mm).

The data of Tables I-1 and I-2 show that neither increasing the thickness of the overlay to 4 inches (102mm) nor decreasing E5 to 5,000 psi (34,450 kPa) had much effect on the maximum tensile stresses.

## Calculated Stresses in the Laboratory Beam Tests

A sketch of the beam set-up for the vertical and horizontal shear loads is shown in Figure J-3. Stresses in the SAL and asphaltic concrete beam were calculated using regular beam theory and also a finite element method.

### Calculated Stresses Under Beam Theory (BT)

The stresses under this theory were calculated for various thicknesses of beam and of SAL. The fundamental assumptions and boundary conditions for the vertical load have been given by DaDeppo in Reference 4. For the horizontal loading, only the boundary conditions were changed, as would be expected. Calculations were carried out for material properties as shown below:

Asphaltic Concrete, E = 200,000 psi and $\mu$ = 0.35

Asphalt-Rubber, E = 2.000 psi and $\mu$ = 0.45

Aluminum, E = 11,000,000 psi and $\mu$ = 0.33

Tables I-3 and I-4 show the maximum values of stresses in the system for the vertical and horizontal loads, respectively. Table I-3 show that the SAL thickness of 0.110 inch (2.80mm) was most effective in reducing the shearing stress in the beam when subjected to the vertical shear load. However, it is noted that there was not a significant reduction in tensile stress in the asphaltic beam. The shear stress was reduced from 0.232 to 0.089 psi (1.60 to 0.61 kPa) while the tensile stress was reduced from 0.811 to 0.731 psi

(5.59 to 5.04 kPa) by varying the SAL thickness from 0.004 to 0.110 inch (0.10 to 2.80mm).

The calculated maximum stress for the horizontal shear load as shown in Table I-4 present the same SAL thickness effect on the shearing and tensile stresses in the asphaltic beam. However, in this case the shearing stress was reduced by a factor of 5.6 while for the vertical load it was 2.6. The tensile stress was reduced by a factor of 1.2 for the horizontal load and by a factor of 1.11 for the vertical load.

Figures J-4 and J-5 show the variations in tensile and shearing stresses along the bottom of the asphaltic concrete beam. Both the tables and the figures show the principal beneficial effect of the SAL was in the great reduction of the shearing stress at the bottom of the asphaltic beam.

Calculated Stresses Under Finite Element Method (FEM)

Stresses in the laboratory beam tests under vertical and horizontal shear were calculated by Fort (11) using a finite element method (FEM) and the aforementioned material properties. He compared the effect of thicknesses of SAL on stresses at various locations and also the differences in values obtained by FEM and those using the equations developed by DaDeppo (4).

Figure J-6 shows the finite element mesh used by Fort and Figures J-7 to J-10 are copies of curves presented by him. It is to be noted that Fort uses the acronym SAMI for "stress absorbing membrane interlayer". The acronym SAMI has been used by Morris and McDonald (2) and others.

Figures J-7 and J-8 show decreases in both tensile and shearing stresses by increasing the SAL or SAMI thickness when the beam system was loaded with a horizontal load. It is noted that the reduction in tensile stress was

# CONCLUSIONS

The laboratory testing and computational program has been aimed at determining differences in the performance of two asphalt-rubber systems designed to perform as a strain attenuating layer. The function of such a layer is to minimize reflection cracking of asphaltic concrete overlays. The composition and application rates of the two A-R systems were those in standard use by ADOT. The conclusions presented below are warranted for the materials tested and are based upon results obtained with the various non-standard tests, but which we believe served adequately for acquiring qualitative values for comparing performance of the SAL systems.

1. The viscosity-temperature susceptibility of the unaged Sahuaro A-R blend was higher than that of the ARCO A-R. However, there was no significant difference between the two materials after exposure in the RTFOT.
2. The relative viscosity values (ageing index) of the two blends after the RTFOT were similar and not considered to be excessive; that is, not unsatisfactory.
3. Responses to the repeated vertical shear test at 25°C (77°F) indicated that the SAL systems without chips had the best performance and that there was a much larger variability in the results obtained for these SALs with chips. The relative performances between the Sahuaro and ARCO SALs showed comparable response for those without chips; however, the ARCO SAL had the better response at low values of deflections.

4. In the static horizontal shear test at 25°C (77°F), both Sahuaro SALs performed better than the ARCO SALs, in that they would seemingly transmit less load to the overlay for a particular opening of a sublayer crack.

5. Responses to the repeated horizontal shear test at 25°C (77°F) showed as before that the systems of SALs without stone chips performed better than did the ones with chips. There was not much difference in performance between the two A-R systems with chips.

6. In the variable beam size experiment, it was found that the best specimen size in view of efficiency and economy was one having a height of 3 inches (76mm) and a length of 24 inches (610mm). Both the repeated vertical shear test as well as the static horizontal shear test showed agreement in this respect. The width of 5 inches (127mm) was held constant.

7. The effects of test temperature on the response to the repeat shear tests were that generally the ARCO system performed better than did the Sahuaro at the lower temperatures.

8. There was no significant difference in resistance to flexural fatigue between the Sahuaro SALs with and without chips.

9. Calculations for shear and tensile stresses at the bottom of the overlay in four different layered pavement systems showed that the shear stresses were greatly reduced through the use of a SAL. However, the tensile stresses were increased and it is suggested that the thickness of the A-R SAL be limited to a thickness of 1/8-inch (3.2mm) which corresponds to a maximum application rate of about 0.7 gallon per square yard.

10. Calculations for shear and tensile stresses at the SAL-beam interface of the laboratory shear tests, using either beam theory or a finite element method gave comparable qualitative performance contributed by the SAL. In these calculations the SAL reduced the shear stress significantly, but caused minimal change in the tensile stress when the system was loaded under the vertical shear.

11. The above finding warrant and emphasize the need for a field installation of a SAL without the chips. Such a trial would serve to verify our findings and, if successful, would reduce the cost of a SAL materially.

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# APPENDICES FOR TESTING PROGRAM

## APPENDIX A



## APPENDIX B

APPENDIX B (Continued)

TABLE A-1. ADOT SPECIFICATIONS FOR AR-1000 AND AR-4000 [6]

| | Viscosity Grade | |
|---|---|---|
| | AR-1000 | AR-4000 |
| Tests on Residue from AASHTO T-240 | | |
| Viscosity, 140°F, p | 750-1,250 | 3,000-5,000 |
| Viscosity, 275°F, cs, min | 140 | 275 |
| Penetration, 77°F, 100g, 5 sec, min | 65 | 25 |
| Percent of original penetration, 77°F, min | -- | 45 |
| Ductility, 77°F, cm, min | 100 | 75 |
| Tests on Original Asphalt | | |
| Flash point, Pensky-Marten, °F, min | 400 | 440 |
| Solubility in trichloroethylene, %, min | 99 | 99 |

10 p = 1 Pa-s

°F = 32 + 1.8°C

TABLE A-2. PHYSICAL CHARACTERISTICS OF ASPHALTIC CONCRETE MIXTURES AND BLOTTING SAND

| Sieve Size | Percent, Passing | | | Blotting Sand |
|---|---|---|---|---|
| | Mixture No. 1 | Mixture No. 2 | Mixture No. 3 | |
| 3/4" (19.0 mm) | 100 | 96 | 100 | |
| 1/2" (12.7 mm) | 96 | 88 | 99 | |
| 3/8" ( 9.5 mm) | 81 | 73 | 89 | |
| #4 | 62 | 53 | 57 | |
| #8 | 45 | 41 | 43 | 100 |
| #16 | 33 | 26 | 30 | 65 |
| #30 | 19 | 14 | 18 | 33 |
| #50 | 11 | 9 | 10 | 10 |
| #100 | 7 | 7 | 6 | 2 |
| #200 | 4.0 | 5.5 | 3.3 | 0.8 |
| Asphalt Content, % by total weight | 5.6 | 5.4 | 4.4 | |

TABLE A-3. VISCOSITIES OF ASPHALT CEMENT AR-1000 BY SCHWEYER RHEOMETER

$$\tau = I_o \dot{\gamma}^c$$

| Temp °F(°C) | Test No. | $I_o$ k Pa | c | n | $R^2$ | $\eta$ @ 0.05 $sec^{-1}$ k Pa-sec* |
|---|---|---|---|---|---|---|
| | | | Unaged Asphalt Cement | | | |
| 59(15) | 1 | 592.0 | 0.693 | 4 | 0.965 | |
| | 2 | 524.0 | 0.596 | 4 | 0.973 | |
| | Avg | 558.0 | 0.644 | | | 1620. |
| 77(25) | 1 | 64.20 | 1.066 | 5 | 0.997 | |
| | 2 | 73.80 | 1.109 | 6 | 0.997 | |
| | 3 | 65.60 | 1.103 | 6 | 0.978 | |
| | Avg | 67.90 | 1.093 | | | 51.50 |
| 95(35) | 1 | 10.40 | 0.864 | 3 | 1.000 | |
| | 2 | 9.30 | 0.688 | 3 | 0.983 | |
| | Avg | 9.80 | 0.776 | | | 19.20 |

TABLE A-3 (Continued)

$$\tau = I_o \dot{\gamma}^c$$

| Temp °F(°C) | Test No. | $I_o$ k Pa | c | n | $R^2$ | $\eta$ @ 0.05 $sec^{-1}$ k Pa-sec* |
|---|---|---|---|---|---|---|
| | | Aged 75 Minutes in RTFOT, Asphalt Cement | | | | |
| 59(15) | 1 | 866.2 | 0.646 | 4 | 0.945 | |
| | 2 | 905.5 | 0.634 | 4 | 0.978 | |
| | Avg | 885.8 | 0.640 | | | 2,605. |
| 77(25) | 1 | 151.2 | 0.839 | 4 | 0.959 | |
| | 2 | 146.0 | 1.003 | 4 | 0.987 | |
| | Avg | 148.6 | 0.921 | | | 188.2 |
| 95(35) | 1 | 17.80 | 0.838 | 8 | 0.987 | |
| | 2 | 16.40 | 0.853 | 6 | 0.966 | |
| | Avg | 17.10 | 0.846 | | | 27.20 |
| | | Aged 225 Minutes in RTFOT, Asphalt Cement | | | | |
| 59(15) | 1 | 1651. | 0.230 | 3 | 0.930 | |
| | 2 | 1561. | 0.377 | 5 | 0.925 | |
| | Avg | 1606. | 0.304 | | | 12,940. |
| 77(25) | 1 | 535.9 | 0.968 | 7 | 0.995 | |
| | 2 | 552.8 | 1.176 | 5 | 0.995 | |
| | Avg | 544.4 | 1.072 | | | 438.3 |
| 95(35) | 1 | 32.10 | 0.982 | 6 | 0.995 | |
| | 2 | 31.00 | 0.947 | 6 | 0.996 | |
| | Avg | 31.15 | 0.965 | | | 34.60 |

* $\eta$ calculated with average values of $I_o$ and c.

1 psi = 6.89 k Pa

1 poise = 10 pa-sec

TABLE A-4. VISCOSITIES OF SAHUARO ASPHALT-RUBBER (A-R) BY SCHWEYER RHEOMETER

$$\tau = I_o \dot{\gamma}^c$$

| Temp °F(°C) | Test No. | $I_o$ k Pa | c | n | $R^2$ | $\eta$ @ 0.05 $sec^{-1}$ k Pa-sec* |
|---|---|---|---|---|---|---|
| | | | Unaged, Sahuaro A-R | | | |
| 59(15) | 1 | 1011. | 0.340 | 4 | 0.968 | |
| | 2 | 1835. | 0.619 | 4 | 1.000 | |
| | Avg | 1423. | 0.480 | | | 6,766. |
| 77(25) | 1 | 333.9 | 0.693 | 4 | 0.991 | |
| | 2 | 295.8 | 0.646 | | 0.993 | |
| | Avg | 314.8 | 0.669 | | | 848.5 |
| 95(35) | 1 | 64.70 | 0.600 | 4 | 0.977 | |
| | 2 | 76.50 | 0.628 | 5 | 0.909 | |
| | Avg | 70.60 | 0.614 | | | 224.4 |
| | | | Aged 75 Minutes in RTFOT, Sahuaro A-R | | | |
| 59(15) | 1 | 1794. | 0.321 | 4 | 0.932 | |
| | 2 | 1690. | 0.344 | 4 | 0.880 | |
| | Avg | 1742. | 0.333 | | | 12,860. |
| 77(25) | 1 | 625.7 | 0.476 | 5 | 0.979 | |
| | 2 | 668.4 | 0.558 | 4 | 0.999 | |
| | Avg | 657.0 | 0.517 | | | 2,794. |
| 95(35) | 1 | 193.0 | 0.648 | 6 | 0.907 | |
| | 2 | 243.2 | 0.854 | 6 | 0.776 | |
| | Avg | 218.1 | 0.751 | | | 465.0 |

TABLE A-4 (Continued)

$$\tau = I_o \dot{\gamma}^c$$

| Temp °F(°C) | Test No. | $I_o$ k Pa | c | n | $R^2$ | $\eta$ @ 0.05 $sec^{-1}$ k Pa-sec* |
|---|---|---|---|---|---|---|
| | | Aged 225 Minutes in RTFOT, Sahuaro A-R | | | | |
| 59(15) | 1 | 1610. | 0.307 | 5 | 0.760 | |
| | 2 | 2628. | 0.415 | 5 | 0.921 | |
| | Avg | 2119. | 0.361 | | | 14,370. |
| 77(25) | 1 | 669.2 | 0.371 | 2 | 1.000 | |
| | 2 | 789.7 | 0.476 | 5 | 0.975 | |
| | Avg | 727.4 | 0.423 | | | 4,105. |
| 95(35) | 1 | 291.2 | 0.749 | 5 | 0.973 | |
| | 2 | 326.8 | 0.682 | 5 | 0.918 | |
| | Avg | 309.0 | 0.715 | | | 724.8 |
| | | Aged 5 Hours in TFOT, Sahuaro A-R | | | | |
| 59(15) | 1 | 1137. | 0.232 | 4 | 0.892 | |
| | 2 | 1246. | 0.240 | 4 | 0.939 | |
| | Avg | 1192. | 0.236 | | | 11,760. |
| 77(25) | 1 | 444.1 | 0.625 | 4 | 0.980 | |
| | 2 | 762.9 | 0.938 | 3 | 0.998 | |
| | Avg | 603.5 | 0.782 | | | 1,161. |
| 95(35) | 1 | 181.3 | 0.906 | 5 | 0.964 | |
| | 2 | 138.3 | 0.767 | 5 | 0.937 | |
| | Avg | 159.8 | 0.836 | | | 260.9 |

* $\eta$ calculated with average values of $I_o$ and c.

1 psi = 6.89 k Pa

1 poise = 10 pa-sec

TABLE A-5. VISCOSITIES OF ARCO ASPHALT-RUBBER (A-R) BY SCHWEYER RHEOMETER

$$\tau = I_o \dot{\gamma}^c$$

| Temp °F(°C) | Test No. | $I_o$ k Pa | c | n | $R^2$ | $\eta$ @ 0.05 $sec^{-1}$ k Pa-sec* |
|---|---|---|---|---|---|---|
| | | | Unaged, ARCO A-R | | | |
| 59(15) | 1 | 1857. | 0.356 | 5 | 0.951 | |
| | 2 | 2346. | 0.391 | 5 | 0.864 | |
| | Avg | 2101. | 0.373 | | | 13,730. |
| 77(25) | 1 | 606.9 | 0.565 | 5 | 0.973 | |
| | 2 | 630.8 | 0.547 | 5 | 0.906 | |
| | Avg | 618.9 | 0.556 | | | 2,340. |
| 95(35) | 1 | 382.1 | 1.147 | 6 | 0.891 | |
| | 2 | 198.7 | 0.533 | 4 | 0.942 | |
| | Avg | 290.4 | 0.840 | | | 469.3 |
| | | | Aged 75 Minutes in RTFOT, ARCO A-R | | | |
| 59(15) | 1 | 2719. | 0.409 | 4 | 0.901 | |
| | 2 | 2070. | 0.305 | 4 | 0.915 | |
| | Avg | 2395. | 0.357 | | | 16,430. |
| 77(25) | 1 | 826.8 | 0.572 | 5 | 0.836 | |
| | 2 | 742.8 | 0.415 | 5 | 0.742 | |
| | Avg | 784.8 | 0.493 | | | 3,579. |
| 95(35) | 1 | 297.3 | 0.450 | 4 | 0.941 | |
| | 2 | 307.3 | 0.519 | 5 | 0.998 | |
| | Avg | 302.3 | 0.485 | | | 1,414. |

TABLE A-5 (Continued)

$$\tau = I_o \dot{\gamma}^c$$

| Temp °F(°C) | Test No. | $I_o$ k Pa | c | n | $R^2$ | $\eta$ @ 0.05 $sec^{-1}$ k Pa-sec* |
|---|---|---|---|---|---|---|
| | | Aged 225 Minutes in RTFOT, ARCO A-R | | | | |
| 59(15) | 1 | 2299. | 0.307 | 3 | 0.971 | |
| | 2 | 2146. | 0.236 | 3 | 0.969 | |
| | Avg | 2223. | 0.272 | | | 19,690. |
| 77(25) | 1 | 759.4 | 0.337 | 6 | 0.985 | |
| | 2 | 965.4 | 0.376 | 5 | 0.963 | |
| | Avg | 862.4 | 0.356 | | | 5,937. |
| 95(35) | 1 | 379.3 | 0.543 | 4 | 0.980 | |
| | 2 | 437.3 | 0.625 | 4 | 0.866 | |
| | Avg | 408.3 | 0.584 | | | 1,420. |
| | | Aged 5 Hours in TFOT, ARCO A-R | | | | |
| 59(15) | 1 | 1778. | 0.230 | 5 | 0.918 | |
| | 2 | 2099. | 0.317 | 5 | 0.871 | |
| | Avg | 1939. | 0.274 | | | 17,070. |
| 77(25) | 1 | 629.0 | 0.489 | 4 | 0.938 | |
| | 2 | 571.2 | 0.455 | 5 | 0.988 | |
| | Avg | 600.1 | 0.472 | | | 2,919. |
| 95(35) | 1 | 258.9 | 0.703 | 5 | 0.993 | |
| | 2 | 238.6 | 0.606 | 3 | 1.000 | |
| | Avg | 248.8 | 0.655 | | | 700.0 |

* $\eta$ calculated with average values of $I_o$ and C

1 psi = 6.89 kPa

1 poise = 10 pa-sec

TABLE A-5-a. CALCULATED RELATIVE VISCOSITY (R.V.) FOR VARIOUS ASPHALT BLENDS

| Exposure Time (minutes) | RTFOT R.V. Temperature, °C | | | TFOT R.V. Temperature, °C | | |
|---|---|---|---|---|---|---|
| **AR-1000** | | | | | | |
| | 15 | 25 | 35 | 15 | 25 | 35 |
| 0 | 1.0 | 1.0 | 1.0 | -- | -- | -- |
| 75 | 1.6 | 2.2 | 1.9 | -- | -- | -- |
| 225 | 3.0 | 8.0 | 3.2 | -- | -- | -- |
| **SAHUARO A-R** | | | | | | |
| | 15 | 25 | 35 | 15 | 25 | 35 |
| 0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 |
| 75 | 1.5 | 2.0 | 3.1 | -- | -- | -- |
| 225 | 2.4 | 2.4 | 2.4 | -- | -- | -- |
| 300 | -- | -- | -- | 1.0 | 1.5 | 2.2 |
| **ARCO A-R** | | | | | | |
| | 15 | 25 | 35 | 15 | 25 | 35 |
| 0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 |
| 75 | 1.5 | 1.3 | 1.1 | -- | -- | -- |
| 225 | 1.6 | 1.4 | 1.9 | -- | -- | -- |
| 300 | -- | -- | -- | 1.3 | 1.0 | 1.1 |

TABLE A-5-b. EFFECTS OF TEST TEMPERATURE AND AGING ON VISCOSITY OF AR-1000 AND ASPHALT-RUBBER ($\dot{\gamma}$ = 1.0 $sec^{-1}$)

$$\eta = aT_F^{-b}$$

| | Unaged, , k Pa-sec | | |
|---|---|---|---|
| Temp. °F (°C) | AR-1000 | Sahuaro A-R | ARCO A-R |
| 59 (15) | 558.0 | 1423. | 2101. |
| 77 (25) | 67.90 | 314.8 | 618.9 |
| 95 (35) | 9.80 | 70.60 | 290.4 |
| n | 7 | 6 | 6 |
| b | -8.443 | -6.190 | -4.265 |
| $R^2$ | 0.996 | 0.973 | 0.943 |

| | Aged 75 Minutes in RTFOT, , k Pa-sec | | |
|---|---|---|---|
| Temp. °F (°C) | AR-1000 | Sahuaro A-R | ARCO A-R |
| 59 (15) | 885.8 | 1742. | 2395. |
| 77 (25) | 148.6 | 657.0 | 784.8 |
| 95 (35) | 17.10 | 218.1 | 302.3 |
| n | 6 | 6 | 6 |
| b | -8.219 | -4.346 | -4.318 |
| $R^2$ | 0.985 | 0.984 | 0.989 |

| | Aged 225 Minutes in RTFOT, , k Pa-sec | | |
|---|---|---|---|
| Temp. °F (°C) | AR-1000 | Sahuaro A-R | ARCO A-R |
| 59 (15) | 1606. | 2119. | 2223. |
| 77 (25) | 544.4 | 727.4 | 862.4 |
| 95 (35) | 31.15 | 309.0 | 408.3 |
| n | 6 | 6 | 6 |
| b | -8.067 | -3.980 | -3.562 |
| $R^2$ | 0.900 | 0.962 | 0.986 |

TABLE A-6. RESISTANCE OF AR-4000 TACK TO SHEARING STRESSES FOR BEAMS 3" x 5" x 24" TESTED AT 25°C, #1 1/2" MIXTURE

Repeated Vertical Shear

| SAL Without Chips | |
|---|---|
| Rep. δ $10^{-3}$ in. | $N_f$ to Fail in $10^3$ |
| 5 | 80 |
| 8 | 120* |
| 15 | 20 |
| 20 | 26 |
| 29 | 3.2 |

* Failure by separation of SAL from A.C. beam. Other specimens failed by cracking of A.C. beam.

---

Static Horizontal Shear

| | SAL Without Chips Speed, in./min | | |
|---|---|---|---|
| | 0.05 | 0.10 | 0.20 |
| Max Load, lb | 148 | 256 | 328 |
| | 158 | 300 | 364 |
| Avg | 154 | 278 | 346 |
| Slip @ Max Load, $10^{-4}$ in. | 51 | 10 | 35 |
| | 20 | 20 | 50 |
| Avg | 36 | 15 | 43 |
| Slip @ Rupture $10^{-4}$ in. | 51 | -- | 45 |
| | 45 | 50 | 60 |
| Avg | 48 | 50 | 47 |
| Load @ Slip Rupture, lb | 148 | -- | 305 |
| | 132 | 256 | 350 |
| Avg | 140 | 256 | 328 |

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Repeated Horizontal Shear

| SAL Without Chips | | |
|---|---|---|
| Total Load, lb at 1,000 Reps | $N_f$ to Fail in $10^3$ | Location of Failure |
| 355 | 32 | Beam |
| 425 | 7 | Beam |
| 485 | 13 | Beam |
| 570 | 2 | Beam |
| 595 | 1.5 | Beam |

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## TABLE A-7. RESISTANCE OF SAHUARO A-R SAL TO SHEARING STRESSES FOR BEAMS 3" x 5" x 24" TESTED AT 25°C, #1 1/2" MIXTURE

### Repeated Vertical Shear

| SAL With Chips | | SAL Without Chips | |
|---|---|---|---|
| Rep. δ $10^{-3}$ in. | $N_f$ $10^3$ | Rep. δ $10^{-3}$ in. | $N_f$ $10^3$ |
| 6 | 50* | 7 | 275 |
| 10 | 30* | 8 | 195* |
| 17 | 11 | 17 | 30 |
| 21 | 24 | 18 | 36 |
| 25 | 4.7 | 29 | 6 |
| 40 | 1.2 | 30 | 5 |

* Failure by separation of SAL from A.C. beam. Other specimens failed by cracking of A.C. beam.

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### Static Horizontal Shear

| | SAL With Chips Speed, in./min | | | SAL Without Chips Speed, in./min | | |
|---|---|---|---|---|---|---|
| | 0.05 | 0.10 | 0.20 | 0.05 | 0.10 | 0.20 |
| Max Load, lb | 42 | 232 | 286 | 116 | 188 | 256 |
| | 194 | 132 | 274 | 130 | 230 | 292 |
| Avg | 194 | 182 | 280 | 123 | 209 | 274 |
| Slip @ Max Load, $10^{-4}$ in. | 450 | 160 | 930 | 240 | 500 | 920 |
| | 660 | 380 | 420 | 430 | 610 | 880 |
| Avg | 555 | 270 | 675 | 335 | 555 | 900 |
| Slip @ Rupture $10^{-4}$ in. | 900 | 910 | 1270 | 280 | 620 | 1200 |
| | 1000 | 750 | 700 | 430 | -- | 1320 |
| Avg | 950 | 830 | 985 | 355 | 620 | 1260 |
| Load @ Slip Rupture, lb | 38 | 200 | 278 | 114 | 176 | 244 |
| | 190 | 120 | 268 | 130 | -- | 270 |
| Avg | 114 | 160 | 274 | 122 | 176 | 258 |

---

### Repeated Horizontal Shear

| SAL With Chips | | | SAL Without Chips | | |
|---|---|---|---|---|---|
| Total Load, lb at 1,000 Reps | $N_f$ to Fail in $10^3$ | Location of Failure | Total Load, lb at 1,000 Reps | $N_f$ to Fail in $10^3$ | Location of Failure |
| 315 | 35 | SAL | 370 | 90 | SAL |
| 340 | 6 | SAL | 470 | 30 | SAL |
| 400 | 15 | Beam | 485 | 40 | SAL |
| 410 | 4 | SAL | 555 | 4 | SAL |
| 410 | 30 | SAL | 570 | 10 | SAL |
| 455 | 5 | SAL | | | |
| 495 | 2.5 | Beam | | | |
| 525 | 3 | SAL | | | |
| 540 | 4 | Beam | | | |

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## TABLE A-8. RESISTANCE OF ARCO A-R SAL TO SHEARING STRESSES FOR BEAMS 3" x 5" x 24" TESTED AT 25°C, #1 1/2" MIXTURE

### Repeated Vertical Shear

| SAL With Chips | | SAL Without Chips | |
|---|---|---|---|
| Rep. δ $10^{-3}$ in. | $N_f$ to Fail in $10^3$ | Rep. δ $10^{-3}$ in. | $N_f$ to Fail in $10^3$ |
| 7 | 1255 | 10 | 235* |
| 8 | 80 | 12 | 152 |
| 17 | 21* | 19 | 32 |
| 17 | 34 | 20 | 33 |
| 20 | 120 | 29 | 4 |
| 30 | 2.3 | 31 | 5.6 |
| 34 | 1.6 | | |

* Failure by separation of SAL from A.C. beam. Other specimens failed by cracking of A.C. beam.

### Static Horizontal Shear

| | SAL With Chips Speed, in./min 0.05 | 0.10 | 0.20 | SAL Without Chips Speed, in./min 0.05 | 0.10 | 0.20 |
|---|---|---|---|---|---|---|
| Max Load, lb | 224 | 282 | 318 | 212 | 308 | 440 |
| | 223 | 258 | 300 | 260 | 342 | 340 |
| Avg | 224 | 270 | 309 | 236 | 326 | 390 |
| Slip @ Max Load $10^{-4}$ in. | 80 | 550 | 130 | 200 | 200 | 720 |
| | 110 | 200 | 140 | 120 | 1010 | 450 |
| Avg | 95 | 375 | 135 | 160 | 605 | 585 |
| Slip @ Rupture $10^{-4}$ in. | 150 | 550 | 190 | 200 | 360 | 860 |
| | 160 | 320 | 170 | 120 | 1010 | 540 |
| Avg | 155 | 435 | 180 | 160 | 685 | 700 |
| Load @ Slip Rupture, lb | 192 | 282 | 308 | 212 | 276 | 416 |
| | 148 | 256 | 235 | 260 | 342 | 324 |
| Avg | 170 | 270 | 270 | 236 | 310 | 370 |

### Repeated Horizontal Shear

| SAL With Chips Total Load, lb at 1,000 Reps | $N_f$ to Fail in $10^3$ | Location of Failure | SAL Without Chips Total Load, lb at 1,000 Reps | $N_f$ to Fail in $10^3$ | Location of Failure |
|---|---|---|---|---|---|
| 370 | 40 | SAL | 485 | 30 | SAL |
| 410 | 15 | SAL | 510 | 25 | SAL |
| 425 | 7 | SAL | 525 | 10 | SAL |
| 485 | 25 | SAL | 680 | 7 | Beam |
| 485 | 10 | SAL | 765 | 3 | Beam |
| 485 | 7 | Beam | | | |
| 540 | 15 | Beam | | | |
| 580 | 7 | SAL | | | |

TABLE A-9. EFFECTS OF SPECIMEN SIZE ON RESISTANCE TO SHEARING STRESSES FOR BEAMS WITH SAHUARO A-R SAL WITH CHIPS TESTED AT 25°C, #2 ½" MIXTURE

## Repeated Vertical Shear

| 2" x 5" x 24" | | 3" x 5" x 24" | | 4" x 5" x 24" | | 2" x 5" x 12" | | 4" x 5" x 12" | |
|---|---|---|---|---|---|---|---|---|---|
| Rep. δ $10^{-3}$ in. | $N_f$ to Fail in $10^3$ | Rep. δ $10^{-3}$ in. | $N_f$ to Fail in $10^3$ | Rep. δ $10^{-3}$ in. | $N_f$ to Fail in $10^3$ | Rep. δ $10^{-3}$ in. | $N_f$ to Fail in $10^3$ | Rep. δ $10^{-3}$ in. | $N_f$ to Fail in $10^3$ |
| 11 | 50 | 14 | 266 | 12 | 220* | 18 | 350 | 28 | 150* |
| 16 | 40 | 18 | 110 | 12 | 120 | 21 | 92 | 34 | 100* |
| 17 | 70 | 26 | 16 | 18 | 39 | 21 | 52 | 38 | 125* |
| 24 | 3.7 | 30 | 28 | 19 | 20 | 28 | 24.5 | 38 | 245* |
| 26 | 16 | 33 | 8.5 | 19 | 6 | 33 | 16 | 40 | 100* |
| 36 | 3.5 | 38 | 2.5 | 22 | 16 | 40 | 5.5 | 48 | 250* |

* Failure by separation of SAL from A.C. beam. Other specimens failed by cracking of A.C. beam.

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## Static Horizontal Shear

| Beam Size, in. | 2" x 5" x 24" | | | 3" x 5" x 24" | | | 4" x 5" x 24" | | | 2" x 5" x 12" | | | 4" x 5" x 12" | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Speed, in./min | 0.05 | 0.10 | 0.20 | 0.05 | 0.10 | 0.20 | 0.05 | 0.10 | 0.20 | 0.05 | 0.10 | 0.20 | 0.05 | 0.10 | 0.20 |
| Max Load, lb | 160 | 208 | 284 | 76 | 126 | 206 | 230 | 308 | 464 | 58 | 110 | 56 | -- | 124 | 292 |
| | 266 | 248 | 380 | 162 | 314 | 262 | 256 | 310 | -- | 62 | 138 | 88 | 88 | 42 | 300 |
| Avg | 214 | 228 | 332 | 120 | 220 | 234 | 244 | 308 | | 60 | 124 | 72 | 88 | 84 | 296 |
| Slip @ Max Load $10^{-4}$, in. | 1820 | 1480 | 1210 | 1120 | 780 | 230 | 390 | 1170 | 620 | 410 | 620 | 680 | -- | 100 | 110 |
| | 1680 | 1420 | 785 | 120 | 240 | 310 | 200 | 1020 | | 650 | 180 | 590 | 280 | 230 | 400 |
| Avg | 1750 | 1450 | 998 | 620 | 510 | 270 | 275 | 1096 | | 530 | 400 | 635 | 280 | 165 | 255 |
| Slip @ Rupture $10^{-4}$, in. | 1820 | 1850 | 1780 | 1250 | 1350 | 800 | 1420 | 1710 | -- | 590 | 780 | 680 | -- | 180 | 420 |
| | 1680 | 2290 | 800 | 300 | 500 | 1620 | 960 | 1120 | | 850 | 310 | 750 | 450 | 250 | 1840 |
| Avg | 1750 | 2070 | 790 | 775 | 925 | 1210 | 1190 | 1415 | | 720 | 545 | 715 | 450 | 215 | 1130 |
| Load @ Slip Rupture, lb | 158 | 206 | 284 | 65 | 120 | 198 | 218 | 284 | -- | 56 | 108 | 56 | -- | 120 | 236 |
| | 256 | 248 | 380 | 142 | 280 | 170 | 170 | 306 | | 56 | 134 | 86 | 84 | 42 | 280 |
| Avg | 208 | 228 | 332 | 104 | 200 | 184 | 194 | 296 | | 56 | 123 | 72 | 84 | 80 | 258 |

TABLE A-10. EFFECTS OF TEMPERATURE ON THE RESISTANCE TO REPEATED SHEAR LOADINGS FOR BEAMS 3" x 5" x 24", #3 1/2" MIXTURE

Repeated Vertical Shear

| SAHUARO A-R SAL With Chips | | | | ARCO A-R SAL With Chips | | | |
|---|---|---|---|---|---|---|---|
| 41°F/5°C | | 23°F/-5°C | | 41°F/5°C | | 23°F/-5°C | |
| Rep. $\delta$ $10^{-3}$ in. | $N_f$ to Fail in $10^3$ | Rep. $\delta$ $10^{-3}$ in. | $N_f$ to Fail in $10^3$ | Rep. $\delta$ $10^{-3}$ in. | $N_f$ to Fail in $10^3$ | Rep. $\delta$ $10^{-3}$ in. | $N_f$ to Fail in $10^3$ |
| 11 | 82 | 6 | 58 | 11 | 54 | 8.5 | 25 |
| 14 | 24 | 6 | 11 | 13 | 10 | 9 | 126 |
| 18 | 1.0 | 6 | 7 | 15 | 40 | 9 | 10 |
| 19 | 2.2 | 9 | 10 | 18 | 5 | 14 | 4 |
| 23 | 1.0 | 11 | 0.7 | 22 | 2.3 | 14 | 0.2 |
| | | 12 | 0.5 | 25 | 0.2 | | |

Repeated Horizontal Shear

| SAHUARO A-R SAL With Chips | | | | | | ARCO A-R SAL With Chips | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 41°F/5°C | | | 77°F/25°C | | | 41°F/5°C | | | 77°F/25°C | | |
| Total Load, lb at 1,000 Reps | $N_f$ to Fail in $10^3$ | Location of Failure | Total Load, lb at 1,000 Reps | $N_f$ to Fail in $10^3$ | Location of Failure | Total Load, lb at 1,000 Reps | $N_f$ to Fail in $10^3$ | Location of Failure | Total Load, lb at 1,000 Reps | $N_f$ to Fail in $10^3$ | Location of Failure |
| 640 | 128 | Beam | 370 | 5 | Beam | 625 | 965 | Beam | 370 | 30 | Beam |
| 655 | 150 | Beam | 370 | 13 | Beam | 710 | 785 | Beam | 410 | 80 | Beam |
| 710 | 40 | Beam | 370 | 25 | SAL | 710 | 56 | Beam | 455 | 3.5 | Beam |
| 740 | 32 | Beam | 425 | 5 | Beam | 710 | 41 | Beam | 485 | 19 | Beam |
| 750 | 37 | Beam | 455 | 15 | SAL | 725 | 100 | Beam | 510 | 5 | Beam |
| 825 | 14 | Beam | | | | 765 | 50 | Beam | | | |
| | | | | | | 795 | 16 | Beam | | | |

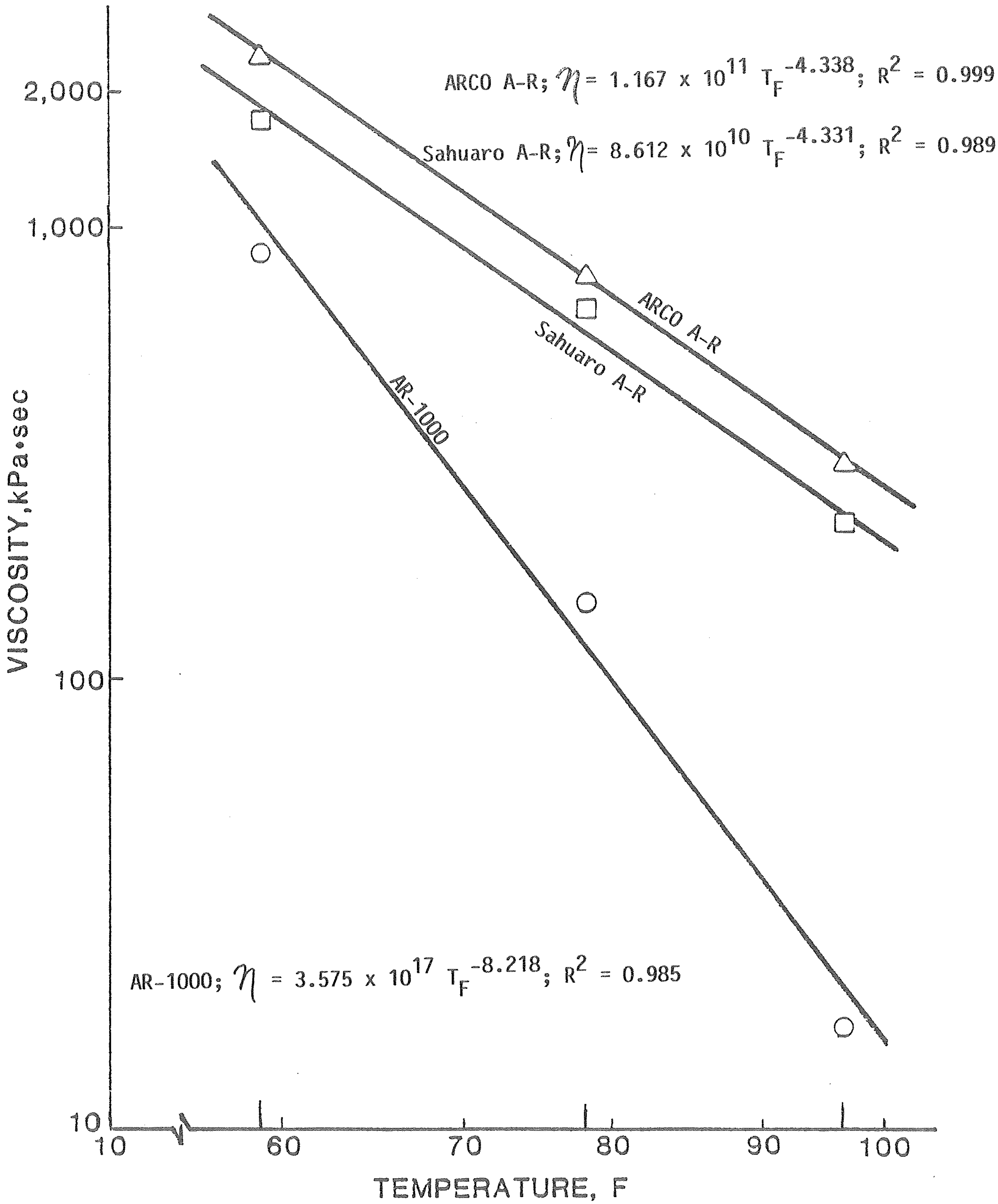



Figure B-2. Effects of Temperature on the Viscosity of an Asphalt and Also A-Rs after 75-Minute Aging by RTOFT.

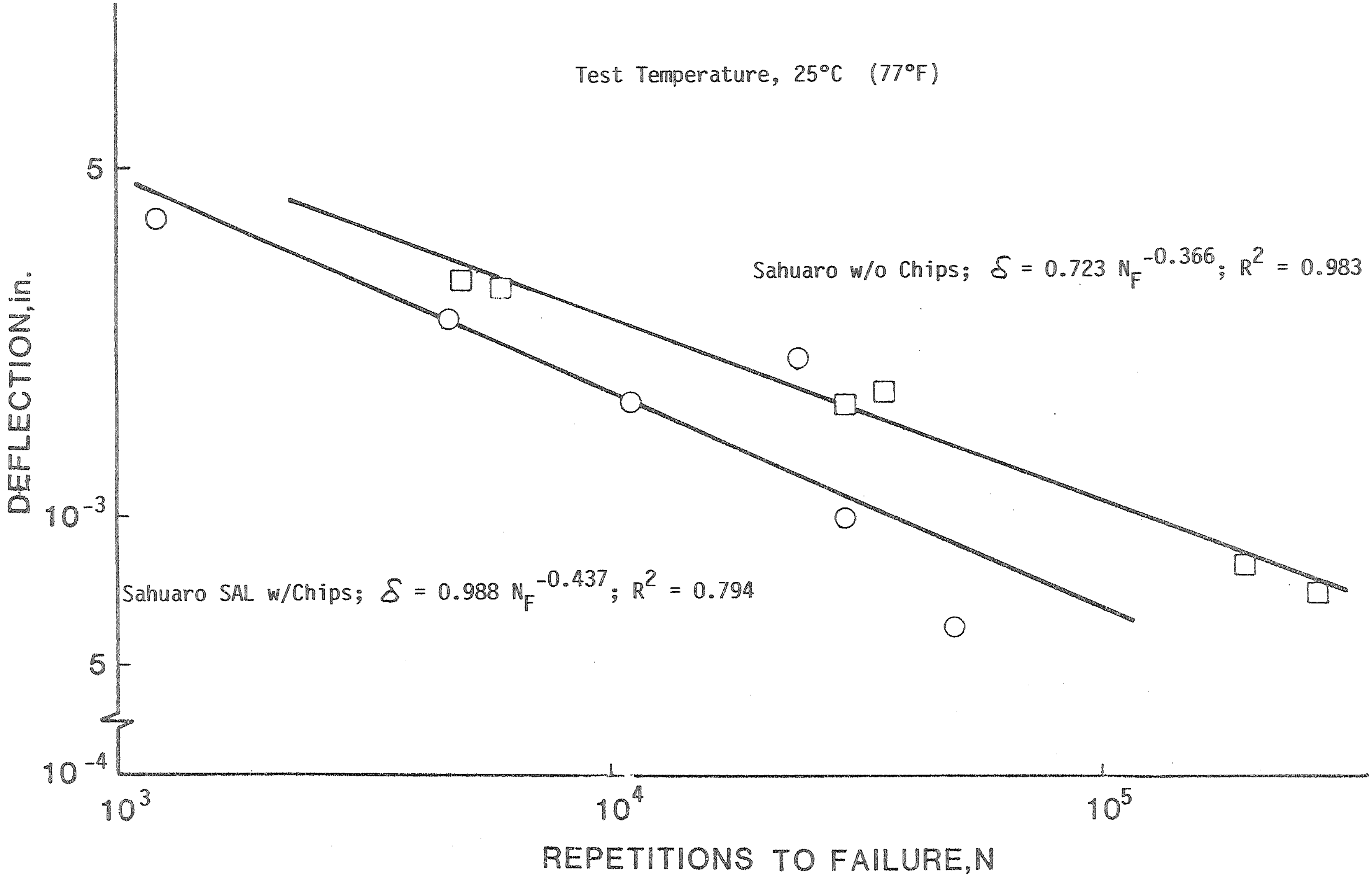



Figure B-3. Fatigue Relationship Under Repeated Vertical Shear for Sahuaro SAL.

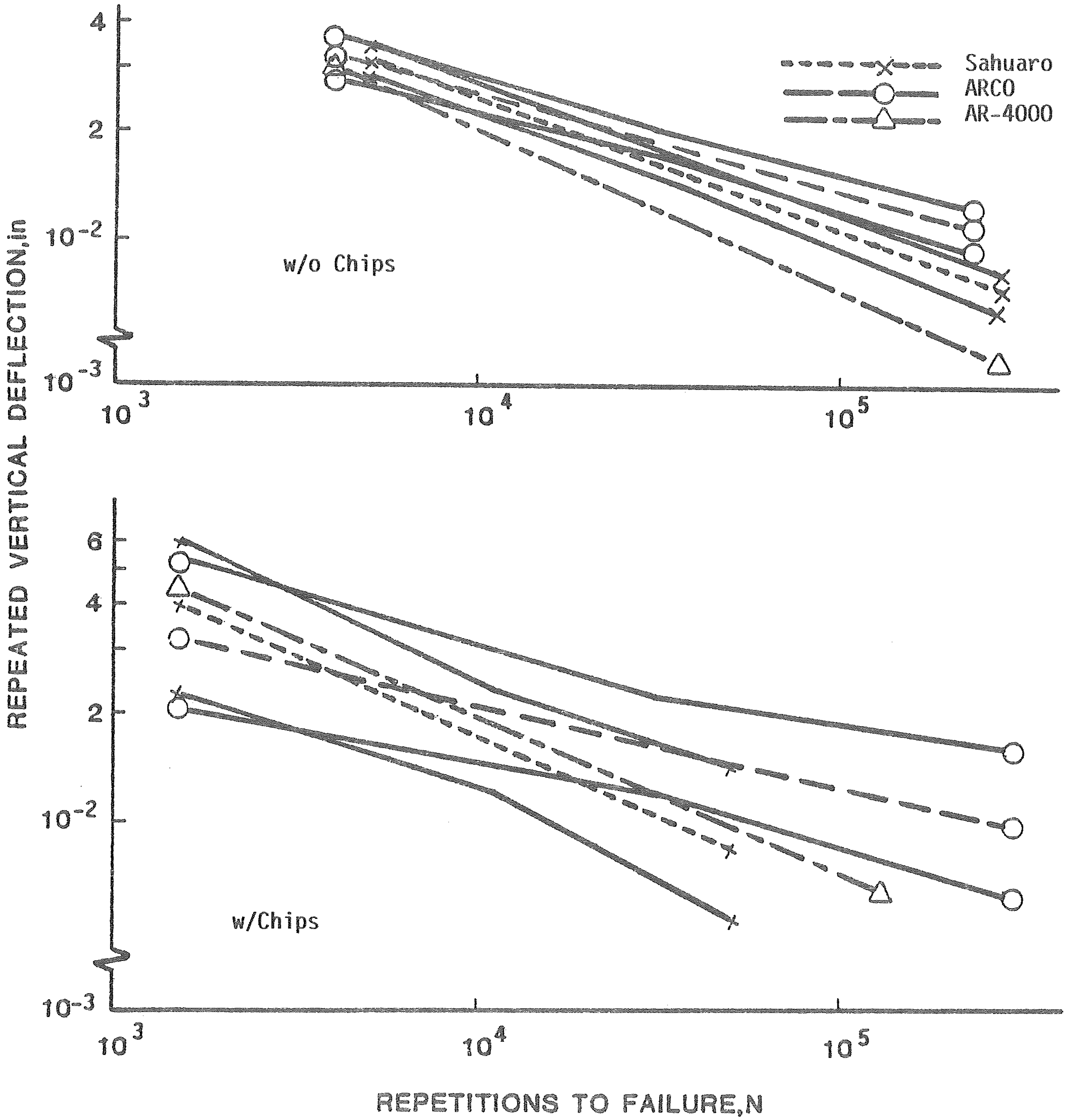



Figure B-4. Ninety-Five Percent Confidence Limits for Fatigue Under Repeated Vertical Shear for Various SALs.

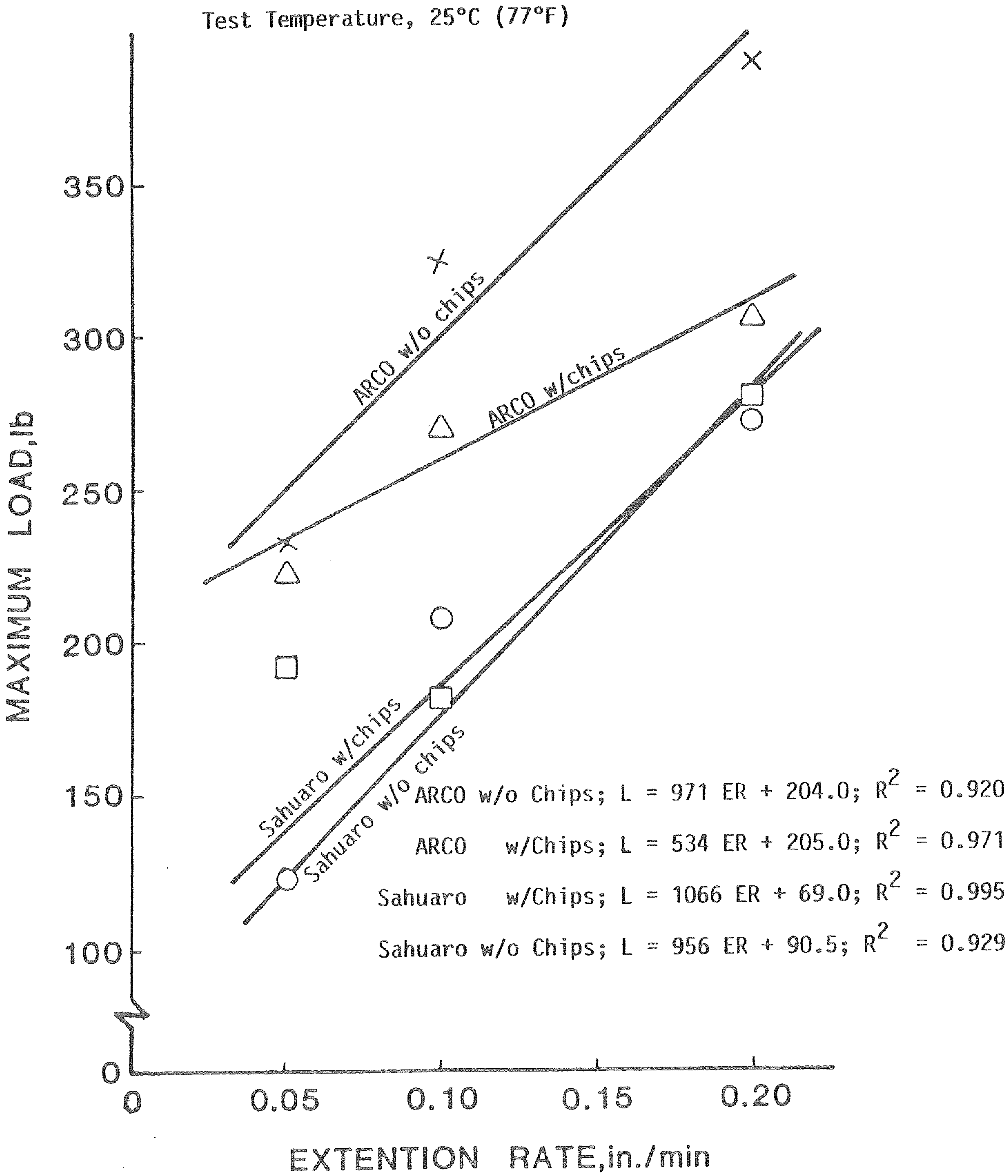



Figure B-5. Effects of Extension Rate on Maximum Load Under Static Horizontal Shear for ARCO and Sahuaro SALs.

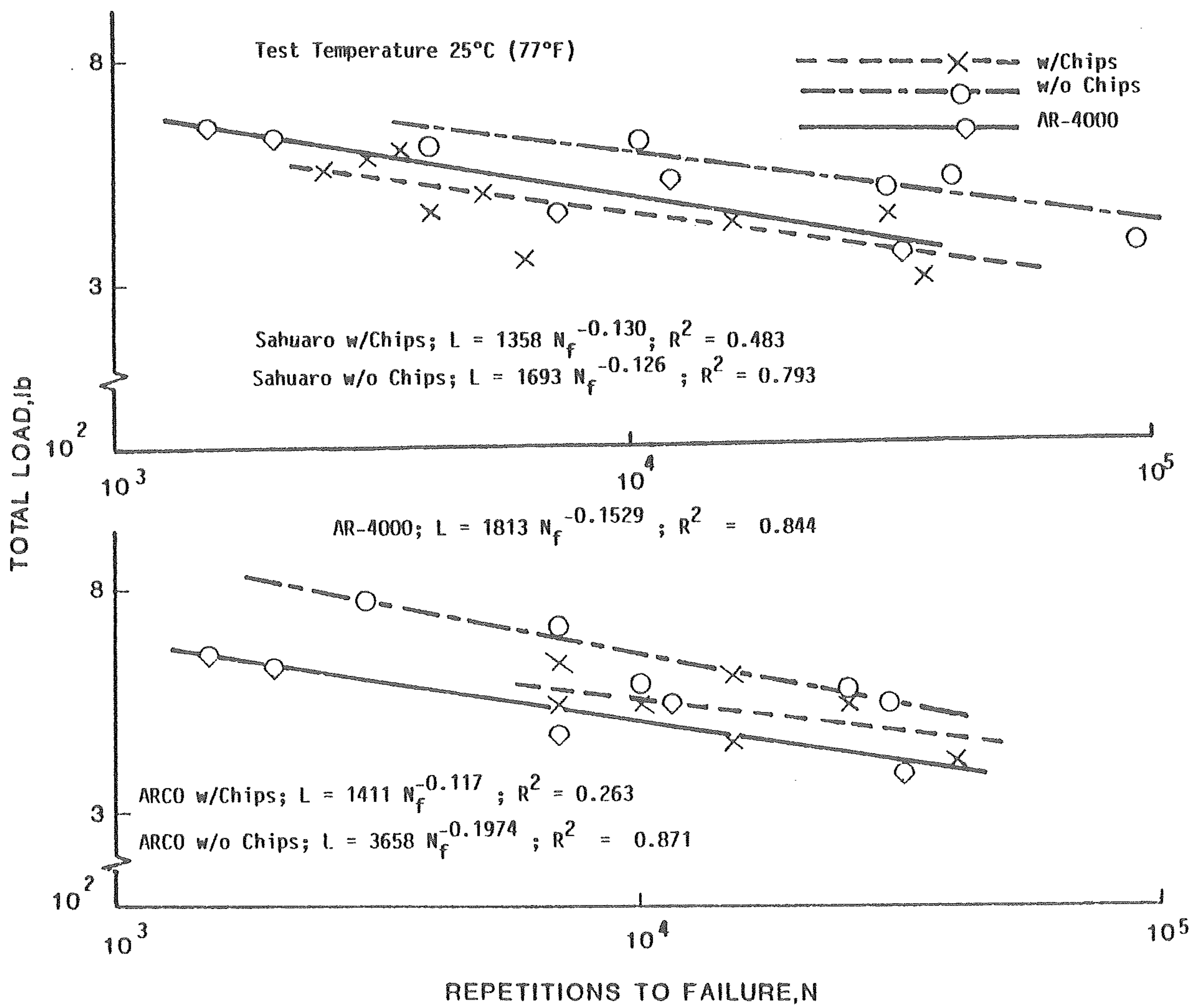



Figure B-6. Fatigue Relationship Under Repeated Horizontal Shear for Various SALs.

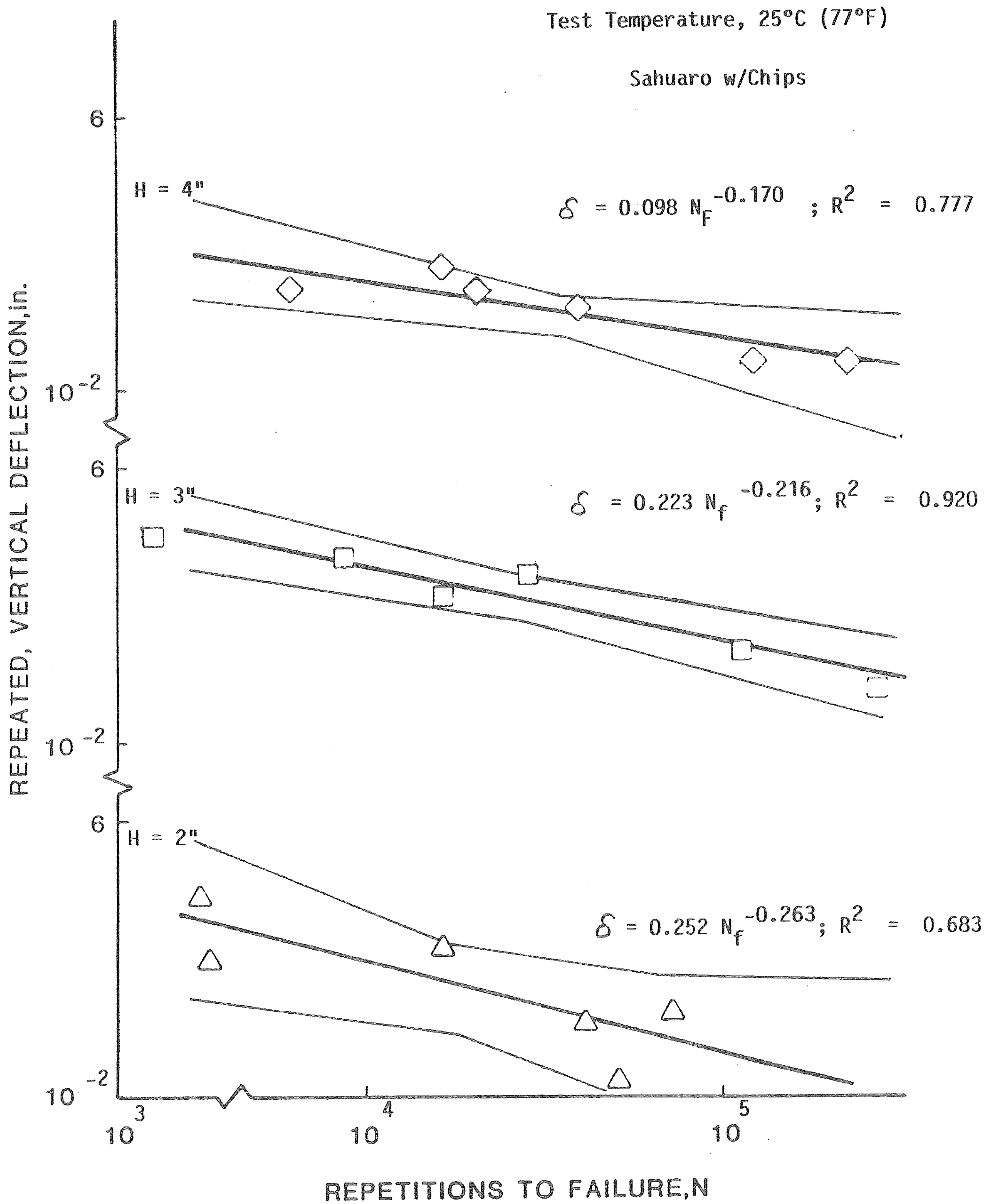



Figure B-7. Ninety-Five Percent Confidence Limits for Fatigue Under Repeated Vertical Shear for Various Sized Beams with Sahuaro SAL with Chips.

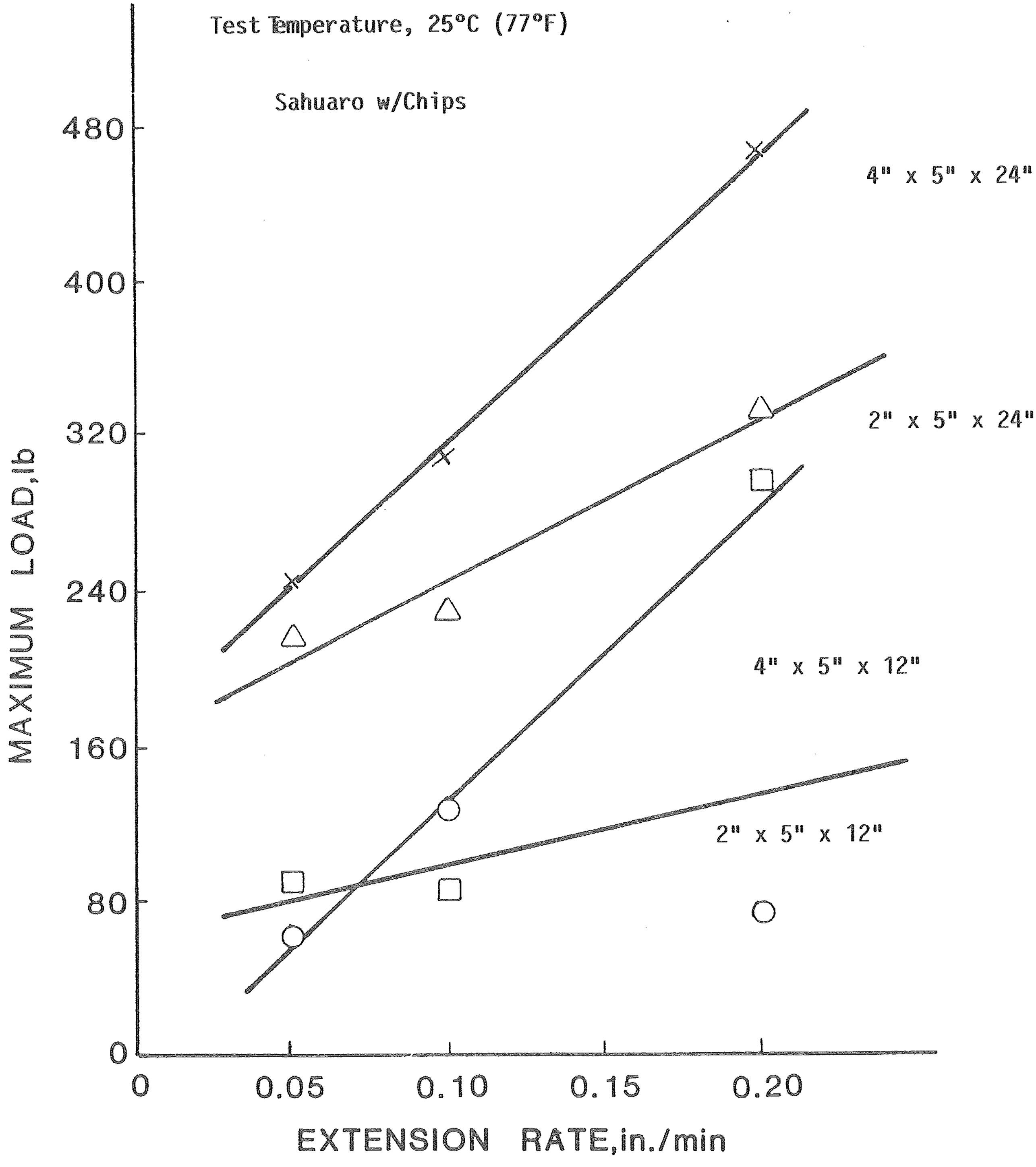



Figure B-8. Effects of Extension Rate on Maximum Load Under Static Horizontal Shear for Various Sized Beams with Sahuaro SAL with Chips.

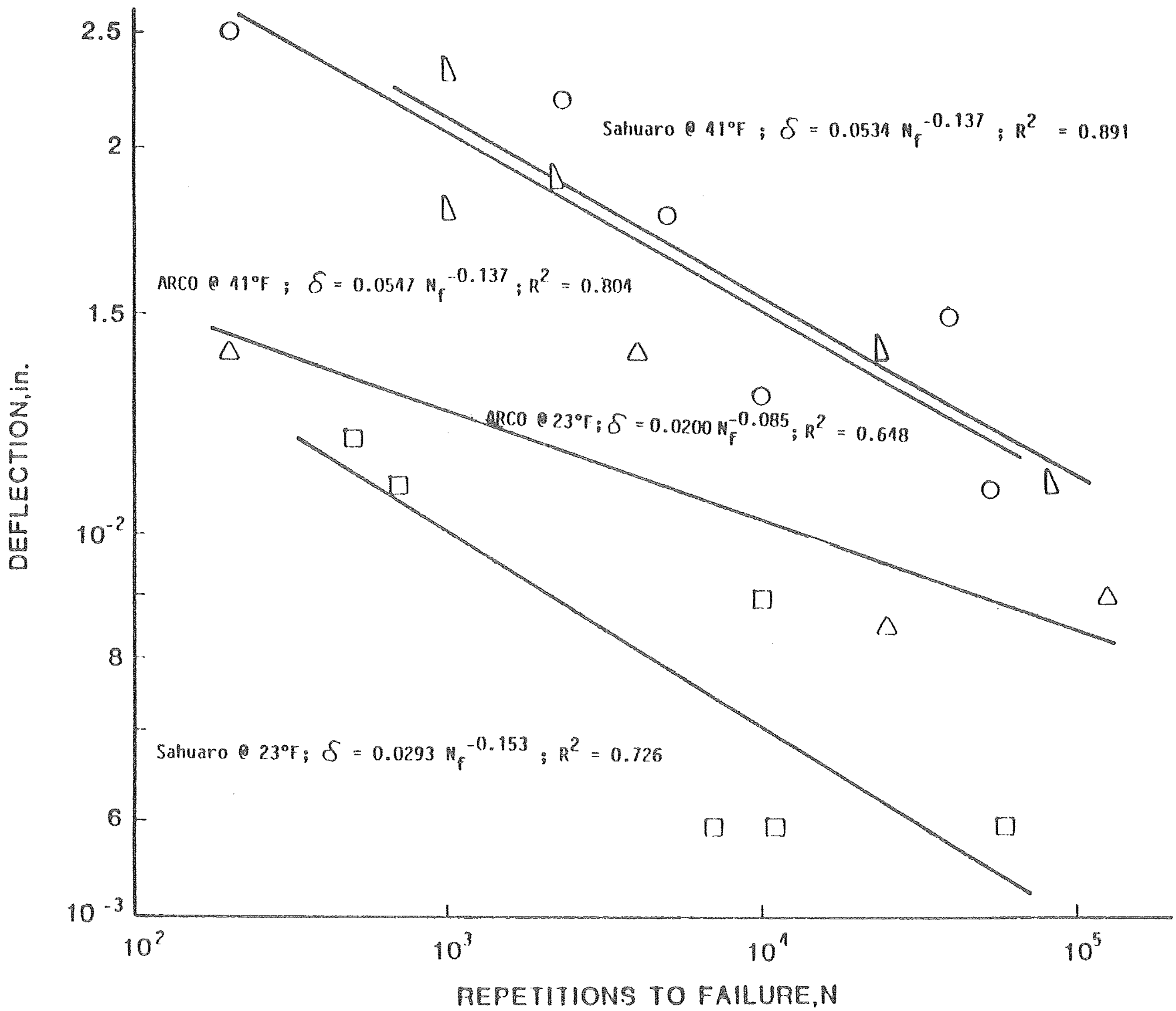



Figure B-9. Fatigue Relationship Under Repeated Vertical Shear for ARCO and Sahuaro SALS with Chips.

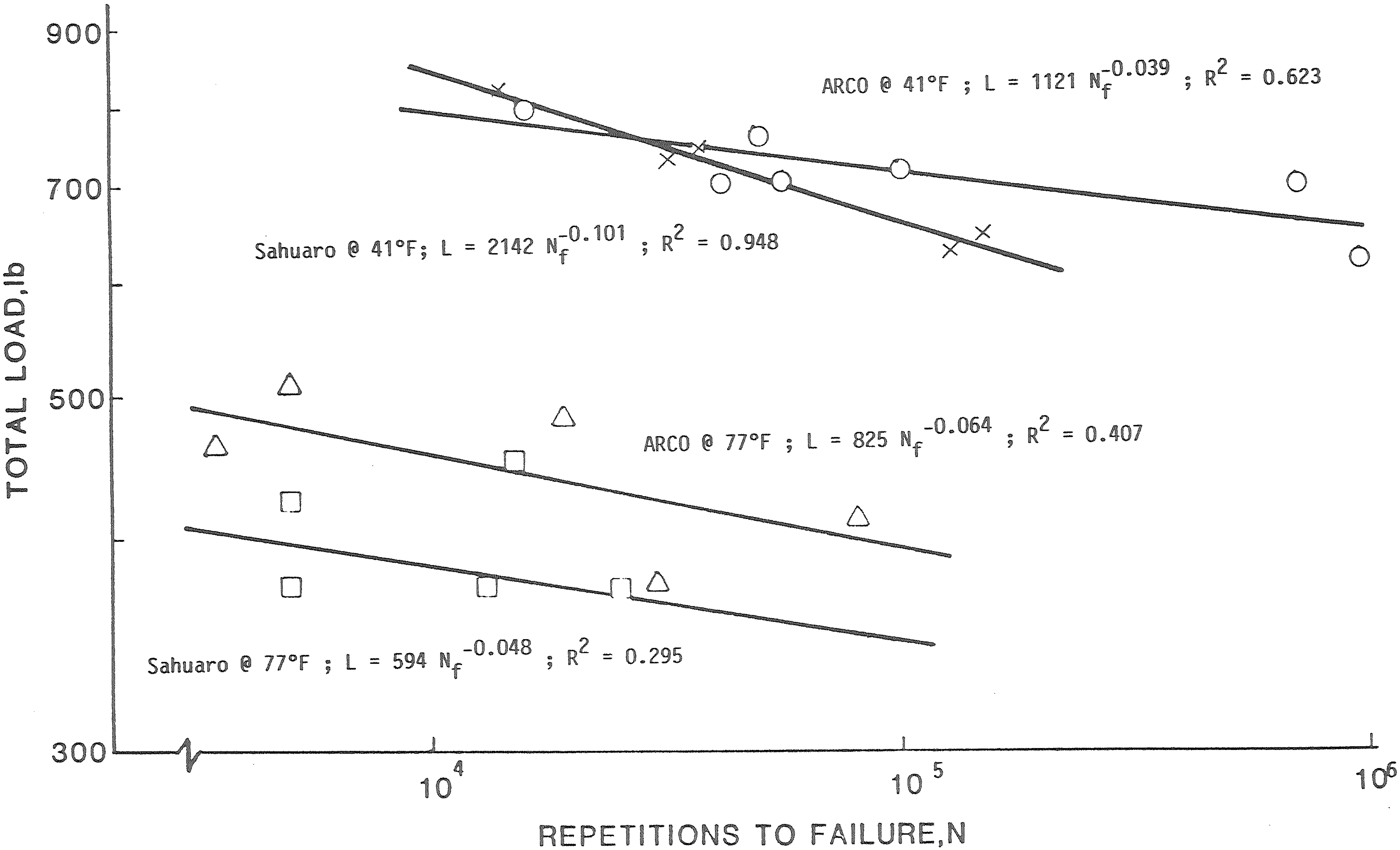



Figure B-10. Fatigue Relationship Under Repeated Horizontal Shear for ARCO and Sahuaro SALs with Chips.

## APPENDIX C

### Procedure for Blending Asphalt and Rubber

1. Equipment
   a. Tin can, 4-inch diameter by 5.5-inch deep (102D x 140H mm) such as a one-pound coffee can
   b. Ring gas burner, 5-inch diameter (127D mm)
   c. Electric motor mixer with powerstat and a 3-inch diameter (76 mm) three-bladed propeller
   d. Ring stand, 5-inch diameter (127 mm) ring, and asbestos wire gage
   e. Thermometer 30° to 760°F (-1° to 404°C), 8C
   f. Watch or clock
2. Two types of asphalt-rubber (approximate total weight, 500 gm):
   a. Sahuaro:

| Proportions | Percentages (by Weight) | Minimum Component Weights, gm |
|---|---|---|
| AR-1000 (Asphalt) | 78 | 400± |
| TP-044 (Rubber) | 22 | 113± |

   b. ARCO:

| Proportions | Percentages (by Weight) | Minimum Component Weights, gm |
|---|---|---|
| AR-4000 (Asphalt) | 78.4 | 400± |
| Extender Oil | 1.6 | 8± |
| G-274 (Rubber) | 20.0 | 102± |

3. Weighed amounts of asphalt and extender oil (ARCO only) in the tin can and the correct amount of rubber in another container, both at ambient temperature. The rubber has been dried in a 140°F (60°C) oven for 15 hours and stored in a sealed container.
4. Assemble mixer and heater as shown in photograph of Figure C-1.
5. Melt asphalt to temperature of 120°-160°F (49°-71°C) and position thermometer and mixer in the hot asphalt. Place and rotate the propeller so that there is no splashing and a vortex is formed between the center and side of pan.
6. Raise the temperature of the asphalt at a rate of 10°-12°F (6°-8°C) per minute to reach 375°F (191°C). Add the rubber to the asphalt at the edge of the vortex in small increments so that the total amount is introduced in five minutes. It will be necessary to increase the power of the stirrer as the viscosity of the mixture increases. Also, the colder rubber will reduce the temperature and adjustment to the gas flow is necessary.
7. Continue the mixing for 30 minutes after all of the rubber has been added. Adjustment to the stirrer and burner are necessary as viscosity and temperature changes occur. Try to hold the mixing temperature at 375°F (191°C). The temperature may drop to 355°F (179°C) at the beginning and may rise to 395°F (202°C). Also, it may be necessary to cut the gas off completely. Additional stirring with a 6-inch (152 mm) spatula is desirable. The thermometer reading is affected by presence or absence of rubber around its bulb.
8. After the final 30 minutes of mixing, place weighed amounts of the hot asphalt-rubber into lidded metal containers for storage at 41°F (5°C). The amounts of asphalt-rubber vary from 30 to 220 grams for making specimens to be tested for viscosity or in the asphaltic-aluminum beam set-up.

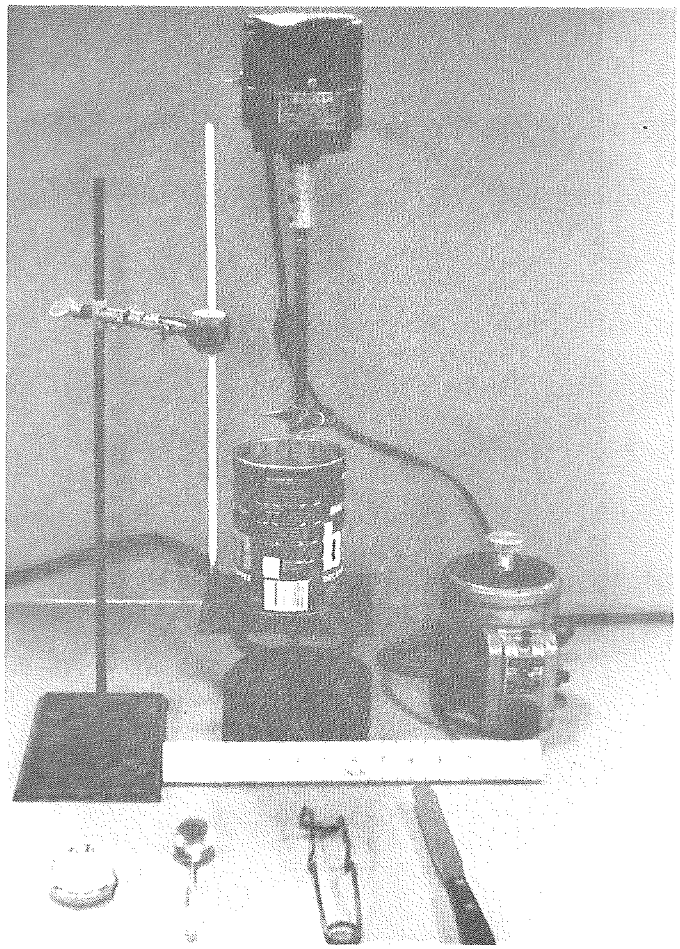


Figure C-1. Set-up for Blending Asphalt and Rubber

# APPENDIX D

## Procedure for the Placement of Tack Coats

NOTE: Three types of tack coats will be used in the study: AR-4000 asphalt cement, asphalt-rubber with chips, and asphalt-rubber with sand. Tack coats are placed upon two 6 x 20 x 1/2-inch (152 x 508 x 12.7 mm) aluminum plates. The ends of these plates are butted together to within a tolerance of 1/32-inch (0.8 mm). These plates form a rigid base plate after 1 x 13 x 1/2-inch (25.4 x 330 x 12.7 mm) aluminum holding bars are bolted to the sides of the plates, symmetrically about the joint. The area of the plates to receive tack coat is outlined using 1/2-inch (12.7 mm) wide strips of masking tape. The area being tack coated is centered on the crack between the aluminum plates. Place the base plate assembly upon a 12 x 24-inch (305 x 610 mm) electric hot plate and warm for approximately 30 minutes prior to placement of tack coat in order to reduce temperature loss during this operation.

a. AR-4000. The asphalt cement is applied at a rate of 0.05 gallons per square yard (0.23 liters per square meter) or 17 grams on a 5 x 24-inch (127 x 610 mm) area. Place a quantity of AR-4000 asphalt cement more than sufficient for one beam into a three-ounce (85 ml) tin can. Place the tin in a 275°F (135°C) oven for a sufficient period of time (1-1/2 to 2 hours) to allow the material to reach temperature. Pour the proper amount of asphalt from the tin onto the heated base plates and quickly spread into a uniform layer over the plate using a spatula. The proper amount is obtained by weight difference. Remove the treated base plate assembly from the hot plate and allow it to cool for a few minutes before removing the masking tape in preparation for the assembly of the beam mold.

b. Asphalt-rubber with aggregate chips. Asphalt-rubber with 3/8-inch (9.5 mm) maximum sized aggregate chips is used as a tack coat for both 12-inch (305 mm) and 24-inch (610 mm) long beams. Apply the asphalt-rubber at the rate of 0.6 gallons per square yard (2.7 liters per square meter) and the chips at a rate of 22.5 pounds per square yard (12.2 kilograms per square meter). This rate requires 220 grams of asphalt-rubber and 945 grams of chips for a 5 x 24-inch (127 x 610 mm) plate area. A 12-inch (305 mm) long beam requires one-half of these quantities. Compaction procedures are set to build either two 24-inch (610 mm) beams or one 24-inch (610 mm) beam and two 12-inch (305 mm) beams on any given day. The quantity of asphalt-rubber to be used on any given compaction day was the amount available from one can containing at least 1.1 pounds (500 grams) of material. Heat the can of asphalt-rubber to 375°F (190°C) in an oven. Place enough aggregate chips for one beam in a metal can and heat to 140°F (60°C) in an oven. Place the correct amount of asphalt-rubber onto a heated aluminum plate assembly while still on the hot plate. Return the can and remaining asphalt-rubber to the oven if another beam is to be prepared. Spread the asphalt-rubber uniformly using a spatula and distribute the heated chips uniformly over the asphalt-rubber. Seat the chips into the asphalt-rubber layer by hand rolling using a 2-inch diameter by 5-inch long (510 x 127 mm) hard-rubber roller. Remove the plate assembly from the hot plate and allow to cool for 10 to 15 minutes before removal of the masking tape in preparation for assembly of the beam mold.

c. <u>Asphalt-rubber with sand</u>. Asphalt-rubber tack coat with a cover coat of clean sand is used for the 24-inch (610 mm) long beams. The sand is a produce of screening and washing from a crushing operation with 100-percent passing a No. 4 (4.75 mm) sieve and less than 1.0-percent passing a No. 200 (0.075 mm) sieve. Apply the asphalt-rubber at a rate of 0.6 gallons per square yard (2.7 liters per square meter) and the sand at a rate of three pounds per square yard (1.6 kilograms per square meter). This rate utilizes 220 grams of asphalt-rubber and 125 grams of sand for a 5 x 24-inch (127 x 610 mm) plate area. Apply the asphalt-rubber to the plate assembly in the same manner used for the application of asphalt-rubber with chips. Immediately following the application of the asphalt-rubber, the correct weight of unheated sand is distributed uniformly over the tack coat area surface using a can with 1/4-inch (6.4 mm) diameter holes in its lid as an aggregate shaker. Remove the plate assembly from the hot plate and allow to cool 10 to 15 minutes before removal of the masking tape in preparation for assembly of the beam mold.

d. Figure D-1 shows SALs placed on the aluminum plates.

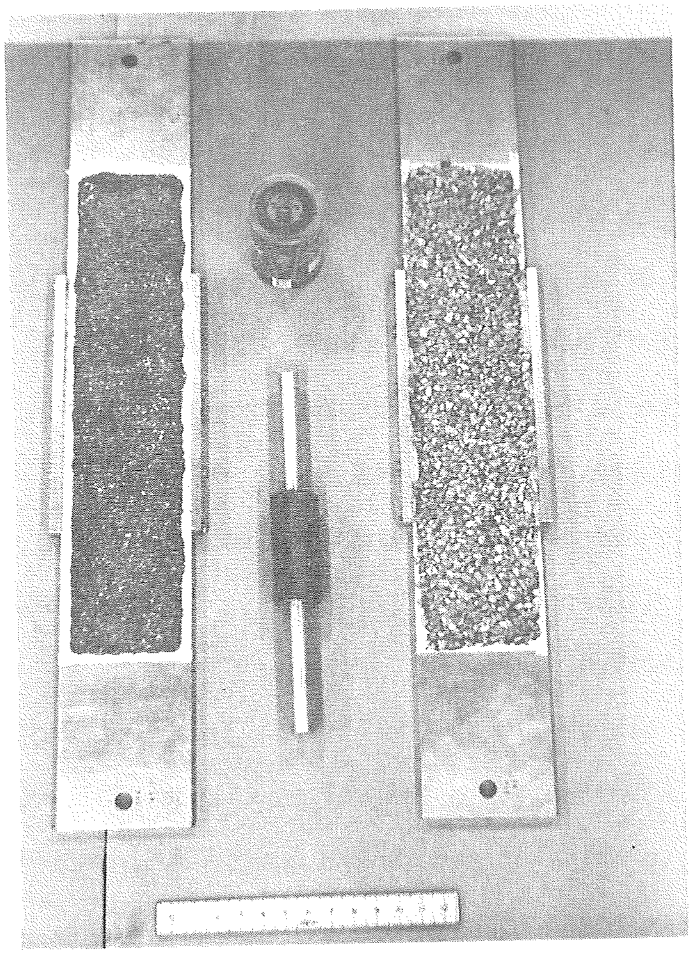


Figure D-1. SALs of A-R with Blotting Sand and Stone Chips.

# APPENDIX E

## Procedure for Compaction of Asphaltic-Aluminum Beams

NOTE: A supply of asphaltic concrete has been obtained and is stored in sealed five-gallon (19 l) cans.

a. Place a sealed can of asphaltic concrete in a 200°F (93°C) oven for about 1-1/2 to 2 hours so it becomes soft enough to sample. The quantity necessary for a desired thickness of beam layer is weighed either into a pan or into a grocery bag for storage and subsequent use.

b. Pans of mixture are brought to a compaction temperature of 250°F (121°C) in an oven on the day that compaction is performed. The mold base plates are prepared on the day of compaction.

c. The sides and ends of beam molds are given a light coating of motor oil on their inside surfaces. Aluminum plate assemblies with asphalt-rubber tack coats having either aggregate chips or sand cover coats are inverted just prior to assembly of the beam molds to remove any loose aggregate. The beam molds are assembled by removing one side holding bar at a time and replacing it with a mold side and end plates.

d. The amount of heated asphaltic concrete required for a desired layer thickness is placed into the beam mold in a uniform thickness with a small hand scoop and the top of the layer is leveled. The maximum layer thickness is 2 inches (51 mm). The sides of the layer are spaded between the mixture and the mold with a steel spatula. The layer is rodded 50 times with a bullet-nosed 3/8-inch (9.5 mm) diameter by 18-inch (457 mm) long steel rod. Thirty blows are positioned around the beams periphery and the remaining 20 are given within the interior of the layer for beams 24-inch (610 mm) in length. Beams of 12-inch (305 mm) lengths are rodded 25 times with 15 blows positioned around the exterior and 15 within the interior of the layer. The rod holes are filled by raking the surface. The surface is manually compacted with a 4 x 5-inch (102 x 127 mm) steel tamping foot. One thickness of heavy wrapping paper followed by a0.090-inch (2.3 mm) thick steel plate, both the size of the specimen, are placed on the layer.

e. The beam mold is placed within the guides on the vibratory kneading compactor (VKC). The compactor foot is lowered onto the asphaltic mixture layer, the compactor is energized and the beam mold is manually moved back and forth to distribute the compactive effort equally over the layer. Compaction for each layer is as follows:

   1. Beams of 12-inch (305 mm) length - use 4 x 5-inch (102 x 127 mm) compaction foot, four minutes of compaction time, and eight back-and-forth cycles per minute per 2-inch (51 mm) layer thickness.

   2. Beams of 24-inch (610mm) length - use 8 x 5-inch (203 x 127 mm) compaction foot, six minutes of compaction time, and four back-and-forth cycles per minute per 1½-inch (38 mm) and 2-inch (51 mm) layer thicknesses.

   The beam is removed from the VKC and the steel plate and paper are removed. If a second layer of asphaltic mixture is to be placed, and surface is scored with the blunt screwdriver to minimize the creation of a plane of weakness between the layers. The second layer is compacted in precisely the same manner as the first.

f. Following compaction of the last layer of a beam, the beam mold assembly is removed from the VKC, the steel plate and paper are removed from the surface, and an I-beam ram fitting the top surface of the beam is placed upon the beam.

The specimen is leveled in universal testing machine by loading the I-beam assembly to produce a compressive load of 300 psi (21.1 kg per sq cm) on the specimen. The head of the testing machine is locked to keep it parallel to the machine platen during loading. This compressive load is 18,000 pounds (8,165 kilograms) for 12-inch (305 mm) beams and 36,000 pounds (16,329 kilograms) for 24-inch (610 mm) beams and is held for two minutes. Compaction of the beam is not affected by this levelling load.

g. The beam-mold assembly is placed in the 77°F (25°C) constant temperature room and allowed to remain there for a minimum period of 16 hours prior to preparation of testing of the beam.

h. During the disassembling of the beam-mold, the aluminum base plates are kept in contact with a flat plate. The reason for this is to ascertain a continuous plane from one plate to the other. The I-beam ram used during leveling is placed on the top of the beam for added weight to assist in this effort. The side and end mold plates are removed and care is exercised to avoid stressing the beam. Aluminum holding bars are placed on the sides of the base plates to allow handling of the beams without stressing of the specimen. The beam's thickness at its midpoint is measured and recorded. The beam is stored in the appropriate controlled temperature room for at least 16 hours prior to testing.

i. Figure E-1 shows equipment for the vibratory compaction of asphaltic-aluminum beams.

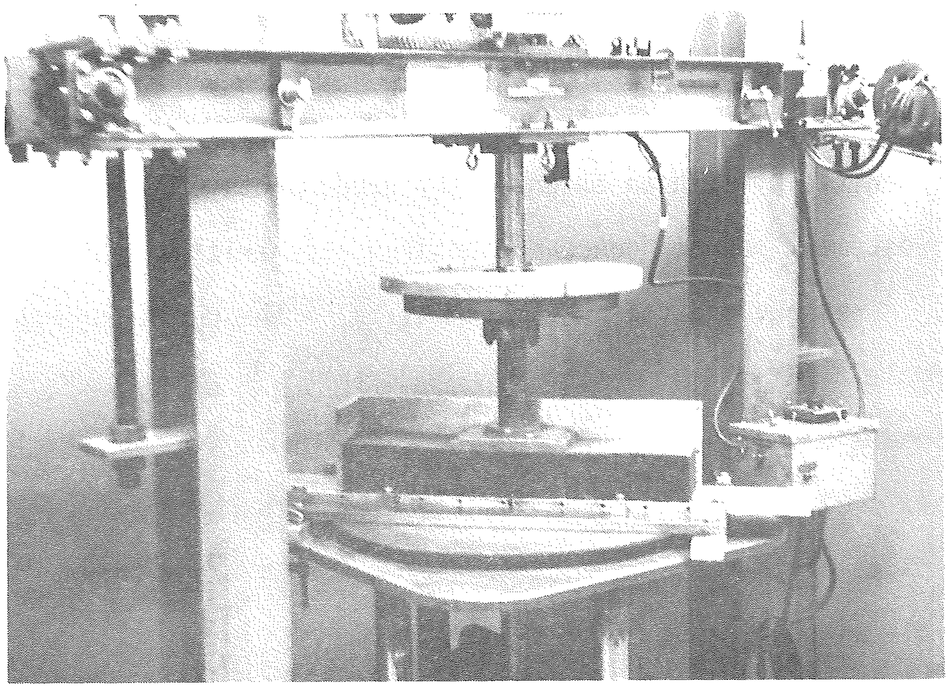


Figure E-1. Vibratory Compaction of 24-Inch Asphaltic-Aluminum Beam.

# APPENDIX F

## Procedure for the Repeated Vertical Shear Test

NOTE: The asphaltic concrete-aluminum beam has been stored in a controlled temperature room. The testing device, which consists basically of a variable eccentricity cam and four supports for the beam, also is in the controlled temperature room.

a. Set the desired cam eccentricity by rotating the outer cylinder and measuring the eccentricity with an extensometer gage. Rotate the driver so it is in its lowest most position once the desired eccentricity setting has been achieved. Make sure the top of the cam is below the under surface of the beam assembly.

b. Place the beam assembly on the supports so that the joint is 1/2-inch (12.7 mm) to the left of the drive shaft axis. Adjust the two supporting aluminum bars on either side of the joint to just make contact with the underside of the aluminum plate and tighten their holding nuts.

c. Remove the side holding bars. Place an extensometer gage to contact the specimen near the center of the beam and directly above the drive shaft. Zero the extensometer gage. Secure the beam assembly by tightening the clamping bars to the supports in the following sequence:

   1) Snug bar No. 2 (inside left)
   2) Snug bar No. 3 (inside right)
   3) Snug bar No. 1 (outside left)
   4) Snug bar No. 4 (outside right)

5) Repeat the above sequence (1-4) to tighten the clamping bars. The beam assembly has been properly secured if the extensometer gage shows a change in elevation of less than 0.012-inch (0.305 mm). If the change is greater, then release all four clamping bars and repeat the securing process.

d. Clamp both ends of the asphaltic beam to the aluminum plate by tightening the bolts through the aluminum clamping bars placed below the aluminum base plate and on top of the asphaltic concrete beam. Clamp the asphaltic concrete beam to the left base plate using bolts attached to the base plate.

e. Position an extensometer gage to determine the deflections of the aluminum plate at a point that is directly above the center of the drive shaft.

f. Loosen the four bolts that secure the base plate of the cam assembly. Turn the wheel of the threaded shaft to raise the cam at its lowest point to produce an upward deflection of 0.002-inch (0.051 mm).

g. Manually rotate the cam 15 or 20 times to seat the total system. Observe the extensometer gages and the point of contact between the cam and the base plate to verify that contact is always maintained. It may be necessary to further raise the cam. If the lowest point of the cam does not touch the plate while rotating, then impact (knocking) will result when it is rotating rapidly. When satisfied with the cam's position, tighten the four base plate bolts.

h. Zero both extensometer gages and the revolution counter. Energize the electric motor and record the time of the start of the test.

i. As the test progresses, record the accumulative and repeated deflections of the asphaltic beam and the aluminum base plate at the corresponding number of load repetitions. Continue recordings to perceive when a crack first appears and also as it progresses through the beam.

j. Figure F-1 shows equipment for the repeated vertical shear test.

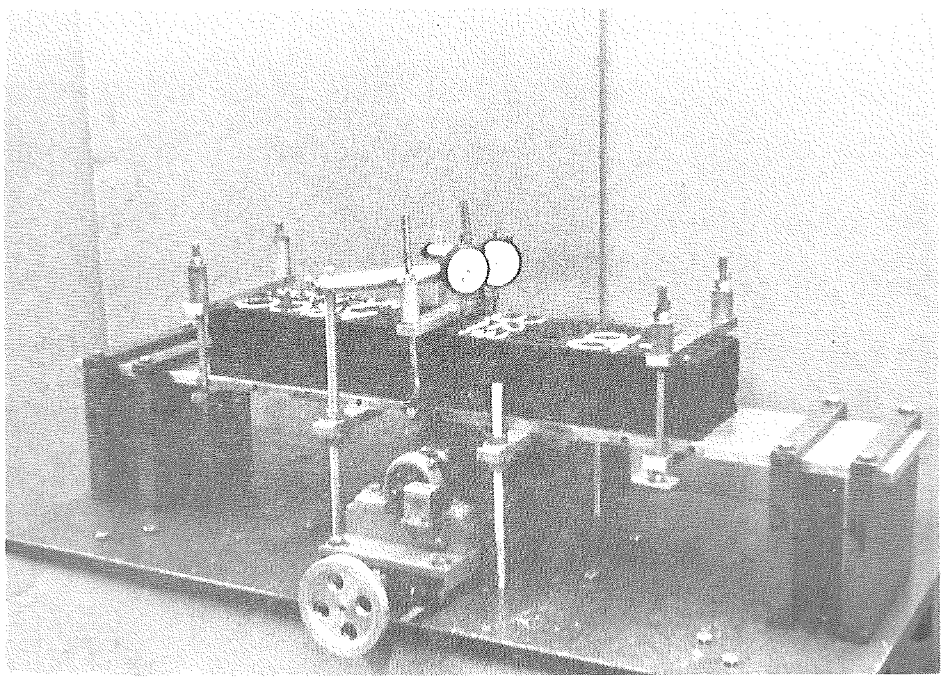


Figure F-1. Set-up for the Repeated Vertical Shear Test.

# APPENDIX G

## Procedure for the Static Horizontal Shear Test

NOTE: The asphaltic-aluminum beam has been stored in a 77°F (25°C) controlled temperature room. Testing will be done in the laboratory on a universal testing machine at ambient temperature.

a. Prepare a 24-inch (610 mm) long beam for testing by removing the last stud bolts from one end of the side holding bars. Position the clamping plate assembly on this end of the beam and uniformly finger-tighten the wing nuts, taking care not to deform the beam. Attach the mounting bracket having an extensometer gage with 0.001-inch (0.025 mm) graduations to the aluminum base plate on the other end of the beam. The beam is now ready to be placed into testing position in the universal testing machine with the extensometer gage at the lower end.

b. The preparation for performance of the test is different for 24-inch (610 mm) and 12-inch (305 mm) long beams to the extent that there is sufficient length of the 24-inch (610 mm) long beam beyond the side holding bars to allow the placement of the test's appurtenances with the holding bars still in place. This is not true for a 12-inch (305 mm) long beam which is positioned in the testing machine prior to removal of the holding bars followed by the attachment of the test appurtenances.

c. Place a 3/4-inch (19 mm) diameter rod through the hold in the upper crosshead of the testing machine. Hang either a 12-inch (305 mm) long beam or a 24-inch (610 mm) long beam prepared as indicated in Step a from this rod. Align the hole in the lower crosshead with the hole in the aluminum base plate. Insert the other 3/4-inch (19 mm) diameter rod through the plate hole and into the crosshead. Move the crosshead as necessary to assure that there is no load on the beam assembly. Remove the side holding bars for either a 24-inch (610 mm) long or a 12-inch (305 mm) long beam.

d. Place the clamping-plate assembly on the upper end for a 12-inch (305 mm) long beam and uniformly finger-tighten the wing nuts. Attach the mounting bracket having an extensometer gage with 0.001-inch (0.025 mm) graduations to the aluminum base plate at the lower end of the beam.

e. Place the support base of a second extensometer gage on the testing machine platen to measure the downward movement of the lower crosshead. This second extensometer gage has graduations of 0.001-inch (0.025 mm).

f. Zero both extensometer gages and set the load scale of the testing machine to the 3,000 pound (0-1,362 kilograms) scale.

g. Set the speed control dial at the desired crosshead displacement rate and apply tensile load (downward movement). Record load and relative displacement (slip of the aluminum plate to the asphaltic-beam end), at selected interval of crosshead displacement. The interval depends on the crosshead speed as shown below:

| Crosshead Speed inch/minute | Crosshead Displacement inch |
|---|---|
| 0.05 | 0.025 |
| 0.10 | 0.025 |
| 0.20 | 0.050 |

Usually three persons will be required to call and record readings. However, with practice, two persons can satisfactorily obtain the data with one person calling out the displacement and recording the slip and the other person recording the load. Loading is continued past the maximum force until the slip rate at the interface of the beam equals the crosshead speed. Of course, the test ends if the asphaltic beam fractures.

h. Reverse the direction of the crosshead until the beam is free for removal and being careful to not jam or compress the assembly.

i. After the aluminum plates and asphaltic beam have been removed, warm them in a 250°F (121°C) oven to facilitate the removal of the asphaltic beam and the cleaning of the plates.

j. Figure G-1 shows a specimen set-up for the static horizontal shear test.

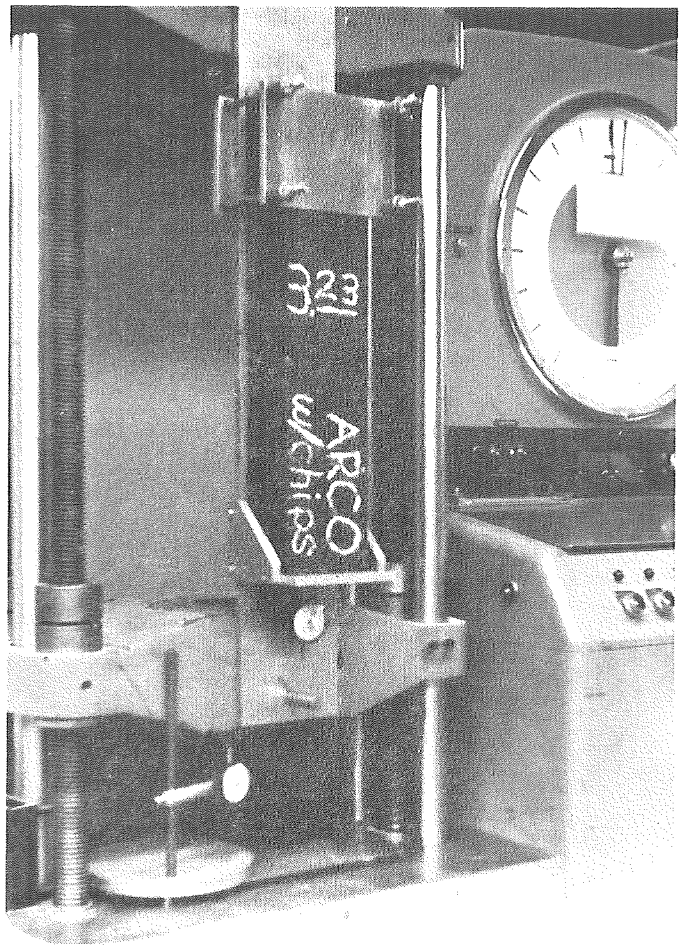



Figure G-1. Set-up for the Static Horizontal Shear Test.

## APPENDIX H

### Procedure for the Repeated Horizontal Shear Test

NOTE: The composite asphaltic concrete-aluminum beam has been stored in a controlled temperature room. The testing device consists of a variable eccentricity cam which transmits a horizontal, repeated tensile-compressive load along the axis of the aluminum beam. The movement of the cam is transmitted through a proving ring to allow determination of the load being applied to the beam. The aluminum base plate nearest the cam is movable while the other end remains fixed to the base of the testing device. The testing device is in the controlled temperature room except for 77°F (25°C) testing when it is located in the laboratory.

a. Set the eccentricity of the cam by rotating the outer cylinder. Manually rotate the cam while measuring its horizontal movement with an extensometer gage at the counter balance on the back of the cam assembly. Continue varying the cam setting until the desired horizontal movement is achieved. Once the desired cam setting is achieved, rotate the cam until the eccentricity is in its fartherest position toward the proving rang so that initial movement of the cam will produce a tensile load.

b. Prepare the beam assembly for placement in the testing device by positioning the clamping-plate assembly on one end of the asphaltic concrete beam and finger-tightening uniformly the wing nuts without deforming the asphaltic concrete beam. Attach the extensometer gage mounting bracket to the aluminum base plate at the other end of the beam. Use an extensometer gage with 0.001 inch (0.0025 mm) graduations. Secure the pin-block connector to the aluminum base plate at the clamped end of the asphaltic concrete beam.

c. Plate the composite beam on the rollers of the testing device with the threaded connector end of the plate in position for the fixed end anchorage. Slight vertical adjustment of the rollers may be necessary such that all are in contact with the underside of the aluminum base plate and establish a plane.

d. Secure the movable end of the beam to the proving ring by placing the 3/4-inch (19 mm) diameter pin through the connector on the proving ring and the hole in the aluminum base plate. Eliminate any slack in the connector by tightening the bolt on the proving ring bracket against the aluminum base plate.

e. Tighten the bolt on the fixed end support to produce a tensile load of approximately 75 pounds (34 kg) on the beam assembly. Tighten the lock against the pin block on the aluminum plate. Lock the nut against the fixed end support until the tensile load in the beam is reduced to zero. If zero load can not be achieved and the lock nut sufficiently tightened simultaneously it may be necessary to loosen all nuts and start at the beginning of the procedure with a slightly different tensile load in the beam assembly.

f. Remove the holding bars on either side of the aluminum plate.

g. Mount an extensometer gage with 0.0001-inch (0.002 mm) graduations on an aluminum plate and near the joint in order to monitor the changes in joint opening. In some cases, it will be necessary to replace the extensometer gage with another one of 0.001 inch (0.025 mm) graduations without interrupting the test.

h. Read and record the initial settings of the extensometer gages for measuring crack movement and horizontal slip; verify from the extensometer gage on the proving ring that the load on the beam in zero; zero the revolution counter and energize the electric motor. Record accumulative and repeated crack movements, repeated horizontal slip, and the minimum and maximum deflections of the proving ring at corresponding repetitions of deflection at increasing interval of time. Continue readings until a log-log plot of the load repetitions versus the repeated joint movement establishes deviation from a straight line.

Note: When a crack appears on the asphatlic concrete beam and follow the propagation of the crack as loading is continued.

i. Figure H-1 shows the set-up for the repeated horizontal shear test.

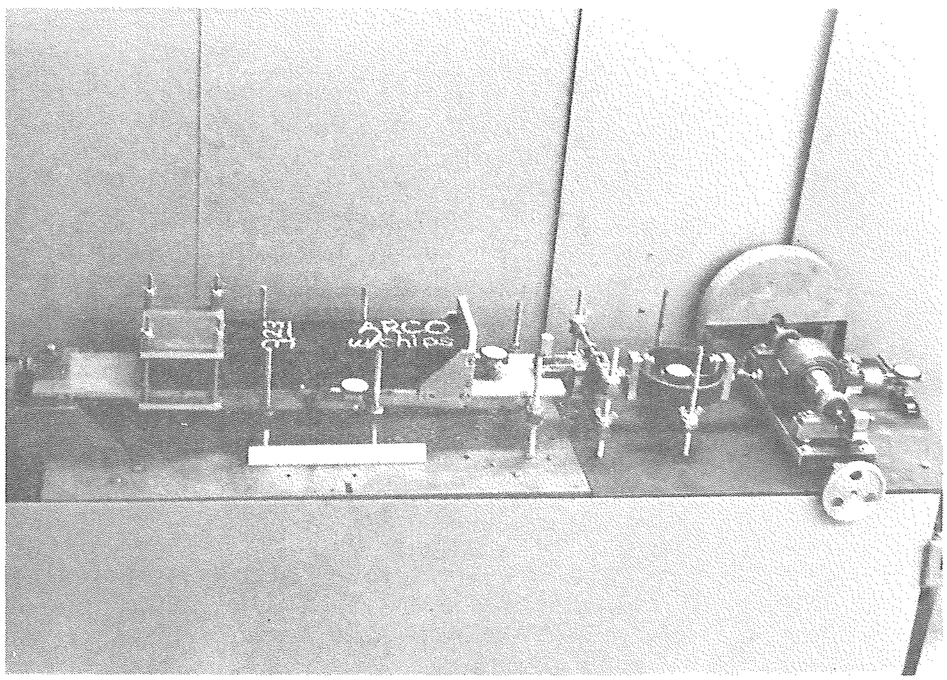
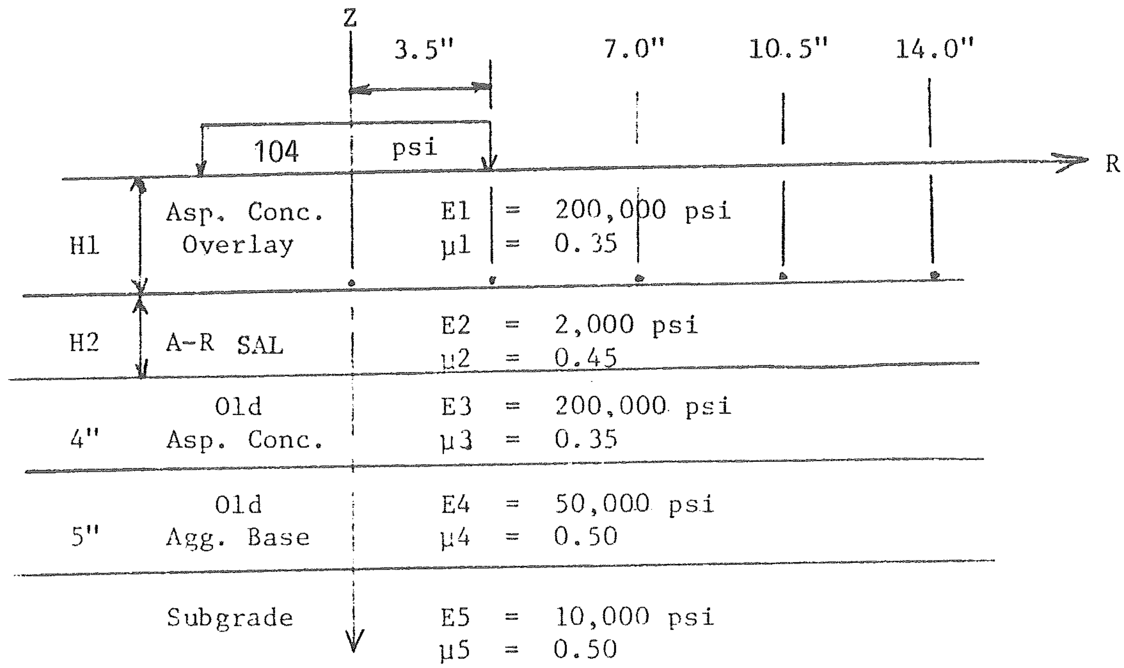



Figure H-1. Set-up for the Repeated Horizontal Shear Test.

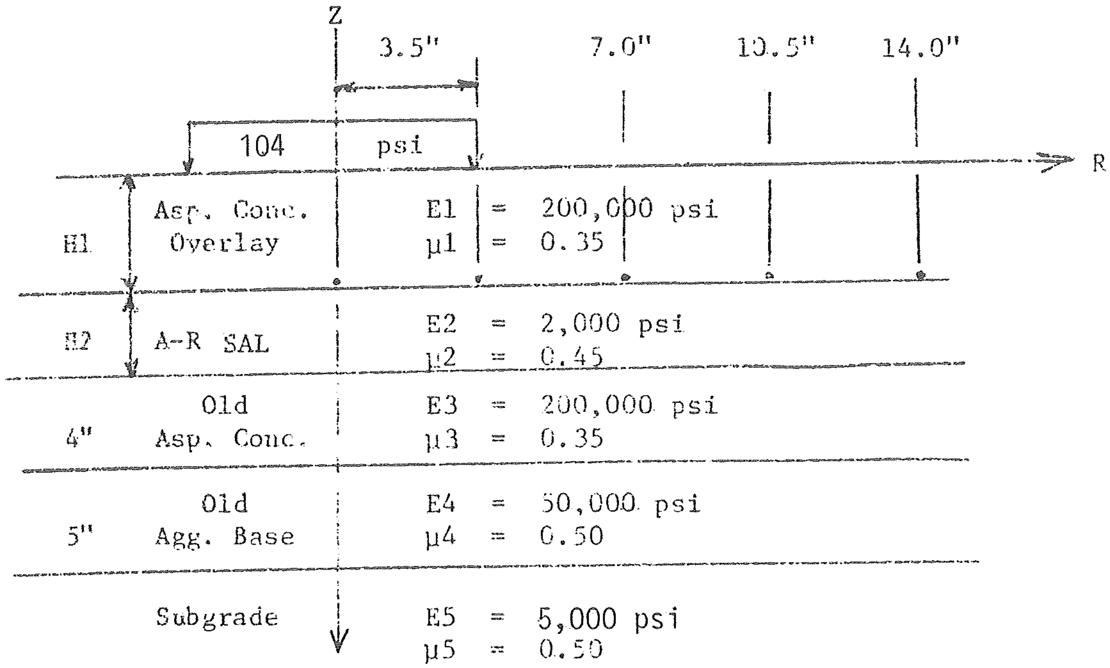
## APPENDICES FOR CALCULATION PROGRAM

TABLE I-1. RADIAL AND SHEAR STRESSES AT BOTTOM OF OVERLAY FOR CONDITIONS SHOWN ON IN-SET (E5 = 10,000 psi)




| | | Figure J-1 | | | Figure J-2 | | |
|---|---|---|---|---|---|---|---|
| Z = H1, in. | | 2 | | | 4 | | |
| H2 (SAL), in. | | 0 | 1/8 | 3/8 | 0 | 1/8 | 3/8 |
| stress, psi | R, in. | | | | | | |
| $\sigma_R$ (a) | 0 | -38.1 | +66.1 | +143 | -4.73 | +66.6 | +102 |
| | 3.5 | -32.1 | - 7.56 | + 13.4 | -9.62 | +19.0 | + 38.0 |
| | 7.0 | -14.5 | -30.6 | - 44.0 | -8.77 | -15.5 | - 14.8 |
| | 10.5 | - 5.5 | -10.9 | - 13.9 | -4.26 | -11.1 | - 14.0 |
| | 14.0 | - 2.0 | - 5.75 | - 6.42 | -2.29 | - 6.76 | - 9.16 |
| $\tau$ (b) | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 3.5 | -32.1 | - 7.21 | - 1.94 | -20.8 | - 5.40 | - 1.97 |
| | 7.0 | -10.2 | - 5.31 | - 2.52 | -12.2 | - 5.44 | - 2.54 |
| | 10.5 | - 4.9 | - 3.37 | - 2.01 | - 6.22 | - 4.00 | - 2.25 |
| | 14.0 | - 2.7 | - 2.24 | - 1.47 | - 3.74 | - 2.83 | - 1.78 |

TABLE I-2. RADIAL AND SHEAR STRESSES AT BOTTOM OF OVERLAY FOR CONDITIONS SHOWN IN IN-SET (E5 = 5,000 psi)




| Z = H1, in. | | Figure J-1 | | | Figure J-2 | | |
|---|---|---|---|---|---|---|---|
| H2 (SAL), in. | | 2 | | | 4 | | |
| stress, psi | R, in. | 0 | 1/8 | 3/8 | 0 | 1/8 | 3/8 |
| $\sigma_R$ (a) | 0 | -41.5 | +64.3 | +143 | -5.46 | +67.2 | +104 |
| | 3.5 | -35.4 | -9.35 | +13.0 | -10.3 | +19.5 | +39.8 |
| | 7.0 | -17.7 | -32.8 | -45.1 | -9.58 | -15.3 | -13.5 |
| | 10.5 | -8.11 | -12.9 | -15.2 | -4.95 | -11.1 | -13.2 |
| | 14.0 | -4.02 | -7.56 | -7.79 | -2.87 | -7.04 | -8.92 |
| $\tau$ (b) | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 3.5 | -32.5 | -7.46 | -2.11 | -21.1 | -5.61 | -2.12 |
| | 7.0 | -10.8 | -5.74 | -2.82 | -12.6 | -5.82 | -2.82 |
| | 10.5 | -5.62 | -3.90 | -2.38 | -6.78 | -4.48 | -2.60 |
| | 14.0 | -3.42 | -2.78 | -1.86 | -4.34 | -3.35 | -2.17 |

TABLE I-3. CALCULATED MAXIMUM VALUE OF STRESSES FOR THE VERTICAL SHEAR SET-UP FOR VARIABLE BEAM AND SAL THICKNESS WITH A UNIT LOAD

**Thickness of SAL = 0.110 in.**

| | | | |
|---|---|---|---|
| Length of beam, in. | | 24 | |
| Thickness of beam, in. | 2 | 3 | 4 |
| Shearing stress on SAL, psi | 0.095 | 0.064 | 0.043 |
| Vertical stress on SAL, psi | (-0.369)<br>0.034 | (-0.261)<br>0.036 | (-0.217)<br>0.016 |
| Shearing stress on beam, psi | 0.095 | 0.089 | 0.060 |
| Tensile stress on beam, psi | 1.358 | 0.731 | 0.445 |

**Thickness of SAL = 0.004 in.**

| | | | |
|---|---|---|---|
| Length of beam, in. | | 24 | |
| Thickness of beam, in. | 2 | 3 | 4 |
| Shearing stress on SAL, psi | | 0.571 | |
| Vertical stress on SAL, psi | | (-0.887)<br>0.201 | |
| Shearing stress on beam, psi | | 0.571 | |
| Tensile stress on beam, psi | | 0.811 | |

$\sigma$ for beam is horizontal (flexural + axial)

$\sigma$ for SAL is vertical and (-) is compression

TABLE I-4. CALCULATED MAXIMUM VALUE OF STRESSES FOR THE HORIZONTAL SHEAR SET-UP FOR VARIABLE LENGTH AND THICKNESS OF BEAM, AND SAL WITH A UNIT LOAD

Thickness of SAL = 0.110 in.

| | | | | | |
|---|---|---|---|---|---|
| Length of beam, in. | 12 | | 24 | | |
| Thickness of beam, in. | 2 | 4 | 2 | 3 | 4 |
| Shearing stress on SAL, psi | -0.049* | -0.044* | -0.032* | -0.030* | -0.029* |
| Vertical stress on SAL, psi | 0.034 | 0.016 | 0.027 | 0.034 | 0.035 |
| Shearing stress on beam, psi | 0.029 | -0.015 | 0.015 | 0.030 | 0.013 |
| Tensile stress on beam, psi | 0.342* | 0.198* | 0.244* | 0.181* | 0.152* |

Thickness of SAL = 0.004 in.

| | |
|---|---|
| Length of beam, in. | 24 |
| Thickness of beam, in. | 3 |
| Shearing stress on SAL, psi | -0.169 |
| Vertical stress on SAL, psi | 0.924 |
| Shearing stress on beam, psi | -0.169 |
| Tensile stress on beam, psi | 0.224 |

* Located vertically of the joint

$\sigma$ for SAL is vertical and + is compressive

$\sigma$ for beam is horizontal and + is tensile

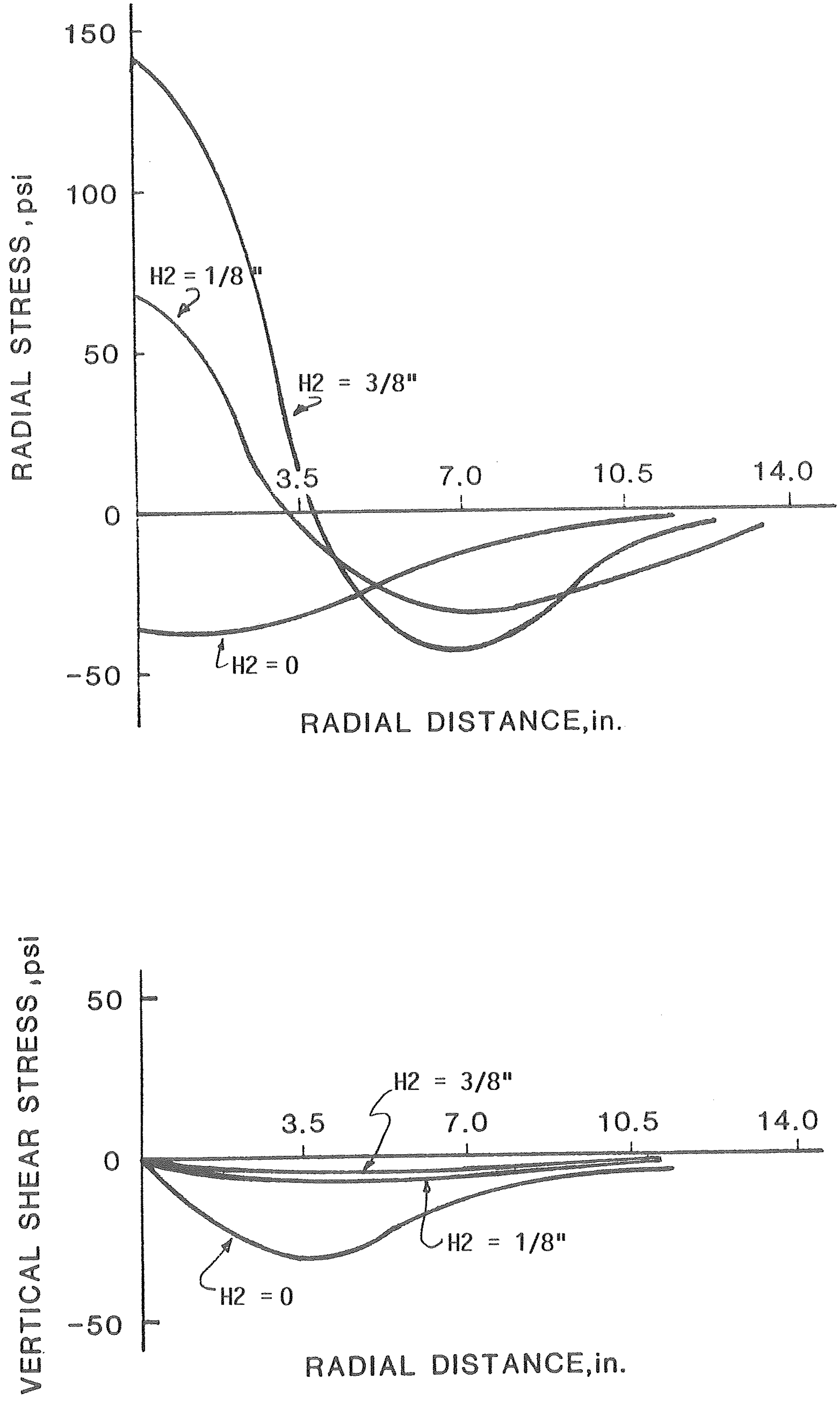



Figure J-1. Calculated Radial and Shear Stresses at Bottom of Overlay in a Five-Layer Pavement with SAL and H1 = 2" (Details on Table I-1).

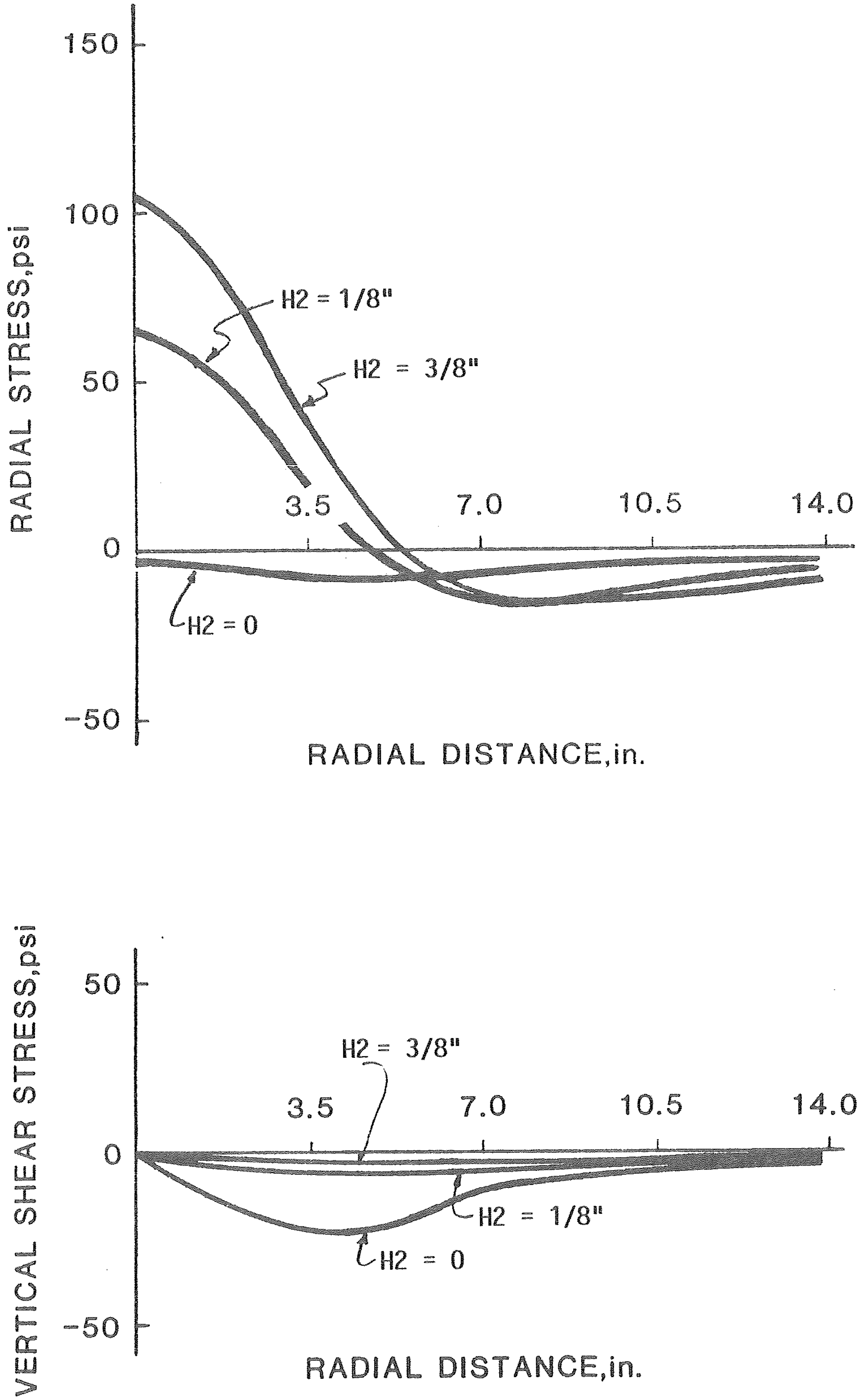



Figure J-2. Calculated Radial and Shear Stresses at Bottom of Overlay in a Five-Layer Pavement with SAL and H1 = 4" (Details on Table I-1).

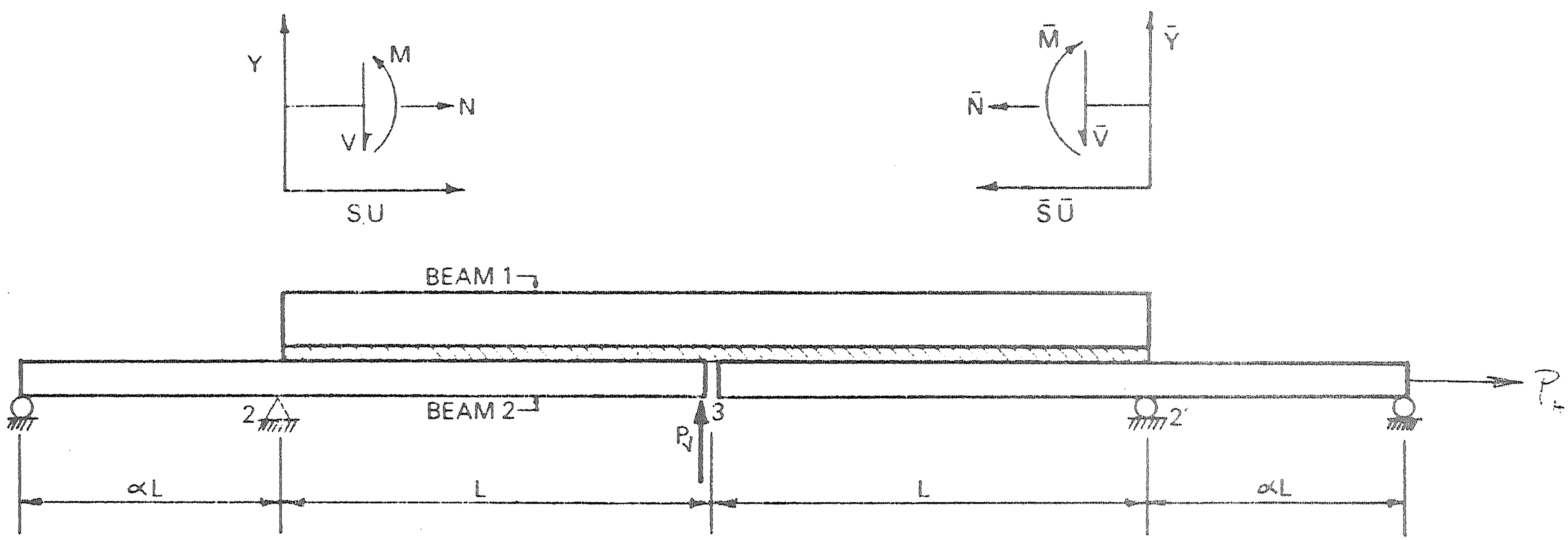



Figure J-3. Beam Set-up for Testing Under Repeated Vertical Load or Repeated Horizontal Load.

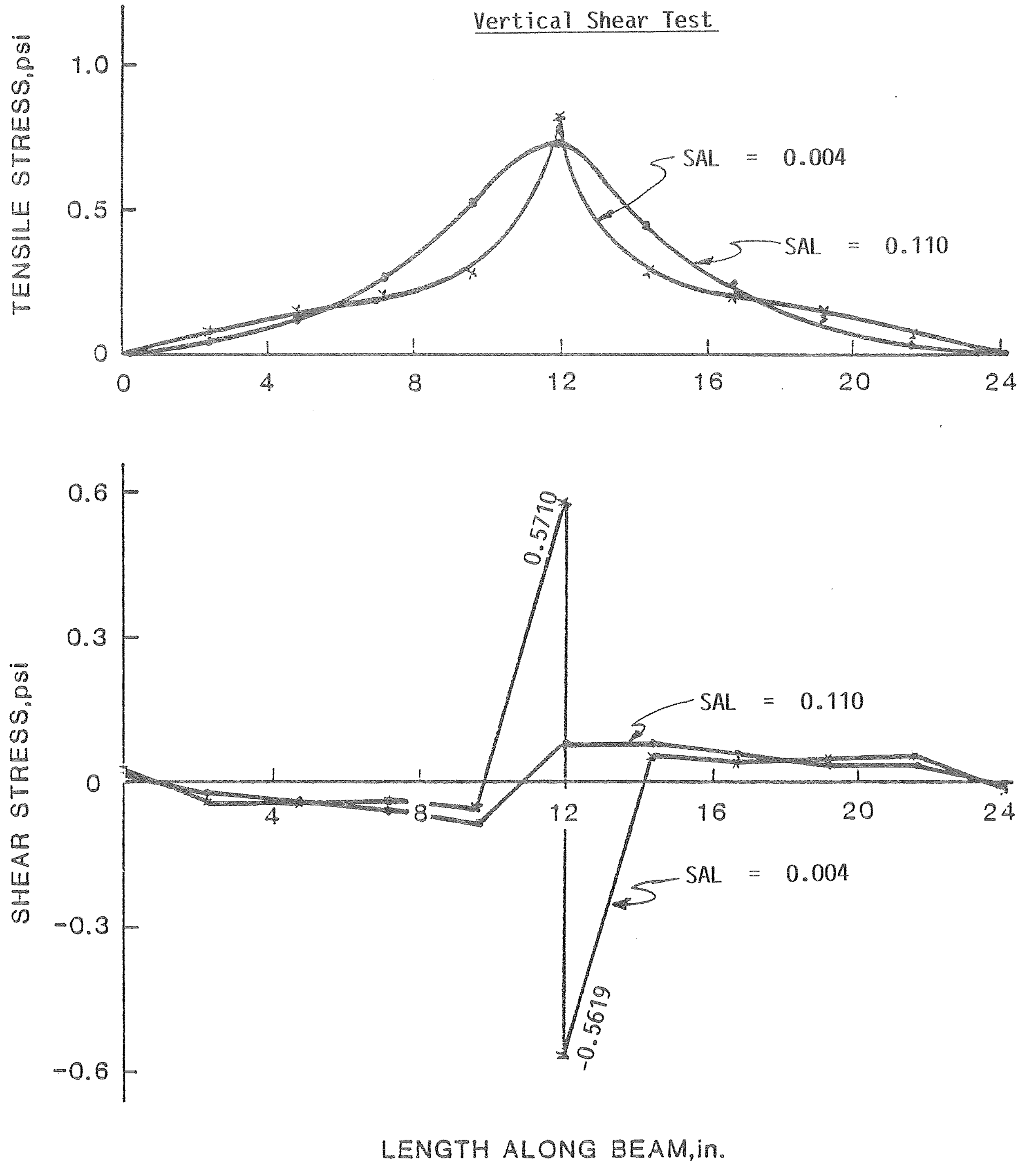



Figure J-4. Calculated Tensile and Shear Stresses in Asphaltic Beam 3" x 5" x 24" with SAL for the Vertical Shear Load.

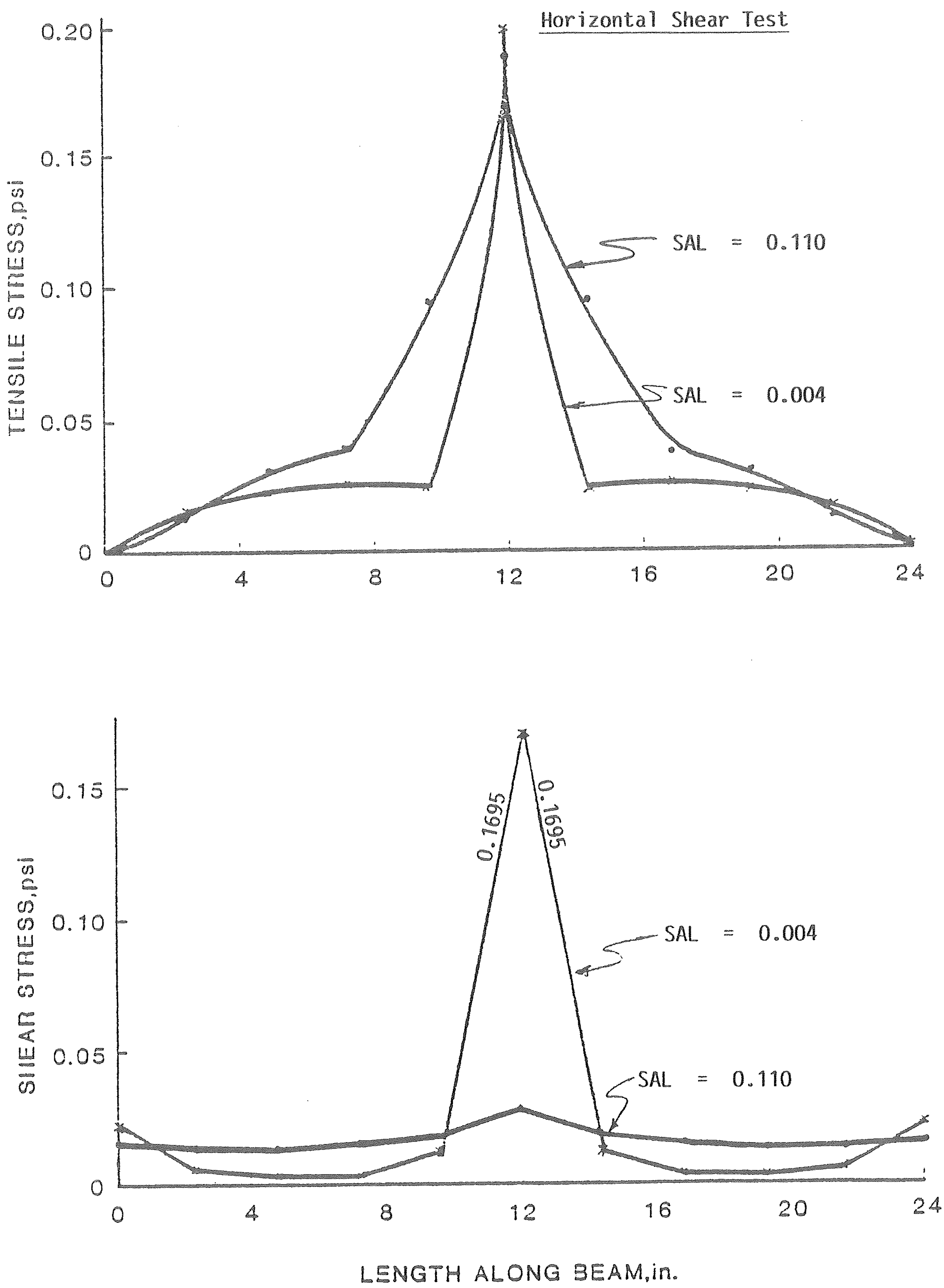



Figure J-5. Calculated Tensile and Shear Stresses in Asphaltic Beam 3" x 5" x 24" with SAL for the Horizontal Shear Load.

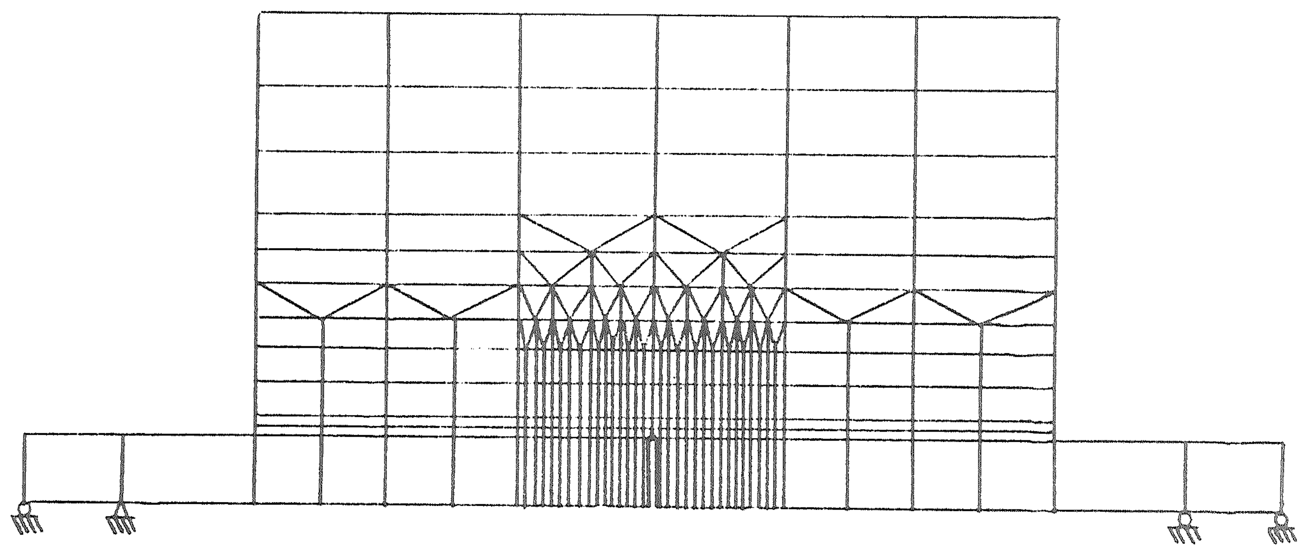


Figure J-6. Finite Element Mesh for Beam Tests; Mesh Exaggerated Four Times in Vertical Direction (Ref. 11).

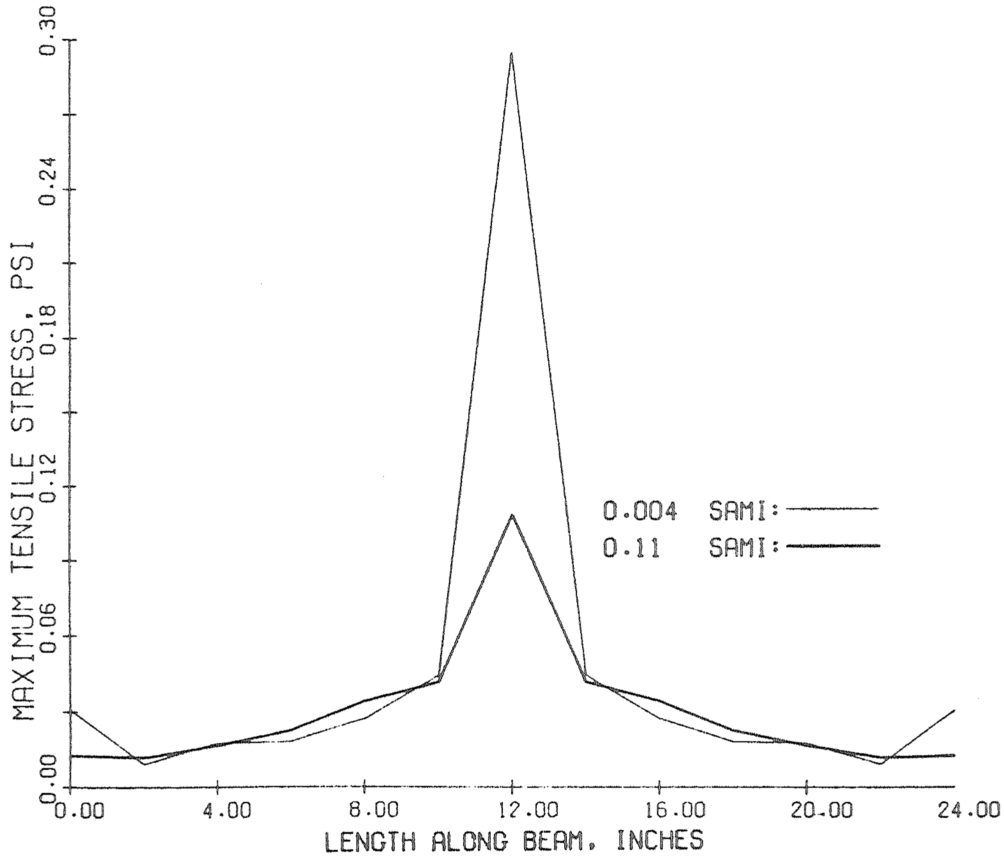



Figure J-7. Maximum Tensile Stresses (by FEM) in Asphaltic Beam 3" x 5" x 24" with SAL (SAMI) for the Horizontal Shear Load (Ref. 11).

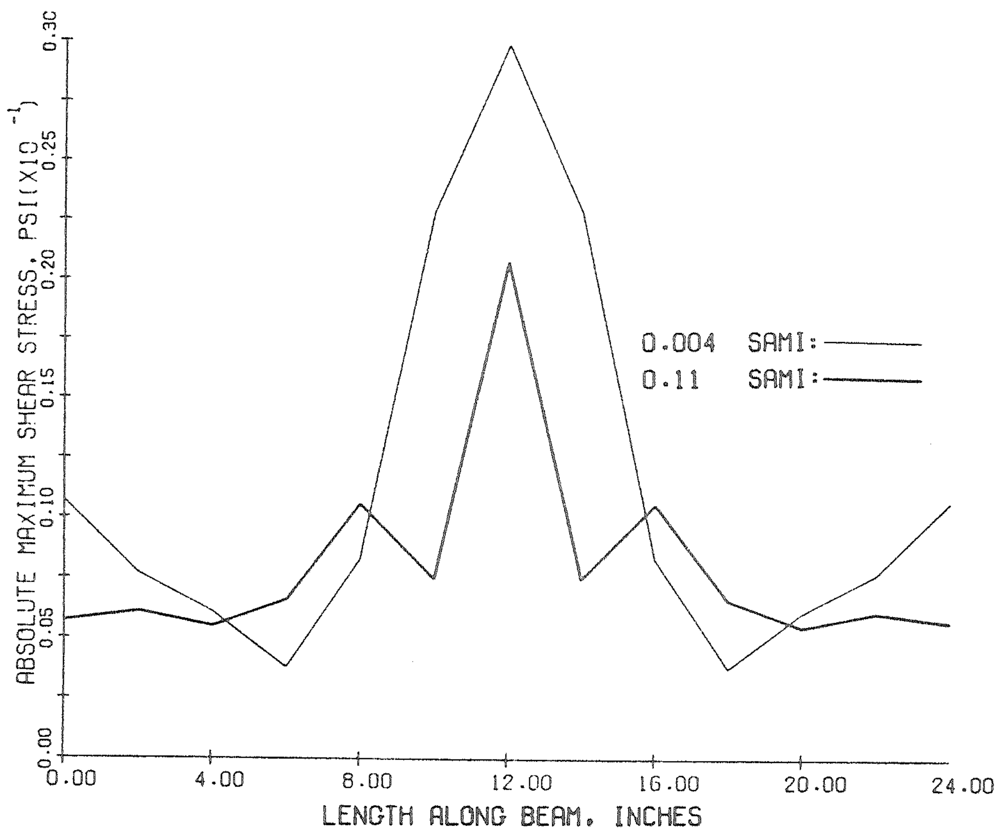



Figure J-8. Maximum Shear Stresses (by FEM) in Asphaltic Beam 3" x 5" by 24" with SAL (SAMI) for the Horizontal Shear Load (Ref. 11).

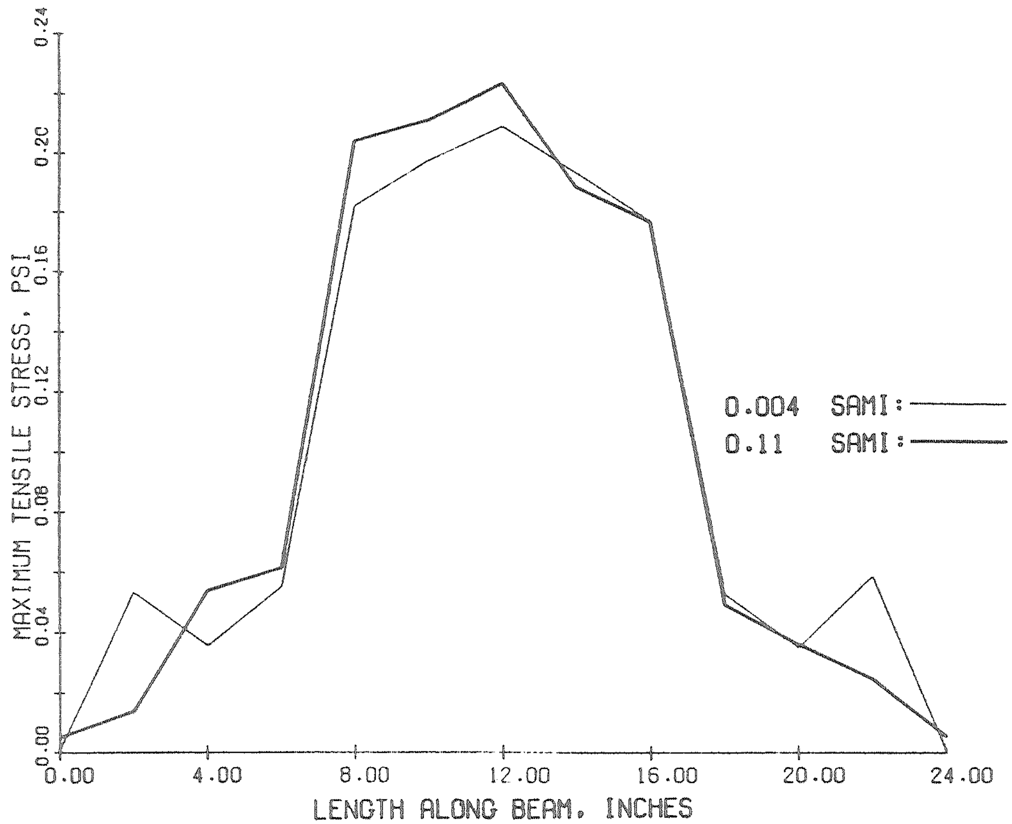



Figure J-9. Maximum Tensile Stresses (by FEM) in Asphaltic Beam 3" x 5" x 24" with SAL (SAMI) for the Vertical Shear Load (Ref. 11).

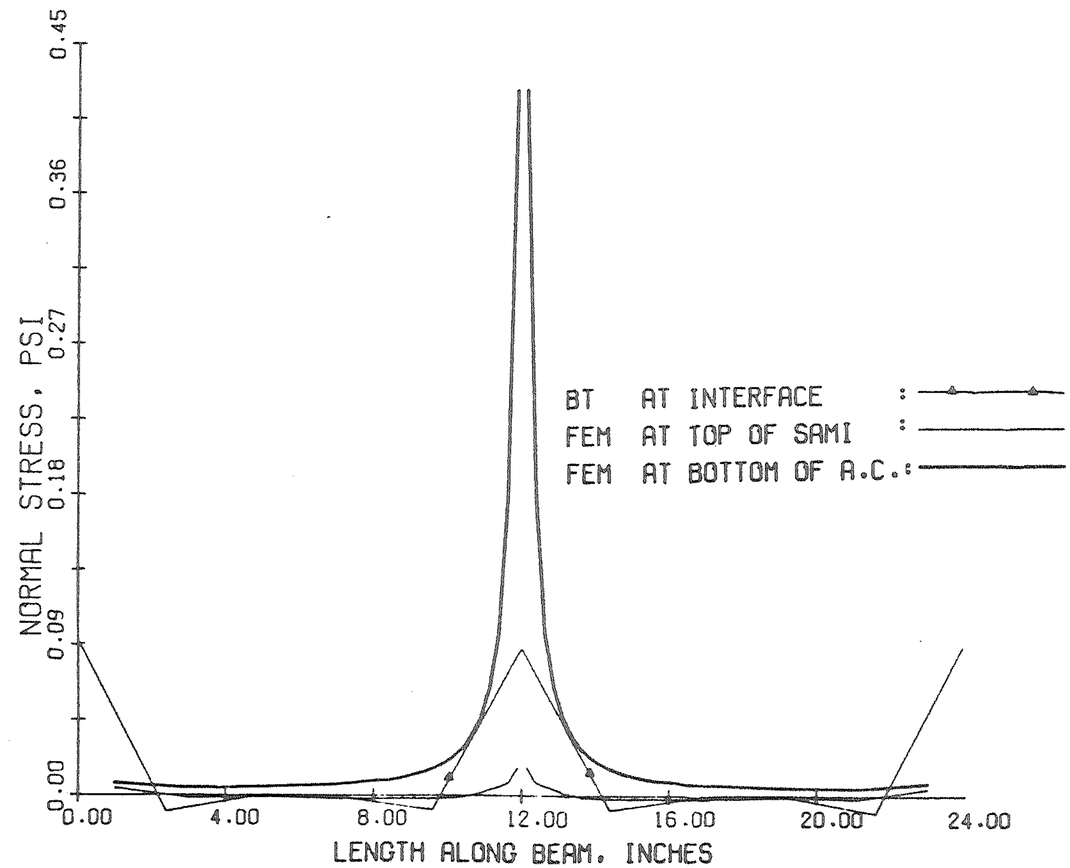



Figure J-10. Vertical Normal Stresses at Interface between Asphaltic Beam 3" x 5" x 24" and SAL (SAMI) 0.004 Inch Thick Calculated through Beam Theory and Finite Element Method for the Horizontal Shear Load (Ref. 11).