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16. ABSTRACT
An analytical study of asphalt concrete (AC) overlays (with fabric interlayers) of Portland cement concrete (PCCP) is presented. The study employs special finite element analysis, suitable for microcomputers, to evaluate the effect of fabric interlayers on stresses and strains in an AC overlay. The influence of fabric location and fabric properties such as thickness, modulus, and Poisson's ratio is investigated.

Another phase of this study determined the tensile properties of various paving fabrics using a special "high aspect ratio" tensile test.

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

ANALYTICAL STUDY OF FABRIC INTERLAYER EFFECTS

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NOTICE

The contents of this report reflect the findings and views of the University of California, Berkeley, which is responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the State of California or the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

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It should be noted that the UCB pavement model is simplistic in that it does not consider all causes of overlay stress and cracking. As an example, the effect of differential vertical movement is not considered. For this reason, the study's findings should not be used in a conclusive, absolute fashion, but rather as a diagnostic tool to help assess the effects of variables such as interlayer thickness and strength.

CONVERSION FACTORS

English to Metric System (SI) of Measurement

Quantity	English unit	Multiply by	To get metric equivalent
Length	inches (in)or(")	25.40 .02540	millimetres (mmm) 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) acres	.09290 .4047	square metres (m^2) 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) feet per second (fps)	.4470 .3048	metres per second (m/s) 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) kips (1000 lbs)	4.448 4448	newtons (N) newtons (N)
Thermal Energy	British thermal unit (BTU)	1055	joules (J)
Mechanical Energy	foot-pounds (ft-lb) foot-kips (ft-k)	1.356 1356	joules (J) joules (J)
Bending Moment or Torque	inch-pounds (ft-lbs) foot-pounds (ft-lbs)	.1130 1.356	newton-metres (Nm) 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)

ANALYTICAL STUDY OF FABRIC INTERLAYER EFFECTS

PART I: Analytical Study of Overlays with Fabrics

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June 1984

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Ms. Phyllis De Fabio typed the manuscript and Ms. Gloria Pelatowski prepared the figures.

The authors also wish to acknowledge the assistance provided by Mr. Roger Smith of the Transportation Laboratory for his willingness to share his experience with us and to be available for discussions when asked by us.

TABLE OF CONTENTS

PART I

ANALYTICAL STUDY OF ASPHALT CONCRETE OVERLAYS WITH FABRICS

INTRODUCTION

For a number of years the staff of the Transportation Laboratory of CALTRANS, in conjunction with the Transportation Districts, have been experimenting with the use of fabrics in asphalt concrete overlays on plain, jointed, portland cement concrete (pcc) pavements to mitigate the problem of reflection cracking in overlays of this type of pavement. The purpose of this investigation, with support from the Transportation Laboratory of CALTRANS, has been to examine the problem analytically.

Specifically, the report describes the results of a series of analyses in which the pavement structure has been idealized as a series of finite elements and programmed for solution on a microcomputer. These analyses included both the effects of load on one side of the joint at the surface of the overlay pavement and a change in pavement temperature. Included were studies to determine:

1. The optimum location of the fabric interlayer in the overlay;
2. Sensitivity of the finite element idealization of the pavement structure to a number of factors including fabric modulus, fabric thickness, and Poisson's ratio of the fabric.
3. Variation of the tensile stresses, shear stresses, and tensile strains in the overlay in the vicinity of the joint (crack tip zone) with change in parameters.
4. The influence of placing two layers of fabric within the overlay at different depths.
5. The thickness of asphalt concrete overlay without fabric providing equivalent response to a 4-in. 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 Fig. 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 above 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

Systems

The finite element analyses have been 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 (Control Program for Microprocessor) system.

A two-drive Radio Shack TRS-80 Model II, TRS-80 Model IV printer, and 8-in. 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

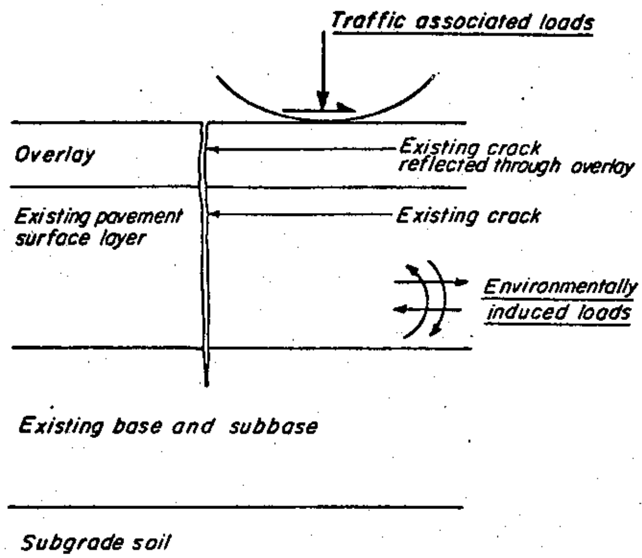


Fig. 1 - Schematic diagram of reflection cracking.

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

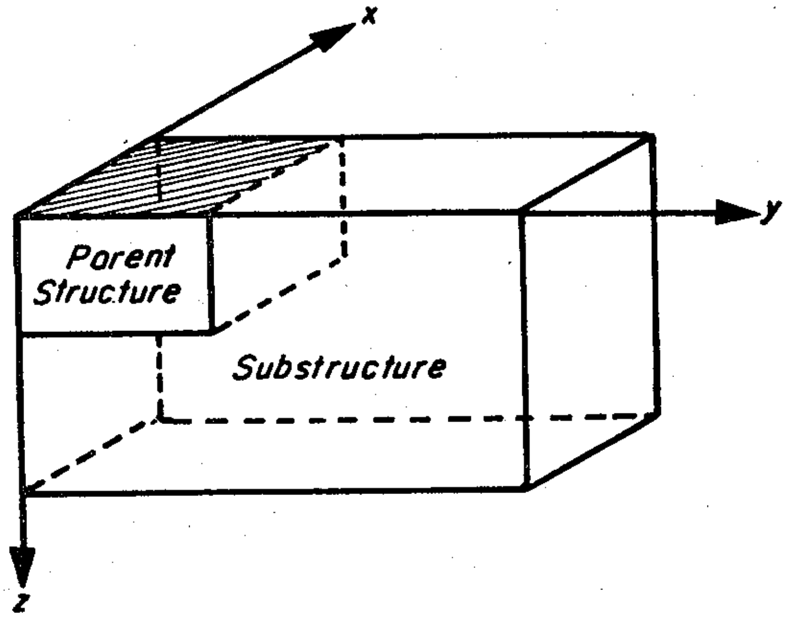
<u>Pavement Model</u>

A plane strain representation was used to model the existing jointed concrete pavement layer, untreated base, and subgrade together with the asphalt concrete overlay with or without a fabric layer or layers. Movements were restrained in the X-direction and were permitted to occur in the Y-Z plane in this instance (a necessary outcome of the plane-strain simplification), Fig. 2.

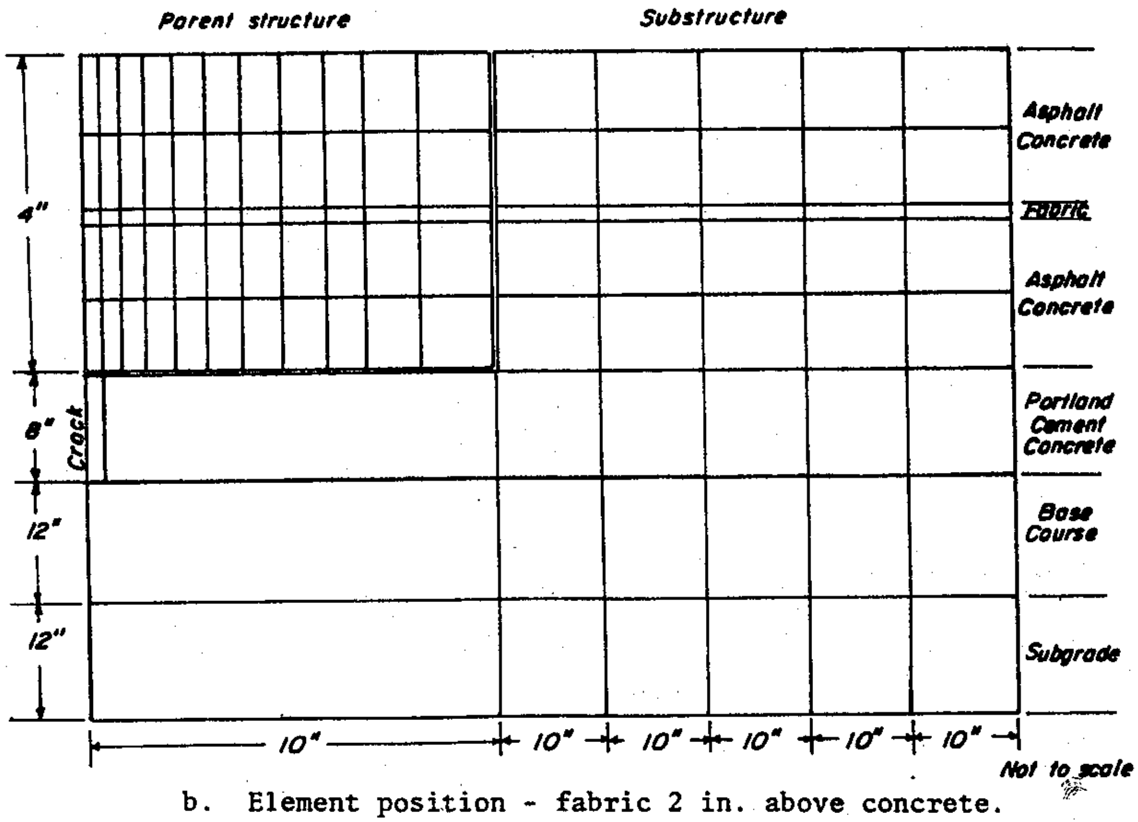
The substructure consisted of the existing cracked concrete section plus the portion of the asphalt concrete overlay outside of the loaded area, Fig. 2. Forty-four (44) elements and 207 nodes were used to subdivide this part of the system including: subgrade , 6 elements; base course , 6 elements; pcc, 6 elements; asphalt concrete overlay, 20 elements; crack (joint in concrete), 1 element; fabric, 5 elements.

The parent structure, the 10-in. wide segment of asphalt concrete overlay subjected to the 90 psi uniformly distributed load on one side of the joint, Fig. 2, contained 55 elements and 253 nodes.

The terms <u>coarse mesh</u> and <u>fine</u> mesh shown in Fig. 2 represent the substructure and parent structures respectively.



a. 3-dimensional view.



b. Element position - fabric 2 in. above concrete.

Fig. 2 - Finite element idealization of overlaid pavement system.

When the substructuring approach is used, the program follows an iterative technique. The program first analyzes the substructure (existing cracked pavement and the part of the overlay not subjected to traffic loads) and determines the stiffness matrix equations for the assigned joints and the superjoints that surround the parent structure (fine mesh subjected to traffic loads). This information is stored in the memory (on disks) of the microcomputer under the file name of substructure (SUBS). The SUBS program is executed prior to the analysis of the parent structure and the information related to the substructure boundary nodes (superjoints) and their interlocking with the parent structure is transferred into the memory. Next in sequence, the program analyzes the parent structure for the given traffic loads and the temperature variations and determines the displacements, stresses, and strains for each node of the parent structure. In the third phase, the substructure is reanalyzed by executing the RECOVER and PLANF programs in order. Displacements, stresses, and strains for each node existing in the structure are determined for the traffic loads transmitted through the parent structure to the superjoints located around the edge elements of the substructure and for the temperature drop assigned.

Analysis Parameters

A number of input parameters were required for the analyses and included: pavement temperatures, traffic loads, stiffnesses and thicknesses of the pavement layers and fabric, and thermal characteristics of the various layers.

Temperature. An average air temperature of 70°F was assumed, and temperature drops of 30°F and 40°F were used to ascertain temperature induced stresses. A solution of the heat conduction equation developed by Barber (6) was used to ascertain the temperature distribution with depth over a 24-hour period. The

30°F and 40°F changes in air temperature correspond to maximum values of temperature changes within the pavement of 26°F and 34.5°F respectively.

Parameters used in the solutions for temperature distribution are:

Parameter	Assumed Value
Surface Coefficent, h	9.95 BTU per ft^2 per hr., °F
Thermal Conductivity, k	0.70 BTU per ft^2 per hr., °F, ft
Unit Weight,	143.2 lb per ft^3
Solar Radiation, L	600 Langleys per day
Specific Heat, C	0.22 BTU per lb, °F

Loading Conditions. An 18,000 axle load was used to provide a guide to the magnitude of stress to be applied to a portion of the pavement idealized by the finite element process. The loads were considered to be applied on dual tires with a total contact area of 200 sq. in. resulting in a contact stress of 90 psi, which was applied to one side of the joint over a 10-in. length as shown in Fig. 2. Since the plain strain finite idealization has been used, the actual total load, if integrated across the pavement width, would be substantially larger than the actual value of 18,000 lb. Thus, while the absolute values for stresses, strains, and displacements may, therefore, be larger than actually observed in-situ, a relative measure of pavement and materials response will be obtained for the conditions analyzed.

Pavement components. The pavement consisted of subgrade, untreated base, jointed portland cement concrete, and an overlay of asphalt concrete with or without a fabric layer. Thicknesses, stiffness characteristics, and thermal characteristics of the various layers are summarized in Table 1.

One thickness of asphalt concrete, 4 in. was used with fabric, while three thicknesses, 4, 6, and 8 in. were analyzed without the fabric material.

As noted in Table 1, the stiffness modulus characteristics of the asphalt concrete were estimated using the Shell procedure (7) with the following parameters:

Time of loading - 0.02^s or 0.2^s

Ring and Ball Softening Point - 55°C

Penetration Index (PI) - 0

Percent air voids - 5 percent

Asphalt volume - 12 percent

Aggregate volume - 83 percent

The resulting stiffness values as a function of temperature are shown in Fig. 3.

To obtain representative characteristics of the fabric to be used in the analyses, data developed by personnel at the Transportation Laboratory were carefully evaluated. In addition, data summarized in the report prepared by Oregon State University (8), as well as that developed by the Transport and Road Research Laboratory (TRRL) of Great Britain (9, 10) were invaluable.

The TRRL researchers have investigated the response of fabrics confined in soil (uniform normal compressive stress) to tensile forces for a range in width to length ratios (W/L) (9, 10). Stress vs. strain results for a needle punched fabric (BIDUM) for these loading conditions are shown in Fig. 4 (9). The researchers suggest that the convenient minimum dimensions of fabrics for this type of testing are w = 200 mm and ℓ = 100 mm (8 in. by 4 in).

Based on available data, the range in stiffness characteristics were selected as shown in Table 1. As seen in Table 1, three different fabric thicknesses were used in the computations. These thicknesses, as seen from the

TABLE 1 - PAVEMENT CHARACTERISTICS

Material	Thickness - in	Stiffness Modulus - psi	Poisson's Ratio	Coefficient of Thermal Expansion in. per in. × 10^{-6} per °F
Subgrade	12	5,000	0.45	10.0
Base	12	20,000	0.40	10.0
Portland Cement Concrete	8	3,000,000	0.20	3.9
Asphalt Concrete	4, 6, 8	Use of Shell procedure (See Fig. 3)	0.30	12.5
Fabric	0.05, 0.075, 0.10	500 - 10,000	0.2 - 0.45	0.1

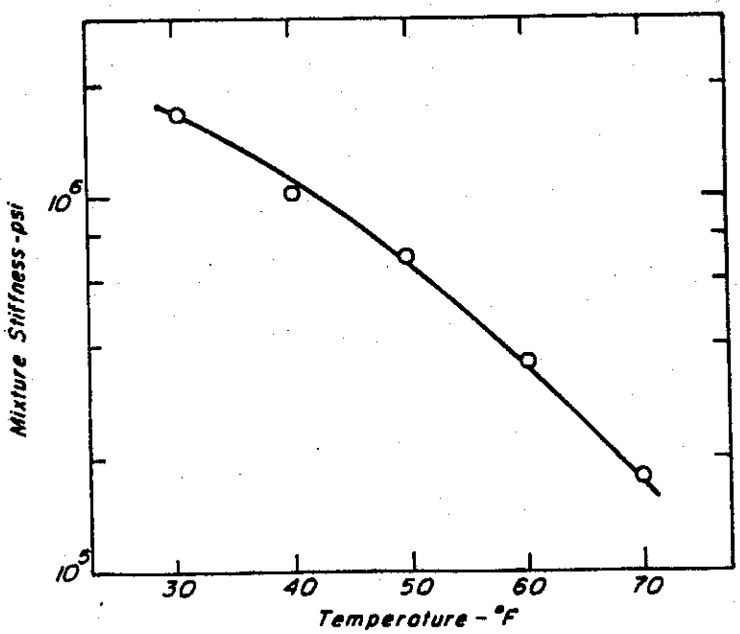
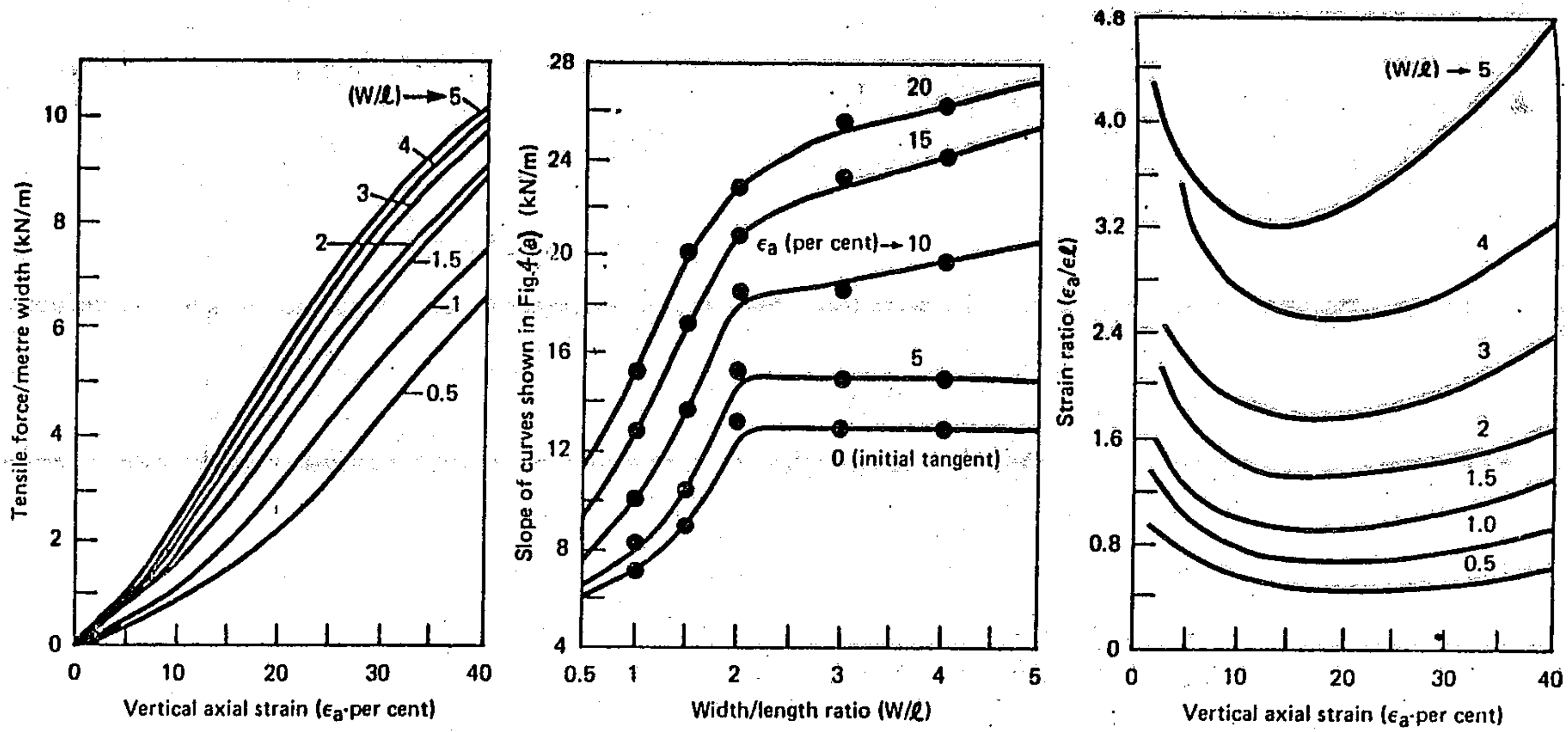


Fig. 3 - Asphalt concrete stiffness vs. temperature.



(a) Relationships between load and strain

(b) Variation of initial tangent and secant slopes

(c) Variation of strain ratio with axial strain

Fig. 4 - Results of uniaxial stress tests carried out on specimens of BIDIM (After Ref. 9).

data developed by CALTRANS staff and shown in Table 2, are representative of the range covered by existing asphalt impregnated fabrics. While a constant modulus was used for the fabric in a particular analyses, it is likely that a temperature dependent stiffness should be considered since the fabric is impregnated with asphalt for its use in these circumstances. This aspect will be examined subsequently.

For purposes of the analyses, the crack -- which extends through the p.c. concrete layer -- was treated as a low modulus element (E = 10 psi, ν = 0.10) with the same coeffcient of thermal expansion as the fabric and a width of 0.15 in.

RESULTS OF FINITE ELEMENT ANALYSES

In this section results of the various analyses are summarized. Essentially, this is a parameter study to ascertain, by analysis, general guidelines for the use of fabrics. A major question not answered by the analyses is the actual magnitude of the stresses and strains occurring in the system. Thus, one cannot guarantee for the optimum conditions found from the analyses that the fabric will actually perform for some prescribed period in-situ.

Optimum Location of Fabric Interlayer.

Analyses to determine the optimum location of the fabric interlayer in the asphalt concrete overlay were made for two different temperature reductions from 70°F, namely 30° and 40°, and for four locations of fabric -- 0, 1, 2, and 3 in. above the existing p.c. concrete layer.

Two thicknesses of fabric were used -- 0.1 in. and 0.075 in.; the modulus of the fabric was set at 1,500 psi and was assumed to be independent of temperature. A value of 0.45 was used for Poisson's ratio of the fabric.

Maximum principal tensile stresses and strains directly above the crack in the concrete (at crack tip) and directly above the crack on top of the

TABLE 2 - ASPHALT-SATURATED THICKNESS

Fabric (Manufacturer)	Average* (mils)
Amopave (Amoco)	40
Bidim C-22 (Monsanto)	55
Bidim C-34 (Monsanto)	67
Truetex MG 75 (TrueTemper)	55
Truetex MG100 (TrueTemper)	70
Repave T376 (DuPont)	21
Fibretex 200 (Crown Zellerbach)	61
Duraglas B65 (Johns-Manville)	83
Quline (Quline)	72
Petromat (Phillips)	45
Nicofab SC (Nicolon)	61
Trevira (Hoechst)	44

*Average of five measurements using 1/4 in. diameter micrometer on fabric discs recovered from permeability test briquettes.

fabric were determined since these were judged to be the most critical locations where reflection cracks would initiate. In addition, shear stresses and principal tensile strains were investigated in the fabric layer since it was judged that these parameters would provide a relative measure of the performance of the fabric.

Variations of principal stresses at the crack tip and over the crack at the upper surface of the fabric are shown in Figs. 5 and 6 respectively for different locations (heights) of the fabric above the p.c. concrete layer. Results of computations for surface temperature changes of 30°F and 40°F are included. A fabric thickness of 0.1 in. was used for the 30°F temperature change, while the 0.075 in. thickness was used in the analysis with the 40°F change.

Crack tip stresses, that is, the stresses on the underside of the asphalt concrete layer directly over the cracked p.c. concrete layer, Fig. 5, decrease substantially as the fabric interlayer is placed nearer the surface of the p.c. concrete. On the other hand, the stresses developed above the crack in the asphalt layer in contact with the fabric decrease as the fabric is placed further from the concrete surface, Fig. 6, the decrease being more significant for the 30°F change in temperature.

Principal stresses and strains (in the asphalt concrete) at both the crack tip and over the crack at the fabric surface are shown in Figs. 7 and 8 respectively for a fabric thickness of 0.075 in. and the 40°F temperature change. Also shown in these figures are crack tip principal stresses and strains for three thicknesses of asphalt concrete without fabric -- 4, 6, and 8 in. It should be noted that for the case where the fabric was placed on the existing p.c. concrete, the stresses and strains at the crack tip were assumed to be the same as the stresses at the fabric surface directly above the crack.

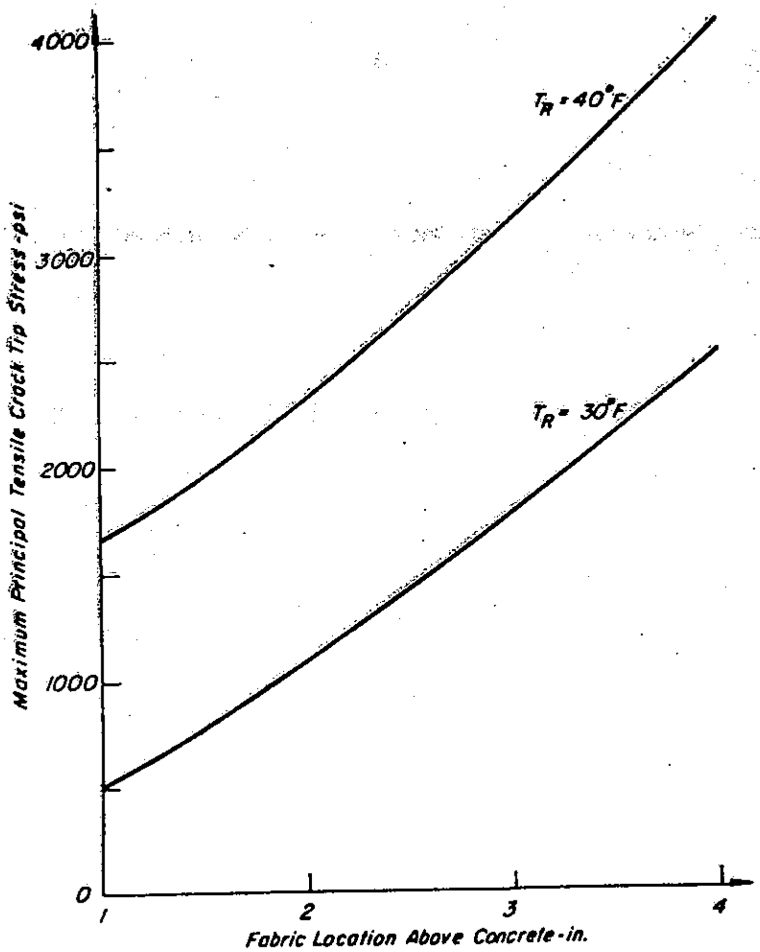


Fig. 5 - Maximum principal tensile stress at crack tip vs. fabric location above concrete; E_{fabric} = 1500 psi, t_{fabric} = 0.075 in., ν_{fabric} = 0.45.

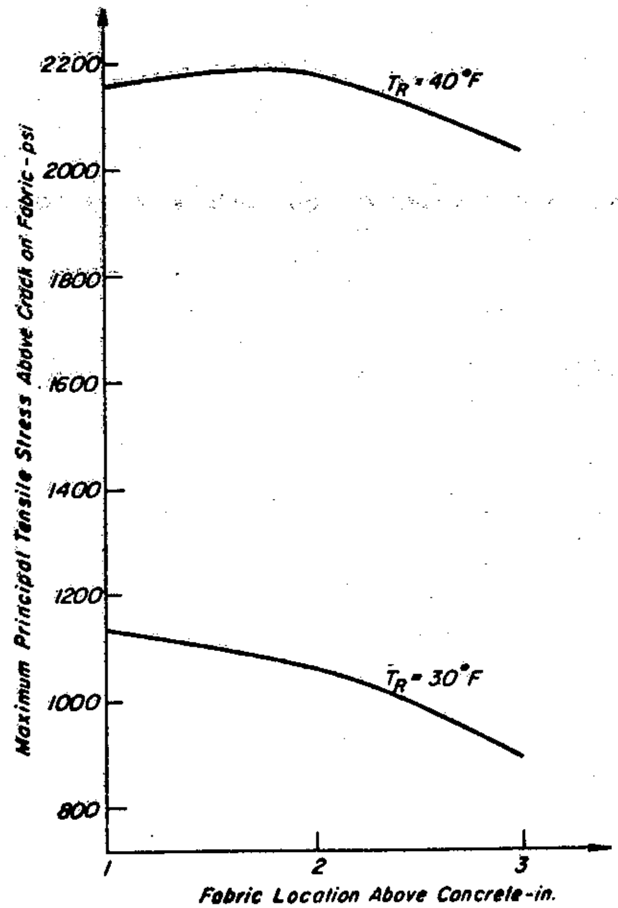


Fig. 6 - Maximum principal tensile stress above crack vs. fabric location above concrete; E_{fabric} = 1500 psi, t_{fabric} = 0.075 in.; ν_{fabric} = 0.45.

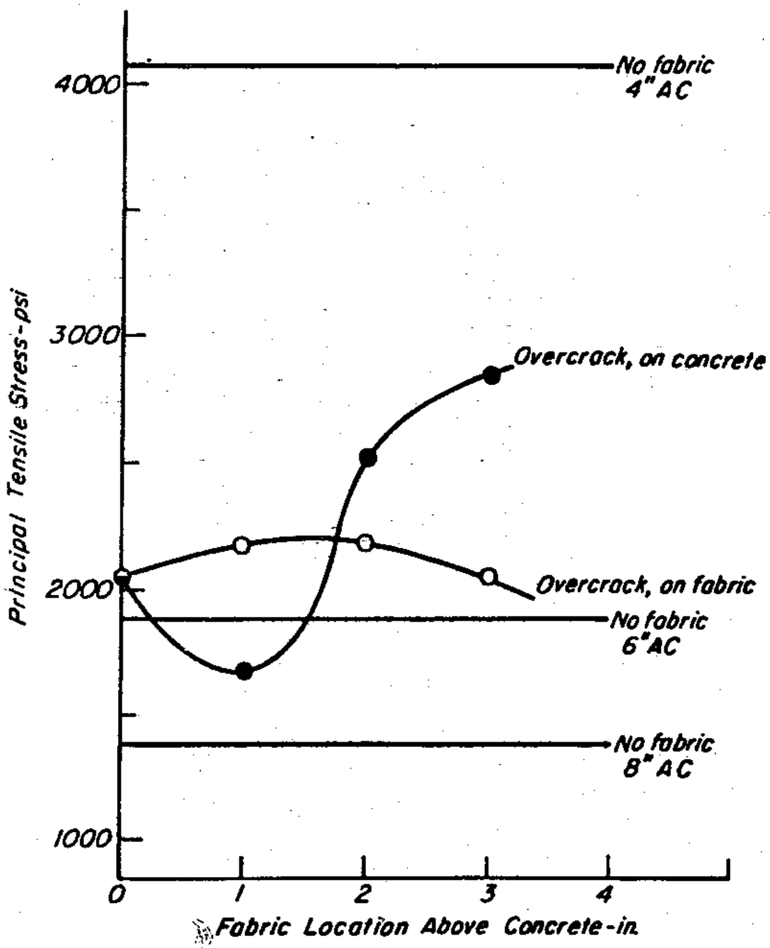


Fig. 7 - Principal tensile stress in asphalt concrete vs. fabric location; E_{fabric} = 1500 psi, t_{fabric} = 0.075 in., ν_{fabric} = 0.45, t_{ac} = 4 in., T_R = 40°F.

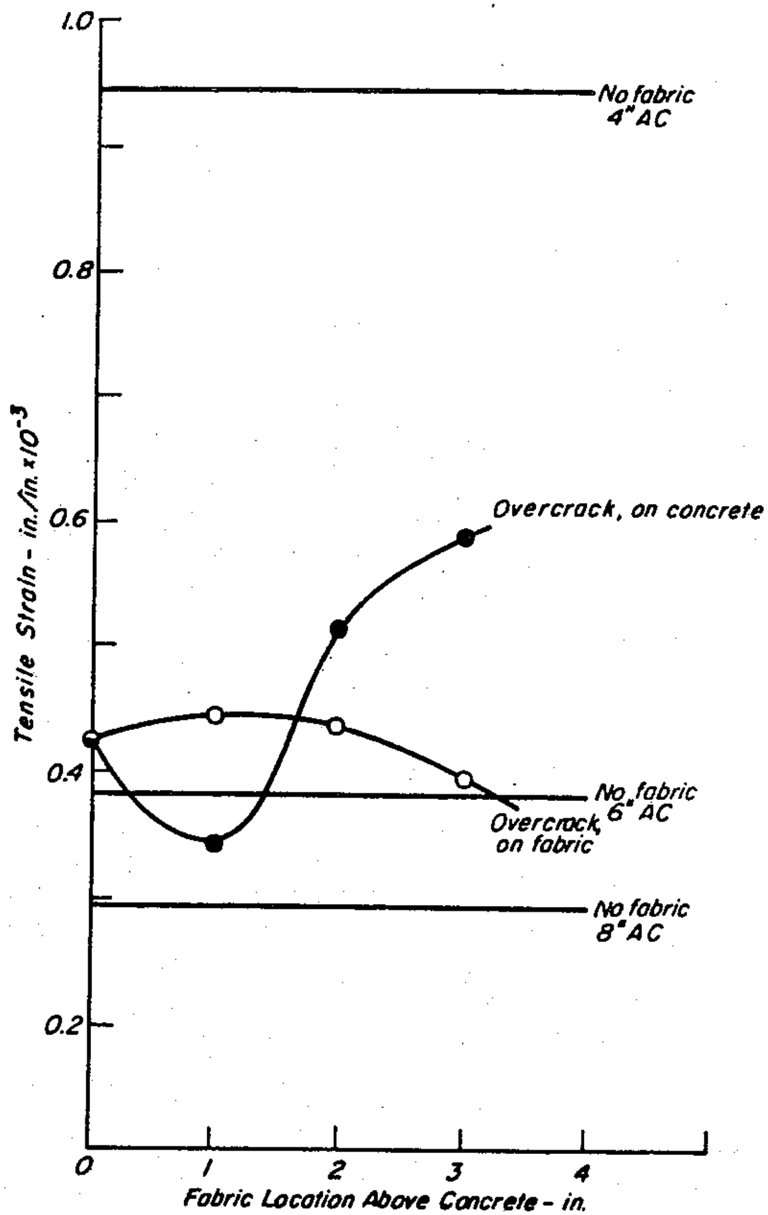
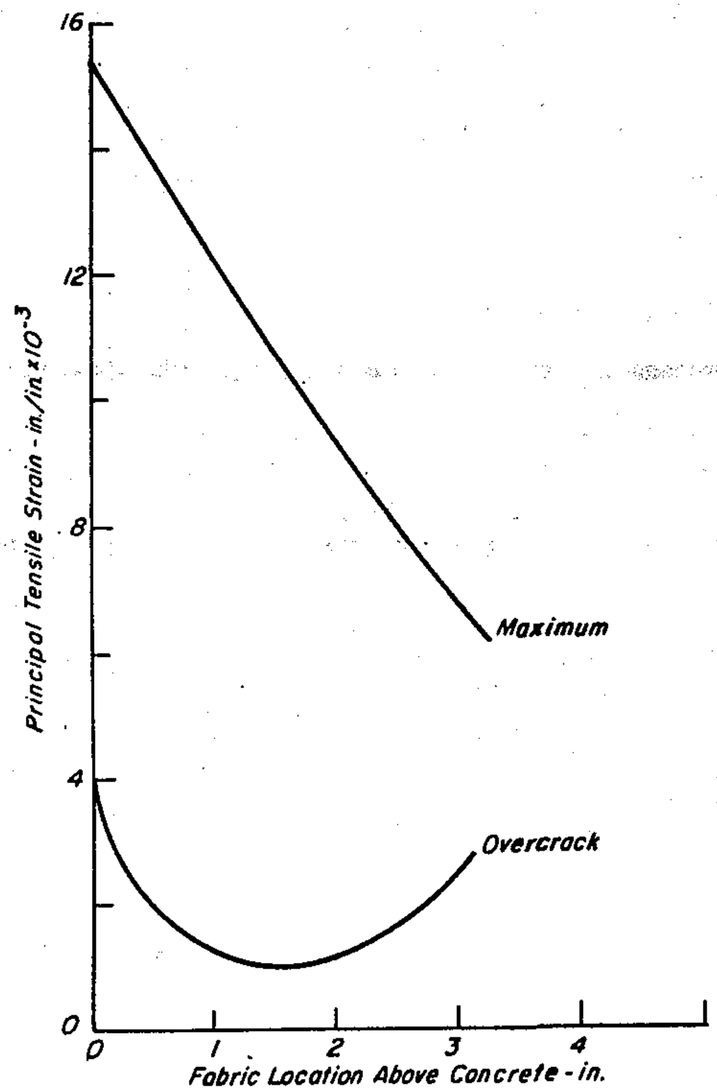


Fig. 8 - Principal tensile strain in asphalt concrete vs. fabric location; E_{fabric} = 1500 psi, t_{fabric} = 0.075 in., ν_{fabric} = 0.45, t_{ac} = 4 in., T_R = 40°F.



.g. 9 - Principal tensile strain in fabric vs. ıbric location; E_{fabric} = 1500 psi, t_{fabric} = 075 in., ν_{fabric} = 0.45, t_{ac} = 4 in., T_R = 40°F.

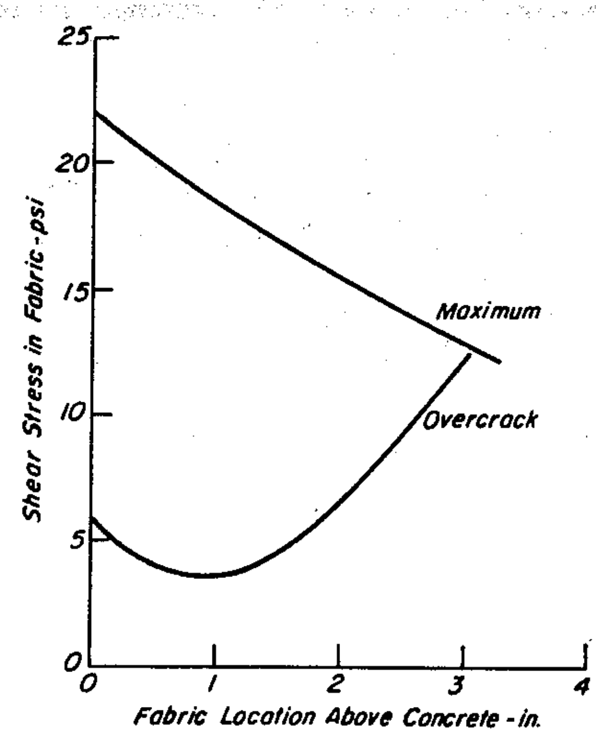


Fig. 10 - Shear stress in fabric vs. fabric location; E_{fabric} = 1500 psi, t_{fabric} = 0.075 in., ν_{fabric} = 0.45, t_{ac} = 4 in., T_R = 40°F.

The results of the analyses shown in Figs. 7 and 8 suggest, at least for the conditions assumed, that the fabric interlayer is equivalent in performance to 2 in. of asphalt concrete.

Principal tensile strains and shear stresses in the fabric itself determined for the various placement locations above the p.c. concrete surface, are shown in Figs. 9 and 10 respectively. In these figures it will be observed that the maximum values of both the principal strain and shear stress do not develop directly over the crack but in the elements near the boundaries of the parent structure (fine mesh) which are located about 10 in. from the crack. It will also be noted that the principal tensile strain and shear stress in the fabric directly over the crack reach their lowest values when the fabric is placed about one inch above the concrete layer. Maximum shear stresses, developing in the edge elements of the parent structure, increase, however, as the fabric is located closer to the surface of the p.c. concrete.

From these analyses, it is concluded that the optimum location of the fabric is about one inch above the concrete pavement. It is interesting to note that the CALTRANS practice has been to place the fabric on a leveling course of asphalt concrete 0.1 ft in thickness rather than directly on the concrete surface.

Influence of Fabric Stiffness Modulus

The influence of fabric stiffness on the pavement model response was investigated in two phases. In the first phase, moduli of 500, 1,500, 5,000, and 10,000 psi were assigned to the fabric. The fabric, 0.1 in. in thickness, was placed at one location, one inch above the p.c. concrete since this had been demonstrated to be an "optimum" location in the previous section. The overlay thickness was taken to be 4 in.

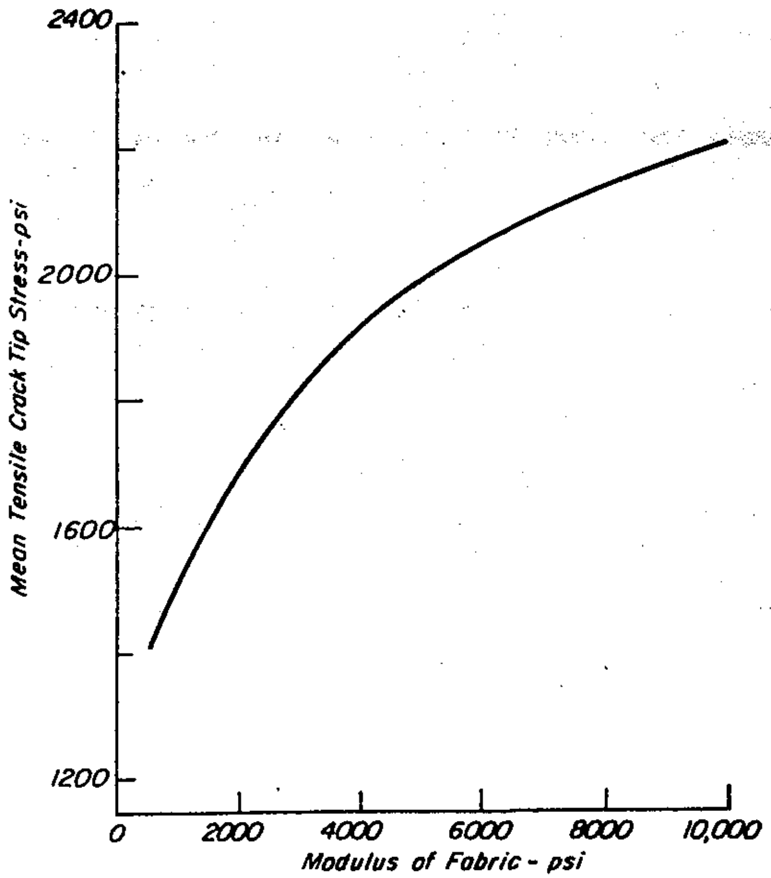


Fig. 11 - Mean tensile crack tip stress vs. fabric modulus; t_{fabric} = 0.1 in., fabric located 1 in. above concrete, T_R = 40°F.

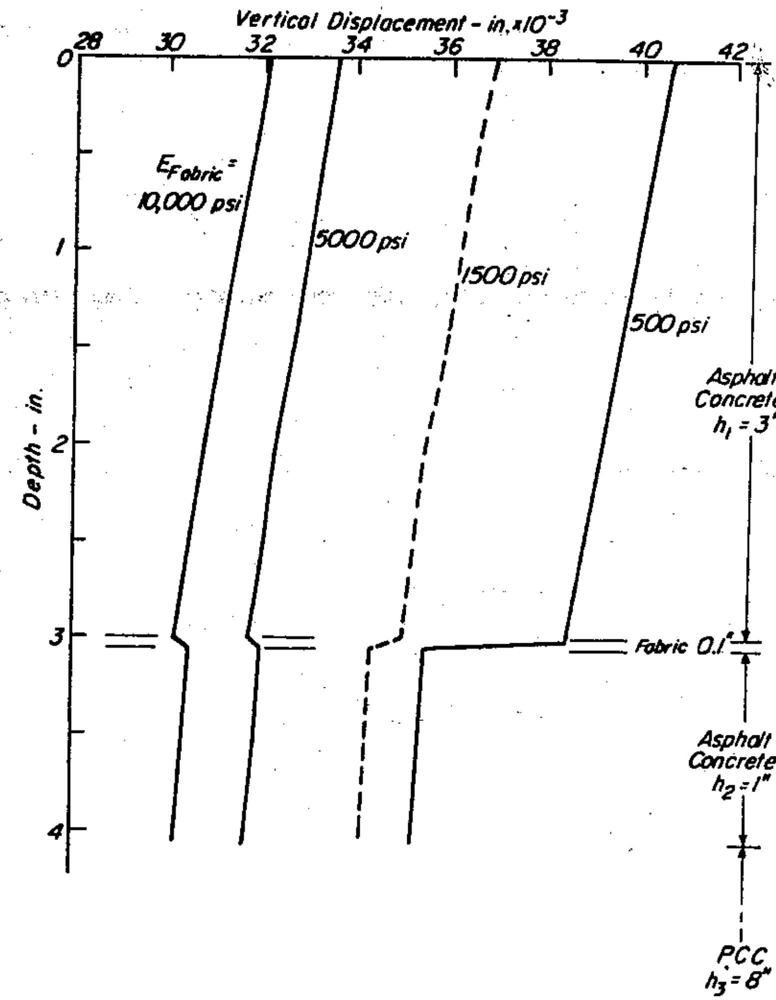


Fig. 12 - Average maximum displacements in asphalt concrete over the crack vs. depth; t_{fabric} = 0.1 in., fabric located 1 in. above concrete, T_R = 40°F.

The influence of fabric stiffness on the tensile stress at the crack tip is illustrated in Fig. 11, while Fig. 12 shows the variation of vertical displacements throughout the thickness of the overlay.

From an evaluation of the information contained in these two figures, one might conclude that the calculated response is more sensitive to fabric stiffness moduli in the lower range, less than 3,000 psi. Accordingly, in the second phase of this study, fabric moduli of 500, 1,000, 1,500, 2,000, and 3,000 psi were used in the analysis together with a fabric thickness of 0.075 in. As before, the fabric was located 1 in. above the p.c.c. layer.

For these conditions, principal tensile stresses and strains in the asphalt concrete in the elements directly over the crack in the concrete and in the same position directly above the fabric were estimated. These values are shown in Figs. 13 and 14. Principal tensile strains and shear stresses were determined for the fabric and are shown in Figs. 15 and 16.

The results of the analysis summarized in Figs. 11 through 14 suggest that the higher the fabric stiffness (modulus), the larger the principal tensile stresses and strains in the asphalt concrete directly over the crack in the p. c. concrete. Figs. 13 and 14 indicate a slight reduction in the principal tensile stress and strain in the asphalt concrete directly above the crack on the surface of the fabric layer for the range of 500 to 1,500 psi for fabric stiffness.

In the fabric layer the shear stresses (both those occurring directly over the crack and maximum values) increased with fabric stiffness. This also occurred for the principal tensile strain in the fabric directly over the crack. However, the maximum principal strains in the fabric reached a maximum value at a fabric stiffness of approximately 1,000 psi as seen in Fig. 16.

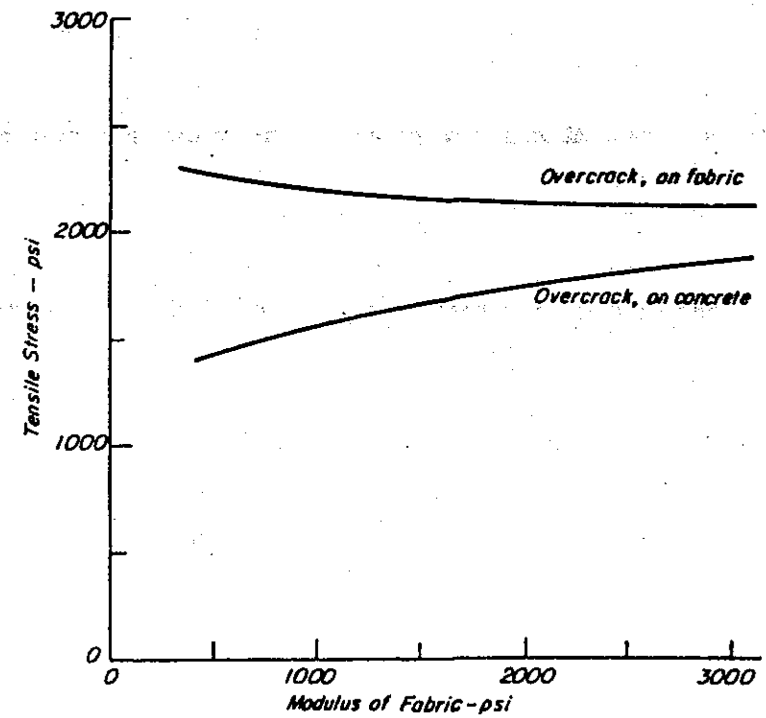


Fig. 13 - Principal tensile stress in asphalt concrete vs. fabric stiffness modulus; $t_{fabric} = 0.075$ in., fabric located 1 in. above concrete, $T_R = 40^oF$.

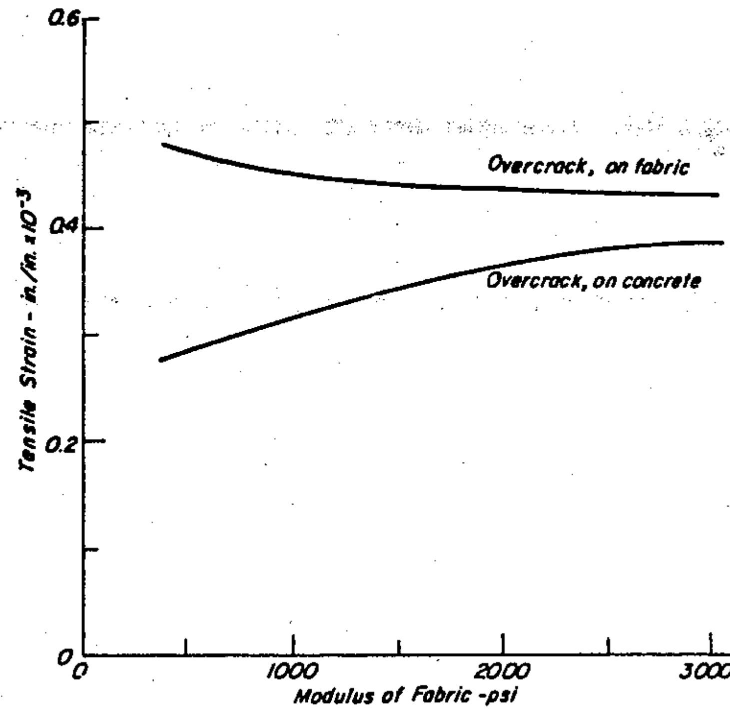


Fig. 14 - Principal tensile strain in asphalt concrete vs. fabric stiffness modulus; $t_{fabric} = 0.075$ in., fabric located 1 in. above concrete, $T_R = 40^oF$.

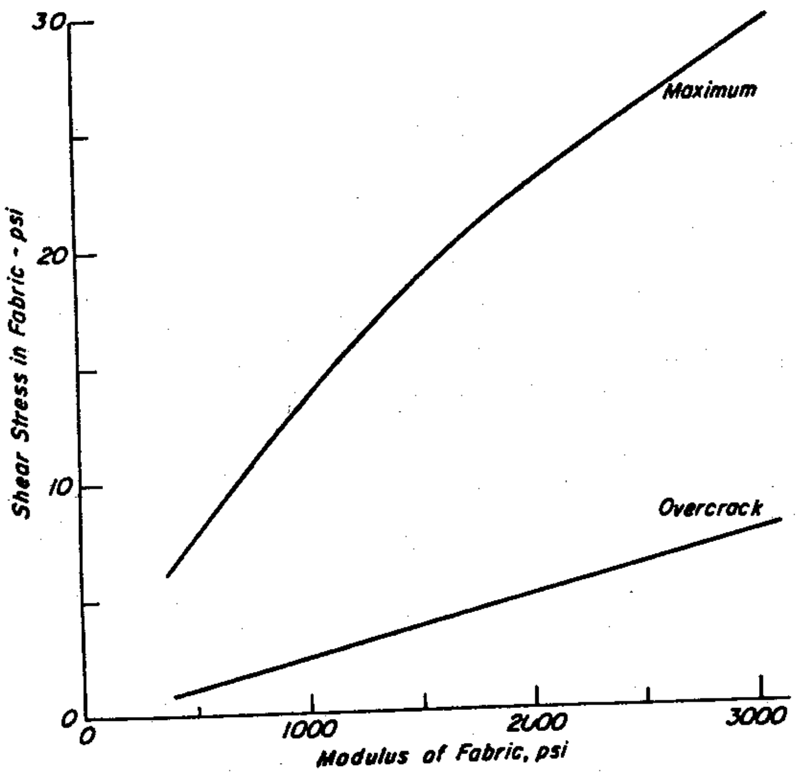


Fig. 15 - Shear stress in fabric vs. fabric stiffness modulus; t_{fabric} = 0.075 in., fabric located 1 in. above concrete.

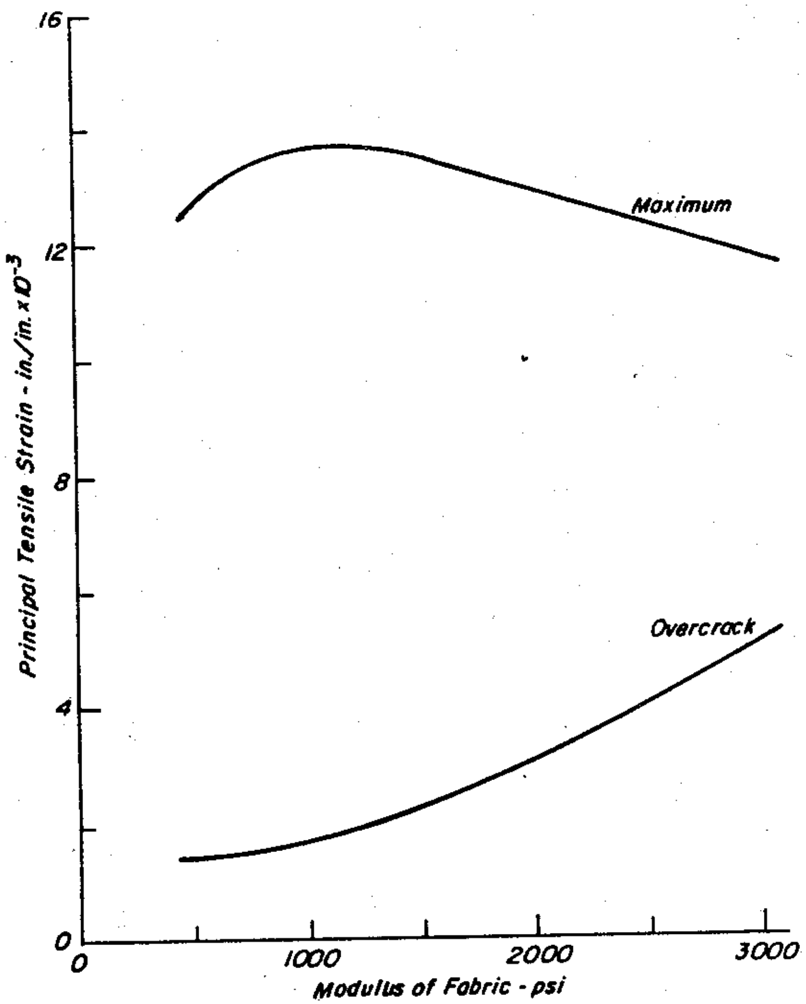


Fig. 16 - Principal tensile strain in fabric vs. fabric stiffness modulus; t_{fabric} = 0.075 in., fabric located 1 in. above concrete.

For these circumstances, that is, for the analyses illustrated in Figs. 12 through 16, optimum behavior for the assumed payment system was achieved when the fabric stiffness was about 1,500 psi or lower.

Influence of Fabric Thickness.

The influence of fabric stiffness on tensile stresses in the asphalt concrete and shear stresses in the fabric were analyzed for three fabric thicknesses -- 0.05, 0.075, and 0.10 in. These values cover the range in available fabric thicknesses as noted in Table 2. One fabric location 1 in. above the portland cement concrete layer, and one fabric stiffness, 1,500 psi, were used in the analysis. Results are shown in Figs. 17 and 18.

In Fig. 17 it will be noted that the principal tensile stress in the asphalt concrete directly over the crack in the p.c. concrete layer decreases with increase in fabric thickness; however, a slight increase in stress above the fabric was obtained. Maximum shear stress in the fabric decreased with increase in fabric thickness, while the shear stresses in the fabric directly over the crack show a slight increase, Fig. 18.

In general, from a stress relief standpoint, thicker fabric layers appear desirable.

Influence of Poisson's Ratio of Fabric

Results of analyses for a range in Poisson's ratios for the fabric from 0.2 to 0.45 are shown in Figs. 19 through 21. In these analyses the thickness of the asphalt concrete overlay was maintained at 4.0 in.; the fabric location was 1.0 in. above the concrete, its thickness was 0.075 in., and its stiffness 1,500 psi; a temperature drop of 40°F was assumed.

With increase in Poisson's ratio, the maximum shear stress in the fabric was reduced somewhat, as seen in Fig. 21; in addition, there was some reduction in the principal tensile stresses and strains in the asphalt concrete

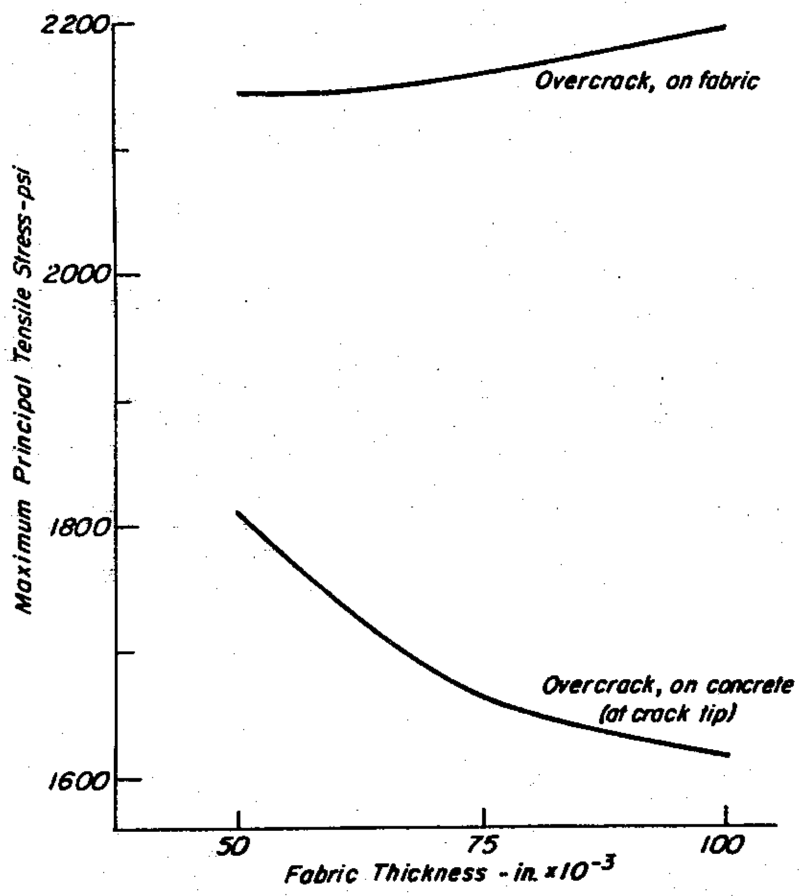


Fig. 17 - Maximum principal tensile stress in asphalt concrete vs. fabric thickness; E_{fabric} = 1500 psi, ν_{fabric} = 0.45, T_R = 40°F, fabric located 1 in. above concrete.

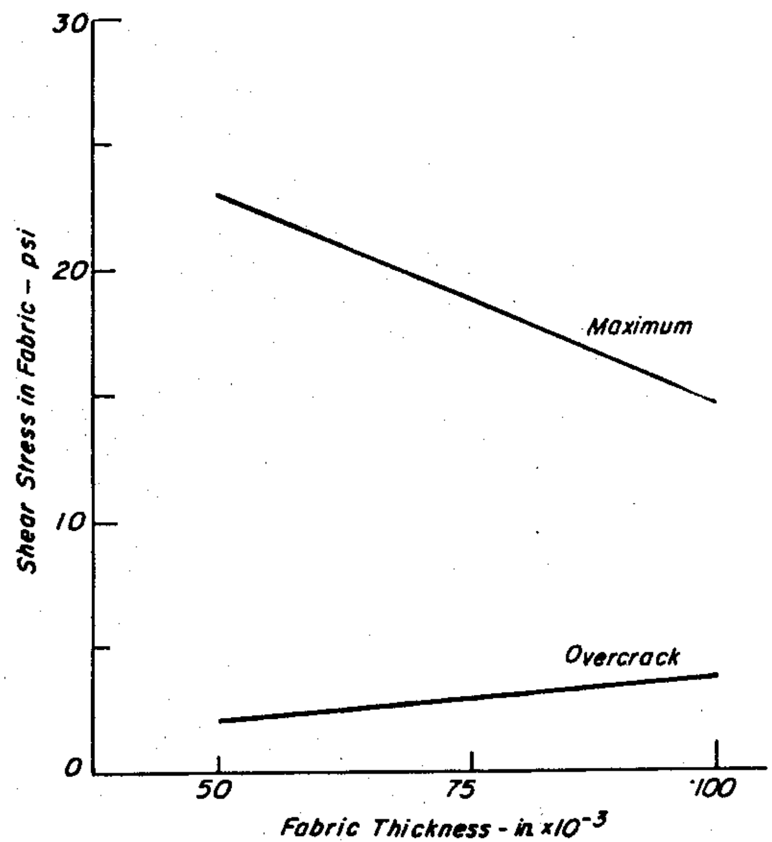


Fig. 18 - Maximum shear stress in fabric vs. fabric thickness; E_{fabric} = 1500 psi, ν_{fabric} = 0.45, T_R = 40°F, fabric located 1 in. above concrete.

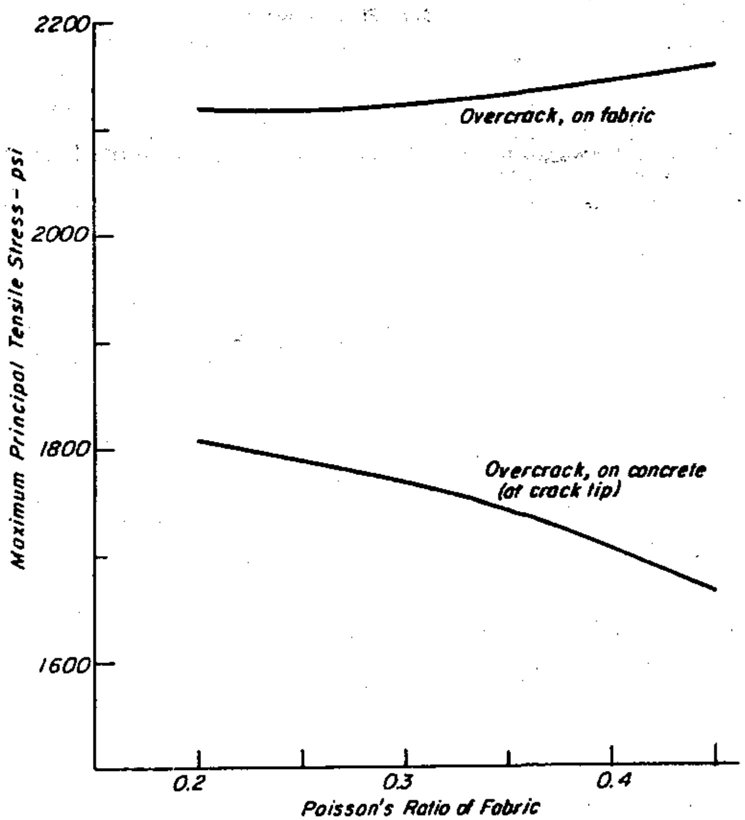


Fig. 19 - Maximum principal tensile stress in asphalt concrete vs. Poisson's ratio of fabric; E_{fabric} = 1500 psi, t_{fabric} = 0.075 in., t_{ac} = 4 in., T_R = 40°F, fabric located 1 in. above concrete.

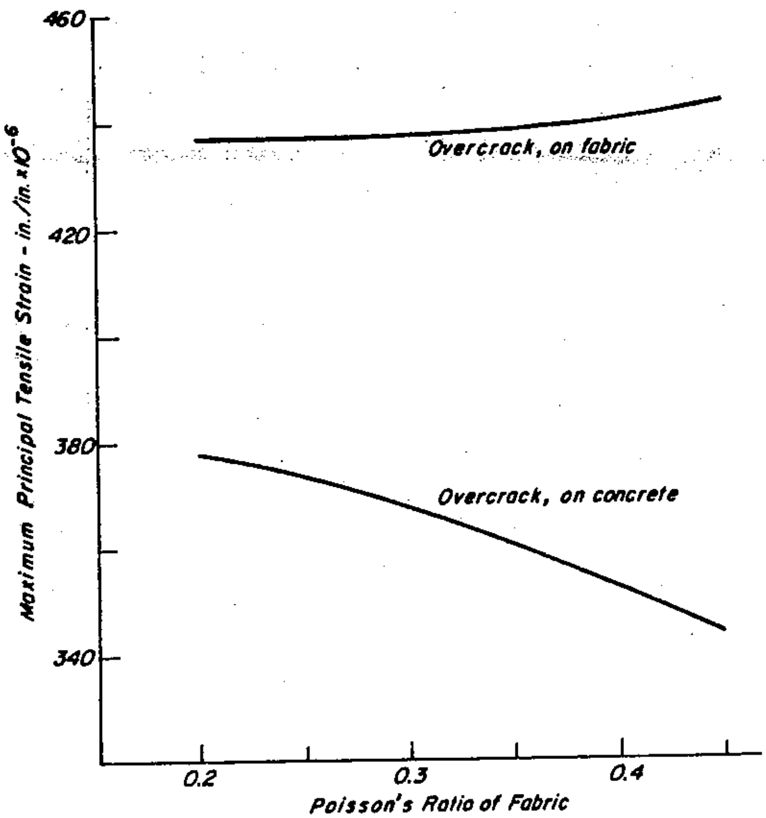


Fig. 20 - Maximum principal tensile strain in asphalt concrete vs. Poisson's ratio of fabric; E_{fabric} = 1500 psi, t_{fabric} = 0.075 in., t_{ac} = 4 in., T_R = 40°F, fabric located 1 in. above concrete.

directly over the crack with increase in this parameter, Figs. 19 and 20.

Influence of Two Layers of Fabric at
Different Heights in Same Overlay

The situation of two layers of fabric in the same overlay was investigated to ascertain if improved performance might be obtained with such an approach. The system which was analyzed is shown in Fig. 22. In this case, the first layer of fabric was placed 0.1 ft above the concrete layer; the second fabric layer was placed 0.1 ft above the first; and the thickness of the fabric was assumed to be 0.075 in. Fabric stiffness was taken as 1,500 psi and its Poisson's ratio as 0.45. The pavement was subjected to a 40°F temperature reduction, and the same stiffness characteristics for the asphalt concrete, p.c. concrete, base course and subgrade were used as for the previous investigation with the single fabric layer.

Table 3 contains a summary of the maximum tensile stresses and strains developed in this configuration. Comparison of these values with the data presented in Figs. 5 through 10 indicate about the same magnitudes are obtained in both situations therefore indicating no additional benefit is obtained by introducing a second fabric layer.

Vertical Displacements

Vertical displacements at the surface of the overlay were determined for all of the cases examined. Fig. 23 illustrates the shape of the deflected surface from the crack to a distance of 60 in. for a number of conditions.

The shape of the deflected surface directly under the load is summarized in Table 4 and illustrated in Fig. 24 through 26 for the cases analyzed. It should be noted that the deflections which have been computed are larger than those which would be obtained in practice, due in part to the assumptions made for the load and in part due to the pavement configuration itself. Neverthe-

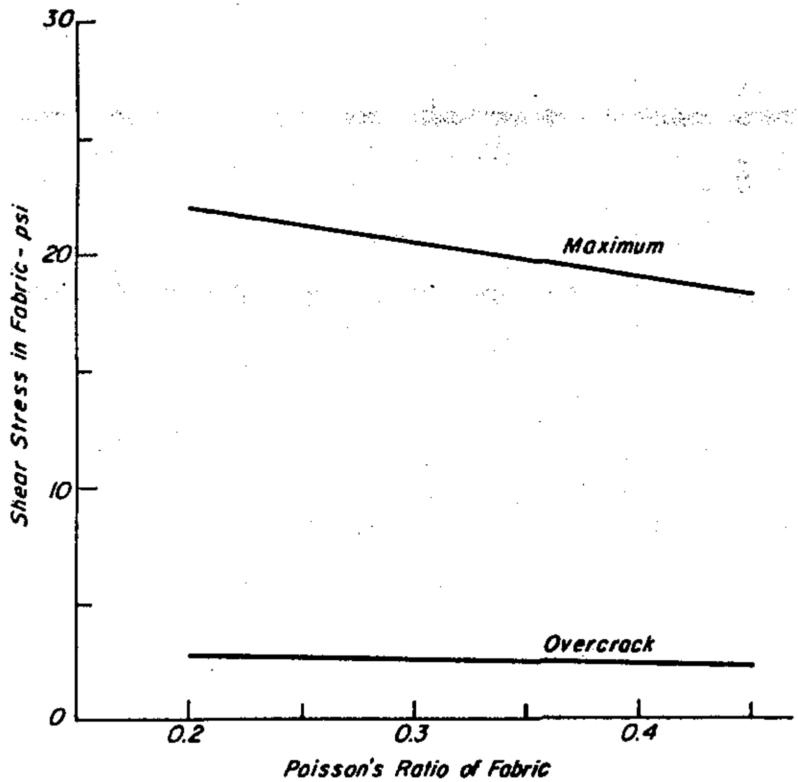


Fig. 21 - Maximum shear stress in fabric vs. Poisson's ratio of fabric; E_{fabric} = 1500 psi, t_{fabric} = 0.075 in., t_{ac} = 4 in., T_R = 40°F, fabric located 1 in. above concrete.

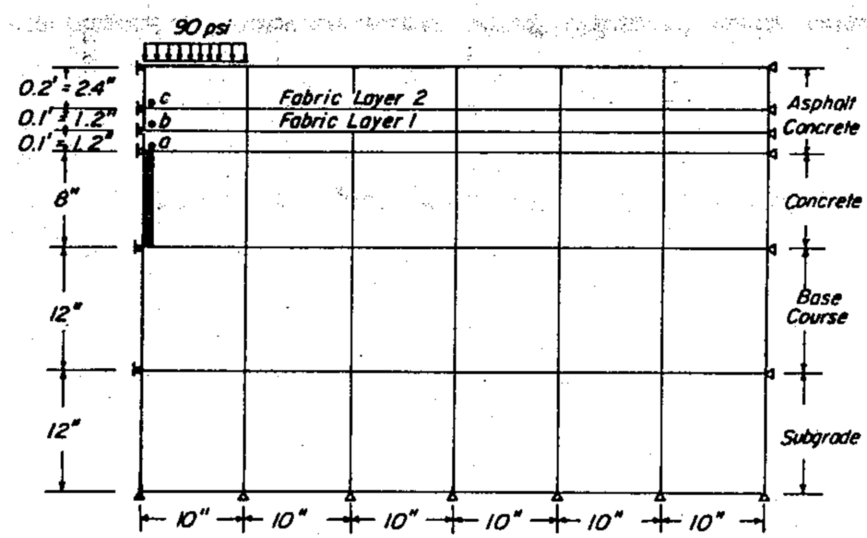


Fig. 22 - Locations of 2 fabric layers in overlay.

TABLE 3 - MAXIMUM STRESSES AND STRAINS DEVELOPED
TWO LAYER FABRIC MODEL

Location / Type of Stress or Strain	Over Crack on Concrete (at "a")	Over Crack on Fabric Layer 1 (at "b")*	Over Crack on Fabric Layer 2 (at "c")*	Over Crack in Fabric Layer 1	Over Crack in Fabric Layer 2	In Fabric Layer 1 (Any element in the model)**	In Fabric Layer 2 (Any element in the model)**
Maximum Principal Tensile Stress (psi)	1,353	1,661	2,596	-	-	-	-
Maximum Principal Tensile Strain (10^{-6} in./in.)	282	340	530	5,988	2,130	9,861	23,043
Maximum Shear Stress (psi)	-	-	-	5.23	4.27	14.6	15.0

*Refer to Figure 22 for the locations of points a, b, and c.

**Maximum principal tensile strains and shearing stresses in fabric layers developed in elements other than crack tip element in the model.

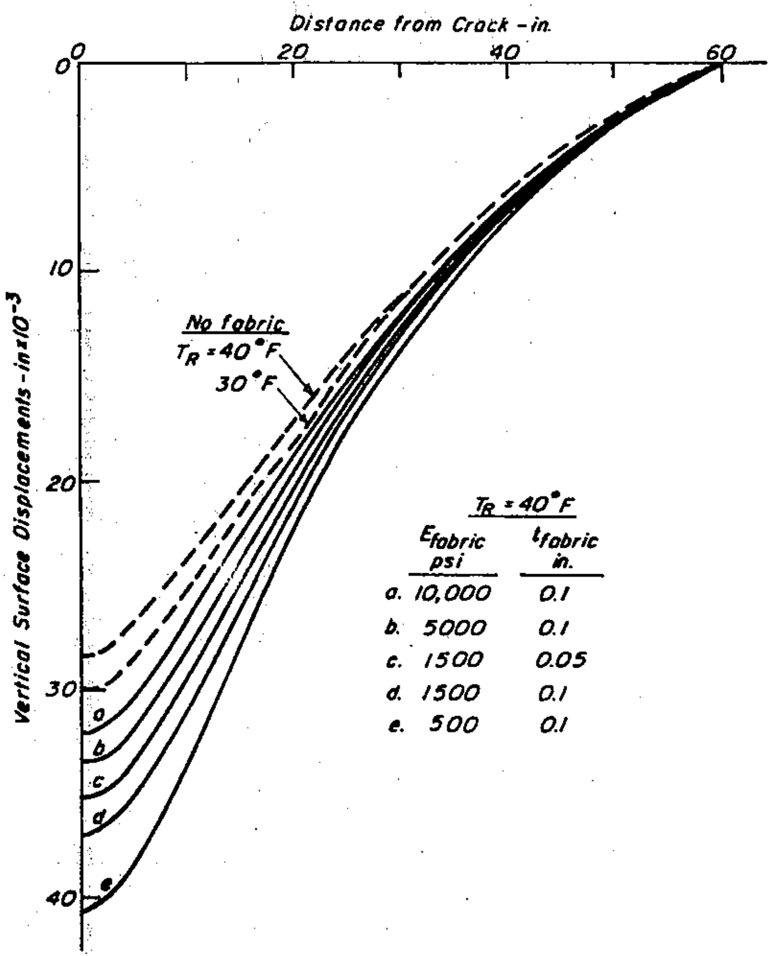


Fig. 23 - Maximum vertical surface displacements to a distance of 60 in. from crack; fabric located 1 in. above concrete.

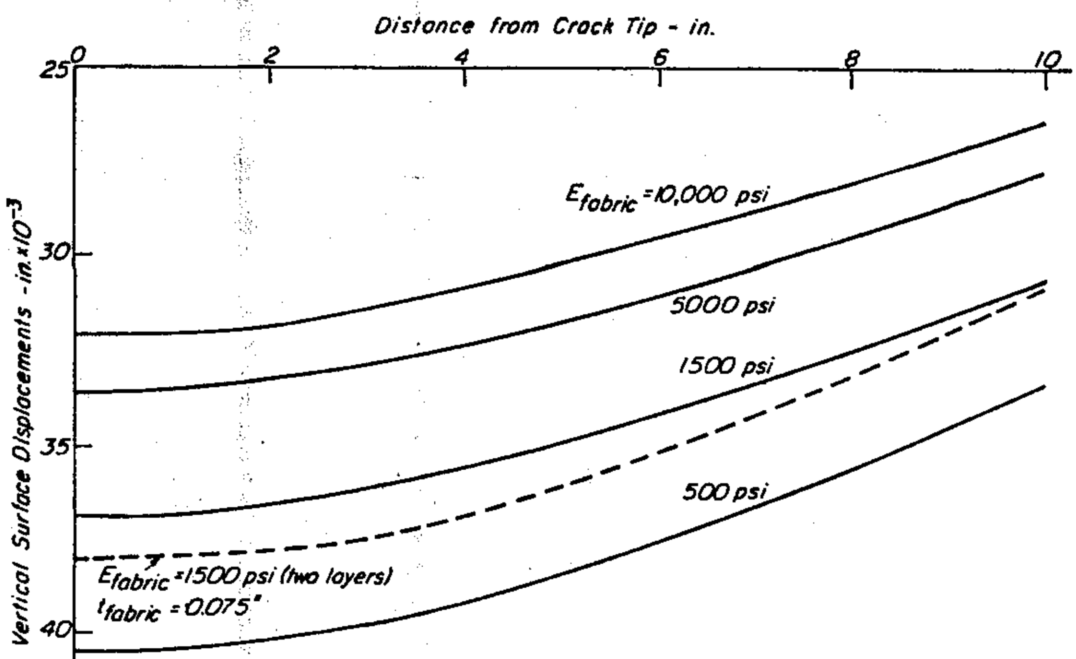


Fig. 24 - Vertical surface displacements under 10 in. wide loaded area; t_{fabric} = 0.10 in., T_R = 40^oF, fabric located 1 in. above concrete.

TABLE 4 - COMPUTED VERTICAL SURFACE DISPLACEMENTS OF ASPHALT CONCRETE OVERLAYS WITH OR WITHOUT FABRIC PLACED OVER P. C. CONCRETE PAVEMENTS, INCHES.

Offset Distance from Crack Tip (Inches)	No Fabric $T_R = 40^oF$ $\Delta T = 34.5^oF$			No Fabric $T_R = 30^oF$ $\Delta T = 26^oF$	Thickness of Fabric = 0.1 in. $T_R = 40^oF$, $\Delta T = 34.5^oF$ Thickness of AC = 4.0 in.			
	h_{AC} = 4.0"	h_{AC} = 6.0"	h_{AC} = 8.0"	h_{AC} = 4.0"	E_F = 500 psi	E_F = 1500 psi	E_F = 5000 psi	E_F = 10000 psi
0.0	0.02854	0.02237	0.01733	0.03020	0.04051	0.03687	0.03364	0.03207
1.0	0.02843	0.02228	0.01726	0.03009	0.04044	0.03682	0.03357	0.03199
2.0	0.02816	0.02212	0.01717	0.02980	0.04016	0.03656	0.03328	0.03170
3.0	0.02778	0.02189	0.01703	0.02939	0.03974	0.03616	0.03288	0.03128
4.0	0.02732	0.02159	0.01684	0.02889	0.03920	0.03556	0.03235	0.03075
5.0	0.02680	0.02124	0.01662	0.02833	0.03847	0.03500	0.03173	0.03014
6.0	0.02623	0.02083	0.01635	0.02772	0.03763	0.03424	0.03102	0.02945
8.0	0.02506	0.02000	0.01579	0.02648	0.03574	0.03259	0.02952	0.02803
10.0	0.02373	0.01901	0.01510	0.02508	0.03342	0.03061	0.02779	0.02643

Offset Distance from Crack Tip (Inches)	Thickness of Fabric = 0.075 in. Thickness of AC = 4.0 in. $T_R = 40^oF$, $\Delta T = 34.5^oF$					
	Two Layers E_F = 1500 psi	E_F = 500 psi	E_F = 1000 psi	E_F = 1500 psi	E_F = 2000 psi	E_F = 3000
0.0	0.03810	0.03953	0.03735	0.03616	0.03556	0.03445
1.0	0.03793	0.03947	0.03722	0.03609	0.03543	0.03432
2.0	0.03780	0.03917	0.03693	0.03582	0.03513	0.03402
3.0	0.03743	0.03876	0.03653	0.03543	0.03473	0.03361
4.0	0.03688	0.03820	0.03600	0.03490	0.03420	0.03307
5.0	0.03613	0.03752	0.03556	0.03427	0.03356	0.03244
6.0	0.03512	0.03671	0.03459	0.03353	0.03283	0.03172
8.0	0.03314	0.03489	0.03291	0.03191	0.03124	0.03018
10.0	0.03075	0.03265	0.03088	0.03000	0.02953	0.02838

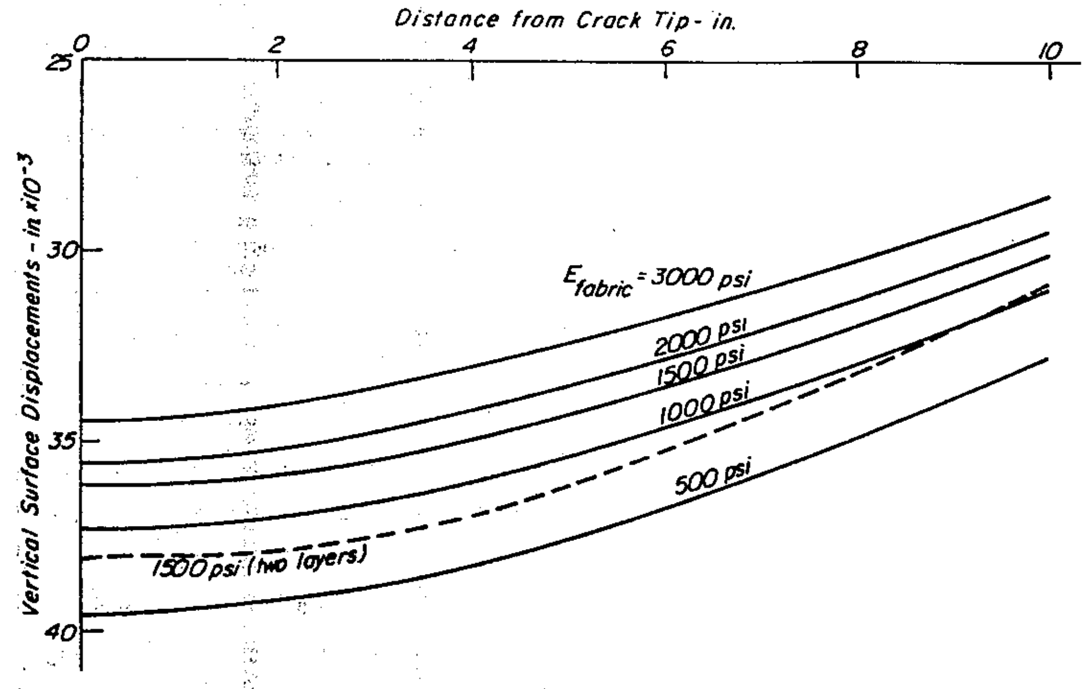


Fig. 25 - Vertical surface displacements under 10 in. wide loaded area; t_{fabric} = 0.075 in, T_R = 40°F, fabric located 1 in. above concrete.

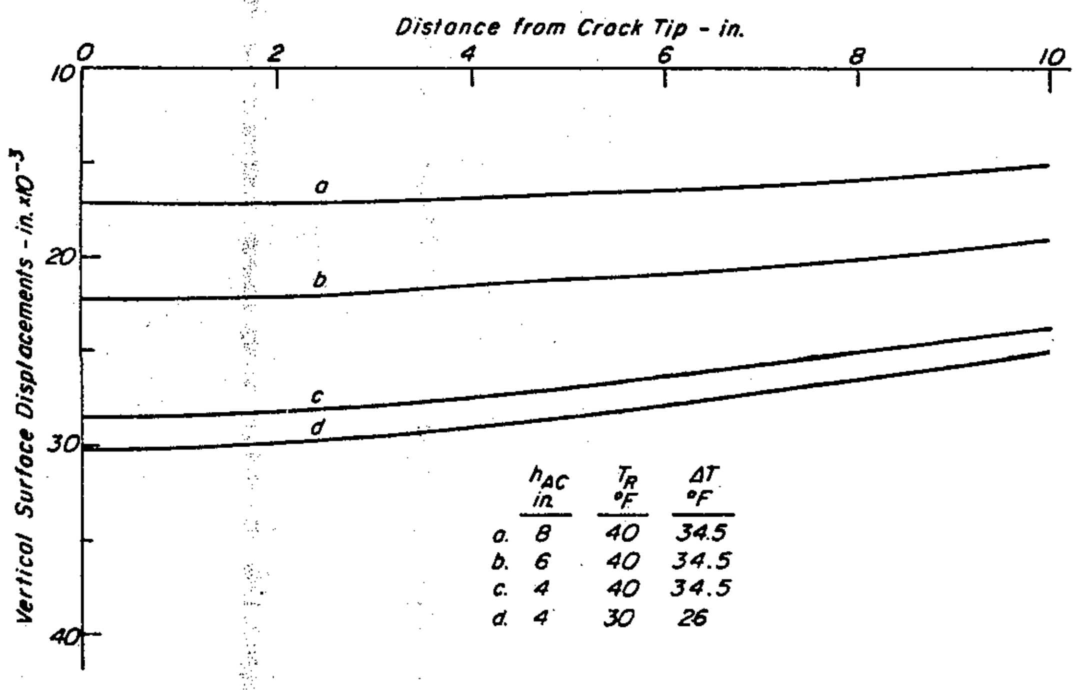


Fig. 26 - Vertical surface displacements under 10 in. wide loaded area; T_R = 40°F, no fabric.

less, the results shown in these figures provide a comparative evaluation of the influence of the various parameters examined.

Temperature Profiles

As noted earlier, temperature profiles were determined with the assistance of the Barber procedure (6). The nodes at the boundaries of the layers were assigned computed temperatures corresponding to the particular depths. Temperatures for the intermediate nodes were determined with the SAP-81 program using linear interpolation. Table 5 illustrates computer output of node temperatures for the substructure of the 4 in. thick overlay system for a daily range of 30°F in air temperature.

Fig. 27 illustrates the variation in temperature with depth for the 4 in. overlay with the fabric located 1.0 in. above the existing p.c.c. surface. For comparison, the variation with depth as computed by the Barber (6) procedure is also shown. Fig. 28 illustrates temperature profiles for the 4 in., 6 in., and 8 in. thicknesses as determined with SAP-81 and with the Barber procedure.

CONCLUSIONS

In this investigation an analytical study has been conducted to attempt to define, through a parameter study, guidelines for the use of fabrics in asphalt concrete overlays on existing pavements with joints or cracks, e.g. plain jointed p.c.c. pavements. It should be emphasized that the results presented do not guarantee that reflection cracking will be mitigated by the use of fabrics. Rather, it provides guidelines as to how to use such material reasonably effectively and provides some indication of desirable properties for the fabrics themselves.

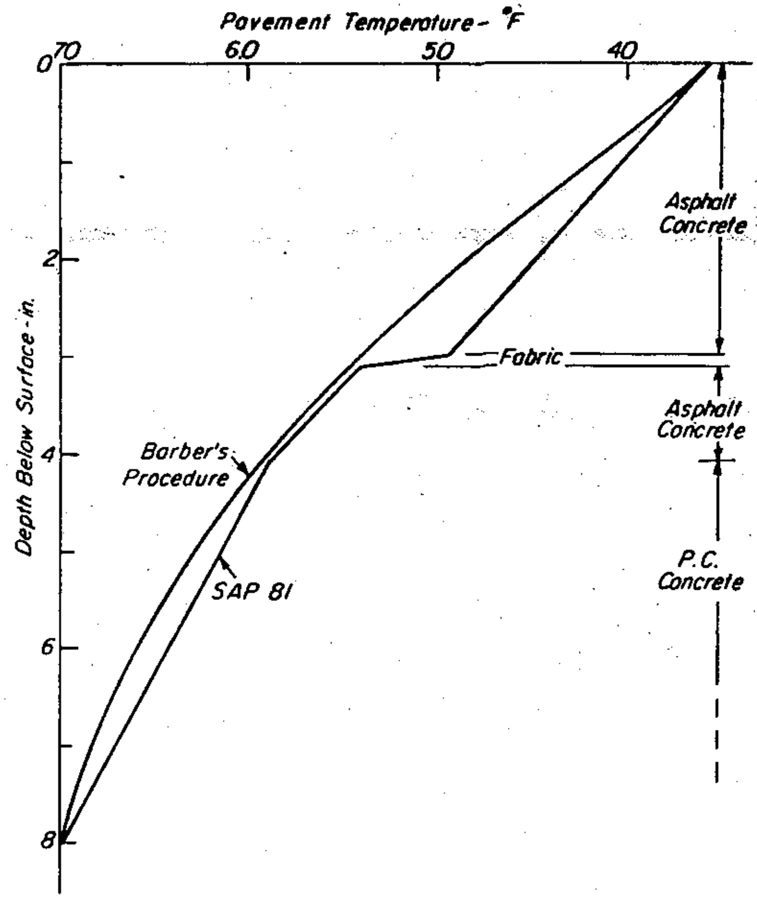


Fig. 27 - Computed temperature profiles in 4 in. thick asphalt concrete overlay; fabric located 1 in. above concrete, T_R = 40°F.

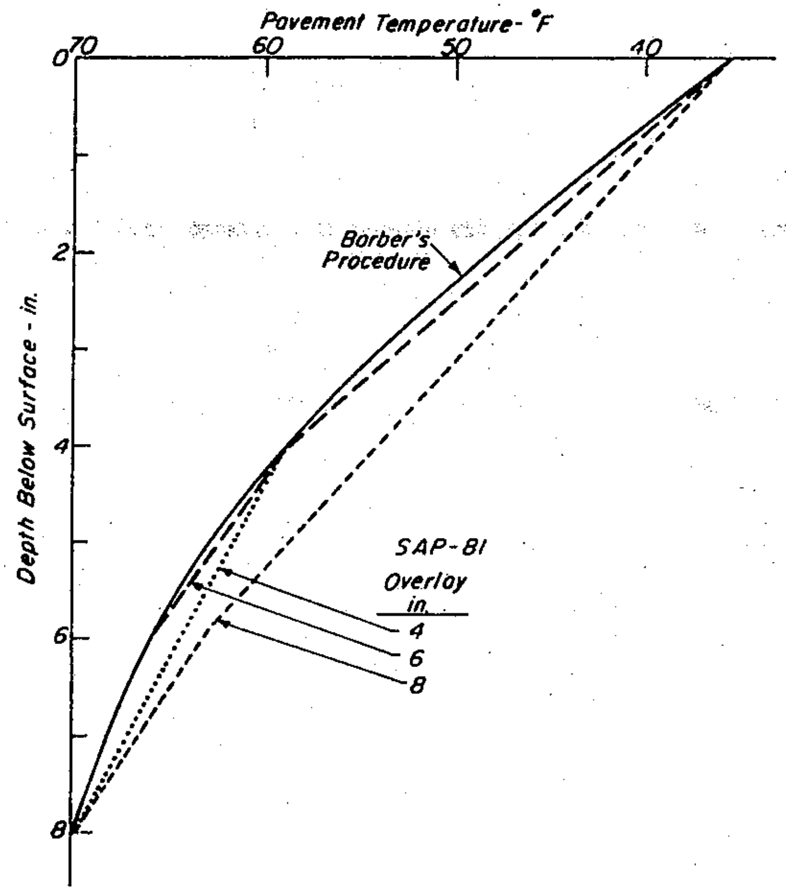


Fig. 28 - Computed temperature profiles for 4, 6, and 8 in. thick asphalt concrete layers; T_R = 40° F.

TABLE 5 - NODE TEMPERATURES ASSIGNED BY SAP-81 PROGRAM FOR $26^{o}F$ ($T_R = 30^{o}F$) REDUCTION THROUGH THE PAVEMENT STRUCTURE FOR 4.0 IN. THICK PLAIN ASPHALT CONCRETE OVERLAY

NODE TEMPERATURES

1	61.50	2	61.50	3	61.50	4	61.50	5	61.50
6	61.50	7	61.50	8	61.50	9	61.50	10	61.50
11	61.50	12	61.50	13	61.50	14	61.50	15	61.50
16	61.50	17	61.50	18	61.50	19	61.50	20	61.50
21	61.50	22	61.50	23	61.50	24	61.25	25	61.25
26	61.25	27	61.25	28	61.25	29	61.25	30	61.25
31	61.25	32	61.25	33	61.25	34	61.25	35	61.25
36	61.25	37	61.25	38	61.25	39	61.25	40	61.25
41	61.25	42	61.25	43	61.25	44	61.25	45	61.25
46	61.25	47	61.00	48	61.00	49	61.00	50	61.00
51	61.00	52	61.00	53	61.00	54	61.00	55	61.00
56	61.00	57	61.00	58	61.00	59	61.00	60	61.00
61	61.00	62	61.00	63	61.00	64	61.00	65	61.00
66	61.00	67	61.00	68	61.00	69	61.00	70	58.87
71	58.87	72	58.87	73	58.87	74	58.87	75	58.87
76	58.87	77	58.87	78	58.87	79	58.87	80	58.87
81	58.87	82	58.87	83	58.87	84	58.87	85	58.87
86	58.87	87	58.87	88	58.87	89	58.87	90	58.87
91	58.87	92	58.87	93	56.75	94	56.75	95	56.75
96	56.75	97	56.75	98	56.75	99	56.75	100	56.75
101	56.75	102	56.75	103	56.75	104	56.75	105	56.75
106	56.75	107	56.75	108	56.75	109	56.75	110	56.75
111	56.75	112	56.75	113	56.75	114	56.75	115	56.75
116	54.62	117	54.62	118	54.62	119	54.62	120	54.62
121	54.62	122	54.62	123	54.62	124	54.62	125	54.62
126	54.62	127	54.62	128	54.62	129	54.62	130	54.62
131	54.62	132	54.62	133	54.62	134	54.62	135	54.62
136	54.62	137	54.62	138	54.62	139	52.50	140	52.50
141	52.50	142	52.50	143	52.50	144	52.50	145	52.50
146	52.50	147	52.50	148	52.50	149	52.50	150	52.50
151	52.50	152	52.50	153	52.50	154	52.50	155	52.50
156	52.50	157	52.50	158	52.50	159	52.50	160	52.50
161	52.50	162	50.37	163	50.37	164	50.37	165	50.37
166	50.37	167	50.37	168	50.37	169	50.37	170	50.37
171	50.37	172	50.37	173	50.37	174	50.37	175	50.37
176	50.37	177	50.37	178	50.37	179	50.37	180	50.37
181	50.37	182	50.37	183	50.37	184	50.37	185	48.25
186	48.25	187	48.25	188	48.25	189	48.25	190	48.25
191	48.25	192	48.25	193	48.25	194	48.25	195	48.25
196	48.25	197	48.25	198	48.25	199	48.25	200	48.25
201	48.25	202	48.25	203	48.25	204	48.25	205	48.25
206	48.25	207	48.25	208	46.12	209	46.12	210	46.12
211	46.12	212	46.12	213	46.12	214	46.12	215	46.12
216	46.12	217	46.12	218	46.12	219	46.12	220	46.12
221	46.12	222	46.12	223	46.12	224	46.12	225	46.12
226	46.12	227	46.12	228	46.12	229	46.12	230	46.12
231	44.00	232	44.00	233	44.00	234	44.00	235	44.00
236	44.00	237	44.00	238	44.00	239	44.00	240	44.00
241	44.00	242	44.00	243	44.00	244	44.00	245	44.00
246	44.00	247	44.00	248	44.00	249	44.00	250	44.00
251	44.00	252	44.00	253	44.00				

For this investigation, the two-dimensional plane strain finite element idealization has been adopted for use in a microcomputer. The system with two disc drives and capable of utilizing discs with 600 k bytes is appropriate for pavement idealizations containing a maximum of 80 elements. The number of elements can be increased beyond this by using the substructuring technique developed by E. L. Wilson.

From the results of the analytic study the following guidelines for the use of fabrics are suggested.

1. If actual test data are not available, fabric stiffness in the range 500 - 3,000 psi appear reasonable for use in finite element analyses.
2. Placing the fabric interlayer about 1.0 in. or 0.1 ft above the existing jointed (cracked) p.c.c. 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.
3. The use of a thick fabric interlayer composed of a low modulus and high Poisson's ratio improves the stress relieving function of the fabric in the overlay.
4. 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
5. A 6-in. asphalt concrete overlay produced the same stress pattern at the crack tip as a 4-in. asphalt concrete overlay

with a fabric layer located 1.0 in. above the existing pavements.

ADDENDUM A

In a recent reevaluation of the SAP-81 program it was determined that the program yielded larger thermal stresses than should have been obtained. The thermal stress equations were reevaluated by Professor E. L. Wilson and a modified version of SAP-81 has been developed. A few cases have been examined with this new program. While the resulting stresses and strains which were obtained were lower than those reported, the same general trends were obtained. Accordingly, the conclusions which have been reported herein are valid.

ADDENDUM B

The two Appendices listed below were originally submitted with the UCB report, but because of their bulk and possible copyright restrictions, they were not included in this publication.

Appendix A: A Structural Engineering Workstation For CP/M Microcomputers and SAP-81 Structural Analysis Programs For Small Or Large Computer Systems

Appendix B: A Typical Output Of A Finite Element Analysis For A Pavement Structure In Microcomputers

Copies of these Appendices are on file at TransLab.

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PART II

ENGINEERING PROPERTIES OF FABRICS

INTRODUCTION

When evaluating whether or not to use fabrics in pavements, it is desirable to answer the following questions:

1. What type of pavement distress is of concern and can the use of fabric mitigate its subsequent influence on pavement performance?
2. What fabric properties are required to develop reasonable pavement performance in the overlay for the particular distress mode?
3. What advantages are obtained by using a fabric as compared to other alternatives?

In this section of the report an attempt will be made to briefly discuss those characteristics of fabrics which should be defined when the fabric is being used to mitigate reflection cracking in asphalt concrete overlays. In addition, the results of tension test data are presented for tests on a number of different fabrics supplied by the Transportation Laboratory of CALTRANS. The tests illustrate one procedure whereby one of the fabric characteristics, in this instance - stiffness, required to answer question No. 2 can be defined. A detailed description of the procedure, together with the requisite equipment required to load the fabric is included.

SUGGESTED LABORATORY TESTS

In this section, laboratory tests, both on the fabric and on asphalt mixtures containing fabrics, are discussed. In developing this suggested series of tests, information contained in References (1) through (7) has been drawn upon.

Tests on Fabrics

Tests on fabrics themselves should include at least the following:

1. Direct tension (1, 2, 3, 4).

2. Temperature - shrinkage (5).

3. Permeability

4. Asphalt retention (saturation) (6, 7).

Direct Tension. It is recommended that direct tension tests be conducted on fabric specimens with a width/length ratio greater than 4 (1, 2, 3). Since the characteristics of fabrics differ in the machine and cross directions, it is recommended that tensile properties be measured in these directions separately.

As a part of the testing, it is recommended that the specimen be preconditioned. That is, each specimen should be loaded to a level corresponding to an elongation in the range 10 to 15 percent. This preconditioning results in a more uniform response during the actual loading phase.

During the actual direct tension test it is recommended that the following characteristics be ascertained (4):

1. Initial modulus - modulus during the initial phases of the loading.

2. Secant modulus - modulus at maximum load. Maximum load may be defined in one of the following ways:

   a. Tearing of the fabric is observed.

   b. An elongation of 50 percent is reached.

   c. A maximum load is reached at less than 50 percent elongation which remains constant with further deformation.

Rate of loading during the test should correspond to that associated with moving traffic.

Results of 52 direct tension tests on 10 different plain (unsaturated) fabrics and 2 asphalt saturated fabrics are reported in a subsequent section. A recommended test procedure, together with associated equipment, is included in Appendix A of this phase of the report.

Temperature - Shrinkage Test. Some fabrics exhibit a relatively large amount of shrinkage when exposed to temperatures corresponding to those associated with asphalt pavement construction (5). Susceptibility to shrinkage can be ascertained in one of the following ways:

1. Immersion of fabric in asphalt at 300°F.
2. Placement of fabric in oven maintained at 300°F for some prescribed time period.

It is recommended that the maximum value of shrinkage, expressed as a percentage of the original dimensions, be limited to a relatively small amount. For example, researchers at Texas A and M University (5) suggest that fabrics which exhibit free shrinkage in excess of 5 percent when exposed to a temperature of 300°F for 30 minutes can cause hairline cracks to appear during construction at wrinkles or improperly overlapped cuts in the fabric.

Permeability Test. Water action may accelerate the deterioriation of asphalt-bound materials, particularly if an existing course is overlaid and water or water vapor which has ingressed to the layer remains for an extended period. The role of the fabric in this instance is to prevent surface water from entering the overlaid layer.

Any type of permeability test which measures the water permeability of the fabric or asphalt saturated fabric should be suitable.

Asphalt Retention (Saturation) Test. The quantity of asphalt which a fabric will absorb when incorporated in an overlay system is an important design parameter and is dependent on fabric type, thickness, and weight (6, 7). Determination of the quantity retained (e.g., gal. per sq yd) can be accomplished by weighing after: 1) soaking the fabric for a one- to two-minute period in asphalt brought to an appropriate viscosity; and 2) pressing the fabric after soaking to remove the excess asphalt.

Tests on Asphalt Mixtures with Fabrics

A number of tests, though not necessarily for specification purposes, appear desirable on the asphalt mixture-fabric system to permit definition of parameters for design purposes and to ascertain the influence of materials and construction procedures. These tests include definition of: 1) shear strength of the interface layer containing the fabric; 2) permeability of the fabric as it might be influenced by aggregate identation - puncture; and 3) fatigue characteristics of the overlay material containing the fabric as compared to the same material without fabric.

Interface Shear Strength. The shear strength of the interface containing the fabric (plus tack coat) should be tested over a range in temperatures and tack coat applications; data reported in References (5, 6, and 7) indicate that these factors have a significant influence on the interface strength for a specific fabric.

It would be desirable to measure this strength in two modes of loading as shown in Fig. 1. The mode indicated in Fig. 1a would provide a measure of the system's response to stresses induced by temperature changes, while that of Fig. 1b would measure the response to traffic loads and indicate whether such loading might lead to debonding or tearing of the fabric.

Permeability. Core specimens from field sections with fabric interlayers together with laboratory prepared specimens representative of the same sections should be tested to determine their water permeability. Differences in the action of aggregate or fabric puncture might occur between laboratory prepared and field compacted sections; hence, the reason for both types of specimens initially.

It should be noted that a recent study (6) has indicated no increase in permeability of the fabric interlayer resulting from punch-through by the aggregate. Nevertheless, it would appear worthwhile to check this for a number of projects.

Flexural Fatigue Characteristics. The flexural fatigue characteristics of asphalt concrete overlays containing fabrics are not well defined. Some studies (8, 9, 10) suggest increases in fatigue lives of asphalt concrete of the order of 4 to 10 times as compared to the same material without fabric. However, other studies (6, 7) do not indicate such significant changes in fatigue response. Thus, it is recommended that investigations be conducted using realistic loading conditions to determine the fatigue response of asphalt concrete-fabric systems.

DIRECT TENSION TEST RESULTS ON SELECTED FABRICS

In this phase of the investigation fifty-two direct tension tests were conducted on ten different plain fabrics and on two of the fabrics saturated with asphalt.

Equipment and Procedures

Details of the testing device and the test procedure are included in Appendix A to this phase of the report. Briefly, the fabric specimens were 16.0 in. wide by 4.0 in. long, thus 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 gal per sq yd for the Quline materials and 0.2 gal per sq yd 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.

Definitions for Fabric Characteristics

Modulus values 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 to the strain.
2. Initial modulus - slope of initial portion of the stress vs. strain (or load vs. displacement) curve obtained from the loading following preconditioning.
3. Secant modulus - ratio of failure stress to strain at failure.

The failure stress (load) is obtained when one of the following conditions is obtained:

1. Tearing of the fabric is observed.
2. The tensile load has reached a peak value and then declines without fabric tearing or other fabric separation with further increase in strain.
3. An elongation of 50 percent (based on original length) is obtained.

To determine Poisson's ratio for each of the fabrics, axial deformation was obtained from the strip chart and lateral deformation was measured from a straight edge as shown in Fig. 2 . Poisson's ratio was then determined from:

$$\nu = \frac{\frac{\Delta_\ell + \Delta_r}{w}}{\frac{\ell_f - \ell_o}{\ell_o}}$$

where

Δ_ℓ = deformation at left edge, Fig. 2;

Δ_r = deformation at right edge, Fig. 2;

w = fabric width (usually 16 in.);

ℓ_o = initial fabric length (4 in.);

ℓ_f = length at failure (failure as defined above).

Test Results

Fabric characteristics determined by staff of the Transportation Laboratory of CALTRANS using ASTM 461 and 1117 test procedures are shown in Table 1. Twelve different types of fabrics were tested in both the machine and cross directions.

Properties determined at the University of California, Berkeley, using a controlled strain type of loading in an INSTRON machine are presented in Tables 2 and 3.

As noted earlier, ten different fabrics were tested in the as-received condition and two of the ten were saturated with asphalt and then tested. The X and Y directions of test referred to in Tables 2 and 3 refer to the cross and machine directions. The reported moduli and Poisson's ratios have been determined according to the definitions described earlier. Fabric thicknesses shown are those determined by the CALTRANS staff (Table 1).

SUMMARY AND EVALUATION OF FABRIC TESTS

The testing unit developed at the University of California, Berkeley, and capable of testing fabric specimens up to 20 in. wide can effectively test

TABLE 1 - FABRIC PROPERTIES*

Type of Fabric	Weight (oz/yd²)	Thickness[1] (mils)	Grab Tensile Strength[2] (psi)		Elongation (Percent)[2]		Secant Modulus[3] (psi)	
			Machine	Cross	Machine	Cross	Machine	Cross
Petromat (Phillip Fibers)	4.5	40	81	132	85	74	2,294	1,483
Bidim G-22 (Monsanto)	3.2	51	125	98	90	98	1,878	871
Bidim C-34 (Monsanto)	9.6	77	178	151	57	73	1,939	1,731
True Tex Mg 75 (True Temper)	6.5	56	170	98	96	97	1,936	666
True Tex Mg 100 (True Temper)	6.5	88	174	114	94	116	896	414
Duraglass B-65 (Johns-Manville)	9.8	77	126	116	3	3	tear	tear
Q Trans-50 (Quline)	7.0	105	93	142	173	107	350	160
Fibretex 200 (Crown-Zellerbach)	6.0	73	183	126	145	175	1,025	368
Reepav 376 (Dupont)	3.0	14	110	79	63	64	4,650	3,250
Nicofab B50 (Nicolon)	4.9	68	80	133	100	79	1,339	552
Amopave 4545 (Amoco)	6.6	40	142	147	73	104	1,890	1,480
Trevira 1117 (Hoechst)	4.4	51	162	119	82	111	1,666	810

*All values are from Trans Lab Testing.
[1]ASTM 461
[2]ASTM 1117; 1-in. grip
[3]At 50 percent strain, unless tearing occurs

TABLE 2 - INITIAL MODULUS VALUE OF FABRICS IN BOTH X AND Y DIRECTIONS AFTER 10 PERCENT - 12.5 PERCENT PRECONDITIONING

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 3 - MODULUS VALUES FOR 16.0 IN. × 4.0 IN. FABRICS TESTED IN TWO DIRECTIONS

Type of Fabric	Thickness of Fabric (inches)	Direction of Test	Number of Tests	Average Modulus During Precondi-tioning (M_{PRE})	Average Modulus During Initial Loading (M_1)	Average Secant Modulus (M_s)	Average Poisson's Ration (V)	Secant Modulus Values Obtained by CALTRANS
Quline	0.105	Y	2	310	426	170	0.17	350
Quline	0.105	X	2	352	427	615	0.14	160
Petromat	0.040	Y	2	1,771	1,874	1,479	0.24	1,483
Petromat	0.040	X	2	2,133	2,501	2,066	0.23	2,294
Trustex MG 75	0.056	Y	2	1,468	2,184	2,937	0.24	1,936
Trustex MG 75	0.056	X	2	879	1,611	1,405	0.22	666
BIDIM - 22	0.051	Y	1	1,886	1,894	2,589	0.27	1,878
BIDIM - 22	0.051	X	1	478	1,000	1,560	0.41	871
Fibretex 200	0.073	Y	1	200	356	404	0.31	368
Fibretex 200	0.073	X	1	615	778	848	0.23	1,025
Trevira	0.051	Y	1	548	961	1,194	0.43	810
Trevira	0.051	X	2	950	2,066	1,704	0.38	1,666
Trustex MG 100	0.088	Y	2	265	512	622	0.24	414
Trustex MG 100	0.088	X	2	767	1,478	1,943	0.25	896
Amopave	0.040	Y	2	1,632	2,069	2,316	0.21	1,890
Amopave	0.040	X	2	2,530	2,448	1,784	0.24	1,480
Quline (impregnated with AR-4000)	0.125[a]	Y	2	248	909	214	0.16	c
	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	c

[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.

[c] No comparable tests were done by Caltrans.

fabrics with thicknesses 40 mils or greater. From the data presented in Tables 2 and 3 a number of items can be observed.

1. All of the fabrics exhibited different characteristics in the X and Y directions.
2. Each fabric yielded different moduli during preloading, initial loading, and at failure. 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. For the majority of tests, however, the initial modulus and secant modulus were higher than the preconditioning modulus.
3. The same Poisson's ratio was obtained in both directions for Petromat, Truetex MG-75, and Truetex MG-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 plain fabrics of the same type. 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.

RECOMMENDATIONS FOR FIELD APPLICATIONS

Based on References (5, 6, 7), the following guidelines for field applications appear warranted.

1. Use thick fabric interlayers to mitigate reflection cracking.
2. A minimum thickness of 1.5 in. 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 in.
3. Existing surface preparation is important. For example, cracks greater than about 1/8 in. in width should be filled prior to the placement of the fabric.
4. RC or MC liquid asphalt should not be used as the tack coat for fabric application.
5. 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.

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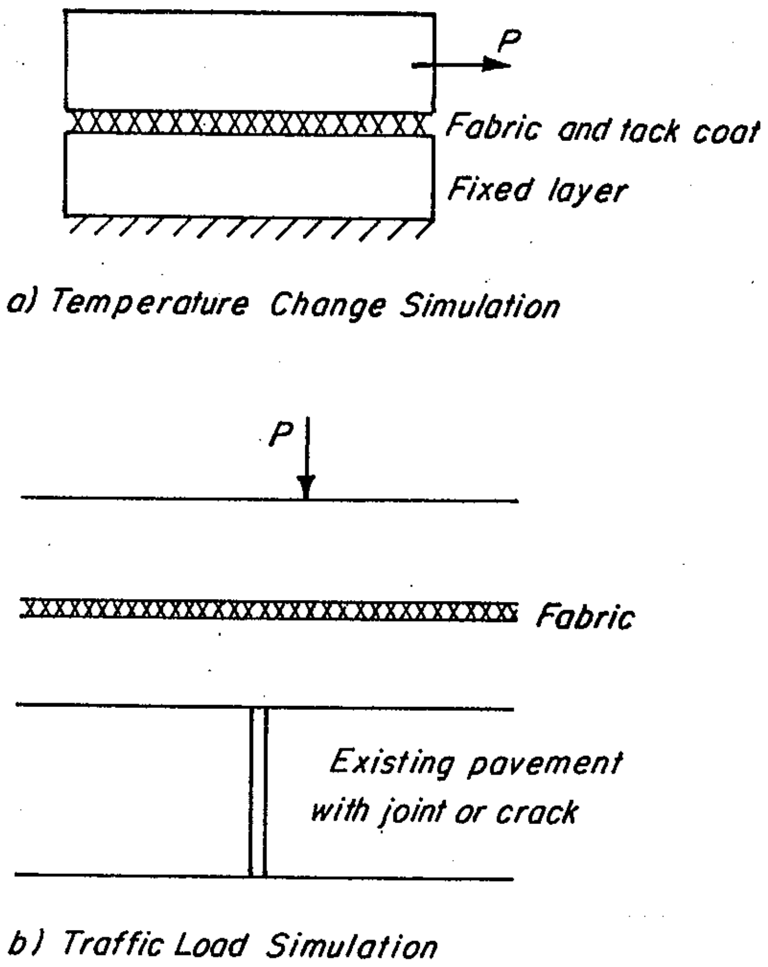

Fig. 1 - Loading modes to define interface strength.

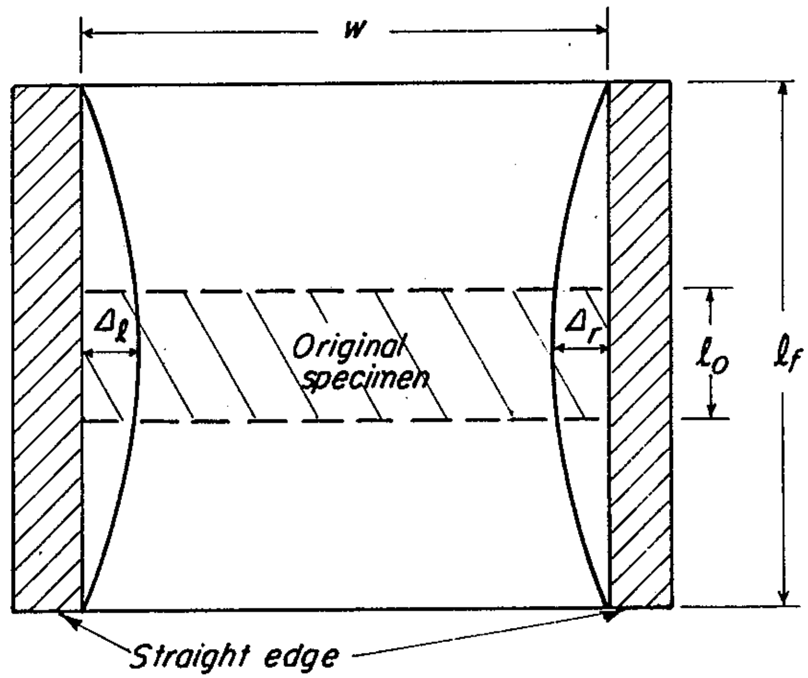

Fig. 2 - Fabric deformation during loading.

APPENDIX A

CONSTANT RATE OF STRAIN TEST METHOD FOR DETERMINING THE STIFFNESS AND POISSON'S RATIO OF GEOTEXTILE FABRICS TO BE USED AS PAVEMENT INTERLAYERS

CONSTANT RATE OF STRAIN TEST METHOD FOR DETERMINING THE STIFFNESS AND POISSON'S RATIO OF GEOTEXTILE FABRICS TO BE USED AS PAVEMENT INTERLAYERS

1. Scope

This method covers the determination of the stiffness modulus and Poisson's ratio of plain and asphalt impregnated geotextile fabrics under slow rates of uniform extension using specimens having a high aspect ratio.

2. Applicable Documents

2.1. Baudonnel, J., J. P. Giroud, and J. P. Gourc, "Experimental and Theoretical Study of Tensile Behavior of Nonwoven Geotextiles," Second International Conference on Geotextiles, Las Vegas, U.S.A., Session 7C: Properties and Tests III, August 1982.

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3. Summary of Method

3.1. Test specimens are obtained in both the warp and fill directions from a geotextile fabric sample. If required, the specimens are impregnated with asphalt by compressing the fabric and heated asphalt between two slabs of asphalt concrete or between a heated metal pan and a corresponding flat metal plate insert.

3.2. With the longer specimen edges held in the special clamps, an initial extension of half an inch is applied. The resulting preconditioning load is recorded and released. The new gauge length is measured and the clamps moved apart at a constant rate until the fabric yields or fails. A continuous record of the load and deformation is obtained along with the maximum load and resulting deformed specimen dimensions.

4. Significance and Use

This text method is of primary significance in determining the fundamental properties -- stiffness modulus and Poisson's ratio -- of plain and asphalt impregnated geotextile fabrics to be used as pavement interlayers. These properties are important for modelling the fabric interlayer as a component of the pavement's structural section and in determining the ability of the fabric interlayer to reduce crack tip stresses and mitigate or retard the propagation of reflection cracks through asphalt concrete overlays.

5. Apparatus

5.1. Test equipment, such as an Instron Table Model Universal Testing Instrument (Model TM-S), capable of applying a constant rate of strain in tension to the specimen and recording continuously the resulting load and deformation. It is desirable that the load cell be able to measure at least 1,000 lbs. of force and the crosshead movement be in the range from 0.5 cm/min to 2 cm/min.

5.2. Clamps for firmly holding the specimen along its longer edges and easily being attached to the testing device. See Fig. Al for detailed drawings and dimensions of the aluminum clamps used at the University of California, Berkeley.

5.3. Micrometer for determining the fabric thickness to the nearest thousandth of an inch.

5.4. Steel ruler for measuring specimen dimensions and deformations to the nearest hundredth of an inch.

5.5. Metal straightedges for marking specimen dimensions on fabric samples and providing a reference against which to measure lateral specimen deformation.

5.6 Miscellaneous tools, such as scissors, screwdrivers, wrenches, china markers, and thermometers, for marking and cutting the geotextile fabric, tightening and loosening the clamps and yokes, and monitoring the temperature of the test area.

5.7. Additional equipment and materials required for impregnating the fabric specimens with asphalt include a controlled temperature oven, two asphalt concrete slabs or a metal pan with a flat metal insert plate, and a standard universal testing machine for applying a compressive load. A chamber for maintaining a constant temperature around the test specimen is also desirable if it is necessary to determine the variation of asphalt impregnated fabric properties with temperature changes.

6. <u>Specimen Preparation</u>

6.1. Since geotextile fabrics may have different properties in the warp and fill directions, it is necessary to test a fabric sample in both directions. Thus, it is necessary to cut several specimens from each sample of fabric. Also, the recommended minimum specimen size is eight inches by sixteen inches. This provides a test aspect ratio of four when the specimen is clamped along its longer edges with a gauge length of four inches.

6.2. To provide at least two test specimens in each direction, the geotextile fabric sample must be at least sixteen inches wide and thirty-two inches long. This allows cutting the sample into the four pieces shown in Fig. A2. With larger samples of fabric the test specimen length should remain at sixteen inches, but the width may be increased up to twelve inches. If an insufficient amount of fabric is available, every attempt should be made to test at least two specimens with aspect ratios of four or greater in each of the warp and fill directions. This may require testing specimens that are less than sixteen inches in length.

6.3. Using the ruler, straightedge, and china marker, outline the specimens on the fabric sample. After indicating the warp and fill directions, the direction the test load will be applied, and labeling each specimen, cut them apart. The length and width of each specimen should be measured and recorded to the nearest hundredth of an inch. The fabric thickness should be determined to the nearest thousandth of an inch.

6.4. To more accurately simulate conditions in an actual pavement, the fabric should be impregnated with the appropriate amount of asphalt and tested at several representative temperatures. The asphalt should be applied to both sides of the fabric at an elevated temperature and then compressed between two heated concrete slabs. The absorption properties of both the asphalt concrete and geotextile fabric need to be taken into account in determining the asphalt application rate. Alternatively, a flat metal pan and corresponding flat metal insert plate can be used to impregnate the fabric with asphalt at an elevated temperature and under a compressive load. It is important that the asphalt be uniformly absorbed by the fabric.

6.5. Separate the two halves of each clamp and remove the metal rods. Place the lower halves parallel to each other and four inches apart. Center the fabric specimen over the lower parts of the clamps with the sixteen-inch long edges parallel to the clamps. Press the rods over the fabric into the indentations and cover the fabric ends. Position the top halves of the clamps over the corresponding bottom halves and tighten the bolts. If properly aligned, the clamps will be parallel and four inches apart when the fabric is pulled tight. Fig. A3 shows the fabric held in both clamps.

7. <u>Test Procedures</u>.

7.1. Turn on the test equipment, balance it, calibrate the tension load cell, and set the correct crosshead and paper chart speeds.

7.2. Carefully attach the clamps and specimen to the test instrument yokes. After the specimen is properly aligned, tighten the yokes. Move the clamps apart until the fabric is spread out but not under a tensile load. Measure the distance separating the two clamps, the gauge length at each end of the specimen and in the middle.

7.3. Move the clamps apart at a rate of 0.5 cm/min until a total extension of one-half inch occurs. Record the preconditioning load and move the crosshead in the opposite direction at the same speed until the load returns to zero. Measure and record the new gauge length at the same three positions.

7.4. Again move the clamps apart at a rate of 0.5 cm/min and record the resulting load versus deformation curve. Continue until the maximum load is reached, the fabric begins to tear, or 50 percent strain is induced in the fabric. Measure the fabric dimensions in its deformed condition: gauge length at the same three points, length of fabric at each clamp and at the narrowest point in the middle, and the amount of indentation at each side using the straightedge in a vertical position. Record all measurements to the nearest hundredth of an inch. Also, record the maximum load reached and the reason for stopping the test.

7.5. Release the load by moving the clamps toward each other at a rate of 0.5 cm/min. Carefully remove the clamps from the test machine yokes and place on a flat surface. Remove the specimen from the clamps and measure its final dimensions. Clean the clamps of any asphalt residue prior to testing a new specimen.

7.6. If an asphalt impregnated specimen is to be tested at different temperatures, it should not be removed from the clamps between tests. Instead, test the specimen at increasing temperatures with sufficient time in between tests to reach the new temperature.

8. Calculations.

8.1. Calculate the stress and strain values from the recorded loads, deformations, and sample dimensions.

8.2. The stiffness modulus is calculated as the ratio of stress over strain. The Poisson's ratio is calcuated as the ratio of lateral strain to vertical strain.

8.3. Of primary interest are the stiffness modulus and Poisson's ratio at the following three positions:

8.3.1. Preconditioning - stress and strain values achieved after the first half inch of deformation;

8.3.2. Initial - stress and strain from the initial straight line portion of the load versus displacement curve during the test load application;

8.3.3. Secant - stress and strain at the maximum load applied to the specimen.

9. Report.

Report the calculated values of stiffness modulus and Poisson's ratio at each condition, indicating the direction in which the fabric was tested, the test temperature, the specimen dimensions, and the mode of failure. Also, make a note of any irregularities, such as slippage of the fabric from the clamps (detected by a saw-tooth pattern on the load versus deformation curve) or if the maximum test equipment load was exceeded.

10. Precision.

The precision of this test method has not been established.

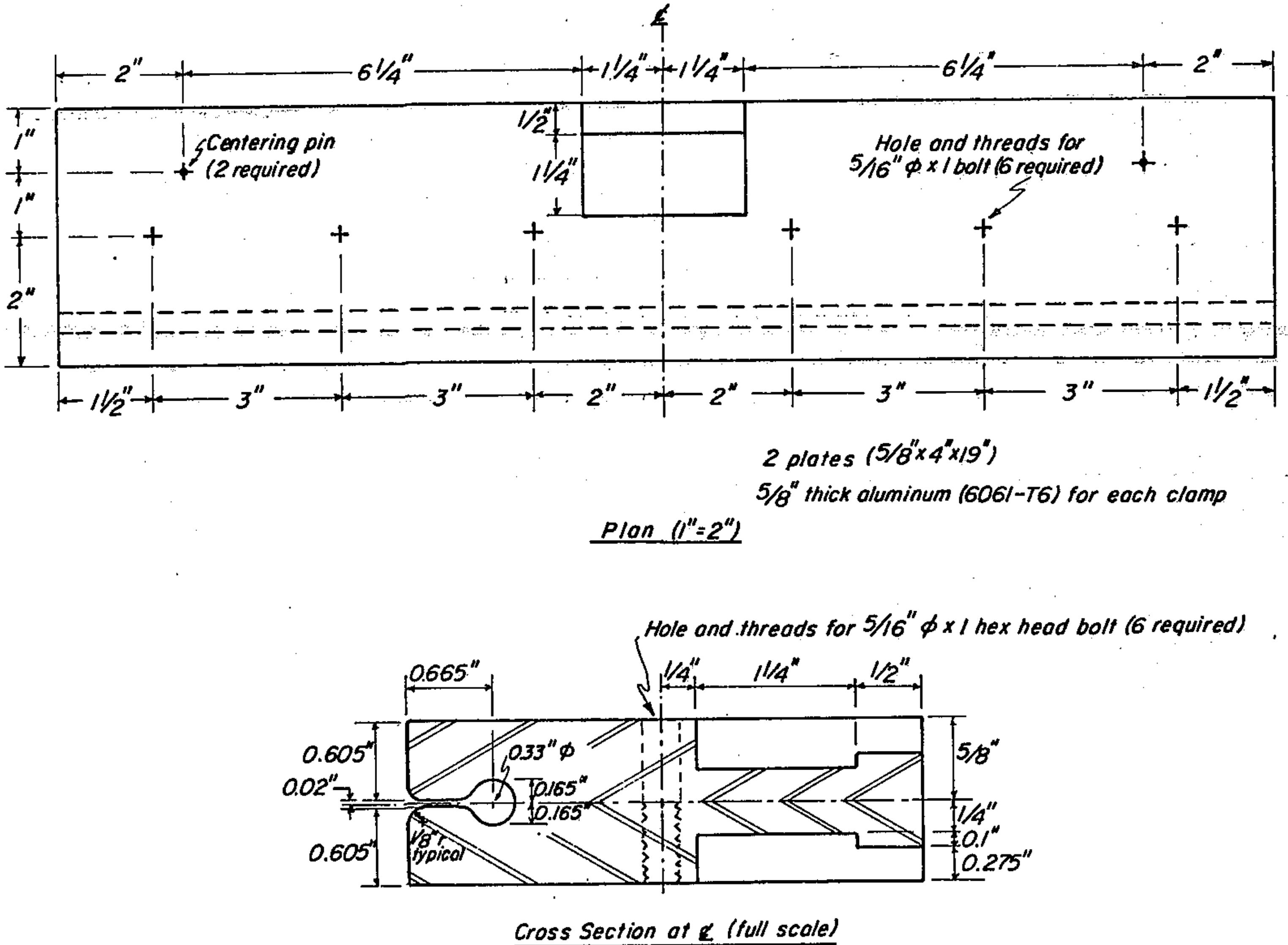

Fig. A1 - Dimensions of special clamps to hold fabric specimens.

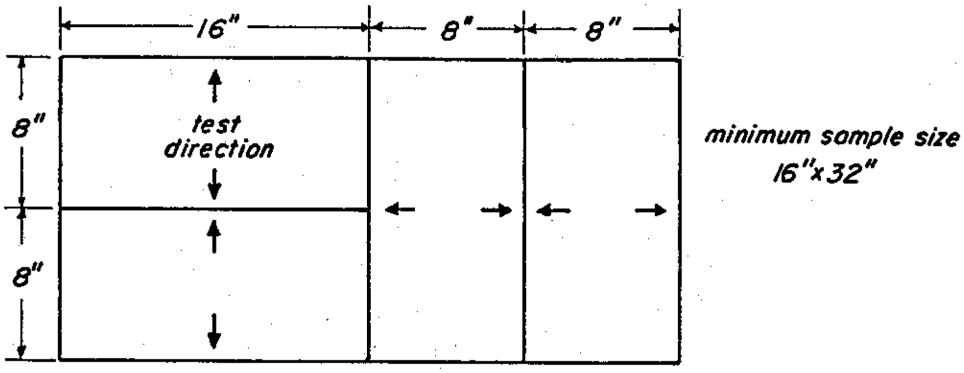

Fig. A2 - Outline of four specimens on fabric sample.

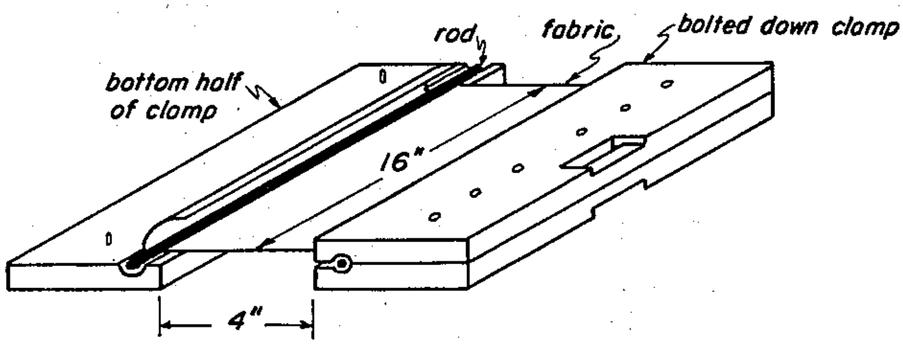

Fig. A3 - Schematic diagram of fabric and clamps.