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16. ABSTRACT
Because of the proliferation of paving products being presented as reflection crack retarders, the need developed for laboratory tests that can be used as a screening device to avoid the extensive costs and delays associated with full-scale field tests. This resulted in an FHWA-financed research project to generate laboratory tests for estimating the effect of various fabric interlayers on AC overlay properties such as:

1. water permeability
2. susceptibility to flexural fatigue reflection cracking
3. susceptibility to vertical shear fatigue reflection cracking
4. susceptibility to horizontal shear failure (slipping).

Testing was also done to characterize popular fabrics in terms of physical/ mechanical properties such as tensile strength, elongation, modulus, weight, thickness, and heat resistance. Possible correlation between these fabric properties and the above four overlay properties was investigated. In addition, methods of estimating a fabric's optimum asphalt tack coat application rate were developed.

As a subproject to this research, a finite element analysis of fabric interlayers was also conducted, and is summarized in the appendix.

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STATE OF CALIFORNIA
DEPARTMENT OF TRANSPORTATION
DIVISION OF ENGINEERING SERVICES
OFFICE OF TRANSPORTATION LABORATORY

LABORATORY TESTING of FABRIC INTERLAYERS for ASPHALT CONCRETE PAVING

(Final Report)

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CONVERSION FACTORS

English to Metric System (SI) of Measurement

Quantity	English unit	Multiply by	To get metric equivalent
Length	inches (in)or(")	25.40	millimetres (mmm)
		.02540	metres (m)
	feet (ft)or(')	.3048	metres (m)
	miles (mi)	1.609	kilometres (km)
Area	square inches (in^2)	6.432×10^{-4}	square metres (m^2)
	square feet (ft^2)	.09290	square metres (m^2)
	acres	.4047	hectares (ha)
Volume	gallons (gal)	3.785	litres (l)
	cubic feet (ft^3)	.02832	cubic metres (m^3)
	cubic yards (yd^3)	.7646	cubic metres (m^3)
Volume/Time (Flow)	cubic feet per second (ft^3/s)	28.317	litres per second (l/s)
	gallons per minute (gal/min)	.06309	litres per second (l/s)
Mass	pounds (lb)	.4536	kilograms (kg)
Velocity	miles per hour (mph)	.4470	metres per second (m/s)
	feet per second (fps)	.3048	metres per second (m/s)
Acceleration	feet per second squared (ft/s^2)	.3048	metres per second squared (m/s^2)
	acceleration due to force of gravity (G)	9.807	metres per second squared (m/s^2)
Weight Density	pounds per cubic (lb/ft^3)	16.02	kilograms per cubic metre (kg/m^3)
Force	pounds (lbs)	4.448	newtons (N)
	kips (1000 lbs)	4448	newtons (N)
Thermal Energy	British thermal unit (BTU)	1055	joules (J)
Mechanical Energy	foot-pounds (ft-lb)	1.356	joules (J)
	foot-kips (ft-k)	1356	joules (J)
Bending Moment or Torque	inch-pounds (ft-lbs)	.1130	newton-metres (Nm)
	foot-pounds (ft-lbs)	1.356	newton-metres (Nm)
Pressure	pounds per square inch (psi)	6895	pascals (Pa)
	pounds per square foot (psf)	47.88	pascals (Pa)
Stress Intensity	kips per square inch square root inch (ksi $\sqrt{in}$)	1.0988	mega pascals $\sqrt{metre}$ (MPa $\sqrt{m}$)
	pounds per square inch square root inch (psi $\sqrt{in}$)	1.0988	kilo pascals $\sqrt{metre}$ (KPa $\sqrt{m}$)
Plane Angle	degrees (°)	0.0175	radians (rad)
Temperature	degrees fahrenheit (F)	$\frac{tF - 32}{1.8} = tC$	degrees celsius (°C)

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INTRODUCTION

Laboratory test methods can be used to predict the relative in-service performance of fabric interlayers in AC pavement overlays as well as the amount of asphalt tack coat to be used with each fabric type.

This report describes:

1) basic causes of AC overlay cracking
2) popular theories regarding fabric interlayer mechanisms pertaining to overlay cracking
3) earlier research efforts to predict interlayer effectiveness using laboratory tests
4) measurement of physical/mechanical properties of twelve commercially-produced fabrics
5) laboratory testing of AC specimens to investigate the effectiveness of fabric interlayers in thwarting the common causes of overlay reflection cracking
6) attempted correlations between fabric physical/mechanical properties and their performance in the above tests.

Findings are summarized in the CONCLUSIONS section.

A supplemental study, funded through this FHWA research project, was conducted by the University of California at Berkeley under the direction of Prof. Carl Monismith. An interim report on that study, published under separate cover, contains the results of a finite element analysis of fabric interlayer effects on AC overlays of PCC pavement. A summary and discussion of that report are also included herein as Appendix A.

CONCLUSIONS AND IMPLEMENTATIONS

°Estimating Tack Coat Requirements

(1) The tack coat application rate required by a paving fabric can be estimated if fabric thickness and weight are known, or by using a simple motor oil retention test.

(2) Saturation of the fabric by the asphalt tack coat requires heat and pressure.

°Flexural Fatigue

(1) In closely controlled fatigue testing of AC specimens, the random error associated with aggregate position and orientation may be sufficient to mask fabric-related differences in fatigue life.

(2) Paving fabrics do not appear to reduce the initial deflection of AC beams in laboratory testing. This suggests that a fabric interlayer is not a significant tensile reinforcing element in an AC pavement.

(3) Fatigue crack growth through the AC beam specimens did not appear to be delayed at fabric interlayers.

(4) Although fabrics improved fatigue performance in the majority of tests, no correlation could be made between performance and fabric physical and mechanical properties.

°Interlayer Shear Strength

(1) The shear strength of interlayers involving nonwoven fabrics is maximum in the 0° to +20°F range and virtually zero above 100°F.

(2) Fabric interlayers reduced the horizontal shear strength of the AC by approximately 50% at any test temperature.

(3) Membrane interlayers having a rubber-asphalt backing (Bituthene, Polyguard) do not weaken in shear by embrittlement at low temperatures (down to -20°F).

(4) Interlayer shear strength could not be correlated to fabric weight or thickness.

°Interlayer Permeability

(1) Fabric/asphalt interlayers can provide drastic reductions in the water permeability of AC.

(2) An asphalt interlayer without fabric (i.e., tack coat only) also provides a drastic reduction in the water permeability of AC.

(3) Punch-through of the fabric by sharp-edged aggregate does not lead to increased water permeability. Apparently the asphalt tack coat provides a sealing effect.

(4) No correlation was observed between a fabric's water permeability (as an AC interlayer) and its physical/mechanical properties.

°Differential Vertical Movement (Δ-vert)

No conclusions; testing was aborted.

°Fabric Heat Resistance

Polypropylene and polyester fabrics do not appear to shrink or suffer other adverse effects from being in contact with hot (325°F) AC mixes.

IMPLEMENTATION

The information derived from this research study has been or will be implemented as follows:

a) revisions to Caltrans Standard Special Provision 39.20, "Pavement Reinforcing Fabric"

b) establishment of guidelines for inspection and quality control in paving fabric installation

c) recommendation of appropriate tack coat for each brand of paving fabric

d) determination or verification of general theories pertaining to paving fabric benefits

BACKGROUND INFORMATION

A. General

The "reflection" of cracks from old distressed pavement through relatively new AC overlays is significantly decreasing the service life of these overlays. Numerous fabric materials, primarily polyesters and polypropylenes, as well as rubber-asphalt combinations, are being proposed as interlayers to retard this reflection cracking, but no laboratory procedures have been developed to evaluate the validity of these claims. Simple laboratory tests are therefore needed to:

1) analyze the mechanisms by which reflection cracking occurs
2) estimate the benefits of using various interlayers
3) define which interlayer properties correlate to crack retardation
4) avoid the extensive cost and delay that are associated with full-scale field testing of inappropriate materials.

Reflection cracking is the propagation of cracks from an existing surface of portland cement concrete (PCC) or asphalt concrete (AC) through the resurfacing layer. The problem is a serious one. Many different remedies have been tried over the years (with varying degrees of success) to eliminate or deter such cracking. Reflection cracking develops from movement of the pavement under the overlay (Figure 1). It can be caused by several mechanisms such as:

1. differential vertical movement at a crack or slab joint in the old pavement, which induces a vertical shear stress in the overlay

2. horizontal movement associated with temperature or moisture changes in the old pavement, which induces tensile stress in the overlay

3. live load flexural stress in the overlay which tends to concentrate directly over discontinuities.

Originally, reflection cracking was described as cracking which propagated through an AC overlay placed over old PCC pavement. Reflection cracking, however, can be just as serious a problem on flexible pavements where an AC overlay is placed on old cracked AC pavement, on a cracked cement treated base, or on a cracked bituminous treated base.

Studies as early as 1932 indicated that thick asphalt concrete retards the development of reflection cracking(1). This has been verified many times. While successful, this solution is costly and often violates vertical controls such as overhead structures, guard rails, gutters, etc. Some of the other materials and methods tried over the years to prevent or retard reflection cracking are as follows:

1. expanded metal reinforcement
2. wire mesh reinforcement
3. aluminum foil
4. wax paper
5. stone dust

6. cushion courses
7. asphalt rejuvenating agents
8. heater remix process
9. asphalt emulsion slurry seal
10. rubberized asphalt cement
11. rubberized seal coats
12. hand-poured filling of cracks prior to overlay placement
13. polypropylene, nylon and polyester fabrics.

The success of fabric in reducing reflection cracking has induced several manufacturers to market paving fabric materials. The increasing number of paving fabrics and other approaches and claims of superiority over competitors have generated the need for a laboratory evaluation procedure to reduce the cost and delay associated with full-scale field test sections.

Since the advent of paving with fabric interlayers in the early 70's, many claims have been made about the benefits and problems that might be expected from this relatively new and unconventional paving technique. There were claims of fabric being nothing short of a "cure all" for all types of overlay cracking and many began assigning a structural equivalency (in terms of AC thickness) to fabric for all applications. This, of course, meant that thinner overlays could be used, resulting in added benefits where vertical controls existed. Over the years and as the result of many field test sections, however, it has become apparent that the use of fabric interlayers in AC overlays is not always cost-effective.

To better understand what role fabric might play in AC overlay performance, a brief discussion of the mechanics of overlay cracking and the popular theories of how fabric might work is presented below.

B. Overlay Cracking Mechanisms

Reflection cracking of AC overlays has several primary causes, as discussed below and depicted in Figure 1:

1. Flexural fatigue is caused by high wheel load deflections which tend to be concentrated at localized structural inadequacies and at joints and cracks in an underlying pavement structure. This situation is often aggravated by water which has entered the structural section, possibly through the deteriorated overlay structure.

2. Thermal strains that develop in the old pavement, especially PCC slabs, during seasonal or diurnal temperature cycles can be transmitted to the overlay if the interlayer bond is strong enough. The resulting overlay stresses are a combination of axial tension and bending caused by upward "curl" in the underlying slab-ends at joints or cracks.

3. Differential vertical movement (Δ-vert) at discontinuities (such as joints or cracks) in the underlying pavement can occur to various degrees under heavy wheel loads, especially when the underlying pavement is curled.

C. Fabric Theory

Several theories have been advanced that support the claim of fabrics' ability to deter reflection cracking. These theories are discussed below and depicted in Figure 2.

1. Stress Relieving Interlayer Theory

This hypothesis suggests that the fabric simply acts as a containment reservoir for the heavy asphalt tack coat and thereby provides a soft, ductile zone that has a blunting effect on an advancing crack tip. The stresses concentrated at the crack's tip are thereby dissipated and the crack's advance is halted. Cracking may still occur in the overlay at or near this point, however, because severe overlay bending will tend to occur at these weak points and the bending strength (i.e., the flexural fatigue strength) of the overlay may be exceeded.

It appears that this theory of fabric performance applies primarily to low and moderate levels of flexural fatigue that exist in an AC overlay immediately above the crack in an old, but relatively stiff, pavement.

2. Slip Plane Theory

This theory holds that an overlay/fabric interlayer system will fail in shear (in the plane of the fabric) prior to transferring any significant amount of stress from the old pavement (underlayer) to the overlay. This hypothesis applys primarily to overlay cracking resulting from tensile stress induced by a cracked or jointed underlayer responding to thermal and/or moisture changes, as in the case of an AC overlay on a PCC pavement.

3. Tensile Reinforcement Theory

This theory holds that the fabric reinforces the AC overlay in a manner not unlike the steel reinforcement in PCC structures. This increased tensile strength results in less cracking no matter what the cause of stress inducement. This theory also suggests that the presence of a fabric in an overlay would tend to reduce deflection to some degree.

4. Waterproofing Theory

It is also commonly believed that fabric makes an overlay less permeable; therefore, base and subase material are not subject to weakening by hydraulic action. This protection results in the overlay being subjected to decreased local deflections and, thereby, less severe flexural fatigue effects.

D. Other Laboratory Research

Prior to this study, the above four theories had been investigated via controlled laboratory testing in a limited fashion, as outlined below.

1. Germann and Lytton(2) of the Texas Transportation Instutute investigated fatigue life of asphalt concrete containing a fabric interlayer in the straight (axial) tensile loading mode. Their study, in effect, dealt with theories 1 and 3 above, and found that beams containing fabric exhibited axial tensile fatigue lives several times those with no fabric. Although they recognized that the fabric's contribution to the AC tensile strength was not sufficient to prevent initial cracking, they did claim that the fabric was beneficial in slowing the rate of crack growth by preventing the crack from opening up to those displacements necessary for crack growth (Table 2).

Also, they reported that the fabrics withstood the strain of crack opening without rupture, an important consideration in the waterproofing theory mentioned above.

2. Perhaps the earliest laboratory flexural testing of AC beams with fabric was done in 1972 by Draper and Gagle(3) of the Phillips Petroleum Company. Although their investigation dealt with the effects of Petromat on flexural yield strength (as opposed to fatigue life), it did disclose marked improvement (300 to 800%) in that property in beams containing Petromat compared to beams with tack coat only.

3. Majidzadeh of Ohio State University(4) has performed research testing with respect to theory 1 above wherein he found that for low stress situations, a fabric interlayer placed at the lower third-point of an AC beam increased its flexural fatigue life by over 1000%. Also, with respect to theory 2, the "rebar" theory, he found that the fabric interlayer was of virtually no value in increasing the fracture toughness of an AC beam specimen, and probably of little value in resisting the high tensile strains associated with thermally induced movements.

4. The Iowa Department of Transportation(5) has attempted some laboratory flexural fatigue testing of sand- asphalt beams with and without various fabric interlayers. Their testing involved four different fabric brands; Petromat, Bidim C-28, TrueTex MG75, and Reepav T-323. They found that the fatigue life of beams with fabric was from two to four times that of control beams without fabric.

5. Another laboratory effort in the area of fabric interlayer effects on the flexural fatigue lives of AC

beams (1/2" max aggregate) was undertaken by the E.I. DuPont Co.(6), producers of Reepav fabric. Their study, in addition to Reepav, involved Petromat and Bidim. This testing showed that the fatigue life of beams with fabric was 2 to 22 times that of beams without fabric (Table 4).

6. Concerning theory 4 above, a limited amount of permeability testing of cores from AC/fabric overlays of AC was performed by Bushey(7) of the California Department of Transportation using a vacuum pump arrangement. These early tests showed that a Petromat interlayer could reduce the water permeability of AC. Also observed was the fact that, in the presence of AC cracking, the Petromat fabric did not appear to rupture. This suggested that even after the overlay has cracked, the fabric can act as a water barrier. However, more recent studies by Caltrans show that at locations of visible cracks in overlays of PCC pavement, fabric can rupture. This is probably due to the fact that the underlying PCC imposes severe, concentrated strain on the overlay and fabric.

Other controlled research in the area of fabric permeability was done by the E.I. DuPont Co.(6). Their testing, which involved subjecting asphalt-saturated fabic specimens to hydrostatic water pressure, showed that 5 test fabrics, with sufficient asphalt saturation, could form an adequate moisture barrier. These results may be of limited significance, however, because no effort was made to simulate the effects of imbedment in an AC pavement structure. They did demonstrate, however, that thin fabrics can provide an impermeable layer using much less asphalt tack coat than thicker fabrics.

RESEARCH TESTING

A. General

Laboratory testing performed as part of this research project involved twelve brands of nonwoven fabric representing ten different manufacturers. These fabrics are listed in Table 4. Also tested were two woven, asphalt-backed membranes, Bituthene and Polyguard. All test specimens of a given fabric brand were cut from a single parent sample which represented one roll of production fabric. In all areas of testing, specimens without any interlayer treatment (control specimens) were also tested.

The varioius test procedures described herein were designed with the primary objective being to reasonably simulate in-service conditions and mimic some critical behavior or failure mechanism inherent in AC overlays. These testing efforts are described below.

B. Fabric Property Measurements

Measurements of physical properties of all test fabrics were made by the TransLab Commodities Unit. A total of eight fabric properties were measured and the results are presented in Table 4. For reference, a copy of Caltrans Standard Special Provision SSP 39.20, "Pavement Reinforcing Fabric," is included as Appendix B.

Although most of these fabric property tests are explained via their ASTM Test method reference, it is felt that the "initial modulus" and "secant modulus" properties should be explained further. Moduli, as used in this report, are simply the "slope" of the stress versus strain plot for tensile loading of a 3 in. x 5 in. fabric specimen using 3 in. wide grips and a 1 in. gauge length. (This "slope" value is the ratio of stress (psi) to strain. Stress here is defined as applied load divided by the product of specimen width (3 in.) and thickness.) Initial modulus was defined as the average of the moduli determined at 10% and 20% strain. Secant modulus was determined at the point of 50% strain. Since the 3 in. x 5 in. specimens in this study used a gauge length (grip separation) of 1 in., the secant modulus was simply the stress (psi) at 0.5 in. elongation divided by 0.50. The values presented in Table 1 are the average of three tests at a loading rate of 12 in./min.

The use of 3 in. wide grips with only a 1 in. separation provided a relatively high aspect ratio (specimen width to specimen length) of 3.0. Supplemental tests described in the Appendix involved an aspect ratio of 4.0. High aspect ratio tests are generally believed to better simulate the conditions of lateral restraint that a paving fabric interlayer is subject to in service. The "necking" and "roping" of fabric that is allowed to occur in conventional (low aspect ratio) "grab" tensile testing (ASTM-D1682) can significantly influence tensile behavior and resulting values of modulus and Poisson's ratio.

It should be noted that in some cases there was confusion as to which was the "cross" and which was the "machine" direction on certain of the test fabrics, so that the reported test directions (Table 4) may be in error.

C. Estimating Tack Coat Requirements

1. General

In order for an overlay/interlayer system to be successful, adequate bond must be developed between the overlay AC and interlayer(s) and between the overlay and the existing pavement or underlayer. In the case of a fabric interlayer, proper bonding depends on the tack coat penetrating the fabric from its underside and providing sufficient excess on the fabric's top surface to effect proper bonding with the next lift of overlay material. In order for this situation to be realized, three things must occur:

(1) The tack coat must be made liquid (melted) enough to enable it to invade the fabric.

(2) The tack coat must stay liquid long enough to migrate through the fabric.

(3) Compressive pressure must be applied to the system while the tack asphalt is still liquid to provide a "sponging" effect on the fabric.

For the above to occur, it is apparent that inputs of heat and pressure are necessary.

The heat must be provided by the overlay mix, adjusted, of course, for the overlay thickness, the temperature of the underlayer, and the air temperature and wind speed during paving. (It is not realistic to consider the initial temperature of the tack coat in estimating heat input requirements because these thin tack coats cool to equilibrium with the underlying surface temperature within a few minutes of placement(8).)

The required pressure will be supplied by the dead weight of the overlay and the compactive effort on the overlay. The need for pressure in addition to heat was substantiated by field observation, which involved digging to expose the fabric after initial spreading and after each roller pass. Using this method, it was seen that fabric saturation almost always occurred subsequent to rolling action.

The target condition is saturation-with-slight excess. Undersaturation can result in reduced overlay bond and even a permeable interlayer. Too much asphalt tack, on the other hand, can create a slippage plane or lead to flushing through the overlay.

2. Testing Discussion

In designing a routine laboratory test for a fabric's asphalt saturation potential, it is prudent to simulate the probable "worst-case" field conditions, namely:

1. low temperature of existing pavement .. 40°F
2. thin overlay .... 0.10 ft
3. a relatively cool overlay mix .... 250°F
4. minimal rolling effort .... 3 passes of a 12-ton roller
5. heat availability/dwell time .... 5 min

These test parameters simulate a field overlay situation where fabric is placed during 40°F weather, with only 0.1 ft. of 250°F dense-graded asphalt concrete (DGAC) as an overlay. The "dwell" time that the fabric is given to reach saturation (5 minutes) is based on the fact that 1 inch of DGAC @ 250°F can cool to 150°F in 5 minutes. The 150°F temperature was considered to be the lowest temperature at which AR-4000 paving asphalt is liquid enough to migrate through fabric.

The details of this method, hereafter referred to as the "Melt-thru Test", are described below and depicted in Figure 3.

In the Melt-thru Test, the existing pavement (underlayer) is represented by a 1-foot square x 2-inch thick DGAC base block cooled at 40°F for 2 hours.

This base block is covered with aluminum foil for cleanliness and uniformity of testing. Because this foil prohibits any of the tack coat asphalt from infiltrating the surface irregularities of the base block, an adjustment (discussed later) must be included in the recommended tack coat rate determined by this method.

Onto one quadrant of the base block is placed an asphalt "cookie" (foil-backed) which provides a candidate tack coat rate (gal/yd^2) appropriate for the fabric being studied. Over this is placed a 5-inch square of the test fabric and a 5-inch square of aluminum foil for separation. A 250°F, 4-inch diameter DGAC briquette contained by a 250°F steel collar is now placed atop this foil centered on the asphalt "cookie" beneath the fabric.

The briquette is left in place for 5 minutes during which a 1500-lb. compressive load is applied three times, at the one, two and three minute marks. These 1500-lb. loads are intended to simulate pressure produced by a 12-ton steel roller, and are, therefore, applied and removed within a 5-second period.

After removing the AC briquette and the aluminum foil separator, the fabric is visually inspected for degree of saturation. The target condition is one of total blackening of the fabric by the asphalt cookie, with a slight amount of excess asphalt evident on the fabric's top side.

Testing of the paving fabrics in this study involved performing a series of "melt-thru" tests using four different asphalt tack coat rates. These four tests were performed in rapid succession in quadrants of the 40°F AC base block without refrigerating the block between tests. If additional tests were required, the block was again refrigerated at 40°F for a minimum of 1 hour.

Enough different tack coat rates were tested to disclose the laboratory minimum rate (LMR) at which the desired saturation-with-slight-excess condition was realized. Based on laboratory tests and field observations, the LMR value was increased 0.05 gal/yd^2 to account for the amount of tack asphalt typically "lost" into a leveling course of new AC. This adjusted value is the "recommended tack coat" or RTC. RTC's for the fabric's tested are found in Table 5.

An investigation was made into correlations that might exist between the RTC and various fabric properties. It was hypothesized that the tack coat demand of a fabric would depend largely on two fabric properties, weight and thickness. After unsuccessful attempts to establish meaningful correlation with either of these properties individually, a reasonably valid (r^2=0.8857) correlation was observed to exist with their product (weight x thickness). This relationship is shown below in Equation (1) and in Figure 4.

$$RTC = 0.05\ T \cdot W^{0.30} \qquad (1)$$

Where: RTC = recommended tack coat rate (gal/yd^2)
T = fabric thickness (mils)
W = fabric weight (oz/yd^2)

Values calculated from fabric weight and thickness using Eq. (1) should be considered estimates, and these estimates rounded to the next higher 0.05 gal/yd^2 to be consistent with the accuracy of field application technique.

3. Other Tests for Estimating Tack Coat Requirements

Recognizing the need for a simpler test than the Melt-thru Test described above, an investigation was made of a test developed earlier by the Texas Department of Transportation(9).

The asphalt retention values obtained using this test correlated well with TransLab RTC determinations (Figure 5). However, the Texas method, although quite simple, was not considered acceptable because it does not simulate field conditions. For example, some fabric samples shrank as much as 50% in their long dimension while in the 285°F oven. This is not comparable to field conditions where the fabric is restrained. Also the Texas test does not consider the role of roller pressure or AC mix weight and heat in accomplishing the saturation. Therefore, it was decided that another equally simple test was needed that would correlate well with RTC values obtained from the Melt-thru Test.

The TransLab Motor Oil Retention Test was developed to meet the above need. In this test, a piece of the fabric is soaked in 20W motor oil @ 70°F for 2 minutes, then removed and placed on an inclined (7.5°) surface. Next, a 3350 gram steel cylinder is rolled down the incline 6 times to remove some of the excess oil on the fabric (Figure 6). No hand pressure is applied during the rolling action. The weight of the oil retained in the fabric is determined and the RTC is estimated using the TransLab correlation shown in Figure 7.

D. Interlayer Permeability

1. General

Failure of AC pavement can often be traced to water damage of the base material. Therefore, placement of a waterproof membrane above the base material will usually increase the longevity of the pavement. Although fabric manufacturers claim their products will create that waterproof membrane necessary to protect base material, little work has been done to measure the water permeability of in-place paving fabrics. This study involved the development of a laboratory test for measuring the permeability of AC containing fabric interlayers and involved measuring and comparing the permeabilities, in AC, of fourteen paving fabrics. Also, measured were the permeabilities of a "tack coat only interlayer" of 0.25 gal/yd^2 asphalt (without fabric) and of "control" specimens (i.e., no interlayer treatment of any kind). Although not yet fully studied, limited permeability testing of pavement cores containing cracks (and fabric) had also been done.

Another aspect of this study involved determining if AC aggregate "punches" through the fabric interlayer during compaction and if such "punch-thru" necessarily leads to higher permeability.

2. Testing Discussion

In order to make the permeability information obtained in these lababortory tests applicable to field conditions, the specimen was made to model an AC pavement containing fabric. This model was a 4-inch diameter DGAC (Type A, 3/4 in. maximum aggregate, 5.3% AR-4000 asphalt binder) briquette 2 inches in height with fabric at mid depth (see Figure 8).

A water permeability test apparatus (Figure 9) developed by Chevron was selected for simplicity after trying other less realistic methods involving waxed briquettes and vacuum pumps. An attempt to seal the sides of the briquette with paraffin wax and draw water through the briquette using a vacuum pump was unsuccessful because the water pressure induced by the small head of water above the briquette broke the seal between wax and briquette.

The Chevron permeability apparatus utilizes of a 4-inch diameter aluminum dome that directs water to the top surface of the briquette and a rubber diaphram that is forced tightly against the sides of the briquette by air pressure. The diaphram alone was not effective in preventing the side flow of water so a coat of AR-4000 asphalt was painted on the sides of the briquette and an elastic adhesive tape was used to prevent leakage at the aluminum dome-to-briquette interface. This apparatus can be used to test either 4-inch diameter laboratory briquettes, or 4-inch diameter pavement cores.

A falling-head permeability test was run with an initial head of 8 inches. Milliliters of flow were noted after 5, 10, 30 and 60 minutes. Aerosol was used in the water as a wetting agent at a ratio of 95 ml to 5 gallons of water. This minimized water surface tension as it passed through the briquette.

At the end of the one-hour test, the taped briquette and dome arrangement was removed from the permeability apparatus and checked for evidence of side leakage. Extremely small leaks along the tape that did not contribute significantly to total flow were considered tolerable, as such leaks were assumed to be eliminated when placed in the test apparatus. This test was repeated at least twice per specimen, each time retaping the dome-to- briquette joint. All values are reported in Table 6.

Next, the briquettes were softened in a 140°F oven to allow removal of the fabric. The fabric was checked for aggregate punch-through and asphalt saturation. To allow a fabric-to-fabric comparison of the amount of punch-through and/or degree of tack saturation, a system was developed for rating the retrieved fabrics. This system involved visual estimation of the amount of light that passed through the fabric. The rating scale ranged from "0", which would represent very little or no light passing through the fabric and would be the best case, to "5", which would indicate a large amount of light passing through the fabric (worst case). Results of the visual fabric condition rating, after testing, can be found in Table 7.

Correlation between the light transmission and the measured permeability was then investigated based on the assumption that those fabrics exhibiting greater light transmission (aggregate punch-through) would yield higher permeability values, but no such correlation was observed. Small discrete holes, apparently made by sharp edges of aggregate, were noticed on some fabrics, but these fabrics did not necessarily exhibit high permeability. This suggests that the openings within the fabric are plugged or otherwise blocked (at least partially) when the fabric is tightly sandwiched in the AC test specimen, and that aggregate punch-through probably is <u>not</u> a major contributor to high permeability.

An investigation was also made into possible correlations between laboratory- measured permeabilities and the following fabric properties:

(1) thickness

(2) grab tensile strength in weaker direction

(3) secant modulus at 50% strain

No acceptable correlation(s) was found to exist.

The apparent randomness of the permeabilities suggests that leakage may have occurred along the sides of the specimen due to incomplete sealing of the rubber membrane with the side of the specimen. However, precautions were taken to prevent this, and each specimen was closely inspected both during and after testing so that the researchers feel confident that the values reported represent only the actual flow through the specimen voids.

Even though no explanation is offered, it should be noted that the following fabrics consistantly provided very low interlayer permeability:

Reepav T376
Bituthene
Duraglass B-65.

Although some interlayers performed better than others, it should be noted that all interlayer treatments provided a significant reduction in permeability. Even those specimens with only the heavy tack coat interlayer (no fabric) generally exhibited very low permeability. This suggests that the primary role of the fabric (from the standpoint of permeability) may be to distribute and secure the tack asphalt as a continuous, uniform membrane within the AC mat.

A limited amount of permeability testing was also conducted using cores removed from cracked AC overlays of both original AC and PCC pavements.

In the case of AC over AC, it was observed that even after cracking occurs, the fabric remains intact and continues to provide waterproofing.

In the case of an AC overlay on PCC pavement, however, it was concluded that once a crack becomes visible, the fabric interlayer has usually ruptured, with loss of the waterproofing effect.

E. Flexural Fatigue

1. General

Overlay cracking due to flexural fatigue is often reflective in nature because high localized deflection (flexure) and attendant stresses tend to occur above points of discontinuity in the underlying pavement. Thus, a laboratory test was developed to simulate this condition and evaluate the effects of interlayers on overlay flexural reflective cracking.

Because of the severe stress-concentrating effect of a joint or crack in an underlying pavement, flexural fatigue reflection cracking can occur with the repeated application of normal truck loads.

To simulate the action of a rolling wheel load, a pneumatic flex-fatigue machine (Figure 10) was designed and built at TransLab to subject an AC beam specimen (Figure 11) to a realistically critical degree of bending. This machine simulates a rolling wheel load by applying the load via a series of four loading feet that "walk" across the beam in sequence (Figure 12).

At the same time that the flexural load is being applied, the beam specimen is subjected to an axial tensile load to simulate thermal induced stress and create a realistic combined stress condition that should assure crack advancement through the entire beam cross section. The support for the beam specimen consists of a simply-supported aluminum T-beam. The top of this beam is covered with a 1/4-in. thick rubber pad which allows Δ-vert movement in the specimen between loading feet.

2. Beam Specimens

The beam specimen consisted of a top and bottom layer, each 1 1/2 in. thick (Figure 11) separated by the fabric interlayer where called for.

The specimen was fabricated in an "inverted" fashion. First, the beam top half was kneading compacted into a 3 3/8 in. deep steel mold.

In an effort to simulate an age-hardened AC mix, the top half was made using a Chemcrete binder, otherwise, it was the same as the bottom half. Chemcrete was chosen for use after investigating it, Gilsabind, and air-blown roofing asphalt for hardening characteristics. Chemcrete was found to provide a binder hardness closest to that of an aged California AC pavement. The Chemcrete AC top half was kneading compacted into the mold at 230°F and leveled using a static load on a 12 in. x 3 in. steel plate. The specimen was then "cured" in the mold in a 230°F oven for 7 days to provide the hardening of the Chemcrete binder (per the hardening study).

Next, a film of AR-4000 of uniform thickness was placed in the mold on the compacted surface of the Chemcrete AC. This film was equivalent to the RTC (gal/yd^2) for the fabric to be tested. Then, the fabric was applied to the middle 6 in. of the specimen and 6-in. tensile pulling "ears" of high modulus fabric were applied so as to imbed 3 in. in each end of the specimen. Finally, the beam's bottom half was kneading compacted into the mold at 230°F and leveled by static loading.

In order to provide a level base for fatigue testing, the remaining volume in the mold was filled with plaster and leveled using thick plate glass.

A 1/4 in. wide saw cut was then made in the beam specimen's bottom half to a depth that left a remaining thickness of 1 3/4 in. This saw cut simulated a crack in an underlying pavement and was positioned between the middle two loading feet. This arrangement permitted Δ-vert movement and vertical shear stress development in the remaining beam cross section. It is felt that the use of a loading scheme that allowed this vertical shear stress development, in conjunction with flexural and axial tensile stresses, was a big step toward realism in laboratory fatigue testing of AC.

The flexural fatigue testing consisted of two phases. Phase I utitlized beam specimens whose top halves had the same aggregate gradation as the bottom halves, i.e., 1/2 in. maximum "medium" gradation (per 1981 Caltrans Standard Specifications). For reasons described later, a Phase II study was conducted using beams whose top halves contained only crushed material passing the No. 4 sieve. Graded Ottawa sand, No. 16 x No. 100, was tried first, but exhibited cohesion problems during fatigue testing. The gradation of the crushed aggregate ultimately used was as follows:

Sieve Size	% Passing
No. 4	100
No. 8	85
No. 16	62
No. 30	45
No. 50	33
No. 100	23
No. 200	16

3. Test Procedure

The force exerted by the loading feet on the beam was chosen to produce a maximum radius of curvature in the beam of approximately 125 feet. Early work by Dehlen(10) had found this to be a critical degree of curvature beyond which cracking could be expected in 1 in. to 2 in. thick AC pavement. This degree of bending also accelerated the testing time per beam and enabled the completion of a test during an 8-hour work shift. (This loading foot force, approximately 450 lb, is produced from a machine control setting of 70 psig.)

It should be noted that the load duration of each of the feet "overlapped" to produce the desired beam curvature through an additive effect. Because the applied load was held constant, this type of testing could be termed "controlled stress" testing. It should be noted, however, that deflective response (bending strain) varied from beam-to-beam.

Degree of curvature in the beam specimen was measured and recorded each time crack length was measured. The device used for measuring curvature is shown in Figure 13. The load cycling frequency was 12 cycles/min. as shown graphically in Figure 14.

The axial <u>tensile</u> load applied to the beam specimen during the fatigue loading was 35 pounds resulting from a machine setting of 5 psig. The intent in selecting this magnitude of the tensile load was to use a low range load that would insure elimination of any top fiber compressive stress in the beam and promote cracking through the full width and depth of the beam top half.

Throughout each beam test, continuous autographic plots of flexural and axial loads versus time were complied. Each specimen's plot provided a complete record of its loading history.

Crack length measurements were made on the front and back faces of the specimen at regular intervals of 200-400 cycles using a divider and an engineer's scale. The average of these two values was used in all analyses. Visibility of the crack was enhanced by coating both faces of the specimen with white spackling compound. The test was considered finished when the crack reached the top surface on both faces. All tests were run at room temperature, which varied within a range of 68°F to 74°F.

Three beam specimens were tested for each interlayer treatment. Interlayer treatments tested were limtied to various fabrics (total of 12), and a heavy asphalt tack coat without fabric. Several control specimens (no interlayer treatment) were also tested.

4. Results

Results of the flexural fatigue testing in both Phase I and II are presented and analyzed in two ways:

1) using an unadjusted plot of crack length (c) versus number of loading cycles (N) for the various beam interlayer treatments (Figures 15 and 16), and

2) using a "normalized" plot of beam fatigue performance (N@c=1.0 in.) versus initial deflection level (Figures 17 and 18).

Each of these approaches is discussed below.

<u>c vs N Plots, Phase I</u> (Figure 15)

A plot of c <u>vs</u> N was constructed for each beam tested. Certain tests were considered invalid because the initial deflection responses were too high or too low. The results of these tests were discarded once it was concluded that there was no correlation between initial deflection and interlayer treatment. From the valid tests, an "average" plot of c <u>vs</u> N was constructed for each treatment. These average plots are presented in Figure 15 along with plots representing the range of control (no interlayer) beam performance.

It should be noted that even after discarding the invalid tests, there was still lack of reproducability exhibited among supposedly identical specimens (same interlayer treatment). This could have been caused by three things:

1. variation in test procedure
2. variation in beam top-half mix properties
3. variation in fabric properties.

The test procedure was closely controlled and was not considered a source of testing error. Fabric property variation was also ruled out, as all test fabric of like brand was cut from a single piece of parent fabric.

The second item, beam specimen top-half mix properties, was considered the most likely cause of the inconsistent fatigue performance. Therefore, a normalization study was undertaken wherein the mix properties of several identical beam specimens without interlayers were determined in hope of divulging normalizing factors which could be used to adjust the c vs N curves.

For each of these beam top halves the following AC physical properties were measured. The results are presented in Table 10:

(1) microviscosity of the Chemcrete binder
(2) shear (rate) susceptibility of the Chemcrete binder
(3) three-point bending strength of the mix
(4) percent air voids of the mix.

First, an attempt was made to correlate each of these parameters individually to fatigue performance, defined as the number of loading cycles (N) required to obtain a crack length (c) of 1.0 inch. No acceptable correlations were found. Then an attempt was made, using multiple linear regression analysis, to unravel any interaction of the above beam properties. This analysis also failed to produce any valid correlation between the mix properties and fatigue performance. Because none of these normalizing efforts were successful, it was concluded that the error must be random and could possibly have resulted from differences in aggregate arrangement and orientation.

c vs N Plots, Phase II (Figure 16)

At the start of this project it was considered a top priority to maintain realism in all testing. A conventional (1/2 in. max aggregate) AC mix was therefore used with extreme precaution taken to insure consistency in mix variables and hopefully minimize random error. But because of these Phase I results, it appeared that in order to avoid this error and to enable the isolation of interlayer effects on fatigue life, additional testing would be required using a more homogeneous beam speciman. Therefore, a Phase II fatigue investigation was undertaken involving beams made of a homogeneous sand-asphalt mix. In this study, as in Phase I, a hardened Chemcrete binder was used to simulate aged AC pavement.

The use of a sand-asphalt beam seems a drastic departure from realism, but it was observed in this study that fatigue cracks in the AC beams invariably grew due to cohesive failure of the binder rather than a failure of adhesion between binder and aggregate. This observation suggests that crack growth in the sand-asphalt beams should be similar to crack growth in an AC beam since the crack's medium is the same and only the crack's path will differ.

Because of limited time and funding, the Phase II testing was not extensive. Only 3 of the 12 interlayer treatments were tested along with control beams. Here, as in Phase I, a validity criterion was established in terms of initial deflection response of the beam to the controlled load. This criterion was cause for discarding almost half of the beam test results.

Plots of all valid c vs N curves (Figure 16) discloses two distinct families of beam performance; the beams with interlayers and those without (control beams). The obvious trend indicates superior performance by the control beams.

Fatigue Performance "Normalized" For Initial Deflection Level; Phases I and II (Figures 17 and 18)

This analytical approach attempts to account for the variation in bending strain attendant to constant stress testing, and to provide a normalizing effect with respect to the strain variable.

Pell(11) and Santucci(12) have reported that the number of load repetitions, N, to initiate a fatigue crack is related exponentially to the inverse of the tensile (bending) strain in the AC. This relationship is expressed below.

$$N \propto K\left(\frac{1}{\varepsilon}\right)^n$$

where: N = number of load cycles to failure or other defined point

ε = bending strain

K and n = constants dependent on mix properties.

Based on controlled-stress fatigue tests, n was determined to be between 5 and 6(11). Assuming a value 5 for n* and using the values of ε, initial strain (deflection) of the beam, and N, number of load cycles for a crack length of one-inch, for the control beams of this study allowed the calculation of average K values for Phase I and Phase II. Curves were then constructed which depict the expected fatigue performance of the average control beam for a range of initial beam deflections (Figures 17 and 18).

*Using a value of 6 changes the location of the resulting d_i versus N curve (Figures 17 and 18) only slightly.

Superimposed on these curves are points representing the performance of the test beams containing interlayers. Points lying to the right of the curve represent an improved resistance to fatigue cracking and points to the left indicate a fatigue crack resistance worse than that of the control beams. Because of the generally poor reproducibility of fatigue test results, these plots should be used only in a qualitative manner to divulge gross effects of the interlayer.

In Phase I (Figure 17) the general effect of the interlayer was as follows:

No. of Tests	Effect
23 of 45 (51%)	Interlayer treatment improved fatigue crack resistance.
13 of 45 (29%)	Interlayer treatment reduced fatigue crack resistance.
9 of 45 (20%)	No effect.

In Phase II (Figure 18) the general effect of the interlayer follows:

No. of Tests	Effect
4 of 6 (67%)	Interlayer treatment improved fatigue crack resistance.
1 of 6	Interlayer treatment reduced fatigue crack resistance.
1 of 6	No effect.

Other noteworthy observations are listed below.

- Fatigue performance does not appear to be related to physical properties of the interlayer.

- Interlayers that consistently exhibited improved fatigue performance were:
  1. TrueTex MG100
  2. Bituthene
  3. Tack coat only.

- No interlayer type consistently exhibited worse fatigue performance than the control specimens.

- This testing was performed using a high degree of flexural strain. Fabric interlayers may demonstrate better resistance to fatigue crack growth in situations of less severe strain.

F. Interlayer Shear Strength

1. General

AC overlays placed on a discontinuous existing pavement - especially on PCC slab pavement - will be subjected to tensile stresses induced by long-term and short-term thermal strain in the underlaying pavement(2). Long-term strains are those associated with the slabs' slow thermal (expansion-contraction) response to seasonal change, whereas short-term strains are those resulting from diurnal slab curling cycles (13). Because these two effects vary with time, they can be additive and produce a net stress in an overlay sufficient to cause reflection cracking.

Although one might expect the PCC slab's thermal action to be greatly reduced because of the overlay's insulating effect, this has <u>not</u> been observed in field experiments. Overlays as thick as four inches have resulted in very little reduction in thermal movement of the underlying slabs(4).

However, no matter what the cause of the PCC slab strain, the axial tensile stress associated with this strain can only be induced in the overlay if it is transferred across the overlay/slab interface. A condition of intimate bonding at this interface would theoretically provide the potential for 100% strain transfer. This condition may be realized at low temperatures.

The introduction of material such as an asphalt tack coat and a fabric at this interface creates the potential for a reduced degree of strain transfer, thereby producing a "stress-relieving" effect on the overlay and a reduced potential for cracking. It was one intent of this study to determine if this effect is, in fact, produced, and to what extent the various interlayer (fabric) properties influence this effect. This information could then be used in several ways such as:

1) to determine the relative potential for stress relief provided by various interlayers

2) to assess the relative effects of the various interlayers on an overlay's horizontal shear strength and potential for slippage under wheel loads(14)

3) to indicate the relative potential for overlay debonding (spalling) associated with the various interlayers.

2. Testing Discussion

Two of the 3 in. x 3 in. x 12 in. flexural fatigue AC beam specimens for each interlayer type were cut roughly into quarters, thereby producing eight specimens each approximately 3 in. x 3 in. x 2-3/4 in. All shear tests were done on the apparatus shown in Figure 19 in conjunction with a Baldwin 6000 lb testing machine.

The bottom half of the specimen was clamped securely and shimmed so that no rotational movement could take place. A vertical load was applied to the other (top) half of the specimen so that a shear force was created on the interlayer. No load was applied normal to the shear (interlayer) plane. A plot of head movement vs load was made for each specimen using an X-Y plotter.

The shear test was performed at five temperatures, -20°F, 0°F, 20°F, 60°F and 100°F, at a shear rate of 0.05 in./min. The specimens were held at the desired temperature in an environmental chamber for at least two hours prior to testing. Specimens were removed from the chamber, one at a time, and tested immediately.

The ultimate shear load was recorded and divided by the interlayer cross-sectional shear area to obtain the ultimate shear strength. Shear strength vs temperature was then plotted for each interlayer. Finally, the "average" curve for each interlayer treatment was plotted to facilitate direct comparison (Figure 20).

The following observations were made based upon these test results:

(1) For thin fabrics (DuPont, Petromat), the beam-to-beam difference was minimal, suggesting that 100% "melt-thru" always occurred.

(2) For thick fabrics (MG75, Quline, C-34) the beam-to-beam shear strength difference was higher, suggesting that partial saturation may have occurred, thereby resulting in incomplete bonding and lower horizontal shear strength.

(3) Fabric interlayers reduced the shear strength of the AC by approximately 50% at any test temperature (-20 to +100°F).

(4) Fabric interlayers with a rubberized asphalt backing (Bituthene, Polygard) do not weaken in shear at temperatures down to -20°F.

(5) Shear strength does not appear to be related to weight or thickeness of the fabric (assuming 100% saturation).

(6) Above 100°F, all the fabric interlayers tested had virtually no shear strength.

When attempting to relate these findings to pavement performance, it should be remembered that these tests were run without a load normal to the shear plane.

Although this laboratory investigation showed that fabric interlayers reduced horizontal (interlayer) shear strength, this reduction is apparently not critical, because no "slippage" failures have occurred, under even the heaviest traffic loadings.

G. Differential Vertical Movement

1. General

Differential vertical movement (Δ-vert) at underlayer discontinuities (such as joints or cracks in overlaid PCC pavement) has long been known to be a major cause of reflection cracking in AC overlays(15,16). Therefore, an attempt was made to design a laboratory test in which an "aged" AC specimen could be subjected to a vertical "shear fatigue" mode of loading. Specimens would be tested with and without interlayer treatments in an effort to see what effect, if any, an interlayer has on an overlay's resistance to this type of reflection cracking.

The original intent of this research was threefold:

1) to determine the effect of interlayers on an overlay's ability to withstand Δ-verts of various magnitudes

2) to compare the benefits (if any) of interlayers with the benefits of a thicker, equivalent cost, AC overlay

3) to provide cracked specimens on which permeability tests could be run to assess the effect of Δ-vert-associated cracking on interlayer permeability.

2. Testing Discussion

A testing apparatus was devised (Figure 21) which would subject a 2 in. thick x 4 in. diameter AC briquette (with interlayer) to Δ-vert levels similar to those occurring in PCC pavement under heavy wheel loads. The of steel and rubber spacers were used in an attempt to develop vertical shear stresses in the specimen during loading. A sawcut was made 3/4 in. into the bottom half of the specimen to simulate a cracked underlayer, leaving a remaining shear cross section of 1-1/4 in. x 4 in. The fatigue load was supplied by a Cox & Sons 40,000 lb testing machine at a loading rate of approximately 20,000 lb/min. The load cycling rate was approximately 1 cycle/sec.

Preliminary tests using 2-in. thick AC briquettes of 3/8-in. max aggregate and Chemcrete binder produced erratic, anomalous results, probably due to specimen rocking and compression creep within the AC structure. It appeared that a significant effort would be necessary to debug this simple-appearing test method.

Because of manpower and funding constraints and because of Caltrns' decision of mitigate Δ-vert by routinely breaking-and-seating PCC slabs prior to overlaying, it was decided to eliminate this aspect of the research.

It is felt, however, that this basic concept, when refined and perfected, could provide meaningful information concerning the contribution of Δ-vert to AC overlay cracking, and could help determine optimal overlay strategies in cases where pretreatments such as breaking-and-seating cannot be used (e.g. rehabilitation of reinforced PCC pavement).

If used, the Δ-vert levels in this test should, of course, be consistent with Δ-vert levels actually measured on PCC pavements. (Field measurements have been made by TransLab on many test sections involving PCC pavement.)

H. Fabric Heat Resistance

1. General

Claims have been made that nonwoven fabrics, especially polypropylene fabrics such as Petromat and Fibretex 200, are severly affected by temperatures greater than 300°F. Earlier TransLab tests that involved exposing a polypropylene fabric sample to oven temperatures around 300°F showed the fabric to shrink considerably, embrittle, and even disintegrate in some cases. Similar findings were reported by Texas(17) based upon tests involving immersion of 4"x4" fabric pieces in 300°F asphalt. Oven or asphalt immersion testing, however, do not simulate the true conditions a paving fabric will experience in service. First, "soaking" the fabric specimen in a hot medium provides more severe thermal exposure than would be experienced by a fabric under a hot overlay mix that is rapidly cooling, at least in the immediate area of contact with the fabric. Secondly, in the overlay situation, the fabric quickly becomes saturated with the rapidly cooling asphalt tack coat, which then effectively insulates individual fiber strands from thermal extremes. Finally, the severe shrinkage of the fabric, observed in oven or immersion testing, has not been observed in an overlay structure, probably because the surrounding AC creates a condition of restraint. A simple test was therefore devised in an attempt to better simulate the in-service conditions that a fabric experiences.

2. Testing Discussion

In TransLab's testing, a 6 in. x 6 in. x 2 in. thick block of 325°F DGAC (confined in a wood mold) was placed on a 1-foot square fabric specimen resting on a wooden base block. No tack coat was used because it was felt that in a construction situation the tack coat cools very rapidly (before the fabric is rolled out) and the primary heat source is the AC overlay mat.

A 1500 pound load was then applied to the top of the hot AC block and held for one minute. After five minutes, the AC block was removed and the fabric specimen was visually inspected for changes.

All of the nonwoven fabrics in this study were tested.

Petromat and Fibretex 200, the two polypropylene fabrics tested, showed no visible signs of damage or dimensional change. Some additional fusing of the individual fiber strands appears to be the only sign of change. This could possibly lead to a slight change of tensile strength or secant modulus. The polyester and fiberglass also showed no signs of shrinkage or damage.

Based on these findings and field observations, it was concluded that the claim of polyprophylene degradation as a result of heat exposure is not applicable to pavement overlay situations. Also, heat-induced shrinkage of fabric in situ does not appear to be significant and should not lead to cracking during construction.

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14. Epps, J. A., and Button, J. W., "The Slippage Question on Airport Pavements," Texas Transportation Institute, Interim Report RF 3424-2.

15. Treybig, H. J., et al, "Overlay Design and Reflection Cracking Analysis for Rigid Pavements," Austin Research Engineers, FHWA-RD-77-66, 1977.

16. McGhee, K. H., "Efforts to Reduce Reflective Cracking of Bituminous Concrete Overlays of Portland Cement Concrete Pavements," Virginia Highway and Transportation Council, 1975.

17. Button, J. W., et al, "Laboratory EValuation of Fabrics For Reducing Reflection Cracking," Texas Transportation Institute, January 1983.

Test Number	u Crack Opening (Inches)	Number of Samples Tested	Sample Size (Inches)	N_f Cycles to Failure (Average)	Gradation and Aggregate Type	Asphalt Type and Content (By Wt. of Agg.)	Fabric Type*
1	0.055	5	3x3x15	2155	Dense Graded Based On ASTM D-1663 -5A Standard Using River Gravel	AC - 10 3.8%	1
	0.065	5		975			
	0.075	5		500			
2	0.065	4		765			2
3	0.055	4		1241			3
4	0.055	5		750			No Fabric
	0.065	3		115			
	0.075	4		42			

* 1. a fabric material composed of two fibers: polypropylene and the other is a polypropylene fiber covered with a nylon sheath,

2. a nonwoven polypropylene fabric, and

3. a woven polypropylene fabric.

Table 1. Results of Tensile Fatigue Testing by Texas Transportation Institute (2)

Reinforcement Material	Number of Loading Cycles Until The Crack Is Reflected 100 Percent Through The Specimen		
None	85, 91, 100	Avg.	92
Petromat	322, 325, 325	"	324
Bidim C-28	475, 575, 625	"	558
True Tex MG-75	210, 230, 225	"	222
Reepav T-323	400, 425, 425	"	417

Table 2. Results of Iowa DOT Flexural Fatigue Tests (5)

REINFORCEMENT GEOTEXTILE	AVG. CYCLE LIFE	NUMBER OF SPECIMENS	STANDARD DEVIATION
Control (no fabric)	480	7	50
Petromat®	1,000	4	55
Bidim®	2,300	4	880
REEPAV*			
- Style T-323	8,830	10	1,600
- Style T-362	10,425	5	753
- Test Fabric A	7,650	5	575

*DuPont Trademark

Table 3. Results of DuPont Co.'s Flexural Fatigue Testing (6)

Fabric	Weight (oz/yd^2)	Thickness(a) (mils)	Grab Tensile(b) (lb)		Elongation(b) (%)		Secant Modulus(c) [Initial Modulus](d) (psi)	
			Mach.	Cross	Mach.	Cross	Mach.	Cross
True Tex MG100 (True Temper)	6.5	88	174	114	94	116	896 [592]	414 [530]
Duraglass B-65 (Johns-Manville)	9.8	77	126	116	3	3	tear [10,780]	tear [12,606]
Q-Trans-50 (Quline)	7.0	105	93	142	173	107	350 [80]	160 [210]
Fibretex 200 (Crown-Zellerbach)	6.0	73	183	126	145	175	1025 [908]	368 [273]

Notes: *All values are from TransLab Testing.

(a) ASTM D 461

(b) ASTM D 1117; 1" grip

(c) @ 50% strain, unless tearing occurs

(d) Avg. of moduli @ 10% and 20% strain

Table 4. FABRIC PROPERTIES*

Fabric	Weight (oz/yd^2)	Thickness(a) (mils)	Grab Tensile(b) (lb) Mach.	Grab Tensile(b) (lb) Cross	Elongation(b) (%) Mach.	Elongation(b) (%) Cross	Secant Modulus(c) [Initial Modulus](d) (psi) Mach.	Secant Modulus(c) [Initial Modulus](d) (psi) Cross
Petromat (Phillip Fibers)	4.5	40	81	132	85	74	2294 [1263]	1483 [1784]
Bidim C-22 (Monsanto)	3.2	51	125	98	90	98	1878 [1759]	871 [582]
Bidim C-34 (Monsanto)	9.6	77	178	151	57	73	1939 [1601]	1731 [1601]
True Tex MG75 (True Temper)	6.5	56	170	98	96	97	1936 [1110]	666 [357]

(continued)

Notes: *All values are from TransLab Testing.

(a) ASTM D 461

(b) ASTM D 1117: 1" grip

(c) @ 50% strain, unless tearing occurs
(d) Avg. of moduli @ 10% and 20% strain

Table 4. FABRIC PROPERTIES*

Fabric	Weight (oz/yd ^{2})	Thickness(a) (mils)	Grab Tensile(b) (lb)		Elongation(b) (%)		Secant Modulus(c) [Initial Modulus](d) (psi)	
			Mach.	Cross	Mach.	Cross	Mach.	Cross
Reepav 376 (Dupont)	3.0	14	110	79	63	64	4650 [10,860]	3250 [5140]
Nicofab B50 (Nicolon)	4.9	68	80	133	100	79	1339 [515]	552 [278]
Amoco 4545 (Amoco)	6.6	40	142	147	73	104	1890 [1020]	1480 [1440]
Trevira 1117 (Hoechst)	4.4	51	162	119	82	111	1666 [1280]	810 [540]

(continued)

Notes: *All values are from TransLab Testing.

(a) ASTM D 461

(b) ASTM D 1117; 1" grip

(c) @ 50% strain, unless tearing occurs

(d) Avg. of moduli @ 10% and 20% strain

Table 4. FABRIC PROPERTIES*

Fabric	Lightest tack coat rate found to be acceptable (gal/yd^2)
Amoco 4545	0.30
Bidim C-22	0.25
Bidim C-34	0.35
TrueTex MG75	0.30
TrueTex MG100	0.35
Trevira T1115	0.30
Nicolon 50	0.30
Petromat	0.25
DuPont T376	0.15
Q-Trans-50	0.35
Fibretex 200	0.30

Table 5. Recommend Tack Coat Rates for Various Fabrics on a New AC Leveling Course

Interlayer Type	5 Minutes			10 Minutes		
	Specimen A	Specimen B	Specimen C	Specimen A	Specimen B	Specimen C
Petromat	10, 120	100, 60	180, 140	10, 180	140, 110	240, 220
Bidim C-22	125, 90	∞, ∞, ∞	290, 280, ∞[b]	210, 160	∞, ∞, ∞	350, 380, ∞[b]
Bidim C-34	130, 70	270, 150	100, 100	200, 120	290, 230	140, 175
TrueTex MG75	20, 20	100, 40, 10[b]	70, 45	50, 30	200, 70, 20[b]	100, 80
TrueTex MG100	85, 50	240, 30, 10[b]	100, 30, 40[b]	150, 80	350, 60, 20[b]	150, 60, 70[b]
JM B-65	15, 20	30, 10	20, 0	30, 30	60, 20	30, 0
Quline 50	70, 80	30, 20	100, 55	130, 130	60, 30	150, 110
Fibretex 200	90, 70	5, 0	230, 50, 120[b]	160, 110	25, 5	310, 120, 90[b]

Notes:
a. not tested in this specimen "group"
b. third replicate test where repeatability was poor
c. all values shown are in milliliters of flow

Table 6. Permeability Test Results[c]

Interlayer Type	5 Minutes			10 Minutes		
	Specimen A	Specimen B	Specimen C	Specimen A	Specimen B	Specimen C
DuPont 376	0, 0	0, 0	20, 5	5, 0	5, 0	30, 10
Nicofab B50	100, 50	110, 60	220, 130, 45[b]	170, 90	180, 70	300, 95, 200[b]
Amoco 4545	210, 30, 30[b]	20, 10	255, 70, 180[b]	260, 50, 50[b]	35, 10	320, 135, 290[b]
Trevira 1117	a, a	a, a	100, 220, 130[b]	a, a	a, a	310, 170, 210[b]
Bituthene	0, 0	0, 0	0, 0	0, 0	0, 0	0, 10
Polyguard	0, 0	0, 10	30, 60	5, 0	10, 10	75, 130
Tack coat only	0, 0	120, 150	20, 0	0, 0	190, 260	30, 0
Control	∞, ∞	a, a	∞, ∞	∞, ∞	a, a	∞, ∞

Notes:
a. not tested in this specimen "group"
b. third replicate test where repeatability was poor
c. all values shown are in milliliters of flow

Table 6. Permeability Test Results[c] (continued)

Interlayer Type	Specimen A	Specimen B	Specimen C
Petromat	0.5	2.0	1.0
Bidim C-22	5.0	4.5	5.0
Bidim C-34	5.0	5.0	5.0
TrueTex MG75	0.0	0.5	3.0
TrueTex MG100	0.0	0.0	0.0
Duraglas B65	a	a	1.5
Quline 50	0.5	0.0	3.0
Fibretex 200	5.0	4.5	5.0
DuPont 376	0.5	0.5	1.5
Nicofab B50	0.0	0.5	5.0
Amoco 4545	0.5	0.0	3.0
Trevira	no test	no test	4.5

a.) Fabric was in badly torn condition

b.) 5.0 = maximum light transmission
0.0 = minimum light transmission

Table 7. Light Transmission Rating of Recovered Fabric

Aggregate	Binder	3-Step Kneading Compaction Procedure				Static Compaction	Remarks
		Step	Temp. (°F)	No. of Tamps	Foot Pressure (psi)		
1/2" max medium Type B	5.5% AR4000 with Chemcrete	1	300	150	250	none	°Preheated the steel mold to 235°F
		2	300-	150	350	none	°Oven-Cured the compacted Chemcrete mix for 7 days at 230°F
		3	300-	60*	350	none	
		*onto steel leveling plate					

Table 8. Fabrication Details of Fatigue Beam Specimen (Top Half)

Aggregate	Binder	2-Step Kneading Compaction Procedure				Final Static Compaction	Remarks
		Step	Temp. (°F)	No. of Tamps	Foot Pressure (psi)		
1/2" max medium Type B	5.5% AR4000	1 2	300 300-	150 150	250 350	35,000 lb onto steel	°Preheat mold and bottom half to 140°F before compacting top half
(Pre-batched)*							

*obtained from hot mix plant

Table 9. Fabrication Details of Fatigue Beam Specimen (Bottom Half)

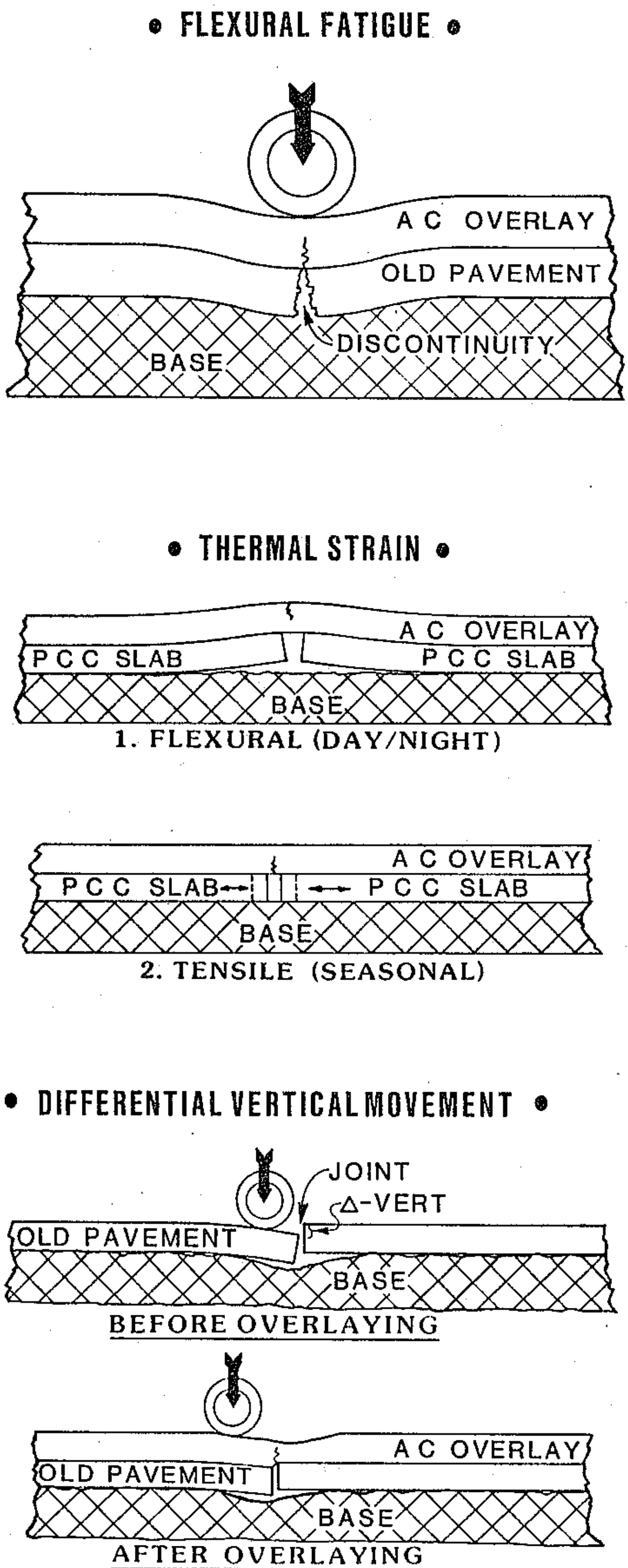
Specimen No.	Interlayer Treatment	Load Cycles @ C=1.0"	Properties of Beam Specimen's Top Half: Micro-Viscosity[a] (MP)	Shear Susceptibility	Bond Strength[b] (psi)	Air Voids[c] (%)
43	None	1500	1020	0.37	940	5
41	"	1100	178	0.30	1022	4
42	"	600	265	0.53	898	5
54	"	1900	670	0.32	980	4
61	"	2000	186	0.32	850	4
38	"	1300	1580	0.21	786	5
69	"	600	225	0.34	841	4
50	"	1400	1080	0.33	844	4
78	TrueTex(MG75)	1900	680	0.42	1005	6
79	"	4100	900	0.23	862	4
80	"	600	920	0.32	944	6

a. Calif. Test Method 348

b. AASHTO Test T177-68 (1978)

c. Calif. Test Method 367

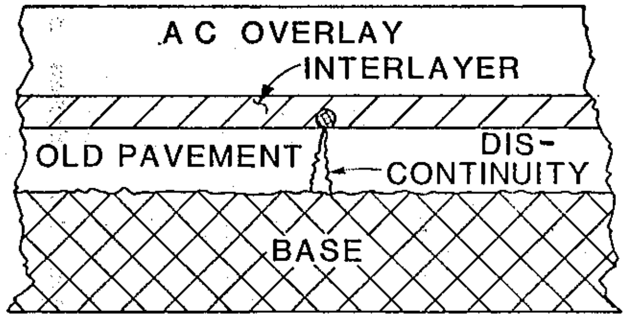
Table 10. Data Used in Normalization Effort



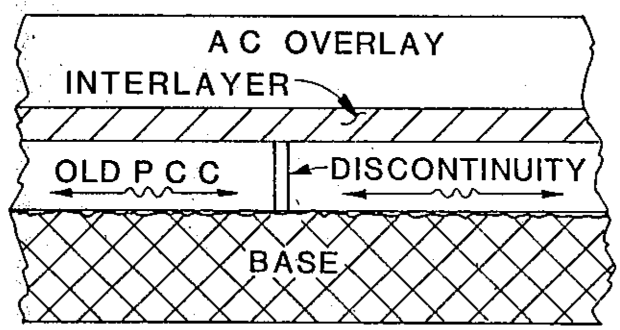
REFLECTION CRACKING MECHANISMS

FIGURE 1

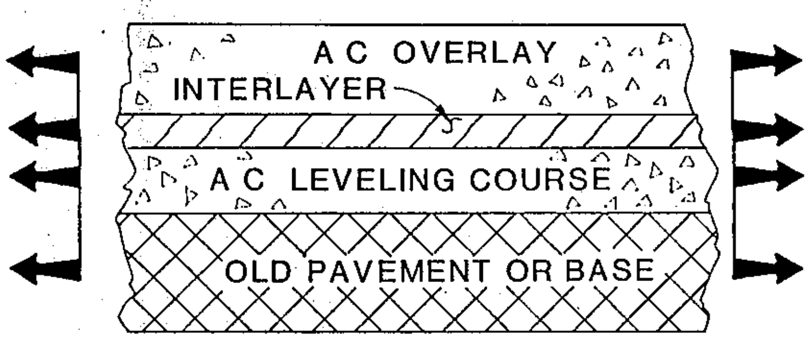
1. STRESS RELIEVING INTERLAYER THEORY



2. SLIP - PLANE THEORY

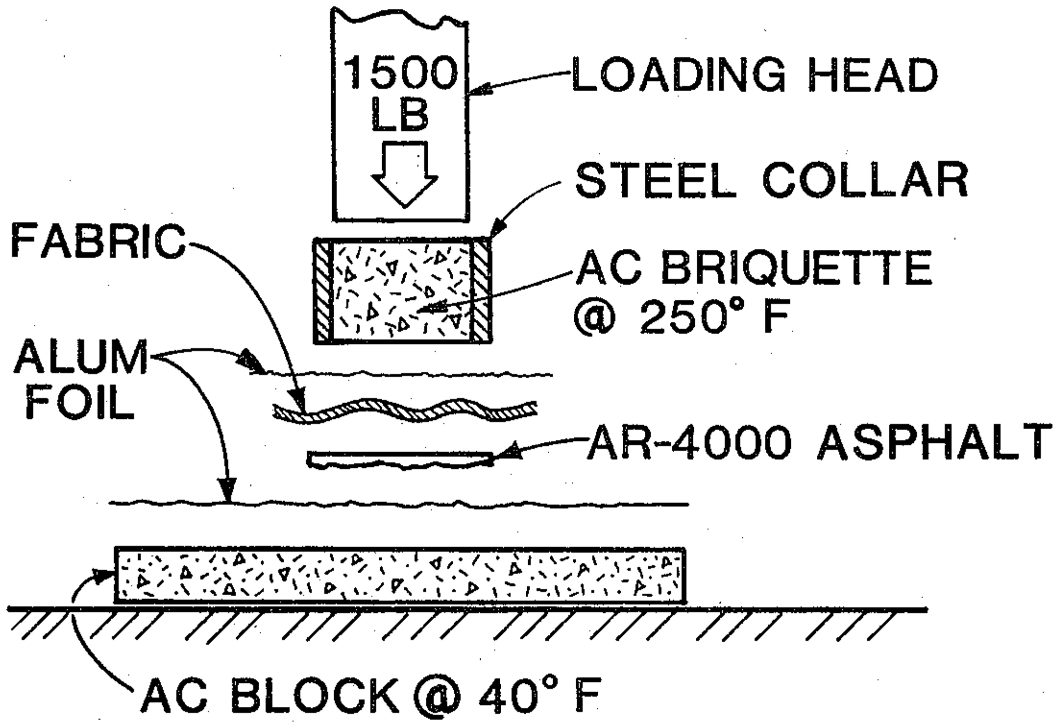


3. TENSILE REINFORCEMENT THEORY



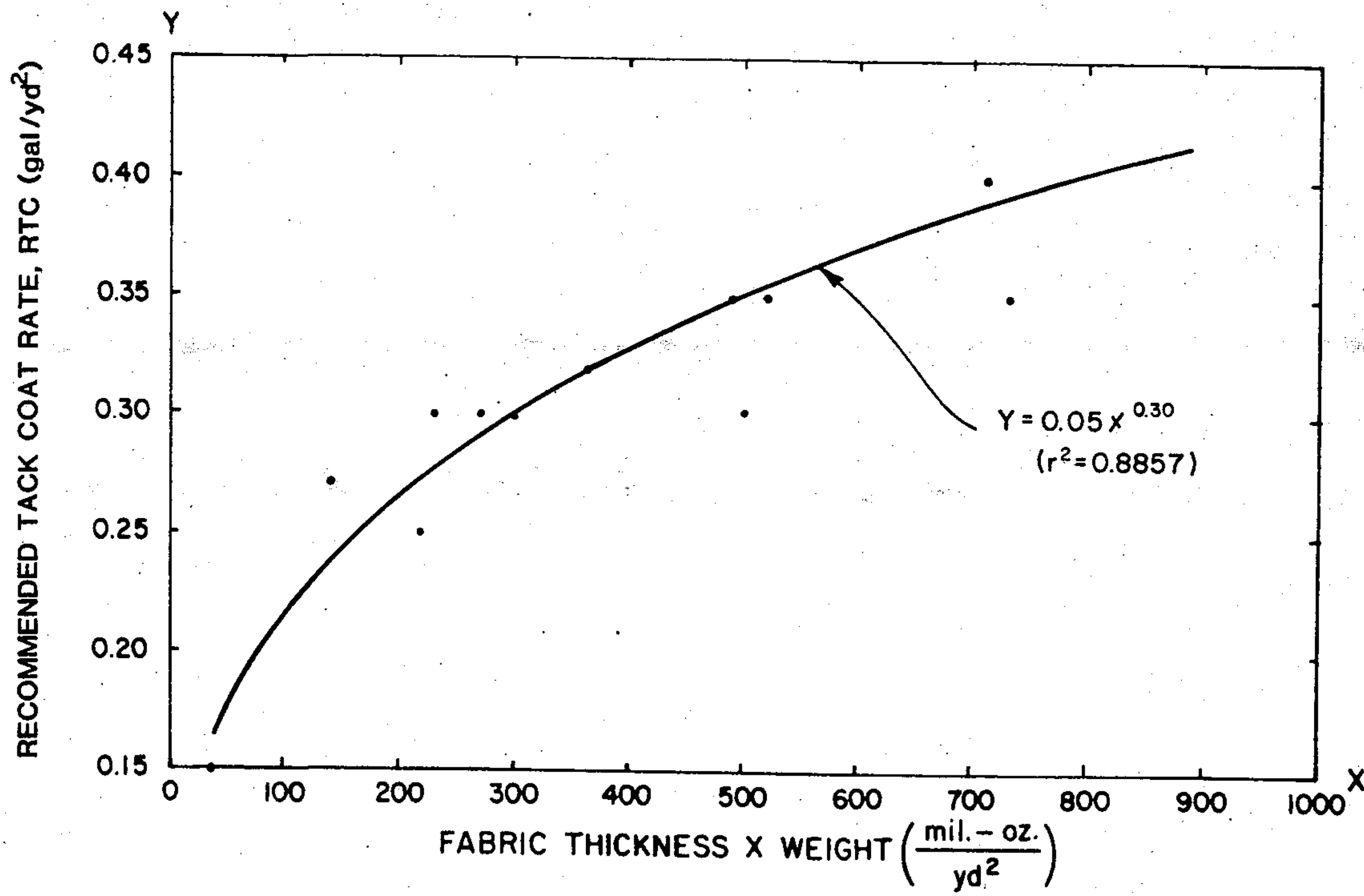
FABRIC THEORIES

FIGURE 2



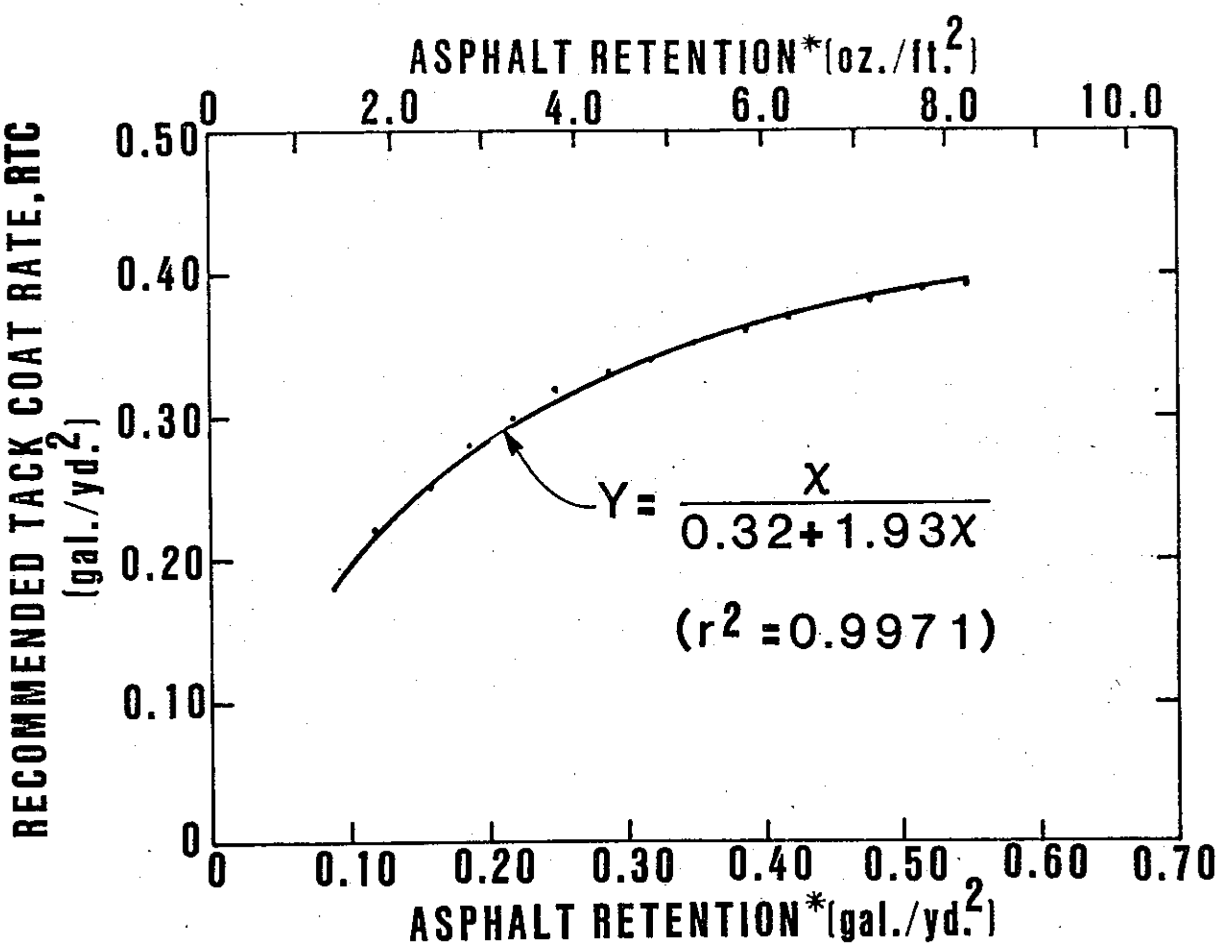
OPTIMUM TACK RATE DETERMINATION
(MELT–THRU TEST)

FIGURE 3



RECOMMENDED TACK COAT RATE vs FABRIC WEIGHT x THICKNESS

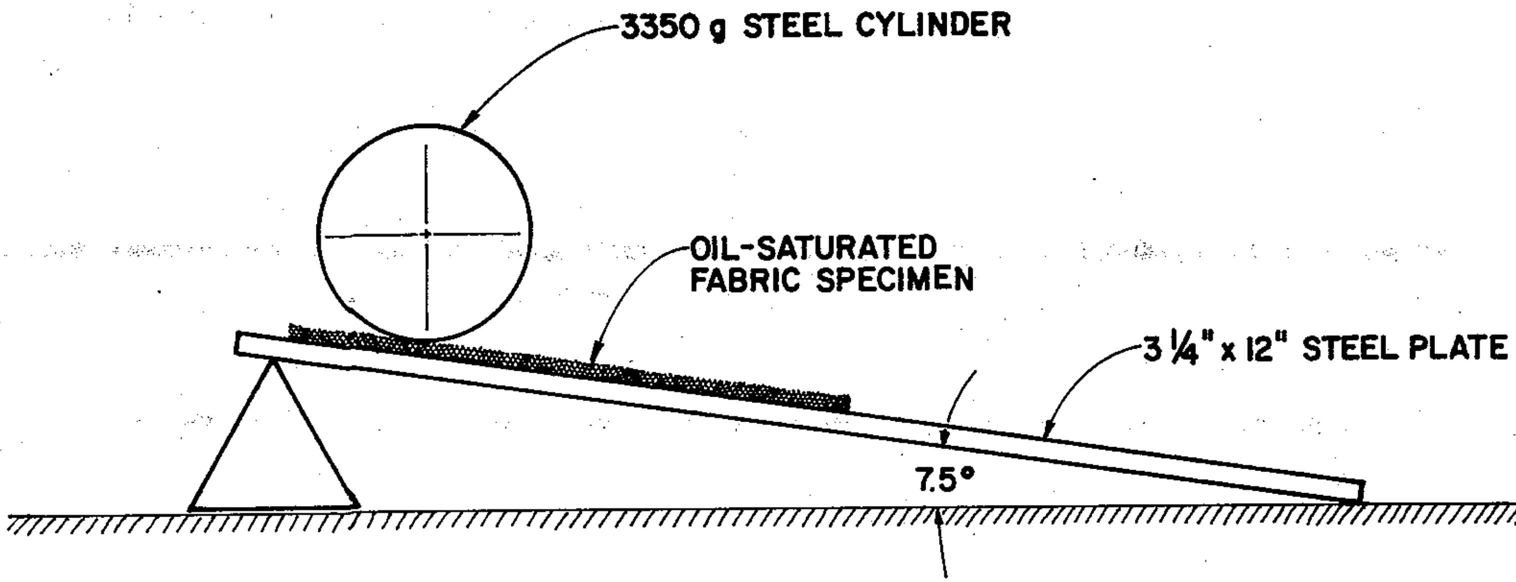
FIGURE 4



*VIA TEXAS DOT METHOD

RECOMMENDED TACK COAT RATE <u>vs</u> ASPHALT RETENTION*

FIGURE 5



MOTOR OIL RETENTION TEST SETUP

FIGURE 6

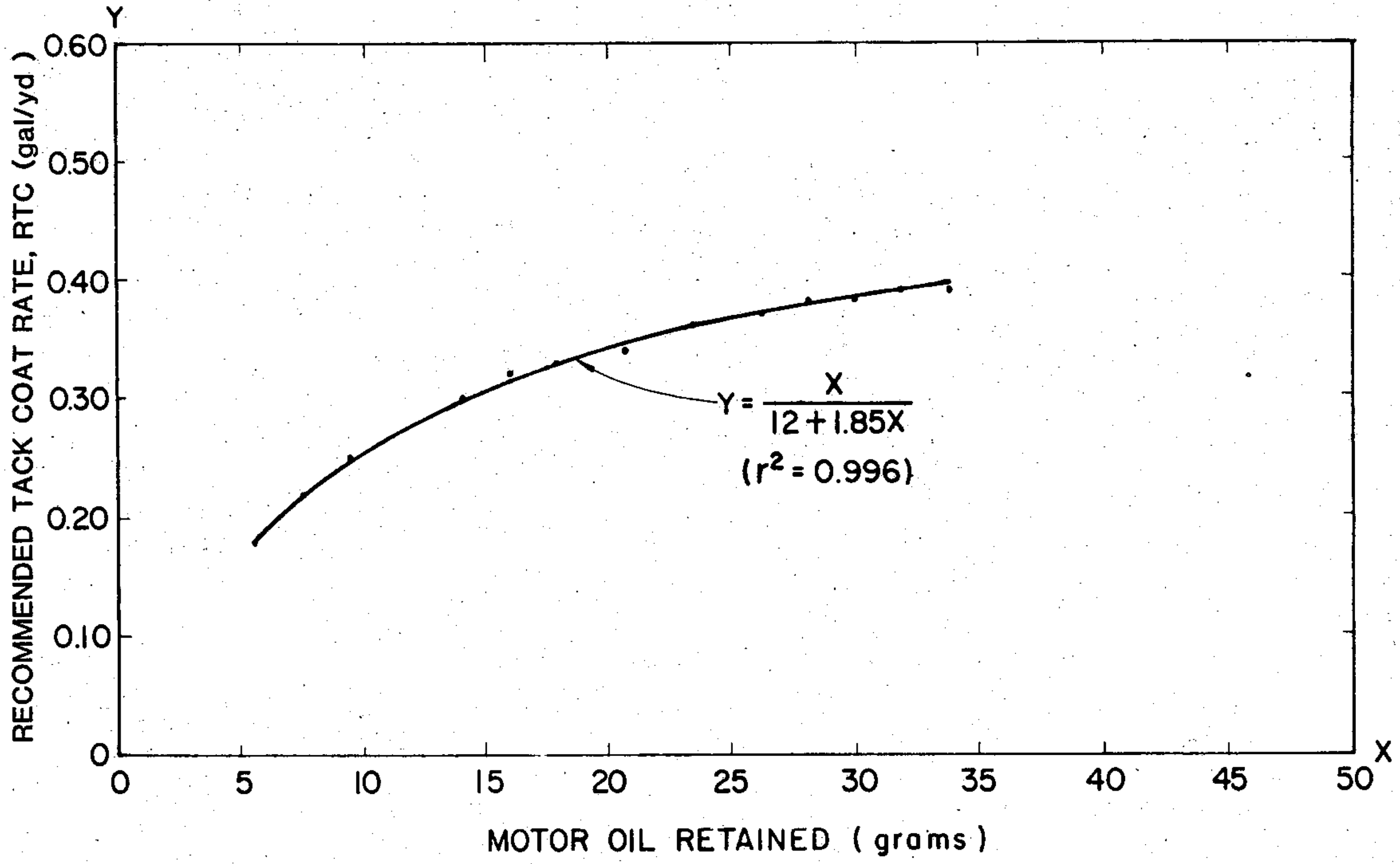
Figure 27 | F78TL03

Note: Two problems

1.) X-axis is wrong scale; curve plot is incorrect.

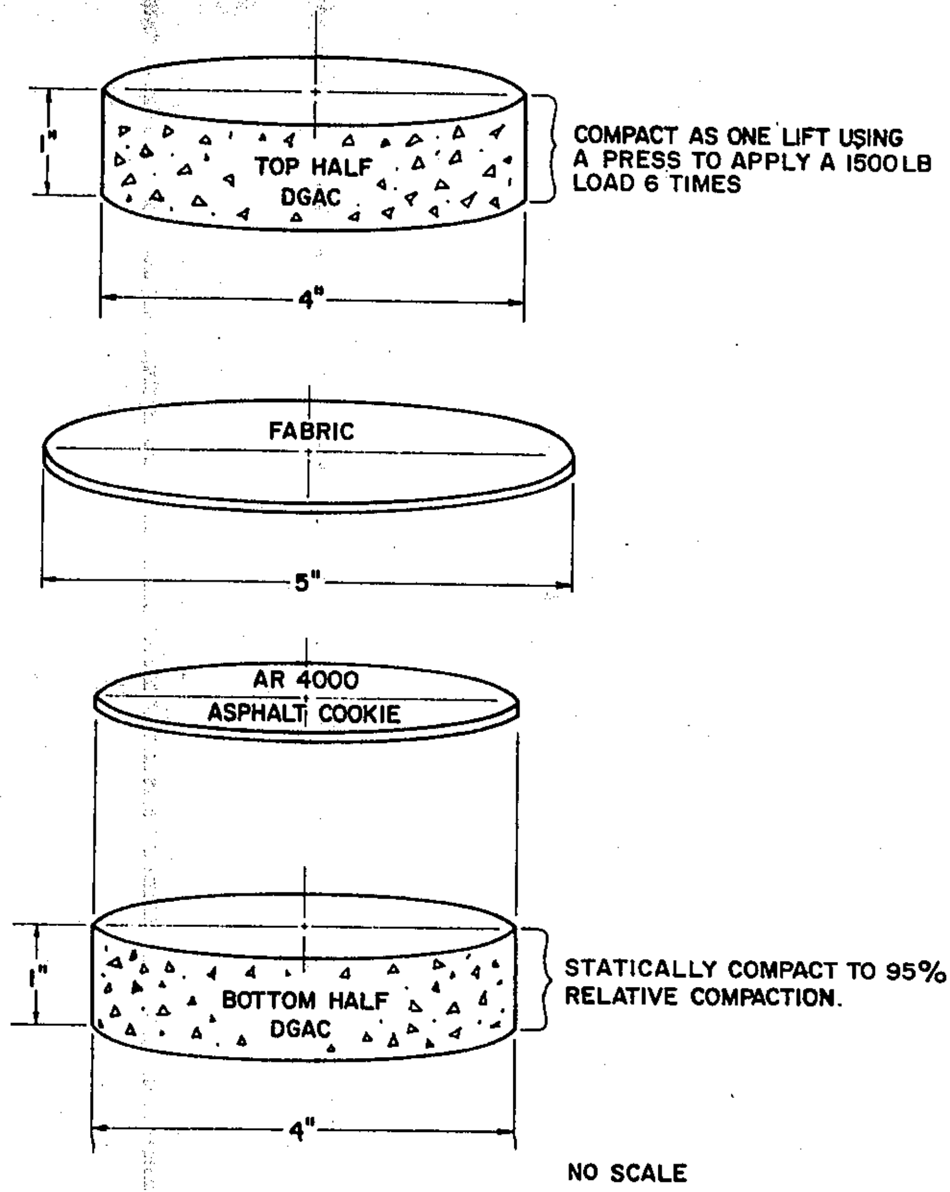
2.) Formula is correct, but Y-axis is labeled wrong; should be "Lab. Minimum Rate, Link" (ie., 0.05 gpsy must be added to this figure to get the RTC)

discovered by Dave Rice of J.M. RDS 1/7/86



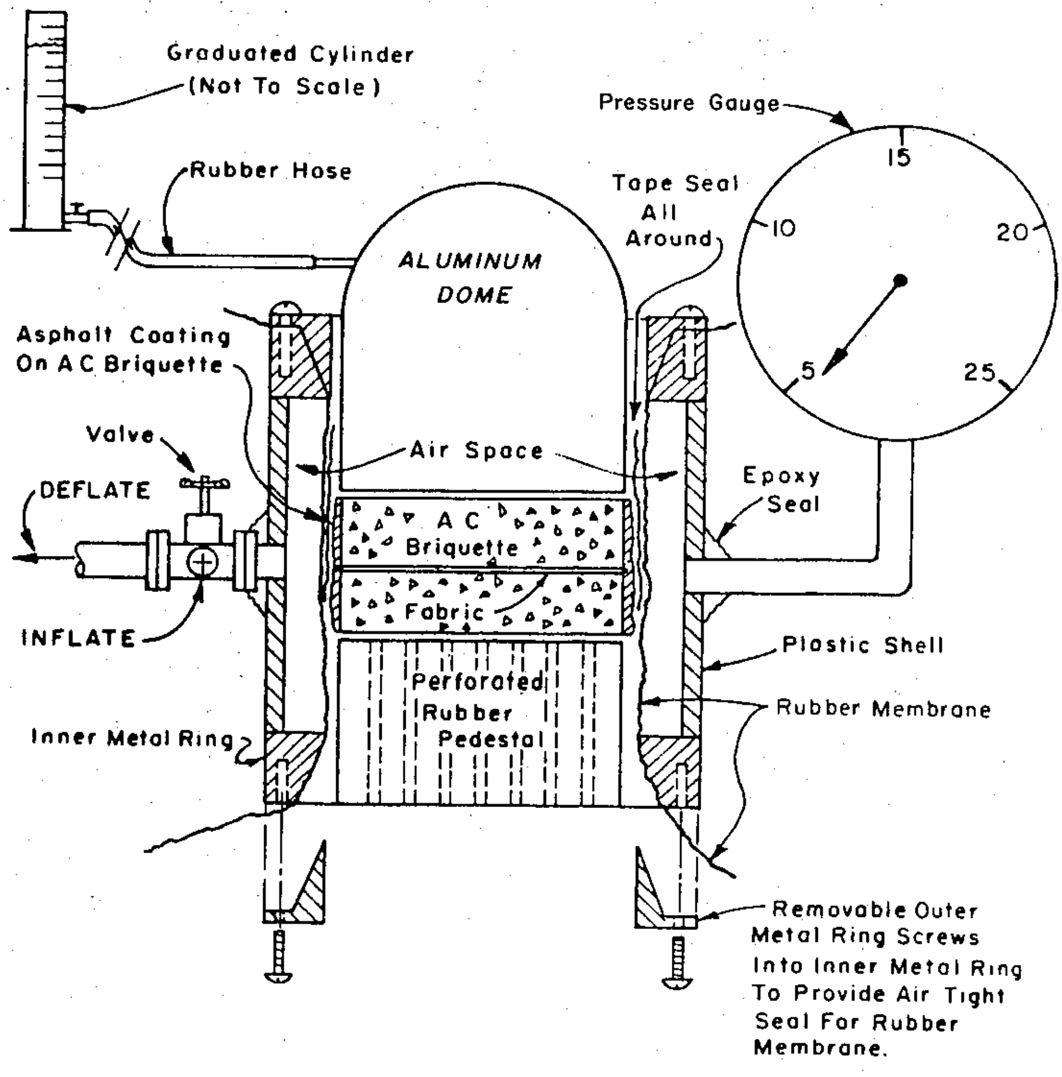
RECOMMENDED TACK COAT RATE VS MOTOR OIL RETENTION

FIGURE 7



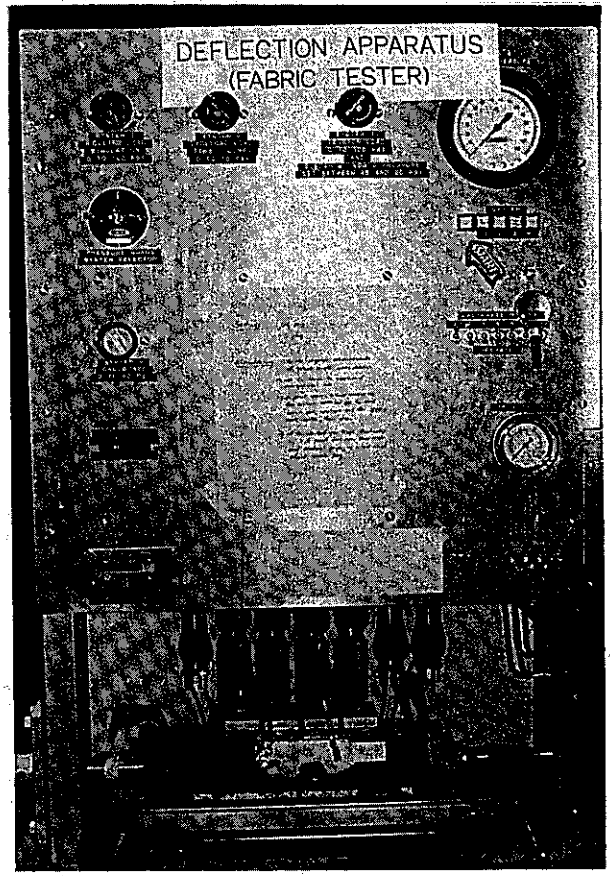
PERMEABILITY TEST SPECIMEN

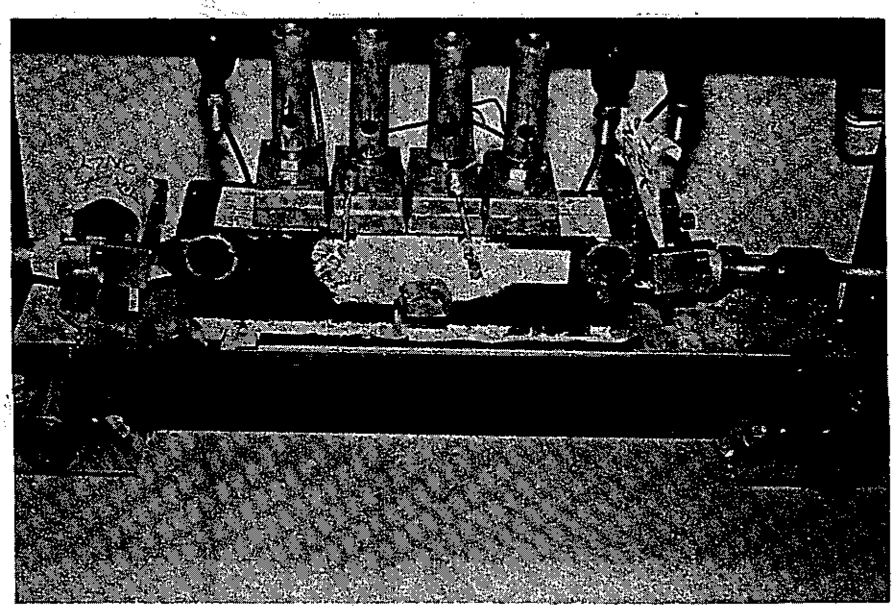
FIGURE 8



WATER PERMEABILITY APPARATUS

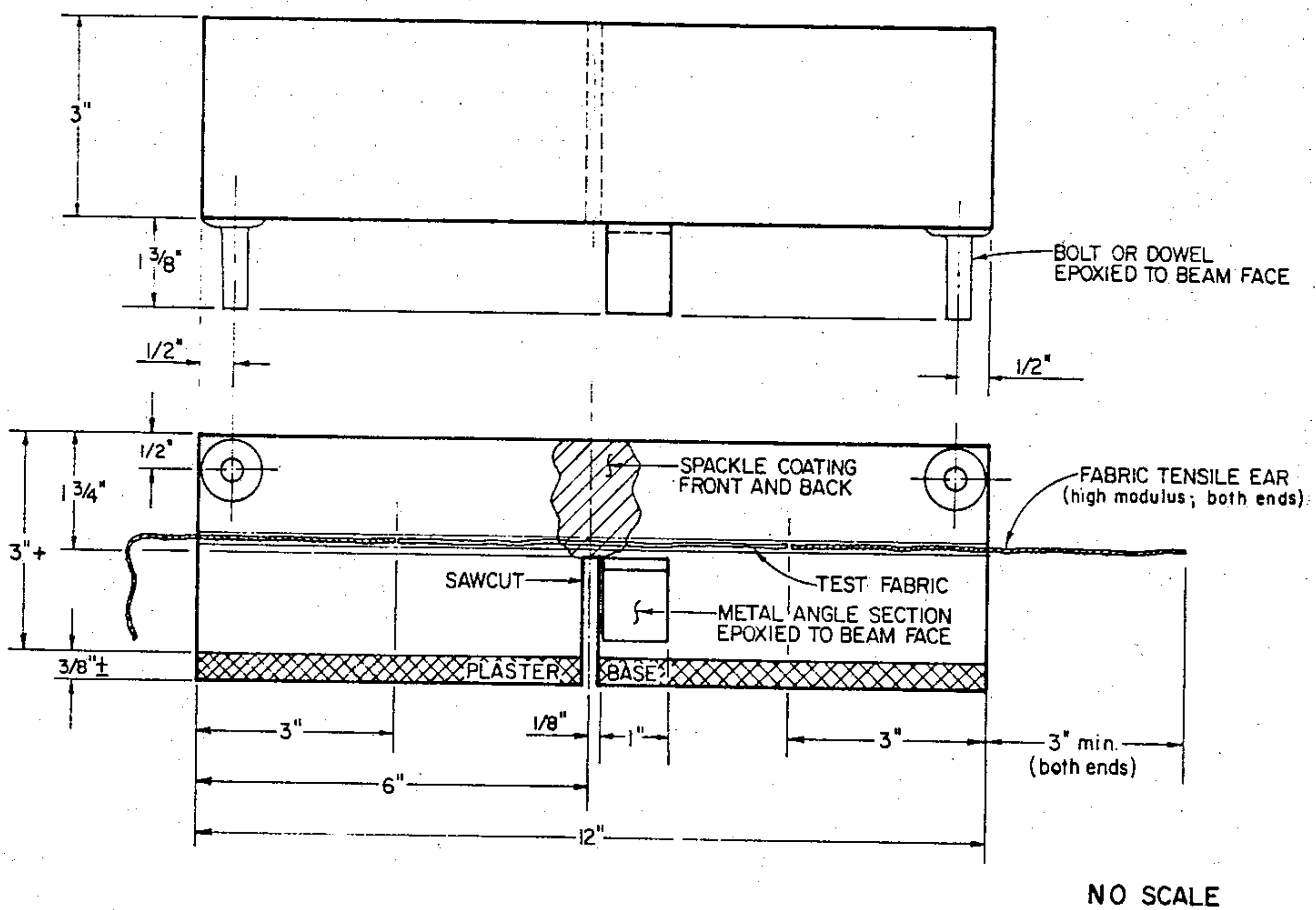
FIGURE 9





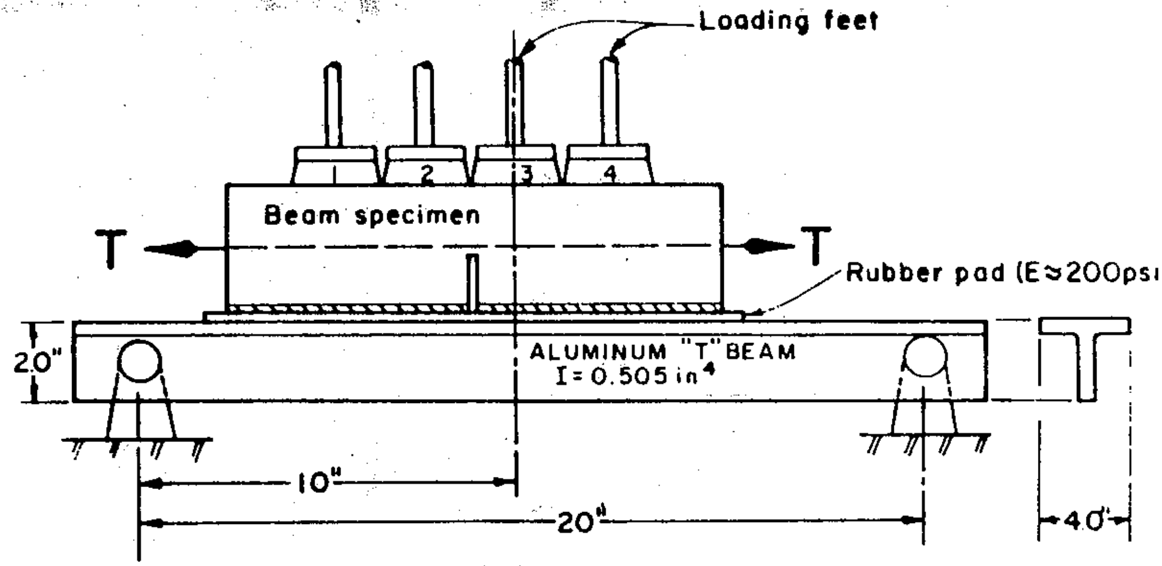
TRANSLAB FLEXURAL FATIGUE TESTING MACHINE

Figure 10

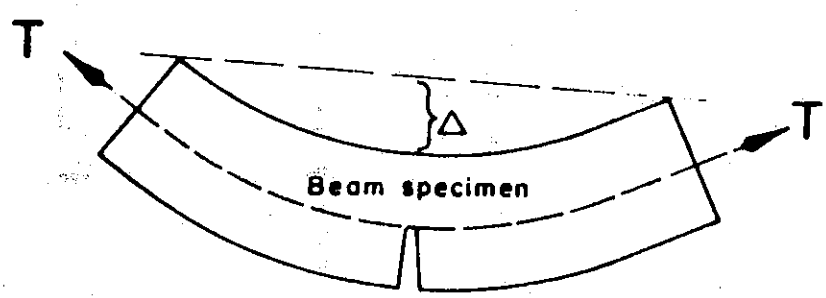


FLEXURAL FATIGUE BEAM SPECIMEN

FIGURE 11



TESTING ARRANGEMENT



T = Tensile Load

Δ = Beam Deflection

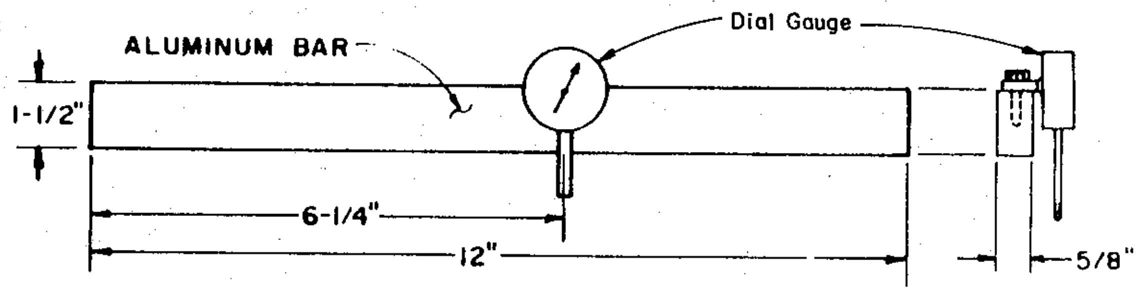
EXAGGERATED BEAM DEFLECTION

NOTE :

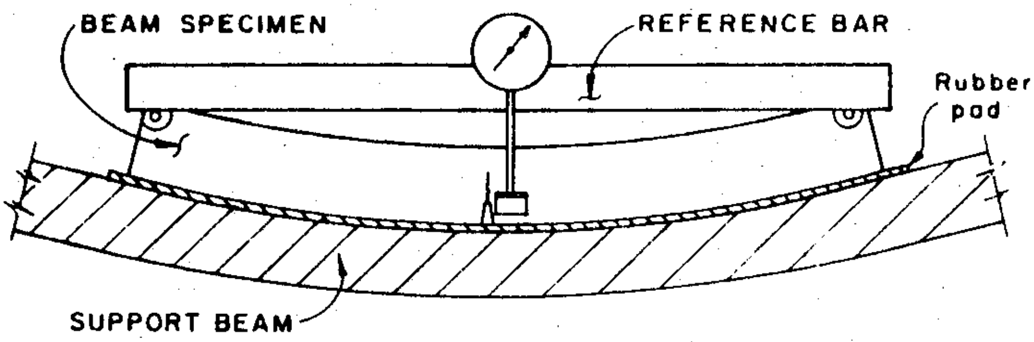
Beam specimen is positioned so that loading feet 2 and 3 straddle the sawcut. This results in the specimen not being exactly centered on the support beam.

FLEXURAL FATIGUE TESTING ARRANGEMENT

FIGURE 12



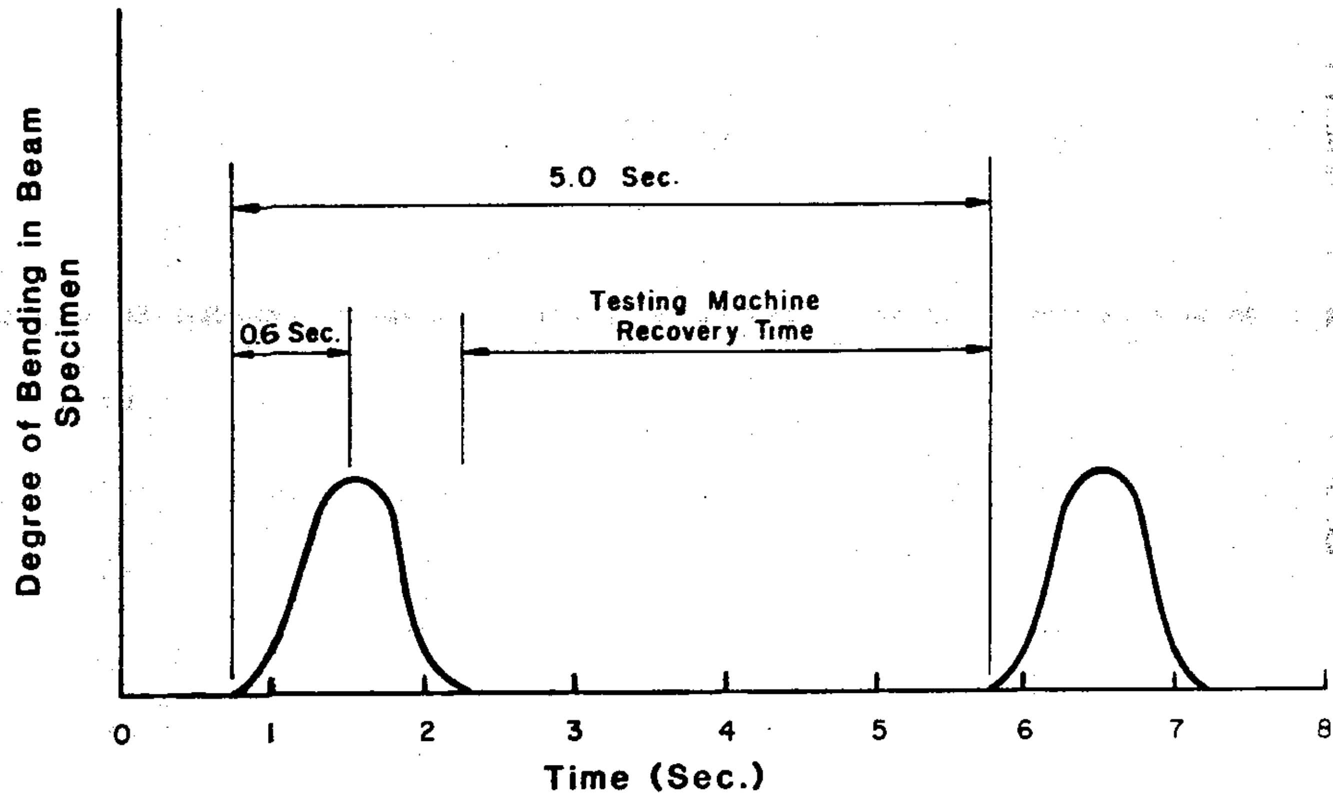
a. REFERENCE BAR



b. MEASURING MID-BEAM DEFLECTION

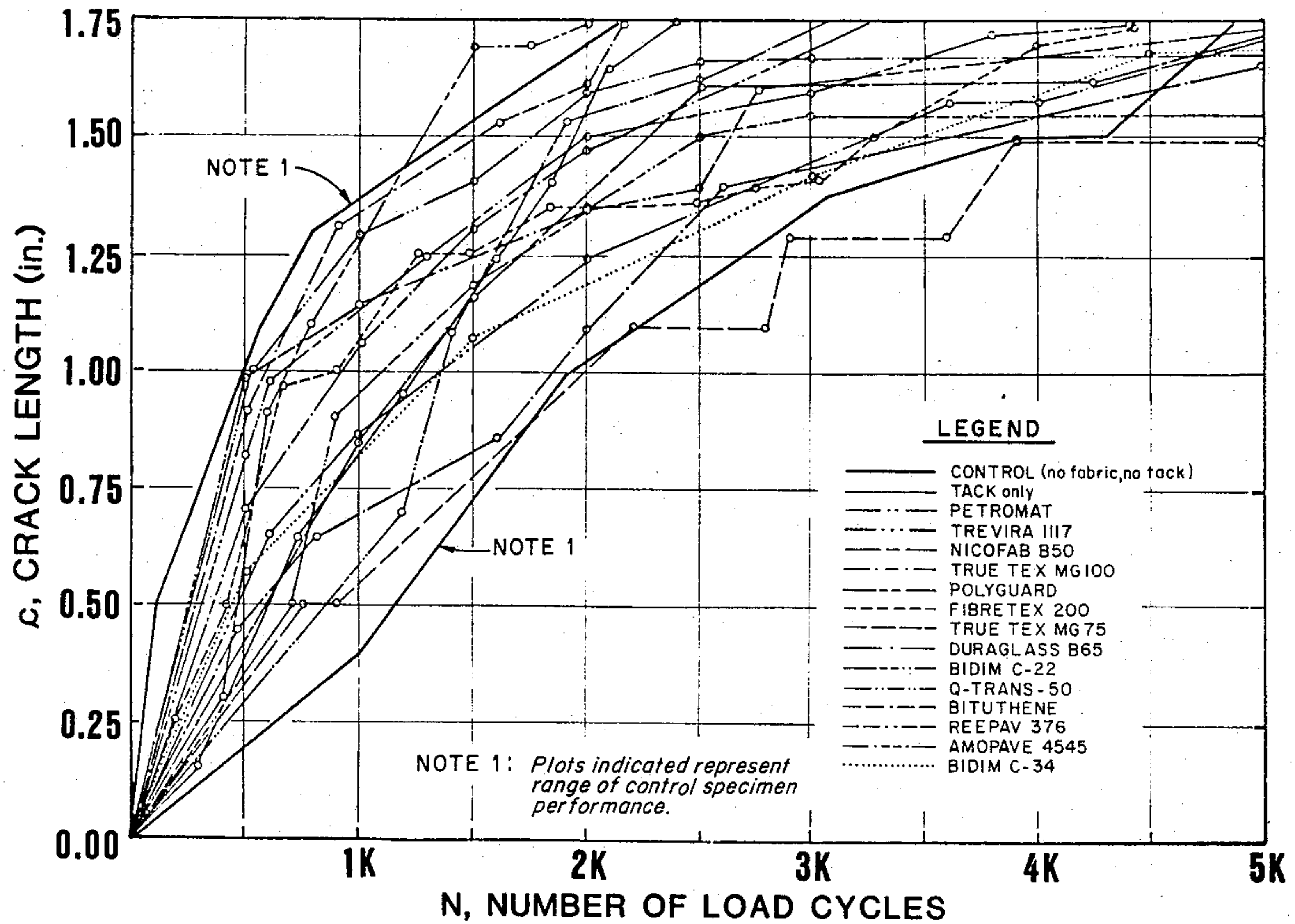
MEASUREMENT OF DEGREE OF BENDING IN BEAM SPECIMEN

FIGURE 13



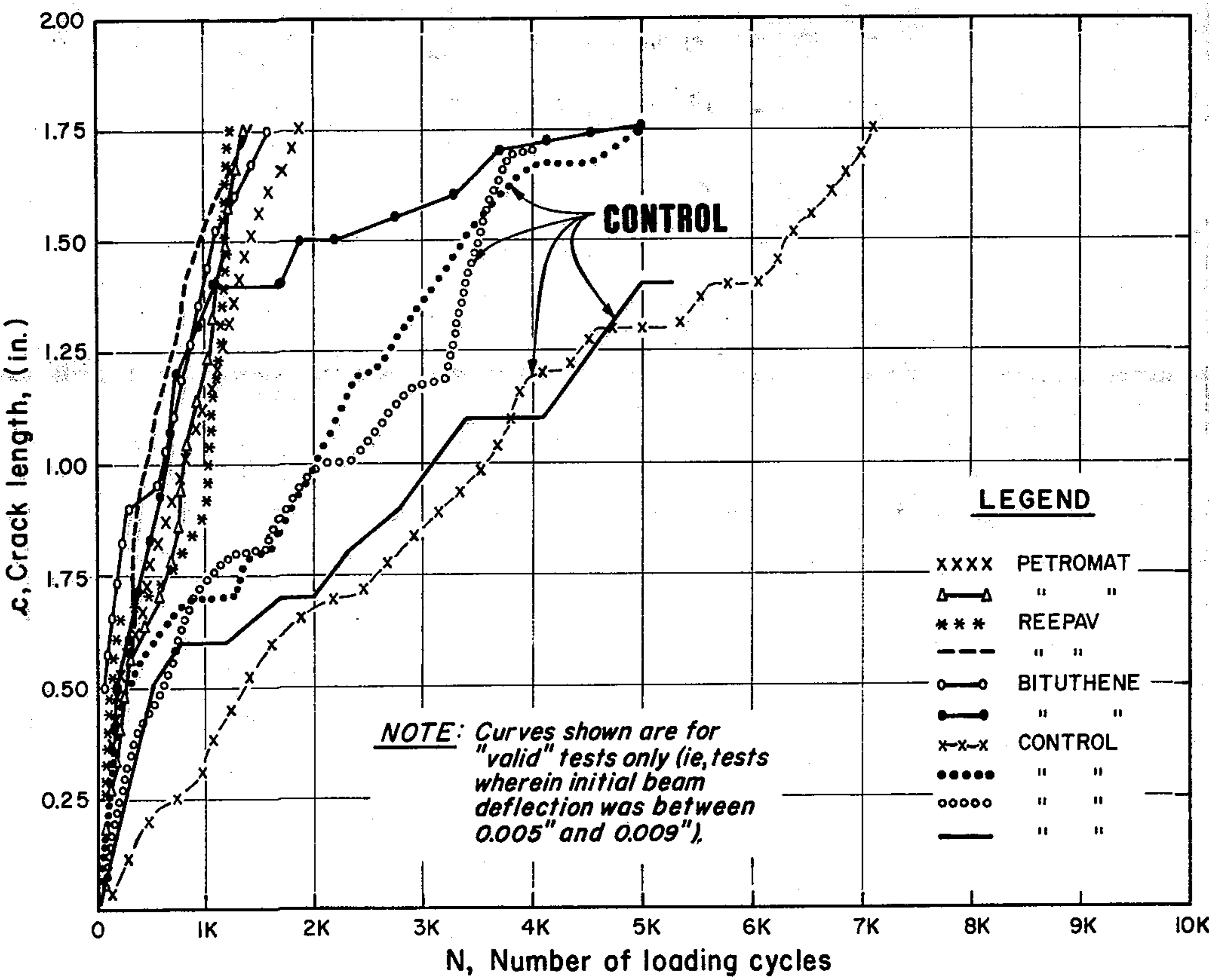
LOADING CYCLE FOR FLEXURAL FATIGUE TEST

FIGURE 14



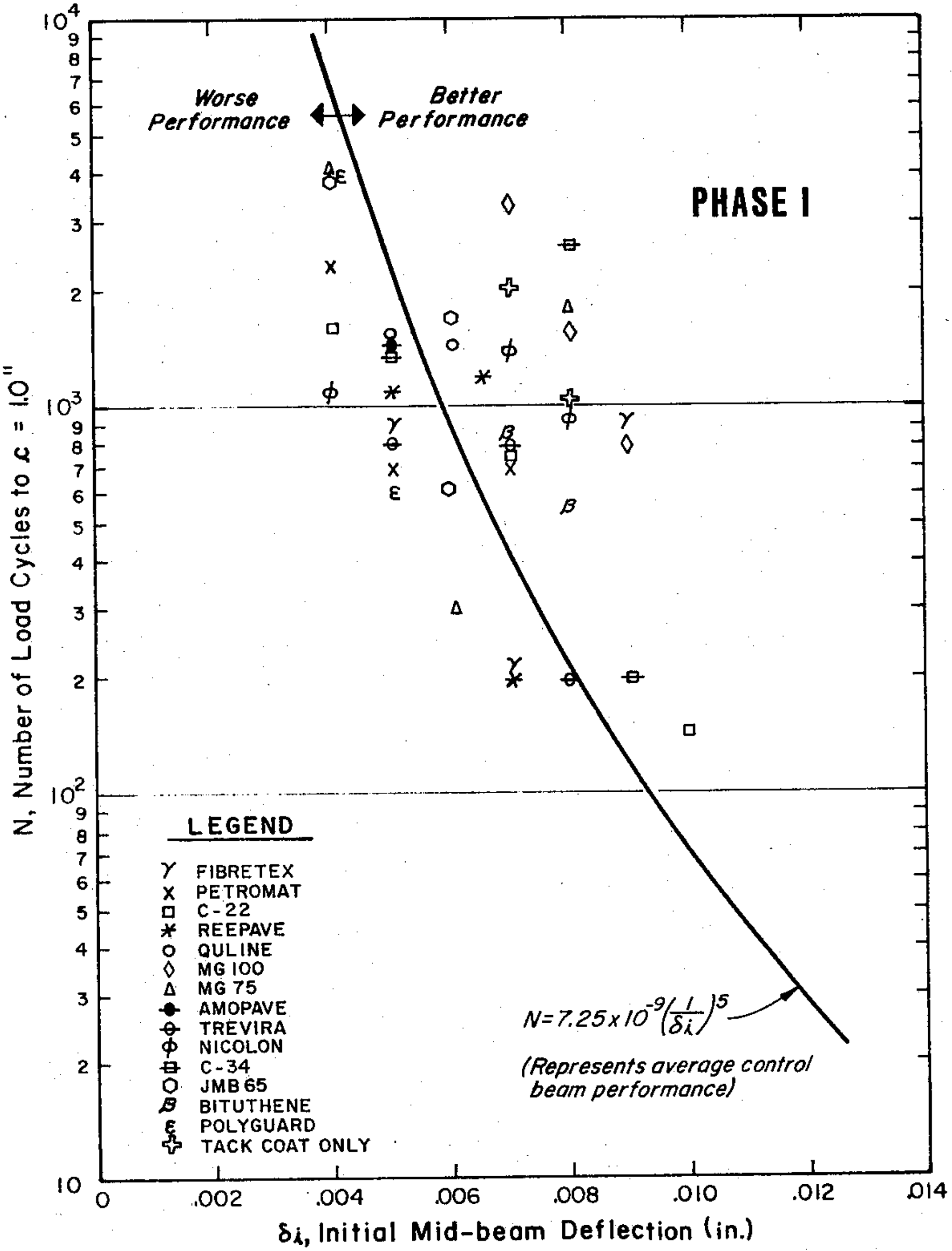
AVERAGED c vs N CURVES FOR EACH INTERLAYER TYPE (PHASE I)

FIGURE 15



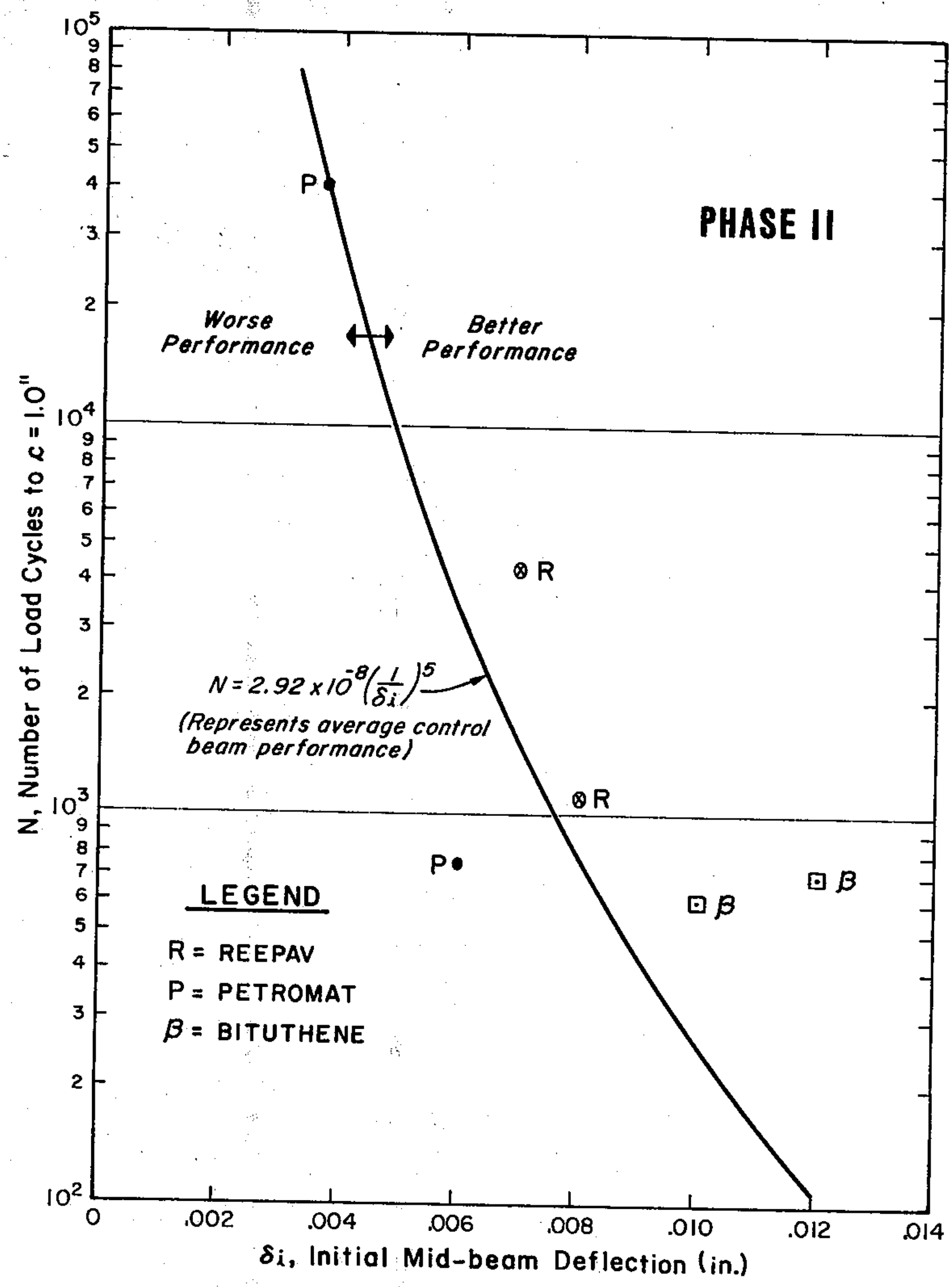
c vs. N CURVES FOR FATIGUE BEAMS (PHASE II)

FIGURE 16



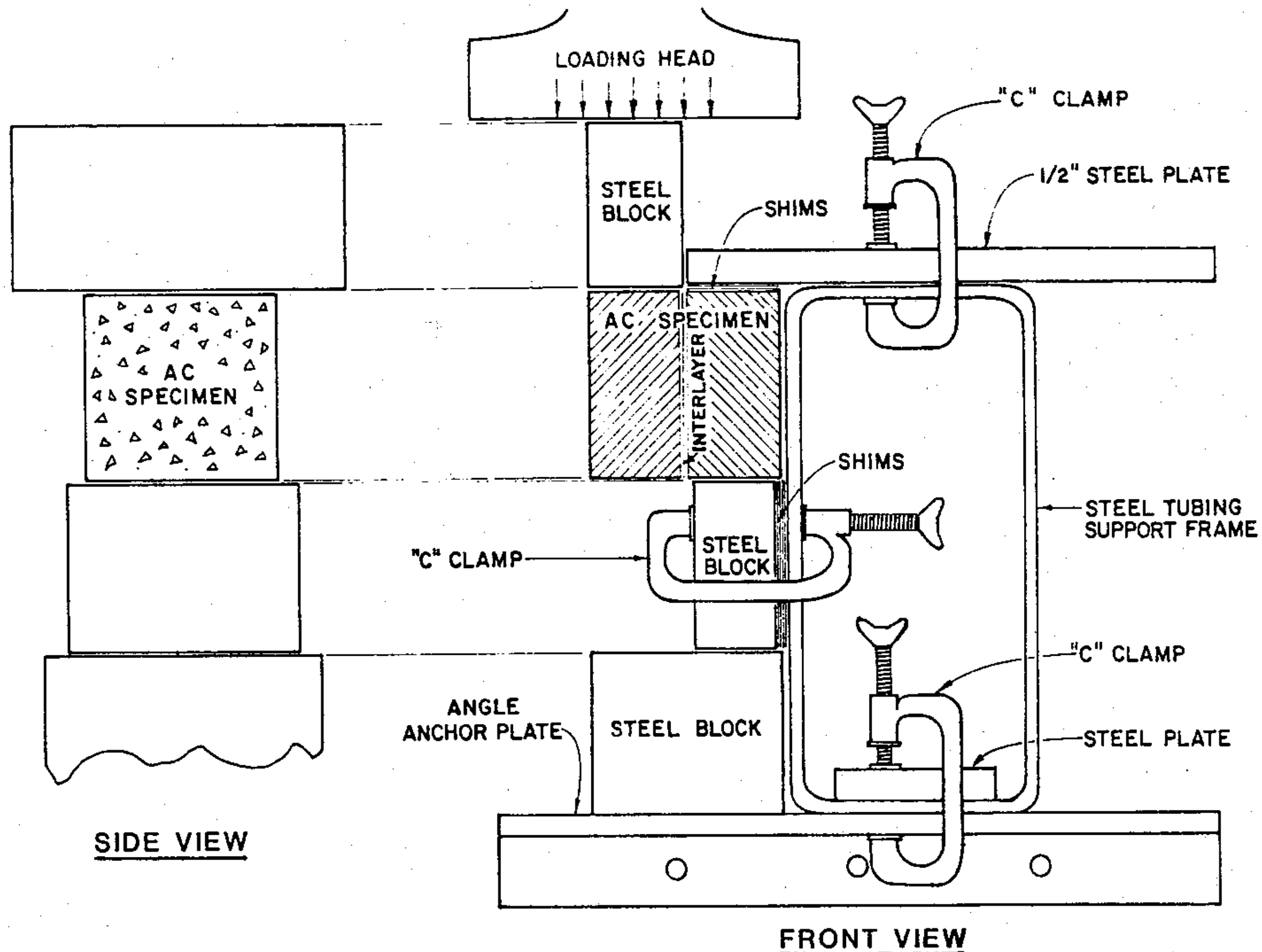
FATIGUE CRACKING RATE vs INITIAL DEFLECTION LEVEL IN BEAM (PHASE I)

FIGURE 17



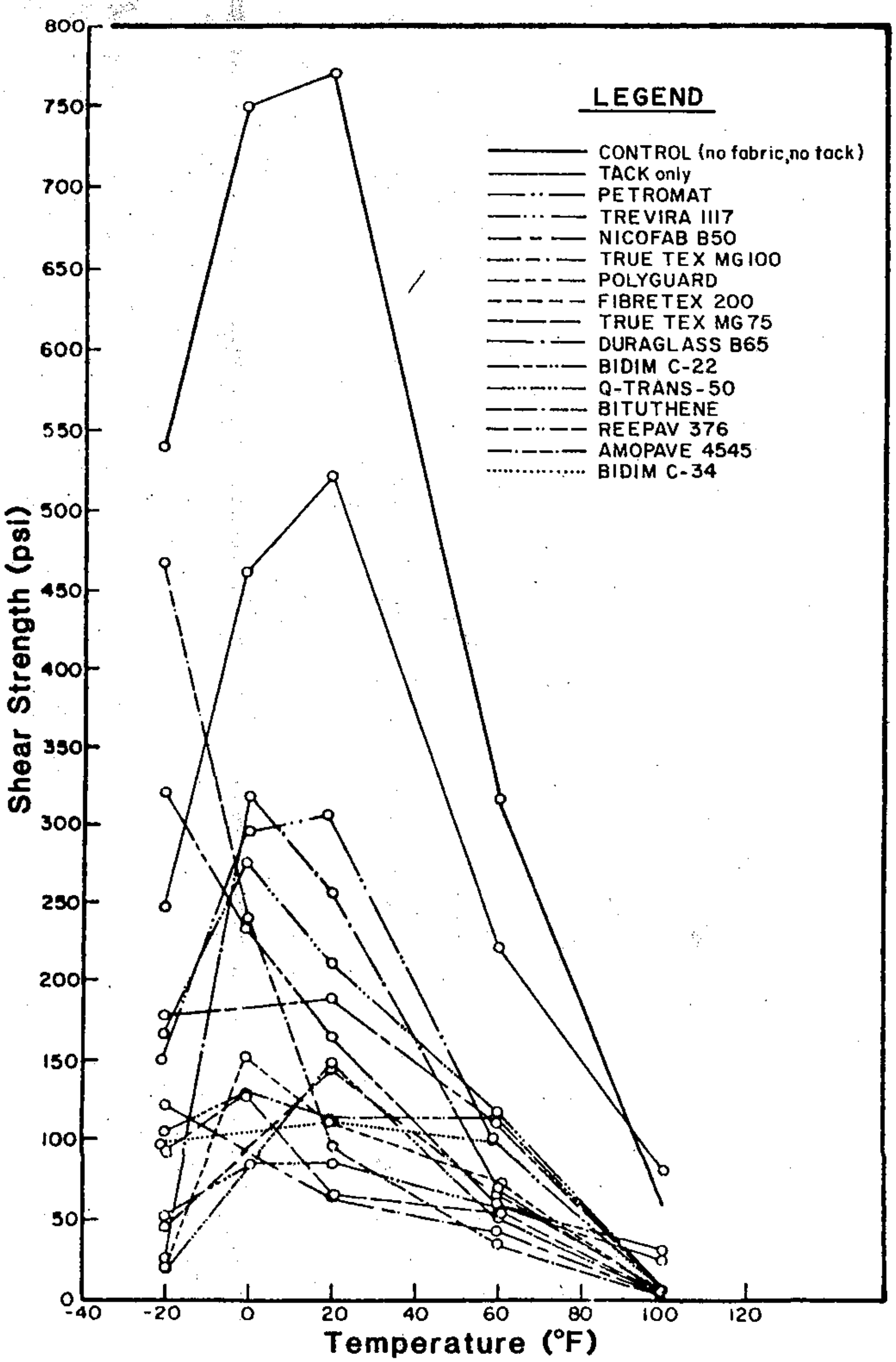
FATIGUE CRACKING RATE vs INITIAL DEFLECTION LEVEL IN BEAM (PHASE II)

FIGURE 18



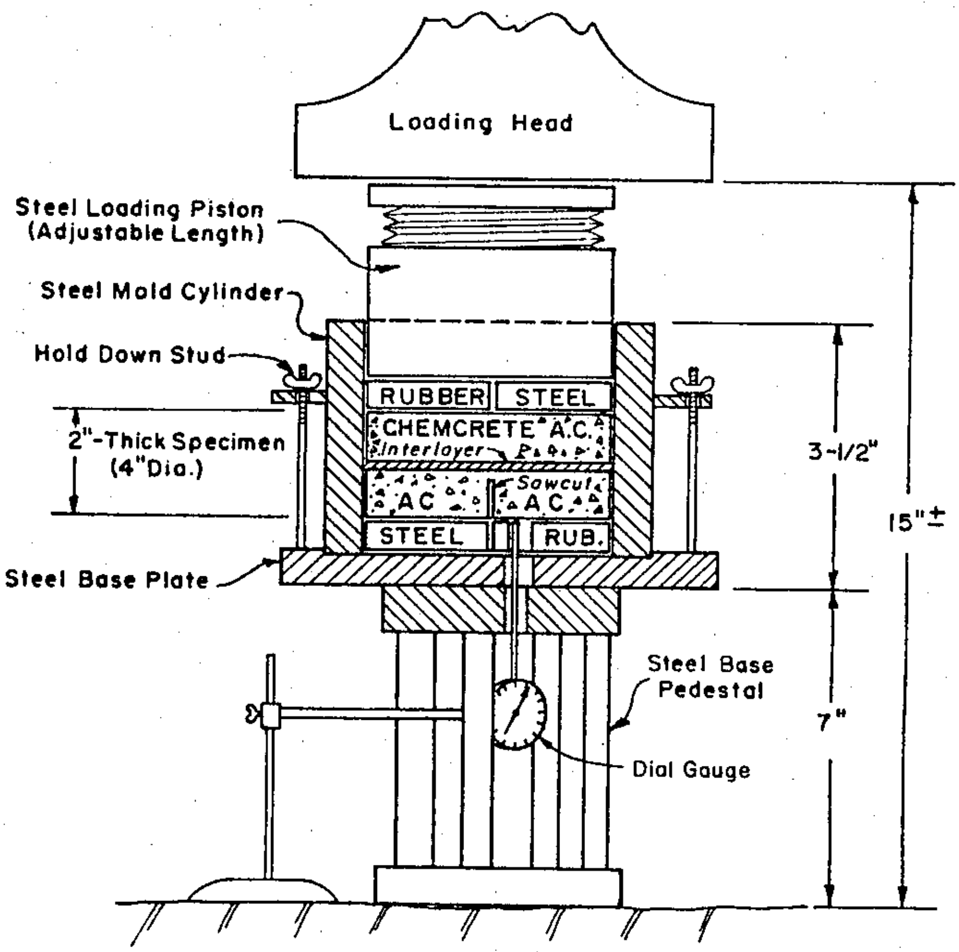
INTERLAYER SHEAR TEST SETUP

FIGURE 19



AVERAGE INTERLAYER SHEAR STRENGTH vs TEMPERATURE

FIGURE 20



SHEAR FATIGUE TEST SETUP

FIGURE 21

APPENDIX A

Summary and Critique of a University of California, Berkeley, Study

Titled

"Analytical Study of Fabric Interlayer Effects"

By

R. Yuce, P. A. Seddon, and C. L. Monismith

Note: This study was performed under contract as part of Caltrans, FHWA-funded parent project F78TL03 (633187)

GENERAL

This study, performed at the University of California, Berkeley (UCB), has been documented under separate cover via an Interim Report for this project. The UCB study consisted of two parts:

PART I: Analytical Study of Asphalt Concrete Overlays With Fabrics

and

PART II: Engineering Properties of Fabrics

Each of these studies is summarized and discussed in the following pages.

PART I

ANALYTICAL STUDY OF ASPHALT CONCRETE OVERLAYS WITH FABRIC

INTRODUCTION

This phase of the UCB study consisted of developing a finite element microcomputer model for an AC overlay of plain (unreinforced), jointed, PCC pavement. The analytical model allowed for the inclusion of an interlayer element, fabric, within the overlay structure, and provided, at least on a relative basis, the following information:

1. the optimum location of the fabric interlayer in the overlay.

2. the effect of fabric modulus, fabric thickness, and Poisson's ratio of the fabric on stresses and strains within the overlay.

3. the effect of placing two layers of fabric within the overlay at different depths.

4. the thickness of asphalt concrete overlay without fabric that provides a response equivalent to a 4-inch thick overlay with fabric.

BACKGROUND

In recent years, there have been a number of studies to examine analytically the problem of reflection cracking of overlays on jointed concrete pavements(1). Examples of such studies include those by Treybig, et al(2), Majidzadeh and Sucharieh(3), Chang, et al(4), and Coetzee(5).

As seen in Figure 1, this form of cracking can result from both traffic and environmentally induced causes and both factors should be considered in an examination of the problem.

The finite element procedure would appear to offer a reasonable way to model pavement response to both load and environmental factors. Majidzadeh and Sucharieh(3) used this methodology to examine the influence of horizontal joint movements and slab curling on asphalt concrete overlay thickness. Coetzee(5) has also used the finite element procedure to examine the effects of both vertical and horizontal joint movements on stresses in the overlay with and without an asphalt-rubber stress absorbing membrane interlayer (SAMI). While both of these studies have been somewhat limited in the examination of reflection cracking, they have provided insight as to a methodology which might be used to examine in some detail this important problem.

METHODOLOGY

The finite element analyses were performed using the SAP-81 program suite prepared by Professor E. L. Wilson (of the Department of Civil Engineering, University of California, Berkeley) for microcomputers incorporating the CP/M (Central Program for Microprocessor) system.

A two-drive Radio Shack TRS-80 Model II, TRS-80 Model IV printer, and 8-inch BASF Flexy Disks were used for the program to analyze the idealization of the pavement structure. Two disks, each holding approximately 600 k bytes, were used; one for programs, the other for the input data, working files, and output. The pavement representation selected for this study used most of this capacity and the process time for each run was about 2-1/2 hours, with another one hour required for a complete printout of displacements, stresses, and strains. While these times seem large when compared with those for operations on a main-frame computer, it should be borne in mind that the capital cost of this equipment is slightly over $6,000 (1982 prices). Moreover, the equipment does not require constant attention; thus other work can be accomplished while a program is being run.

Output consists of displacements and normal stresses in three dimensions together with shear stresses, principal stresses, and principal strains.

Details of the SAP-81 program and typical outputs were not included in the Project Interim Report but are on file at the Transportation Laboratory.

RESULTS

1. Placing the fabric interlayer about 1.0 inch or 0.1 foot above the existing jointed (or cracked) PCC pavement appears to be the optimum location for stress relief at the crack tip. Since reflection cracking can be mitigated by reducing stresses in the zone of the crack tip, location of the fabric on the surface of a leveling course appears to be the best solution.

2. The use of a thick fabric interlayer with a low modulus and high Poisson's ratio improves the stress relieving function of the fabric in the overlay.

3. The use of two or more layers of fabric provides no additional stress relieving effects as compared to the fabric layer placed on a leveling course.

4. A 6-inch asphalt concrete overlay produced the same stress pattern at the crack tip as a 4-inch asphalt concrete overlay with a fabric layer located 1.0 inch above the existing PCC pavements. Thus, for thickness in this range, the fabric layer is equivalant in performance to about 2 inches of asphalt concrete as indicated by internal stresses.

It should be emphasized that the results presented did not guarantee that reflection cracking will be mitigated by the use of fabrics. The results did, however, suggest guidelines as to how to use such material reasonably effectively and provided some indication of desirable properties for the fabrics themselves.

DISCUSSION

The success of the UCB researchers in adapting the SAP-81 finite element program for use by a microcomputer is a significant accomplishment and should allow more widespread utilization of this analytical tool. This analytical model, like any other, is only as reliable as the accuracy of its supporting theory and input parameters. A few prominent anomalies in the findings suggest that perhaps more refinement is needed in the program.

1. The model shows that maximum levels of tensile strain and shear stress in an overlay do <u>not</u> occur directly above the crack/joint, but rather about 12 inches away.

2. Higher modulus fabrics are shown to result in <u>higher</u> tensile stresses at the crack tip (base of the overlay) than lower modulus fabrics.

3. In the vicinity of the joint/crack in underlying PCC pavement, tensile stresses directly on top of the fabric are shown to be higher than those at the crack tip (base of the overlay).

It is hoped the UCB development of this tool will continue and that additional program "runs" will be made involving different temperature ranges and a wider range of fabric properties.

With the advent of in-house personal microcomputers at <u>TransLab</u>, this program will be utilized to its fullest extent.

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PART II

ENGINEERING PROPERTIES OF FABRICS

INTRODUCTION

In this phase of the UCB study, a special direct tension test was used to determine the following mechanical properties of various popular nonwoven paving fabrics:

1. Moduli (stiffness) at various stages of loading

2. Poisson's ratio.

Testing involved 10 brands of nonwoven fabric supplied by TransLab. All of the brands were tested "dry" (i.e., without asphalt impregnation), and two of the brands were also tested after asphalt impregnation. Results of these tests for both "machine" and "cross" directions are shown in Tables A1 and A2.

TEST PROCEDURE

The testing unit developed at the University of California, Berkeley, is capable of testing fabric specimens up to 20 inches wide and can effectively test fabrics with thicknesses $\geq$40 mils. The fabric specimens in this study were 16.0 inches wide by 4.0 inches long, resulting in an "aspect ratio" (width/length) of 4.0. A rate of loading of 0.5 cm/min was used in an INSTRON testing device. For the tests on asphalt saturated fabric, the amount of asphalt used for saturation was 0.3 gallon per square yard for the Quline materials and 0.1 gallon per square yard for the Petromat.

A test temperature of 77°F was maintained for the tests with the asphalt-filled materials. The axial load _vs_ axial deformation data were recorded on a strip chart recorder.

Modulus values as used herein are defined as follows:

1. _Modulus during preconditioning_ - ratio of the stress obtained at a strain of 10.5 to 12.0 percent during the preconditioning phase.

2. _Initial modulus_ - slope of the initial portion of the stress _vs_ strain (or load _vs_ displacement) plot obtained from the loading following preconditioning.

3. _Secant modulus_ - ratio of stress to strain at failure.

The _failure stress_ (load) was obtained when one of the following conditions was realized:

1. tearing of the fabric

2. tensile load reached a peak value and then declined without fabric tearing or other fabric separation with further increase in strain

3. an elongation of 50 percent (based on original length).

To determine Poisson's ratio for each of the fabrics, axial deformation was obtained from the strip chart and lateral deformation was measured manually using a scale.

RESULTS

The results of this study, as reported by the UCB researchers, are presented below.

1. All of the fabrics exhibited different characteristics in the X and Y directions.

2. Each fabric exhibited different moduli during preloading, initial loading and at failure (Figure A1). There is no general trend in modulus values obtained during the different stages of loading. For some fabrics, higher moduli were obtained during initial loading; for others at failure, and for some during preconditioning.

3. The same Poisson's ratio was obtained in both directions for Petromat, Truetex MG-75, and Truetex MH-100, whereas different values in the two directions were obtained for the other fabrics. Poisson's ratios for the fabrics ranged from 0.14 to 0.41.

4. The failure load used to determine the secant modulus was defined by the 50 percent elongation criterion for all fabrics except Amopave. For this fabric, tearing was observed, thus, the secant modulus is defined by the maximum load at tear. A slight tearing was also observed in one of the Bidum-22 specimens.

5. The saturated fabrics yielded lower preconditioning and secant moduli than "dry" fabrics of the same type (Figure A2). However, the initial moduli values of the asphalt-saturated material were higher than those for the plain fabrics. This performance seems reasonable since the initial moduli are obtained at relatively short times of loading.

UCB RECOMMENDATIONS FOR FIELD APPLICATIONS

Based on an evaluation of the field trials described in References(5,6,7), the UCB researchers feel that the following guidelines for field applications are warranted.

1. Use thick fabric interlayers to mitigate reflection cracking.

2. If the fabric is to be placed directly on the existing pavement, the existing surface should be milled prior to fabric placement.

3. A minimum thickness of 1.5 inches of asphalt concrete should be placed over the fabric layer. If severe braking stresses occur, the thickness should be increased to a minimum of 2 inches.

4. Existing surface preparation is important. For example, cracks greater than about 1/8 inch in width should be filled prior to the placement of the fabric.

5. RC or MC liquid asphalts should not be used as the tack coat for fabric application.

6. The surface texture of the fabric and its shrinkage characteristics must be considered. If, for example, the fabric shrinks excessively when heated to 300°F, there is the likelihood of cracks developing in the overlay.

DISCUSSION

General

With respect to the above UCB field recommendations, the following comments are offered, based on Caltrans field and laboratory use of paving fabrics.

1. Although Caltrans has constructed overlay test sections using both thick and thin fabrics, it is too early to draw conclusions as to comparative long-term performance.

2. Caltrans does not require milling of existing AC surfaces on which fabric will be placed. The omission of this treatment has not led to any known problems.

3. Caltrans currently recommends 0.15 foot as a minimum AC overlay thickness, regardless of whether fabric is placed or not. Slippage problems have been very rare, even in extremely warm climates.

4. Caltrans currently requires filling of large cracks and spalls, or placement of a thin AC leveling course prior to placement of the fabric.

5. RC or MC liquid asphalts are not permitted as tack coats for fabric on Caltrans paving jobs.

6. Overlay cracking resulting from fabric shrinkage has not been observed on Caltrans paving jobs. As discussed in Part I of this report, it is the opinion of TransLab that immersion-type tests, whether oven or liquid, do not simulate field conditions.

Fabric Tension Testing

The fabric testing by UCB focused on determination of various moduli by means of special direct tension tests. These tensile tests were special in that they involved a high aspect ratio (specimen width/specimen length). High aspect ratio tests are generally believed to better simulate the conditions of lateral restraint that a paving fabric interlayer is subject to in service. The "necking" and "roping" of fabric that is allowed to occur in conventional (low aspect ratio) "grab" tensile testing (ASTM-D1682 and ASTM-D1117) can significantly influence tensile behavior and resulting modulus and Poisson's ratio values.

Preconditioning Modulus (M_{PRE})

Preconditioning moduli (M_{PRE}) were generally lower (sometimes by as much as 50%) than the initial modulus values. This behavior would seem to be desirable from the standpoint of tolerating placement strains and achieving wrinkle-free laydown. As an example, a fabric with a low M_{PRE} should be less likely to wrinkle when placed on horizontal curves.

Initial Modulus (M_i)

The initial modulus (M_i) of a fabric, theoretically, could be of significance at higher temperatures where the stiffness (modulus) of the AC mix is drastically reduced. In these instances, fabrics with high M_i, say greater than 10,000 psi, might provide a tensile reinforcement (provided a condition exists where the fabric modulus actually exceeds the modulus of the AC). Using the AC stiffness vs temperature information provided in the UCB report, it could be hypothesized that high M_i fabrics could provide this tensile reinforcing effect at temperatures above about 90°F.

Comparison of TransLab and UCB M_i (Table A3) reveals that UCB values are consistently higher than TransLab values.

This difference is probably attributable to the fact that the aspect ratio was 3.0 in the TransLab testing and 4.0 in UCB testing. The fact that the UCB tests were conducted at a much lower strain rate (0.2 in/min) than tests performed by TranLab (12 in./min) should not have had a significant effect(4).

It should also be remembered that nonwoven fabrics are not homogeneous materials and tend to exhibit significant variations in density and construction which limit repeatability in mechanical property testing.

Secant Modulus (M_s)

In terms of performance, it could be expected that fabrics with a high secant modulus (M_s) value would better resist crack "opening" and/or growth of cracks through the overlay. M_s values, as determined by UCB direct tension tests, usually represented the modulus at 50% strain. Because TransLab-determined M_s values (reported herein) were likewise determined at 50% strain, a comparison of results was made.

However, because of uncertainties in determining the "cross" and "machine" directions in some of the test fabrics, the comparison of UCB and TransLab results was done on the assumption that directionality of a fabric's M_s remained independent of the test method (agency). This allowed for comparison on the basis of stronger vs. stronger and weaker vs. weaker directions, regardless of the reported testing direction.

As with M_i levels, this type of comparison (Table A3) resulted in UCB-determined M_s levels typically being greater than those obtained in TransLab testing.

Poisson's Ratio

No direct application or significance is seen for the Poisson's Ratio values determined by the UCB researchers, although the subsequent finite element analysis did show slight sensitivity to this variable.

It is interesting to note that the UCB-determined Poisson's Ratio values were drastically lower than those typically determined by Haliburton(4). This is no doubt due to the higher, more realistic aspect ratio employed in the UCB testing program.

Asphalt-Impregnated Fabric Properties

For the two fabrics tested, asphalt saturation produced a significant (30% to 100%) increase in M_i and a decrease (25% to 35%) in M_{PRE} at room temperature. Therefore, it appears that fabric potential should be evaluated in terms of tests involving asphalt-saturated fabric specimens. Considering that this is relatively difficult, perhaps correction factors could be generated to be applied to the results of "dry" fabric testing.

The effect of asphalt impregnation on M_S was not consistent in this study.

CONCLUSIONS

1. The direct tension test developed by the UCB researchers offers an added degree of realism in the testing of fabrics for pavement overlay applications.

2. No general relationship exists between preconditioning modulus, initial modulus, and secant modulus for the fabrics tested. However, in all but one case, the initial modulus was greater than the preconditioning modulus. The relationship between secant modulus and initial modulus was quite erratic.

3. M_i and M_s values determined by the UCB special tension test were typically higher than those determined in TransLab testing.

4. None of the fabrics tested by UCB exhibited modulus levels high enough to provide tensile reinforcement to AC pavement within a realistic service temperature range.

5. Impregnation with AR4000 asphalt significantly increases the M_i and decreases the M_{PRE} of nonwoven paving fabrics at room temperature.

SUMMARY

It would seem that the ideal fabric would have the following characteristics:

1. An "off-the-shelf" (preconditioning) modulus just low enough to absorb the strains that occur during its placement on the roadway, and thereby resist fabric wrinkling.

2. An initial modulus high enough to permit the fabric to act as a reinforcing element in the AC pavement structure and help resist cracking.

3. A secant (@50% strain) modulus adequate to resist crack opening and prevent rupturing of the fabric after cracking commences in the AC pavement. (Of course, this secant modulus would have to be accompanied by adequate elongation and rupture strength.)

Of the fabrics tested by UCB, all exhibited precondition moduli low enough to facilitate placement, however, none exhibited initial or secant moduli high enough to allow the fabric to provide tensile reinforcement to an AC overlay.

One higher modulus fabric, DuPont Reepav, was not able to be tested in the UCB apparatus because its thinness (12 mils) would not permit good gripping. This fabric was, however, tested by TransLab (Figure A1) and based on those results, would have probably exhibited a M_i in excess of 15,000 psi via the UCB test method. Although this fabric appears to offer an M_i capable of resisting cracking (at least at higher temperatures), its M_{PRE} is also high, which necessitates special placement procedures and skills.

The effect of asphalt impregnation on fabric moduli is most pronounced on M_{PRE} and M_i, and should be considered in any analytical model of pavements.

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Type of Fabric	Direction of Test	Thickness of the Fabric (inches)	Initial Length of the Fabric ℓ_o (inches)	Initial Load (P) (lbs)	Initial Elongation (Δ) (inches)	Initial Stress (psi) $\sigma_i = \frac{P}{A}$	Initial Strain (in./in.) $\varepsilon_i = \frac{\Delta}{\ell_o}$	Initial Modulus (psi) $M_i = \frac{\sigma_i}{\varepsilon_i}$
Trevira	Y	0.051	4.45	7.4	0.042	9.07	0.0094382	961
Trevira	X	0.051	4.40	14.0	0.038	17.16	0.00863636	1,987
Trevira	X	0.051	4.40	87.50	0.220	107.23	0.05000	2,144
Polyguard	Y	0.100	4.00	80.00	0.035	50.00	0.008750	5,714
BIDIM - 22	Y	0.051	4.25	20.00	0.055	24.51	0.01294	1,894
BIDIM - 22	X	0.051	4.45	17.2	0.095	21.35	0.02135	1,000
Fibretex 200	Y	0.073	4.50	8.3	0.090	7.11	0.0200	356
Fibretex 200	X	0.073	4.40	21.0	0.105	18.56	0.02386	778
Petromat	Y	0.040	4.20	20.0	0.070	31.25	0.01667	1,875
Petromat	Y	0.040	4.10	19.0	0.065	29.69	0.01585	1,873
Petromat	X	0.040	4.20	30.0	0.080	46.88	0.01905	2,461
Petromat	X	0.040	4.20	30.0	0.080	48.39	0.01905	2,540
Dupont T376	Y	0.014	4.00	Could not be tested. Since the fabric was very thin, slippage occurred in the clamping heads.				
Truetex MG 75	Y	0.056	4.25	24.00	0.060	26.79	0.01412	1,897
Truetex MG 75	Y	0.056	4.30	35.00	0.068	39.06	0.01581	2,471
Truetex MG 75	X	0.056	4.50	26.00	0.075	29.02	0.01667	1,741
Truetex MG 75	X	0.056	4.42	24.00	0.080	26.79	0.01810	1,480
Truetex MG 100	X	0.088	4.25	24.00	0.075	17.05	0.017647	966
Truetex MG 100	X	0.088	4.20	40.00	0.060	28.41	0.014286	1,989
Truetex MG 100	Y	0.088	4.10	15.00	0.095	11.52	0.023171	497
Truetex MG 100	Y	0.088	4.15	16.00	0.095	12.04	0.022892	526
Amopave	X	0.040	4.00	36.00	0.080	56.25	0.020000	2,813
Amopave	X	0.040	4.00	25.00	0.075	39.06	0.01875	2,083
Amopave	Y	0.040	4.10	40.00	0.100	62.50	0.024390	2,563
Amopave	Y	0.040	4.03	25.00	0.100	39.06	0.02481	1,574
Quline	Y	0.105	4.25	18.00	0.1102	10.71	0.02593	413
Quline	Y	0.105	4.10	60.00	0.3346	35.71	0.0816	438
Quline	X	0.105	4.00	12.00	0.07874	7.14	0.01969	363
Quline	X	0.105	4.25	13.00	0.06693	7.74	0.01575	491
Quline impregnated with AR-4000	Y	0.125	4.22	20.00	0.045	10.00	0.0106635	938
Quline impregnated with AR-4000	Y	0.125	4.00	44.00	0.100	22.00	0.025000	880
Quline impregnated with AR-4000	X	0.125	4.35	39.00	0.100	19.50	0.0252873	771
Quline impregnated with AR-4000	X	0.125	4.10	24.00	0.050	12.00	0.0121951	984
Petromat impregnated with AR-4000	Y	0.070	4.125	60.00	0.090	55.84	0.0218181	2,559
Petromat impregnated with AR-4000	Y	0.070	4.10	54.00	0.085	50.26	0.0207317	2,424

TABLE A1 - INITIAL MODULUS VALUE OF FABRICS IN BOTH X AND Y DIRECTIONS AFTER 10 PERCENT - 12.5 PERCENT PRECONDITIONING

Type of Fabric	Thickness of Fabric (inches)	Direction of Test	Number of Tests	Average Modulus During Preconditioning (M_{PRE})	Average Modulus During Initial Loading (M_i)	Average Secant Modulus (M_s)	Average Poisson's Ration (V)
Quline	0.105	Y	2	310	426	170	0.17
Quline	0.105	X	2	352	427	615	0.14
Petromat	0.040	Y	2	1,771	1,874	1,479	0.24
Petromat	0.040	X	2	2,133	2,501	2,066	0.23
Truetex MG 75	0.056	Y	2	1,468	2,184	2,937	0.24
Truetex MG 75	0.056	X	2	879	1,611	1,405	0.22
BIDIM - 22	0.051	Y	1	1,886	1,894	2,589	0.27
BIDIM - 22	0.051	X	1	478	1,000	1,560	0.41
Fibretex 200	0.073	Y	1	200	356	404	0.31
Fibretex 200	0.073	X	1	615	778	848	0.23
Trevira	0.051	Y	1	548	961	1,194	0.43
Trevira	0.051	X	2	950	2,066	1,704	0.38
Truetex MG 100	0.088	Y	2	265	512	622	0.24
Truetex MG 100	0.088	X	2	767	1,478	1,943	0.25
Amopave	0.040	Y	2	1,632	2,069	2,316	0.21
Amopave	0.040	X	2	2,530	2,448	1,784	0.24
Quline (impregnated with AR-4000)	0.125[a]	Y	2	248	909	214	0.16
	0.125	X	2	340	878	516	0.16
Petromat[b] (impregnated with AR-4000)	0.070[a]	Y	2	1,317	2,492	1,147	0.21

[a]Thickness of the fabric measured by a hand micrometer.

[b]16 in. × 8 in. Petromat sample shrunk to 11 in. × 5.5 in. when heated in oven at 300°F.

TABLE A2 - MODULUS VALUES FOR 16.0 IN. x 4.0 IN. FABRICS TESTED IN TWO DIRECTIONS

	Direction of Test	M_s TransLab Value (psi)	M_s UCB Value (psi)	M_s Diff. (%)	M_i TransLab Value (psi)	M_i UCB Value (psi)	M_i Diff. (%)
Quline	S[1]	350	615	+75	80	427	+434
	W[1]	160	170	+6	210	426	+103
Petromat	S	2294	2066	-11	1263	2501	+98
	W	1453	1479	0	1784	1874	+5
TrueTex MG75	S	1936	2937	+51	1110	2184	+97
	W	666	1405	+111	357	1611	+351
Bidim C-22	S	1878	2589	+38	1759	1894	+8
	W	871	1560	+79	582	1000	+72
Fibretex 200	S	1025	848	-21	908	778	-14
	W	368	404	+10	273	404	+48
Trevira	S	1666	1704	+23	1280	2066	+61
	W	810	1194	+47	540	961	+78
TrueTex MG100	S	896	1943	+117	592	1478	+150
	W	414	622	+50	530	512	-3
Amopave	S	1890	2316	+23	1020	2069	+103
	W	1480	1784	+20	1440	2448	+70

[1] S = stronger direction
W = weaker direction

TABLE A3 - COMPARISON OF SECANT MODULI VALUES FROM TRANSLAB AND UCB TESTING

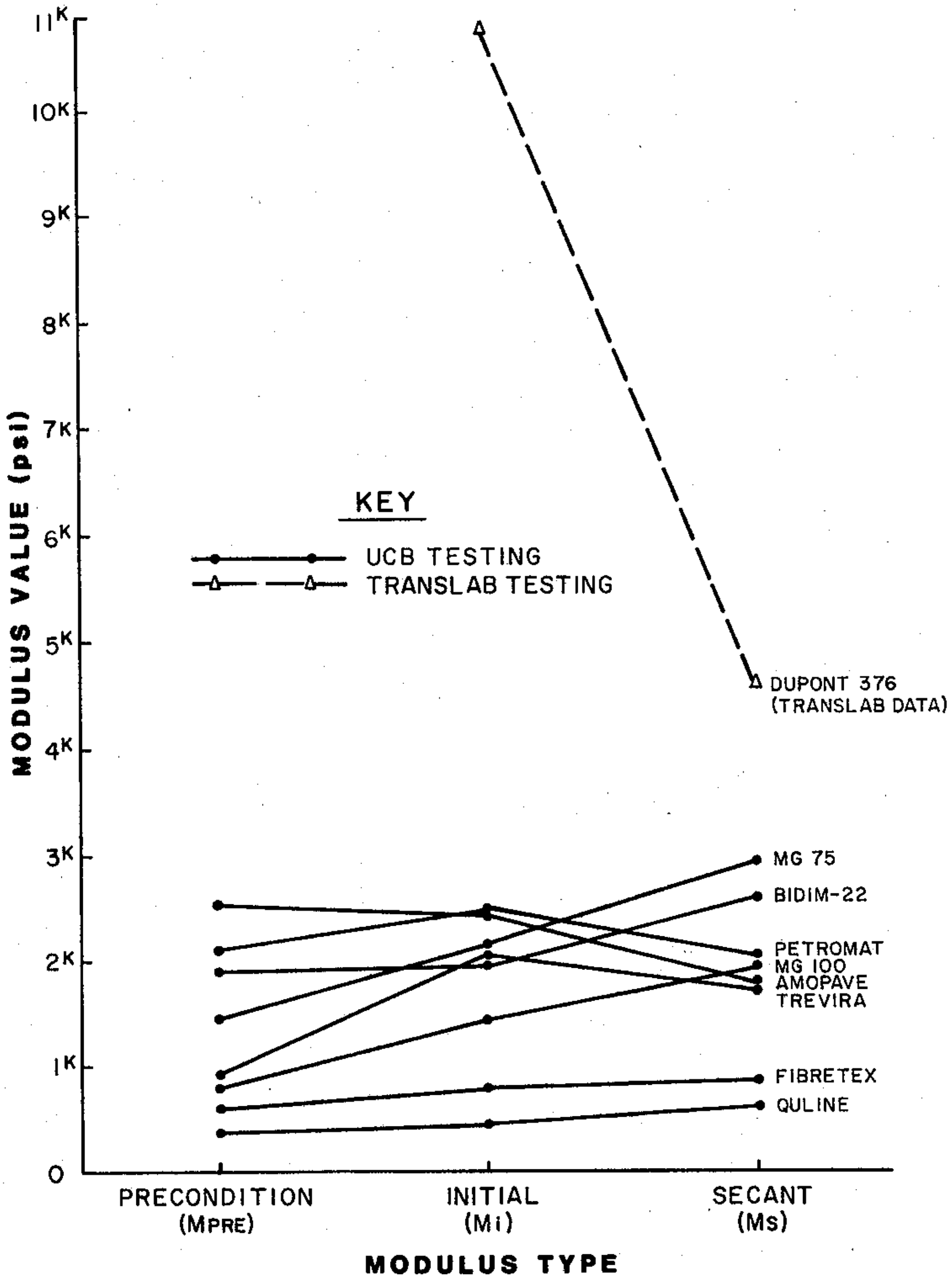

FIGURE A1. Comparison of Moduli for Different Fabrics (Stronger Direction Only)

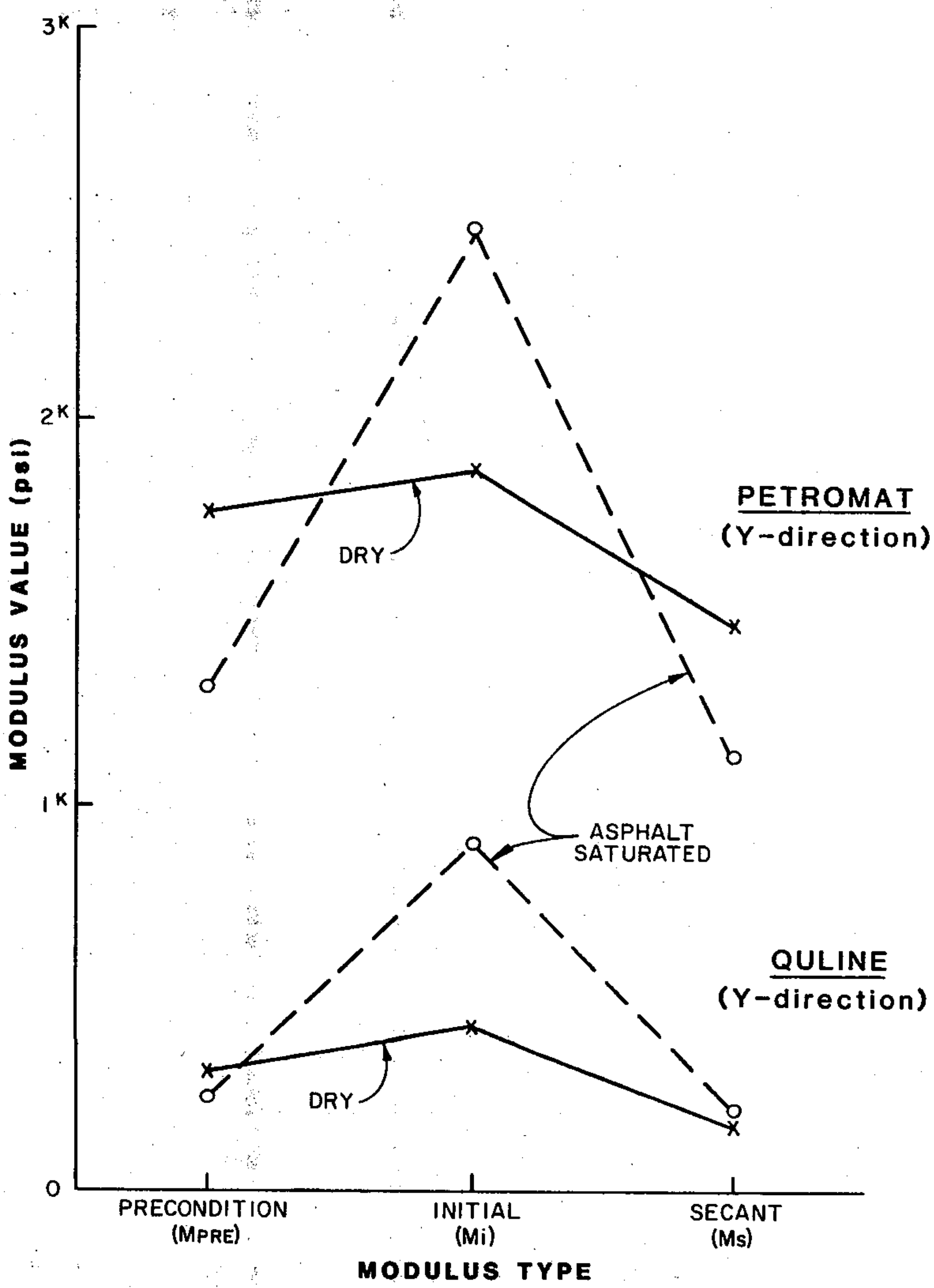

FIGURE A2. Effect of Asphalt Saturation on Fabric Moduli of two Fabrics

APPENDIX B

Caltrans SSP 39.20

Pavement Reinforcing Fabric

(Paras. 2, 4, 8, and 11 revised, Para. 9 new.)
(Use for reinforcing asphalt concrete only.)
(Use in Central Valley and Southern Counties. Not approved for mountainous/heavy precipitation nor severe freeze/thaw areas.)
[Para. 18 - Revise "paving asphalt (paint binder)" to read "asphaltic emulsion (paint binder)" if quantity of asphalt binder is small and there is a contract item for asphaltic emulsion (paint binder).]

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CALIFORNIA DEPARTMENT OF TRANSPORTATION

39.20
12-16-82

10-1.____ PAVEMENT REINFORCING FABRIC.--Pavement reinforcing fabric shall be placed where shown on the plans, and at locations designated by the Engineer.

Pavement reinforcing fabric shall be nonwoven polyester, polypropylene, or polypropylene/nylon materials conforming to the following when tested in conformance with the listed ASTM Designation: 2

Weight, Oz./sq.yd., ASTM Designation: D 1910	3.0 to 8.0
Grab Tensile Strength (1-inch grip), Pounds, ASTM Designation: D 1117	90 min.
Elongation at Break, Percent, ASTM Designation: D 1117	40 min.
Fabric Thickness, ASTM Designation: D 461	12 to 100 mils.

Pavement reinforcing fabric shall be accompanied with a Certificate of Compliance conforming to the provisions in Section 6-1.07, "Certificates of Compliance," of the Standard Specifications. 3

The fabric shall be protected from exposure to ultraviolet rays and kept dry until placed. 4

Before spreading asphalt binder, large cracks, spalls and chuckholes shall be repaired as directed by the Engineer, and such repair work will be paid for as extra work as provided in Section 4-1.03D of the Standard Specifications. 5

Asphalt binder for pavement reinforcing fabric shall conform to the provisions of Section 92, "Asphalts," of the Standard Specifications and shall be Grade AR-4000 unless otherwise ordered by the Engineer. 6

Asphalt binder for pavement reinforcing fabric shall be applied at an approximate rate of 0.25-gallon per square yard of surface covered. The exact rate of application will be determined by the Engineer. The width of the asphalt binder spread shall be the width of the fabric mat plus 3 inches on each side. 7

The fabric shall be stretched, aligned, and placed with no wrinkles that lap. The test for lapping shall be made by gathering together the fabric in a wrinkle. If the height of the doubled portion of extra fabric is 1/2 inch or more, the fabric shall be cut to remove the wrinkle, then lapped in the direction of paving. Lap in excess of 2 inches shall be removed. 8

Pavement reinforcing fabric shall be omitted for the portion of conform tapers that are less than 0.08[redacted] thick. 9

If manual laydown methods are used, the fabric shall be unrolled, stretched, aligned, and placed in increments of approximately 30 feet. 10

Adjacent borders of the fabric shall be lapped 2 to 4 inches. The preceding roll shall lap 2 to 4 inches over the following roll in the direction of paving at ends of rolls or at any break. At fabric overlaps, both tack coat and fabric shall lap the previously placed fabric by the same amount. 11

Seating of the fabric with rolling equipment after placing will be permitted. Turning of the paving machine and other vehicles shall be gradual and kept to a minimum to avoid damage. 12

A small quantity of asphalt concrete, to be determined by the Engineer, may be spread over the fabric immediately in advance of placing asphalt concrete surfacing in order to prevent fabric from being picked up by construction equipment. 13

Public traffic shall not be allowed on the bare reinforcing fabric, except that public cross traffic shall be allowed to cross the fabric, under traffic control, after the Contractor has placed a small quantity of asphalt concrete over the fabric. 14

Care shall be taken to avoid tracking binder material onto the pavement reinforcing fabric or distorting the fabric during seating of the fabric with rolling equipment. If necessary, exposed binder material shall be covered lightly with sand. 15

Full compensation for advance spreading of asphalt concrete over the fabric shall be considered as included in the contract prices paid per ton for aggregate (asphalt concrete) and paving asphalt (asphalt concrete) and no additional compensation will be allowed therefor. 16

Pavement reinforcing fabric will be measured and paid for by the square yard for the actual pavement area covered. 17

Paving asphalt used as binder will be measured and paid for by the ton as paving asphalt (paint binder). 18

The contract price paid per square yard for pavement reinforcing fabric shall include full compensation for furnishing all labor, materials (except binder), tools, equipment and incidentals, and for doing all the work involved in furnishing and placing pavement reinforcing fabric, including lapping, complete in place, as shown on the plans, as required by the Standard Specifications and these special provisions, and as directed by the Engineer. 19

Fabric	Lightest tack coat rate found to be acceptable (gal/yd^2)
Amoco 4545	0.30
Bidim C-22	0.25
Bidim C-34	0.35
TrueTex MG75	0.30
TrueTex MG100	0.35
Trevira T1115	0.30
Nicolon 50	0.30
Petromat	0.25
DuPont T376	0.15
Q-Trans-50	0.35
Fibretex 200	0.30

Table 5. Recommend Tack Coat Rates for Various Fabrics on a New AC Leveling Course