NASA Technical Memorandum 81900

ROOM TEMPERATURE SHEAR PROPERTIES OF THE STRAIN ISOLATOR PAD FOR THE SHUTTLE THERMAL PROTECTION SYSTEM

(NASA-TM-81900) ROOM TEMPERATURE SHEAR PROPERTIES OF THE STRAIN ISOLATOR PAD FOR THE SHUTTLE THERMAL PROTECTION SYSTEM (NASA) 40 p HC A03/MF A01 CSCL 20K
N81-18411
Unclas
G3/39 41480

James Wayne Sawyer and William Allen Waters, Jr.

January 1981

NASA
National Aeronautics and
Space Administration

Langley Research Center
Hampton, Virginia 23665

ROOM TEMPERATURE SHEAR PROPERTIES OF THE STRAIN ISOLATOR PAD FOR THE SHUTTLE THERMAL PROTECTION SYSTEM

SUMMARY

Tests have been conducted at room temperature to determine the shear properties of the strain isolator pad (SIP) material used in the thermal protection system of the Space Shuttle. Tests were conducted on both 0.23 cm (.090 inch) and .41 cm (.160 inch) thick SIP material in the virgin state and after fifty fully reversed shear cycles. The shear stress-displacement relationships are highly nonlinear, exhibit large hysteresis effects, are dependent on material orientation, and have a large low modulus region near the zero stress level where small changes in stress can result in large displacements. Shear and normal cyclic loadings further degrade the shear-displacement relationship for the material by increasing the length of the low modulus region. Shear tangent modulus values are highly dependent on the shear stress level. The values at the higher stress levels generally increase with normal and shear force load conditioning. Normal force applied during the shear tests reduces the low-modulus region for the material. Shear test techniques which restrict the normal movement of the material give erroneous stress-displacement results. However, small normal forces do not significantly effect the shear modulus for a given shear stress. Poisson's ratio values for the material are within the range of values for many common materials. The values are not constant but vary as a function of the stress level and the previous stress history of the material. Ultimate shear strengths of the .23 cm (.090 inch) thick SIP are significantly higher than those obtained for the .41 cm (.160 inch) thick SIP.

INTRODUCTION

The thermal protection system (TPS) used for high heating areas of the Shuttle orbiter is composed of arrays of reusable surface insulation (RSI) tiles bonded to Nomex felt strain isolator pads (SIP) which, in turn, are bonded to the aluminum external skin of the orbiter. The SIP and RSI are bonded using a silicon rubber adhesive RTV-560. The SIP material serves to isolate the rigid, fragile tile material from the relatively large deformations of the aluminum substructure due to mechanical and thermal loads. The mechanical properties of the SIP material are needed to evaluate the stress levels and motion of the tiles due to the expected flight loads.

Tension and compression static characteristics of the SIP material were obtained and reported in reference 1. The tension/compression fatigue characteristics of the various SIP/tile systems were obtained and reported in reference 2. The present investigation was undertaken to obtain the shear characteristics for the two most commonly used thicknesses of SIP. The effect that a limited number of cyclic loadings has on the shear characteristics of the material is also investigated.

SPECIMENS AND TESTS

Specimens

The test specimen used to obtain the shear properties of the SIP material must be carefully chosen. When the SIP is subjected to a shear deformation, large transverse normal deformations are also obtained due to the strong directional coupling of the material. As a result of the flexibility of the SIP material, small normal loads may significantly effect the shear characteristics of the material. The usual test specimen for such materials would be made by bonding the material between two blocks and applying an axial load so that the material is loaded in shear. However, small normal forces are inherently present in such tests and may affect the measured shear properties. To avoid the problems caused by these small normal forces, a double lap joint (see Fig. 1) has been chosen for the present tests. The doublers are free to move in the normal direction and thus do not introduce any large external normal loads in the test material.

Materials: The .23 cm (.090 inch) and .41 cm (.160 inch) thick SIP material were tested in this investigation. The SIP is a needled (non-woven) Nomex felt and is used as a strain isolator pad between the RSI tiles and the aluminum primary structure of the vehicle. The specimen fixtures were made from 2024-T4 aluminum. The SIP was bonded to the aluminum fixtures using a room temperature curing silicon rubber adhesive, RTV-560. The SIP was obtained from the same supply as that used for the Shuttle orbiter. Fresh RTV-560 was obtained from the manufacturer to insure that the shelf life had not been exceeded. The aluminum fixture surfaces that were to be bonded to the SIP were chemically etched, sprayed with a protective primer (Koropon), and vacuum baked to remove all volatiles. The bonding procedure used to make the specimens is a very close duplicate of that used on the actual orbiter. The bonding and quality control personnel received special training at the NASA Kennedy Space Flight Center pertaining to the correct procedure to use in making the specimens. Care was taken to insure that the RTV had cured to a Shore hardness of 50 or greater before testing the specimen.

Configuration: Detail dimensions of the test specimen are given in Figure 1. Four identical pieces of SIP are bonded between the two aluminum adherends and the doublers. Relatively large (6.35 by 7.62 cm (2.5 by 3.0 inch)) pieces of SIP are used to minimize the influence of edge effects. A .018 cm (.007 inch) thick layer of RTV-560 is used on each side of the SIP to bond it to the aluminum. During the manufacturing process, the SIP is passed through a needled roller which may result in the material having different shear properties in the roll and cross-roll directions. Tests were conducted for the SIP material with the shear loads applied in each direction Care was taken to insure that the SIP for each specimen was properly oriented with respect to the applied load.

TESTS

All tests were conducted in a hydraulically actuated test machine that can be operated in either the load or displacement control mode. A 44 kN (10,000 lb) tension-compression load cell was used to measure the load applied to the specimen and to control the test machine when in the load control mode. Specimen axial displacement was measured using a displacement transducer which indicated testing machine head motion. Normal displacement of the doublers with respect to the adherends were measured using displacement transducers mounted on the doublers. Data were recorded using a x-y recorder and a digital data acquisition system.

The test setup is shown in the photograph in Figure 2. The procedure followed in setting up a test is to zero the load cell with a weight equivalent to one-half of a typical specimen attached to the load cell. The specimen is then installed with the test machine in the displacement control mode. After specimen installation, the test machine control mode is switched to load control which removes any residual setup loads that were applied to the SIP. The x-y recorder is then calibrated and the load and displacements taken as zero.

Shear cyclic tests were run at .01 cycle per second with a fully reversed (R = -1) sinusoidal load cycle. Ultimate shear strengths were determined by applying a shear load at the rate of 1.5 kPa (.2 psi) per second. A few tests were conducted with a constant normal force applied to the doublers by means of pulleys and dead weights. Tests were run with both tension and compression normal loads applied. Certain specimens were also given a normal static proof load and cyclic loading before testing in shear. The proof load was applied to simulate the proof tests performed on the vehicle and the cyclic loading was applied to simulate material conditioning due to flight. The normal proof and cyclic loads were applied by mounting the double lap joint specimen horizontal in the test machine and attaching the doublers to the load cell and hydraulic ram. The proof loads were applied and removed at the rate of 3.5 kPa (.5 psi) per second. Tension proof loads of 55 kPa (8 psi) and 62 kPa (9 psi) were each held for 30 seconds. The maximum tensile load of 69 kPa (10 psi) was held for 60 seconds and the maximum compression load of 69 kPa (10 psi) was held for 30 seconds. After the proof loads, fully reversed normal cyclic loads of 36.5 kPa (5.3 psi) were applied to some of the specimens at the rate of 1 cycle per second. After the normal proof and cyclic loading, the specimen was removed from the machine and reinstalled vertically for shear loading.

RESULTS AND DISCUSSION

Shear results from the tests are presented as a function of the material inplane differential displacement between the faying surfaces of the SIP (see the sketch in Figure 3). Normal displacements are the changes in the thickness of the SIP due to the shear load. Shear modulus values presented are based on the nominal unstressed thickness of the SIP.

Typical shear stress-differential-displacement curves for the complete load-unload cycle are shown in Figure 3 for the SIP material during the first and fiftieth fully reversed shear loading cycle. Although the curves shown in Figure 3 are for the .41 cm (.160 inch) thick SIP, they are similar to those for the .23 cm (.090 inch) thick SIP. The shear stress-differential displacement relationships are highly nonlinear, exhibit large hysteresis effects, and have a large low-modulus region near the zero stress level where small changes in stress can result in large differential displacements. Cyclic loading further degrades the stiffness characteristics of the material by increasing the length of the low-modulus region.

.41 cm (.160 inch) thick SIP - Normal and differential displacements are shown in Figure 4 as a function of stress level for the SIP material during the first and fiftieth cycle. The maximum cyclic stress level in Figure 4a was 34.5 kPa (5 psi) and in Figure 4b was 69.0 kPa (10 psi). For each stress level, the normal and differential displacements increase with cycling, however, the increase is larger for the higher cyclic stress level. Even though the normal displacements are relatively large, the Poisson's ratio values are in the same range as most materials. Poisson's ratio values will be discussed in a later section.

Shear tangent modulus values for the first, tenth, and fiftieth cycle are shown in Figure 5 as a function of shear stress and in Figure 6 as a function of differential displacement. The maximum cyclic stress level for Figures 5a and 6a is 34.5 kPa (5 psi) and for Figures 5b and 6b is 69.0 kPa (10 psi). Increasing the maximum shear stress level (Fig. 5) results in an almost linear increase in the shear modulus. At the higher stress level, cycling results in a higher shear modulus and thus causes the material to become stiffer. At the lower stress levels, the shear modulus is very low and cycling has little effect. The shear modulus is a highly nonlinear function of the differential displacement (Fig. 6)—low modulus values that are nearly constant for small displacements but increase sharply for larger displacements. Shear load cycling increases the range of the low modulus region for the material but results in higher modulus values for a given stress level.

The effect of material orientation on the shear-differential displacement relationship and the shear tangent modulus is shown in Figures 7a and 7b, respectively. With the material oriented in the roll direction, the low modulus region is longer and larger displacements are obtained for a given stress level than for the material oriented in the cross-roll direction. Material orientation has only a small effect on the normal displacement. Shear modulus values shown as a function of the stress level are not significantly different for the different material orientations, especially for the first cycle. Some differences in the modulus values are evident for the fiftieth cycle but are probably within the data scatter.

The effect of normal proof and load cyclic conditioning on the shear stress-differential displacement relationship and the modulus values are shown in Figures 8a and 8b, respectively. The normal proof level was ±69 kPa (10 psi) and the conditioning consisted of 50 fully reversed normal load cycles at a stress level of 35 kPa (5.3 psi). The proof test and the cyclic conditioning both increase the length of the low modulus region and increase the normal and differential displacement over that obtained for the virgin material. Shear modulus values at the lower stress levels are not affected by the proof and normal load cyclic conditioning but at the higher stress levels are considerably higher than that obtained for the virgin material. The variations in displacement and modulus values noted are largely due to the normal proof load and are only slightly effected by the normal load cyclic conditioning.

The effect of a normal force on the shear stress-differential displacement relationship and the tangent modulus are shown in Figures 9a and 9b, respectively. Data are shown for the SIP material with no normal load (solid line) and with a normal stress level of 11 kPa (1.6 psi) tension or compression (large dashed line). Data from reference 3, obtained using the block shear specimen which has an unknown normal load applied, are also shown (small dashed lines) for comparison. A normal stress (either tension or compression) reduces the low modulus region for the material and reduces the displacement for a given stress level. Thus, shear test techniques which restrict the normal movement of the material give erroneous stress-displacement results. The 90% minimum block shear data obtained from reference 3 agrees closely with the data obtained with the 11 kPa (1.6 psi) normal stress applied and the average block shear data shows even smaller displacements for a given stress level. Tangent modulus values at a given stress level, however, are not significantly different for the block shear data and the double lap joint data with or without the normal forces applied. Therefore, the normal force has a large effect on the stress-displacement relationship but the major effect is to reduce the low modulus region for the material.

.23 cm (.090 inch) thick SIP - Test results for the .23 cm (.090 inch) thick SIP are presented in Figures 10 through 14. The normal and differential displacements for the first and fiftieth cycle as a function of stress level are shown in Figure 10. Shear tangent modulus values for the first, tenth, and fiftieth cycle are shown, respectively, in Figures 11 and 12 as a function of shear stress and differential displacement. The effects of material orientation on the normal and differential displacements and the shear modulus are shown in Figure 13. The block shear data presented in reference 3 are shown for comparison with the double lap joint data in Figure 14.

The data for the .23 cm (.090 inch) thick SIP shows trends that are almost identical to those noted for the .41 cm (.160 inch) thick SIP. Thus, the discussion in the previous section is applicable for the .23 cm (.090 inch) thick SIP and is not repeated in this section.

Ultimate Strength - Measured ultimate shear strengths for both the .23 cm (.090 inch) and the .41 cm (.160 inch) thick SIP are presented in Table I. The number of specimens of each configuration tested are indicated. For the .41 cm (.160 inch) thick SIP, material orientation does not have a significant effect on the ultimate shear strength. Average measured ultimate shear strength for specimens with a constant applied normal stress of 11 kPa (1.6 psi) does not significantly differ from specimens in the unrestrained condition. For the .23 cm (.090 inch) thick SIP, the ultimate shear strength is significantly higher than that obtained for the .41 cm (.160 inch) thick SIP and is significantly higher for the cross-roll direction than the roll direction. Block shear test results from reference 3 are shown for the .41 cm (.160 inch) thick SIP and are in agreement with the measured values. Block shear results for the .23 cm (.090 inch) thick SIP were not given in reference 3.

Poisson's Ratio - Poisson's ratio values as determined from the ratio of the normal displacement to the differential displacement for both the .23 cm (.090 inch) and .41 cm (.160 inch) thick SIP are presented in Table II for the virgin material and for the material after it had been cycled 50 times at a fully reversed stress level of 69 kPa (10 psi). Values are given for the material oriented in both the roll and cross-roll direction and for stress levels of 14, 28, 41, 55, and 69 kPa (2, 4, 6, 8, and 10 psi). For both material thicknesses, increasing the stress level and cycling the material generally increases the Poisson's ratio whereas material orientation has only a small effect. The Poisson's ratio values obtained for the .23 cm (.090 inch) thick SIP are significantly larger and show more variations with stress level than those obtained for the .41 cm (.160 inch) thick SIP.

CONCLUDING REMARKS

Tests have been conducted at room temperature to determine the shear properties of the strain isolator pad material used in the thermal protection system of the Space Shuttle orbiter. Tests were conducted on both the .23 cm (.090 inch) and .41 cm (.160 inch) thick SIP material. Shear stress-displacement relationships, Poisson's ratio, and ultimate shear strengths are determined for the virgin material and for the material after 50 fully reversed shear cycles.

The test results show that the shear stress-differential displacement relationships are highly nonlinear, exhibit large hysteresis effects, are dependent on material orientation, and have a large low modulus region near the zero stress level where small changes in shear stress can result in large differential displacements. Shear cyclic loading, normal proof loading, and normal load cycling further degrades the stiffness characteristics of the material by increasing the length of the low modulus region. Shear tangent modulus values are highly dependent on the shear stress level. The shear tangent modulus at the higher stress levels generally increase with normal and shear force cyclic conditioning. Normal forces applied during the shear tests reduce the low modulus region for the material. Thus, shear test techniques which restrict the normal movement of the material give erroneous stress-displacement results. However, small normal forces do not significantly effect the shear modulus values for a given shear stress level. Poisson's ratio values for the material are within the range of values for many common materials. The values are not constant but vary as a function of the stress level and the previous stress history of the material. Ultimate shear strengths of the .23 cm (.090 inch) thick SIP are significantly higher than those obtained for the .41 cm (.160 inch) thick SIP.

REFERENCES

1. Sawyer, James Wayne; and Rummler, Donald R.: Room Temperature Mechanical Properties of Shuttle Thermal Protection System Materials, NASA TM-81786, April 1980.

2. Sawyer, James Wayne; and Cooper, Paul A.: Fatigue Properties of Shuttle Thermal Protection System, NASA TM-81899, October 1980.

3. Materials Properties Manual, Vol. 3. Thermal Protection System Materials Data, Rockwell International Publication, Pub. 2543-W, Rev. 5-79, May 1979.

TABLE I - ULTIMATE SHEAR STRENGTH OF SIP

	AVERAGE ULTIMATE SHEAR STRENGTH - kPa (PSI)				
SIP MATERIAL THICKNESS	.41 CM (.160 INCH)			.23 CM (.090 INCH)	
MATERIAL DIRECTION	CROSS-ROLL		ROLL	CROSS-ROLL	ROLL
*RESTRAINT	NO	YES	NO	NO	NO
DOUBLE LAP JOINT	18** 483 (70)	4** 455 (66)	5** 462 (67)	5** 703 (102)	5** 530 (77)
BLOCK SHEAR (REF. 3)	427 (62)		510 (74)	--	--

* NORMAL RESTRAINT OF 11 kPa (1.6 PSI) STRESS LEVEL IN SIP

** NUMBER OF SPECIMENS TESTED.

TABLE II - POISSON'S RATIO FOR SIP

STRESS LEVEL kPA (PSI)	POISSON'S RATIO							
	.41 CM (.160 INCH) SIP				.23 CM (.090 INCH) SIP			
	CROSS-ROLL DIRECTION		ROLL DIRECTION		CROSS-ROLL DIRECTION		ROLL DIRECTION	
	1ST CYCLE	50TH* CYCLE	1ST CYCLE	50TH* CYCLE	1ST CYCLE	50TH* CYCLE	1ST CYCLE	50TH* CYCLE
14 (2)	.23	.27	.20	.24	.28	.23	.28	.23
28 (4)	.23	.29	.21	.27	.30	.30	.31	.30
41 (6)	.23	.30	.23	.29	.31	.36	.31	.34
55 (8)	.23	.31	.24	.29	.33	.41	.37	.36
69 (10)	.23	.32	.23	.30	.35	.44	.38	.38

* 50 CYCLES AT FULLY REVERSED LOADING OF 69 kPA (10 PSI)

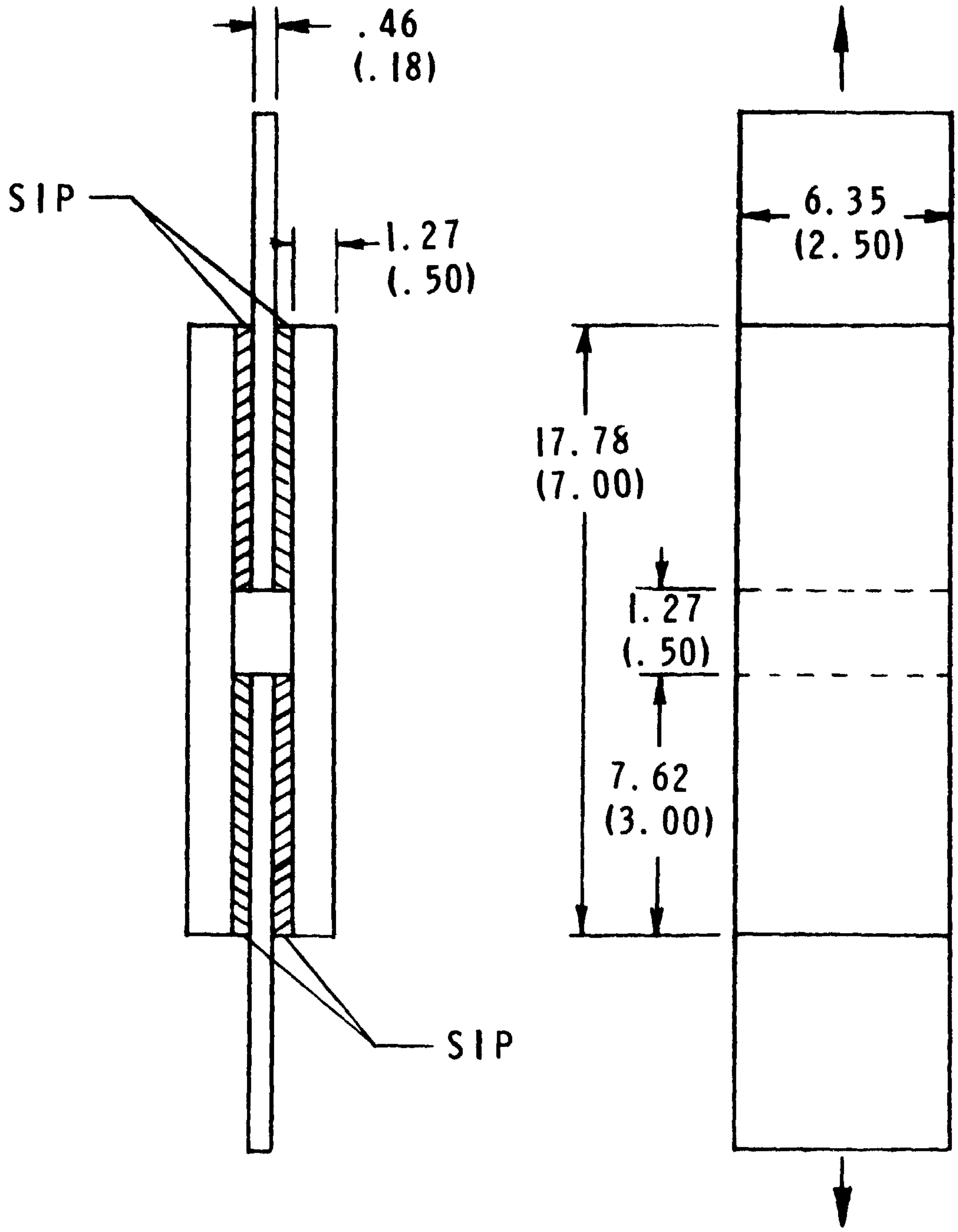


Figure 1.- Double lap joint shear test specimen. Dimensions given in centimeters (inches).

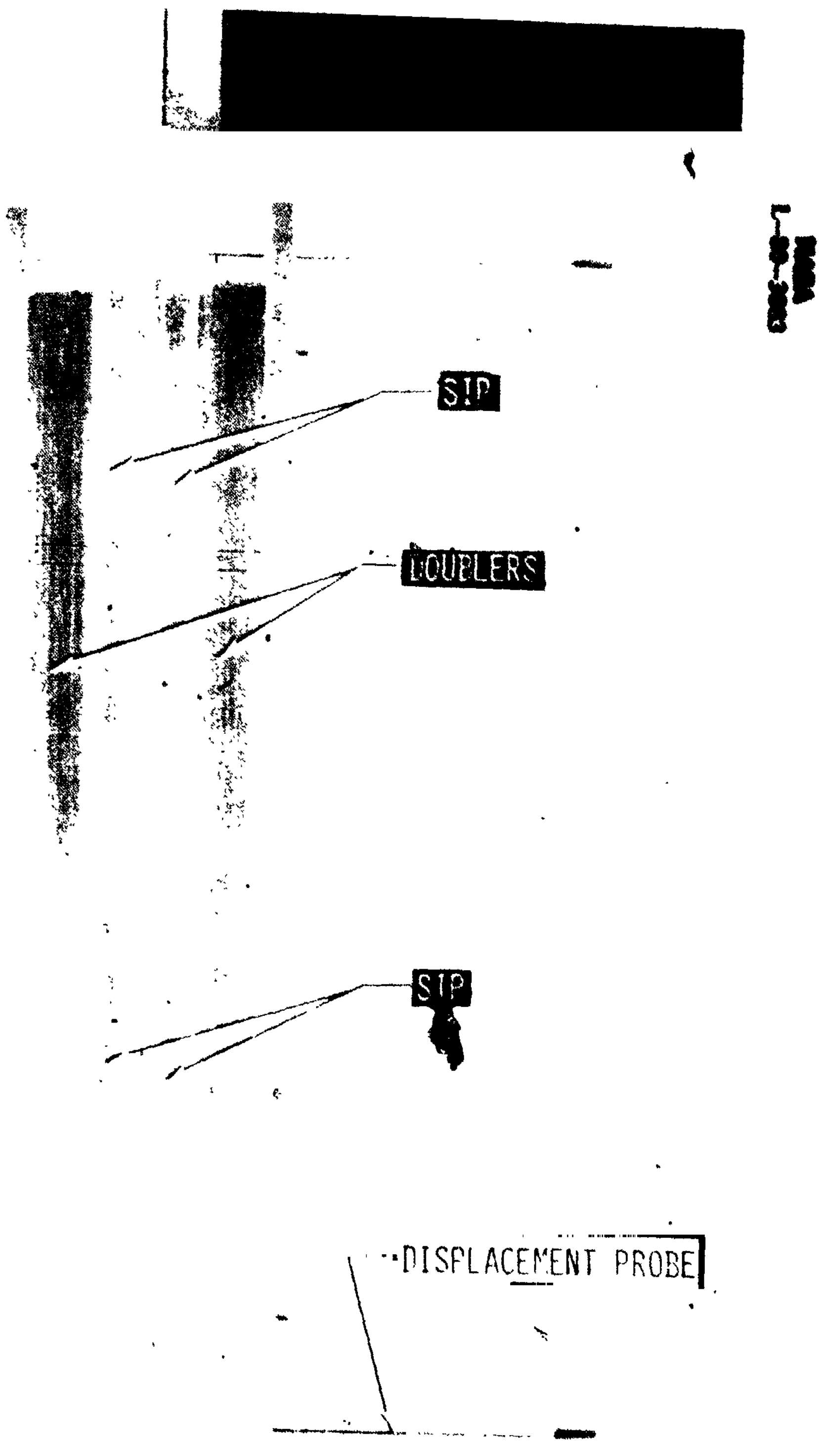


Figure 2.- Photograph of shear test setup.

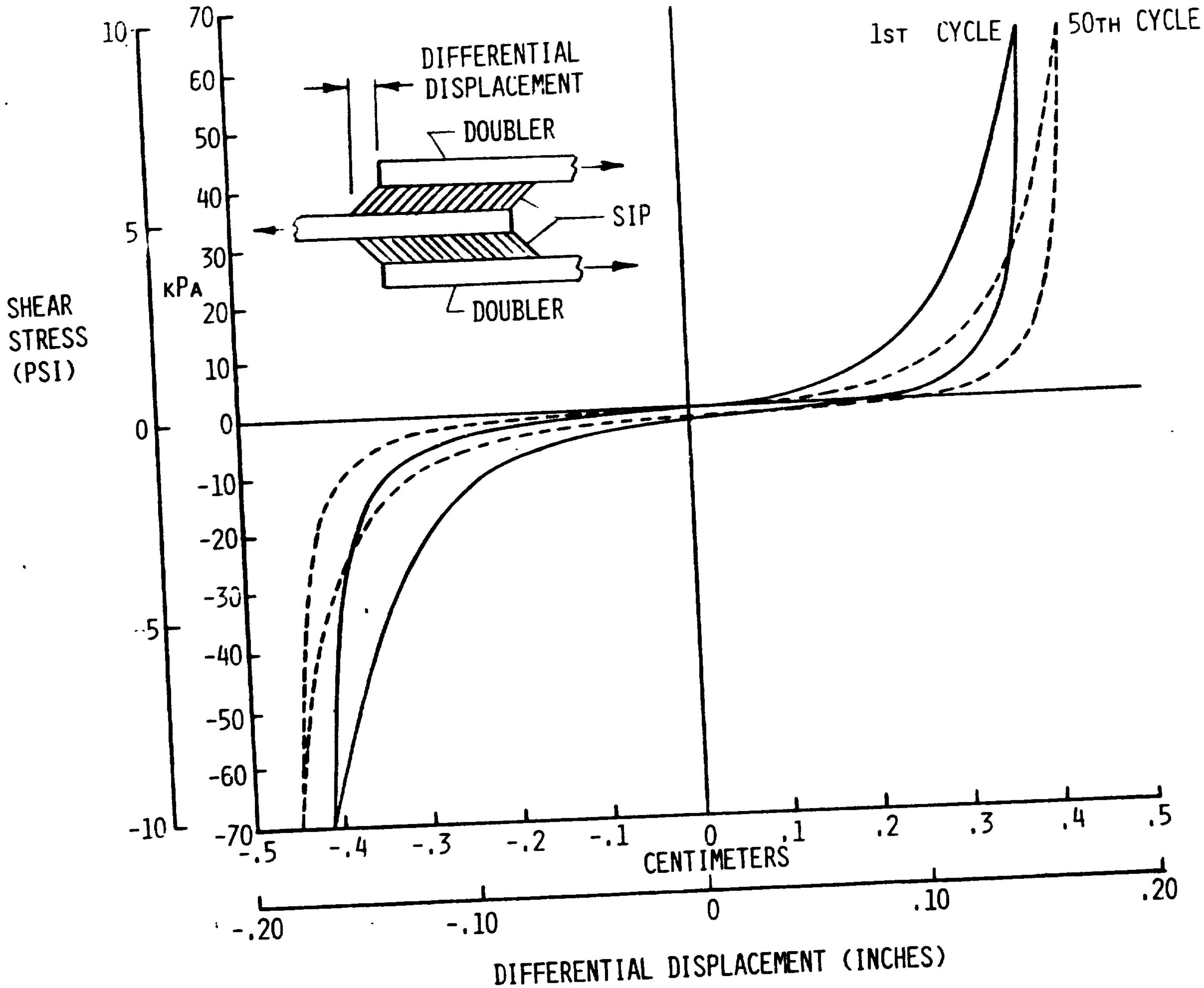
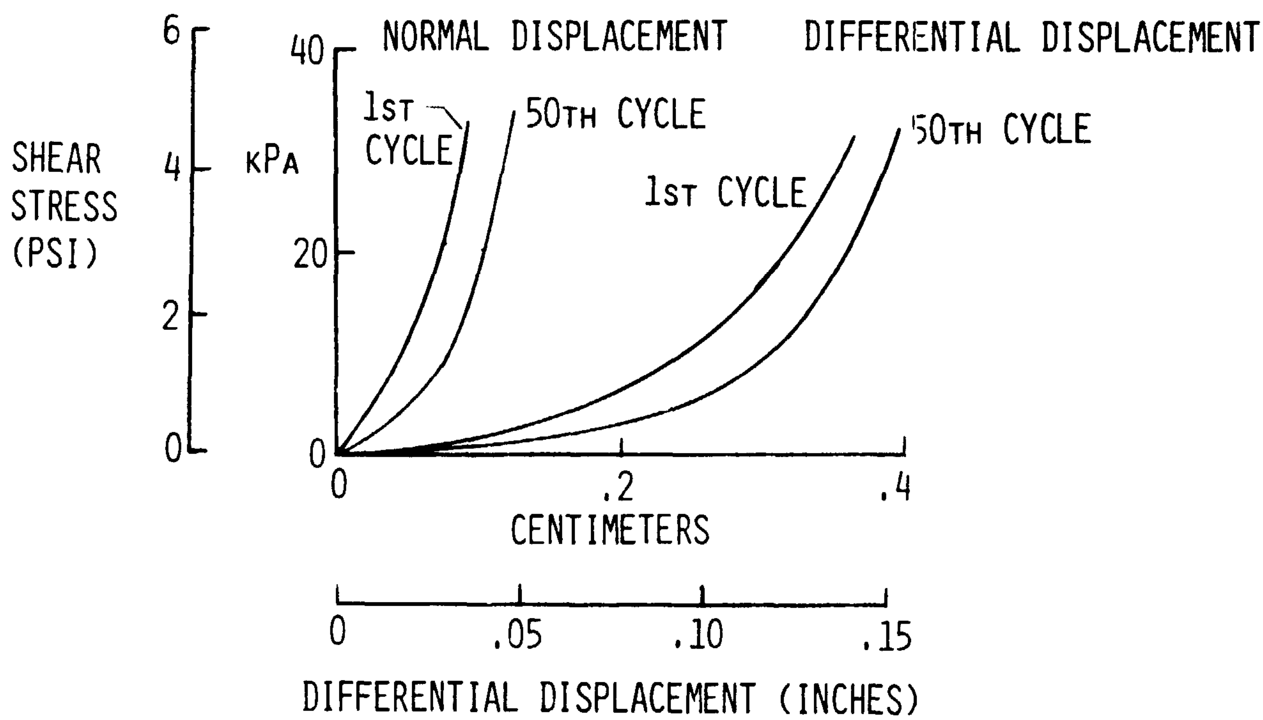
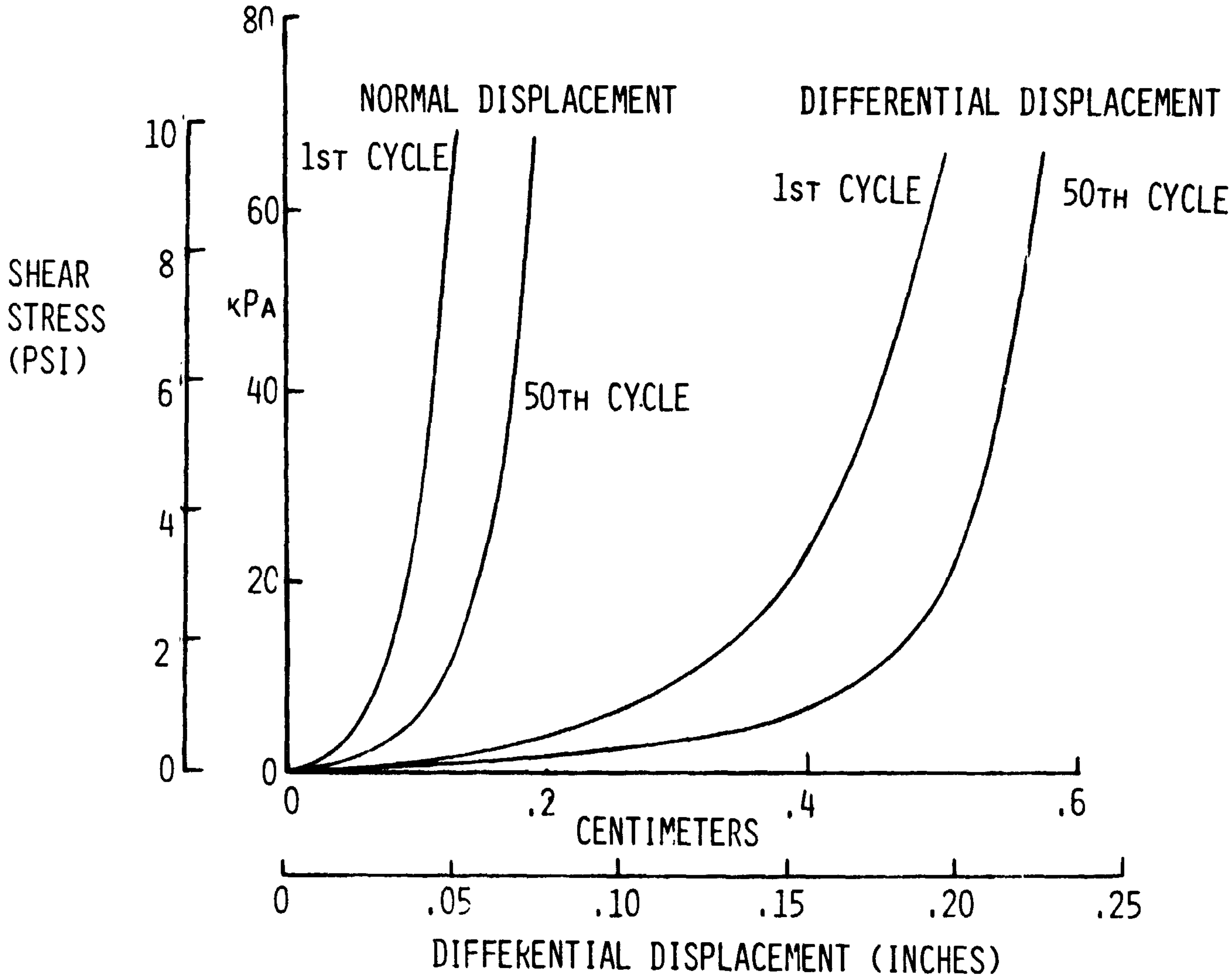


Figure 3.- Typical shear stress-differential displacement behavior for SIP material.



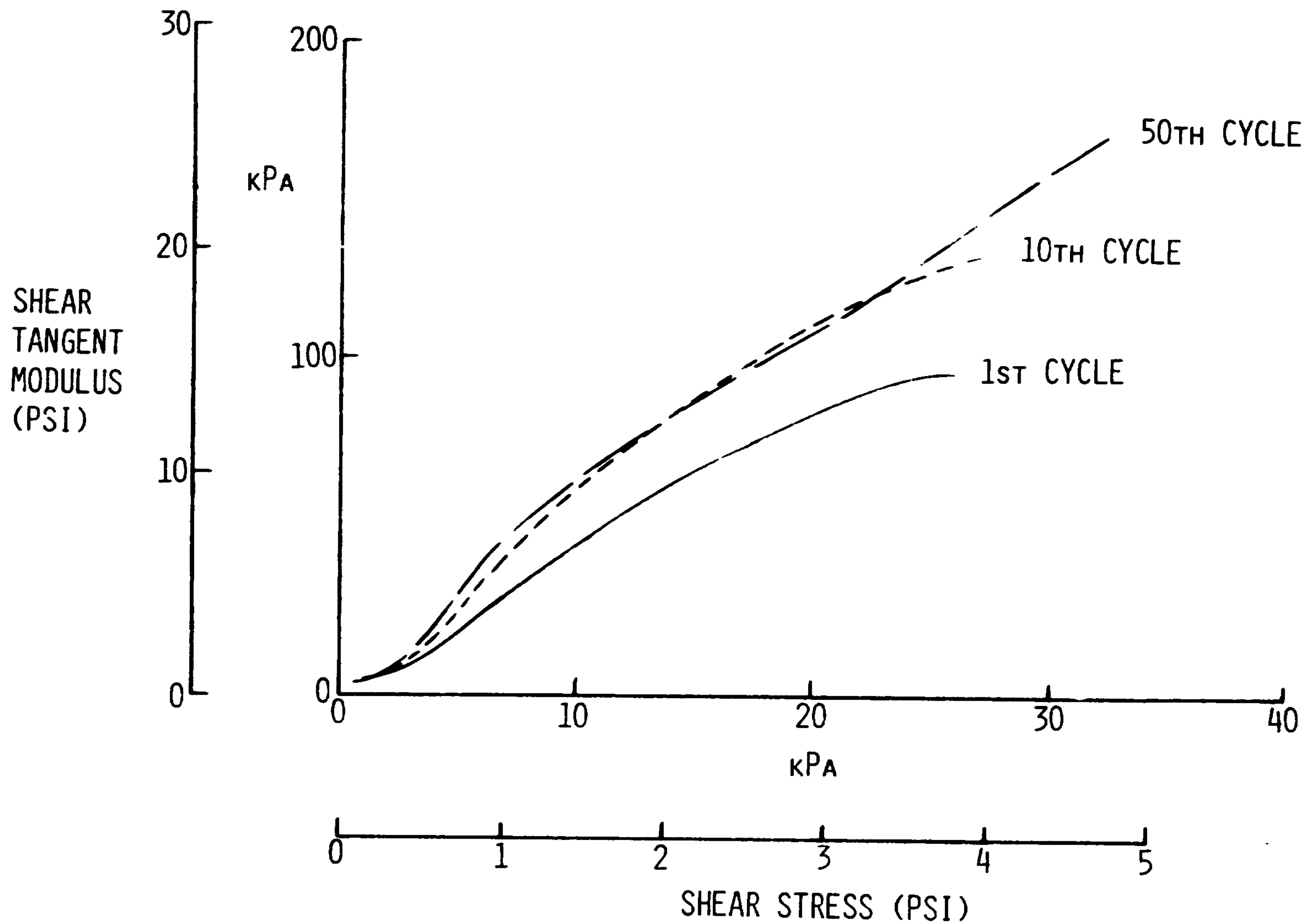
(a) Cyclic load level-34.5 kPa (5 psi)

Fig:. e 4.- Shear stress-differential displacement behavior for virgin and load conditioned .41 cm (.160 inch) thick SIP. Material stressed in cross-roll directi-r.



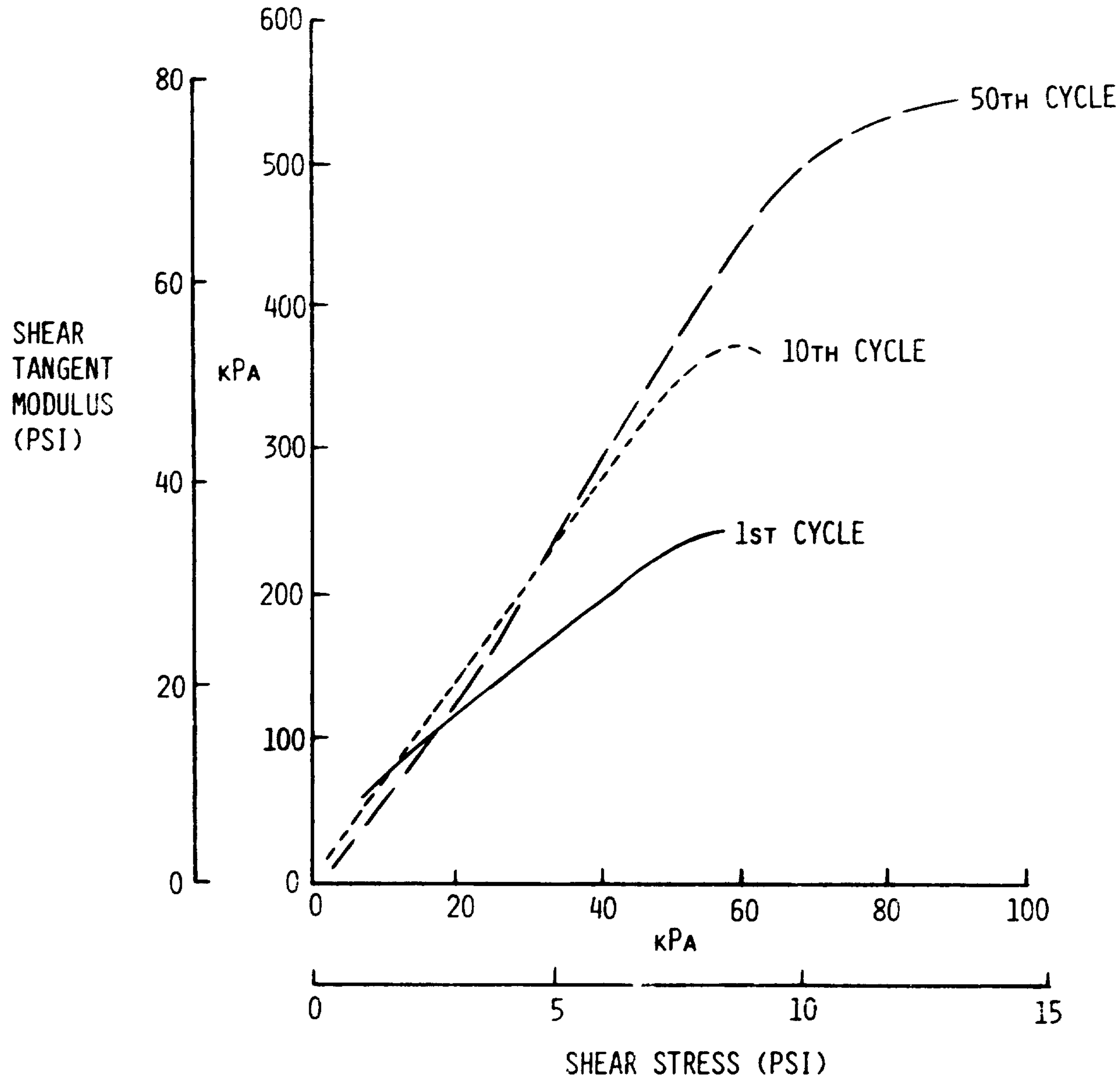
(b) Cyclic load level-69.0 kPa (10 psi)

Figure 4.- Concluded.



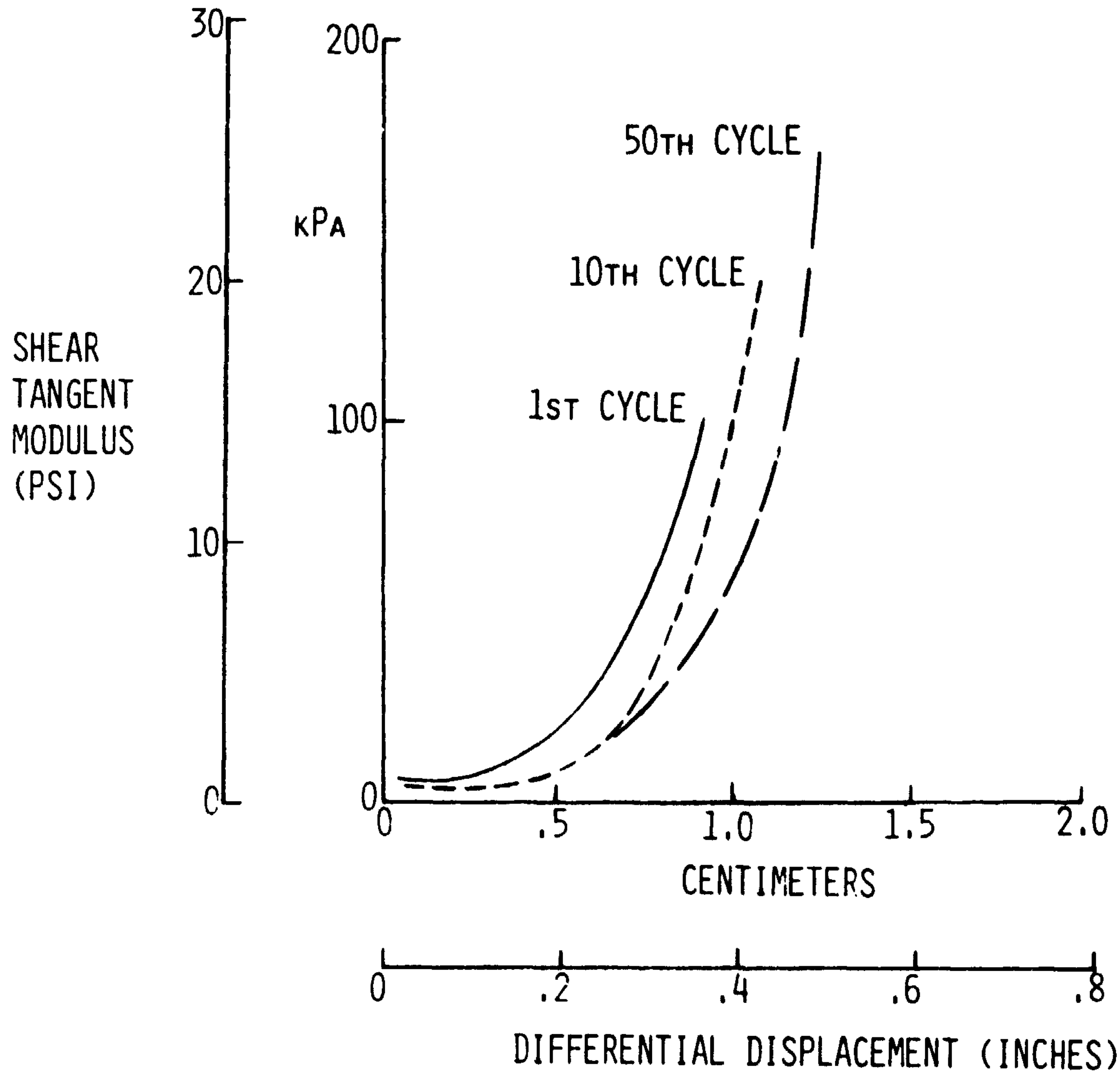
(a) Cyclic load level - 34.5 kPa (5 psi)

Figure 5.- Shear tangent modulus as function of shear stress for virgin and load conditioned .41 cm (.160 inch) thick SIP. Material stressed in cross-roll direction.



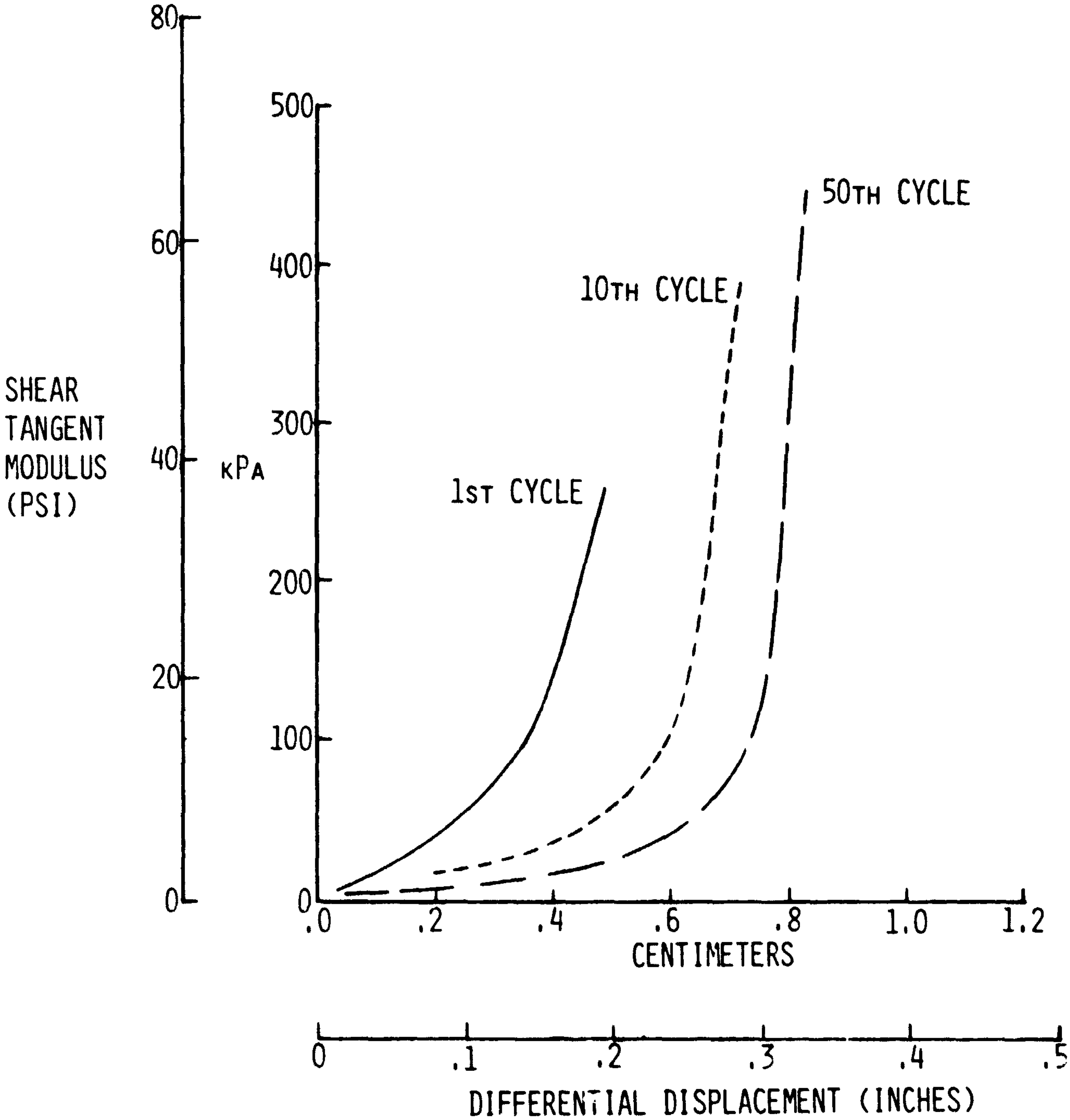
(b) Cyclic load level - 69.0 kPa (10 psi)

Figure 5.- Concluded.



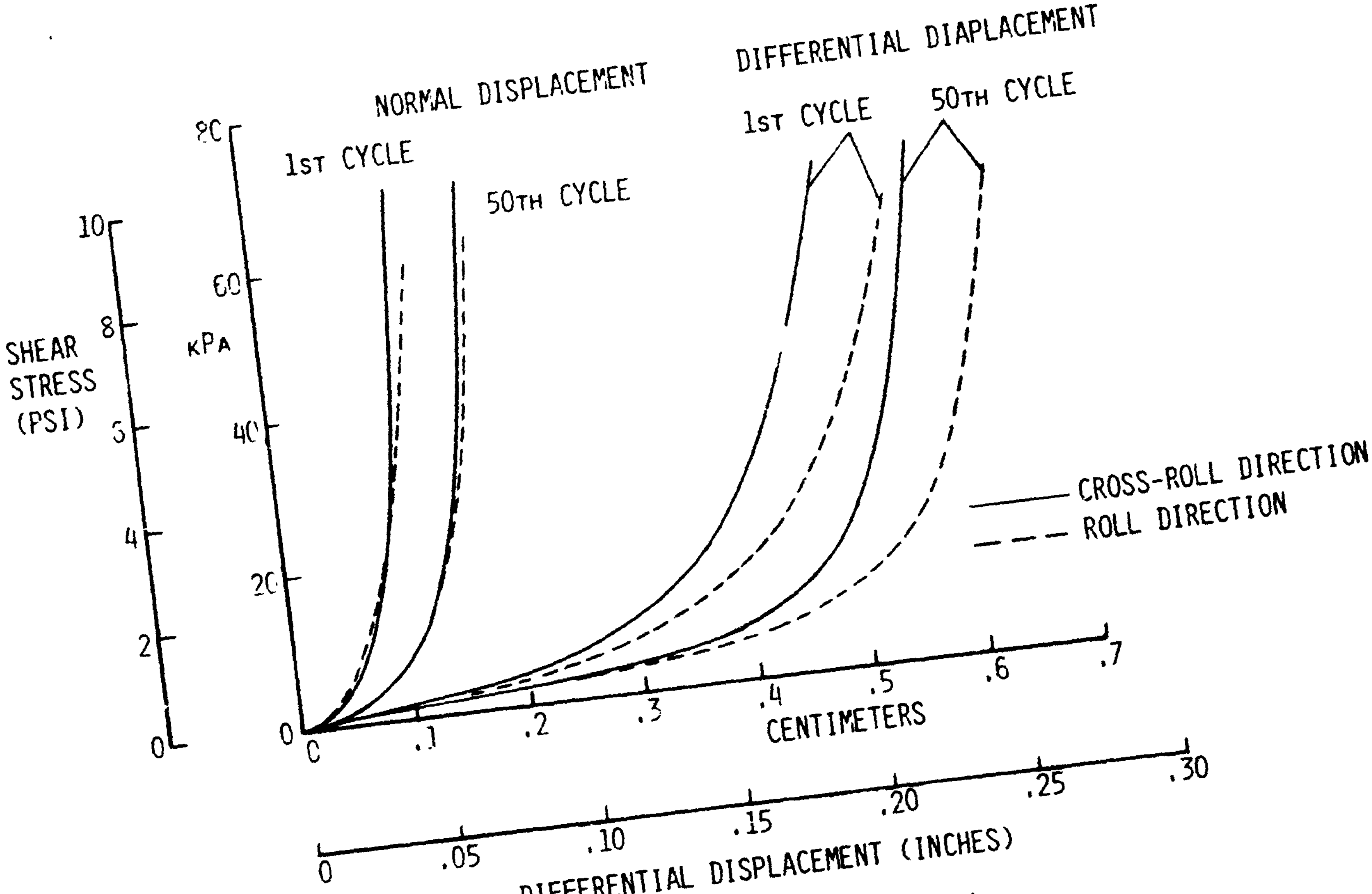
(a) Cyclic load level - 34.5 kPa (5 psi)

Figure 6.- Shear tangent modulus as function of differential displacement for virgin and load conditioned .41 cm (.160 inch) thick SIP. Material stressed in cross-roll direction.



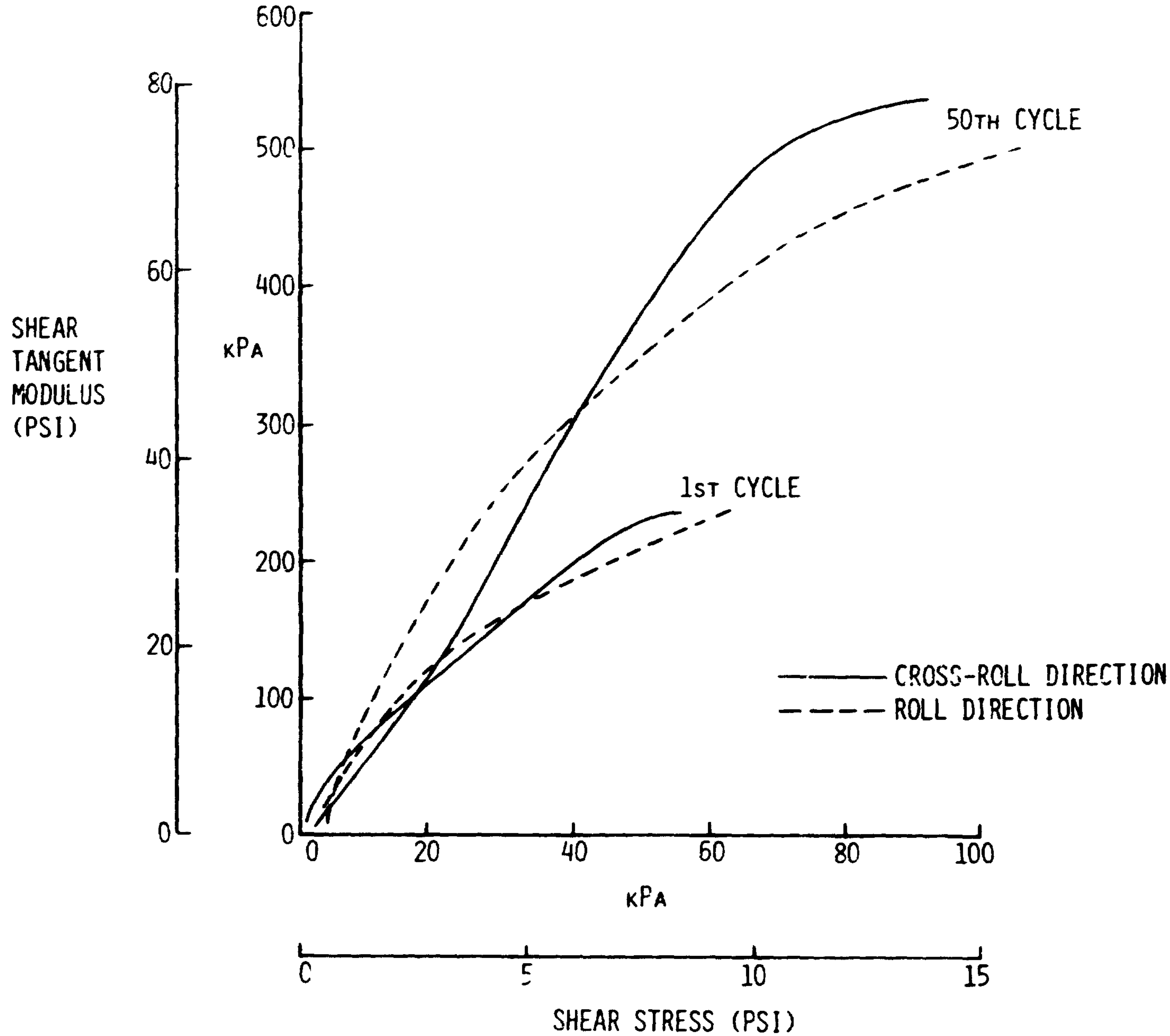
(b) Cyclic load level - 69.0 kPa (10 psi)

Figure 6.- Concluded.



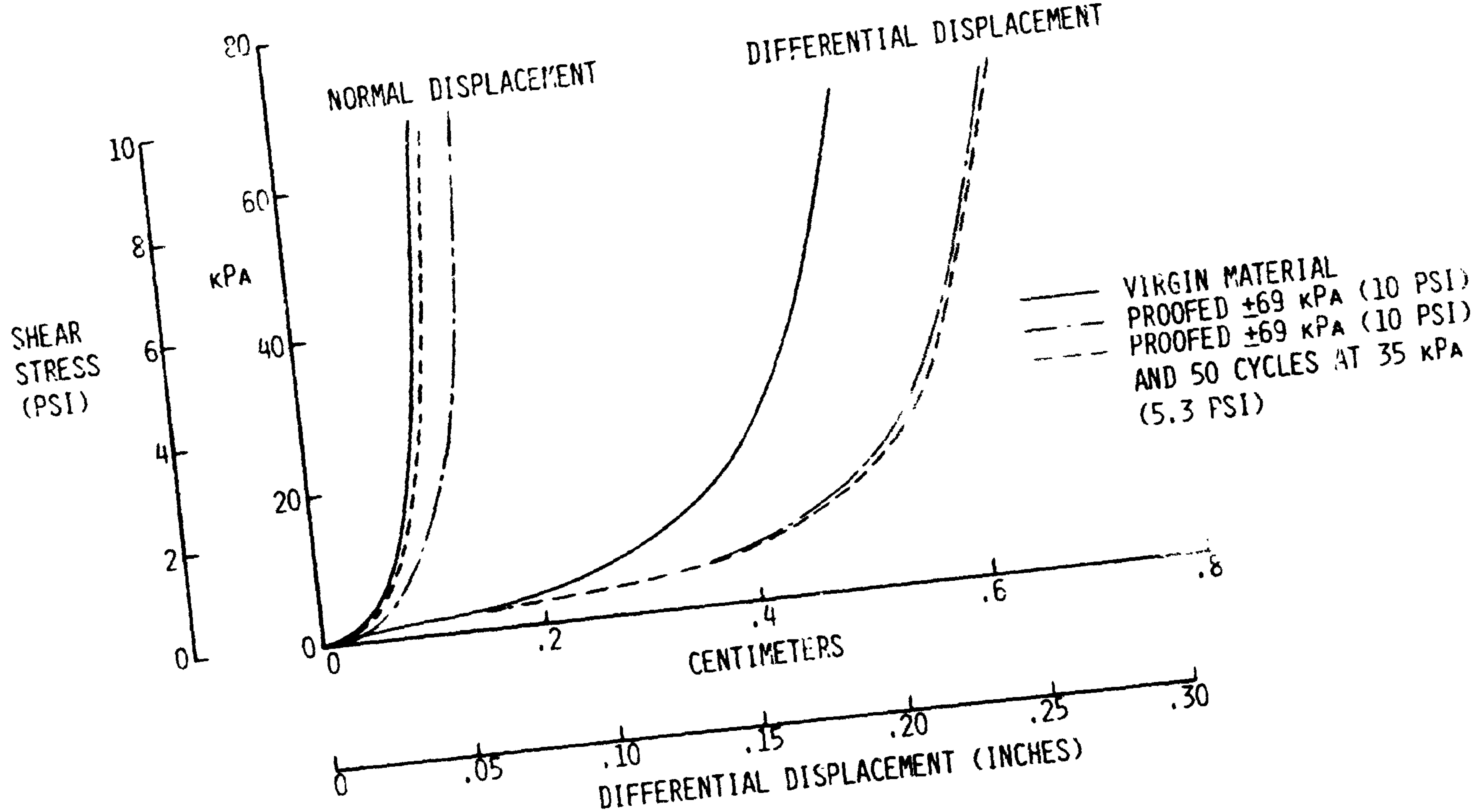
(a) Shear-differential displacement behavior.

Figure 7.- Effect of material orientation on shear behavior of .41 cm (.160 inch) thick SIP. Cyclic load level - 69.0 kPa (10 psi).



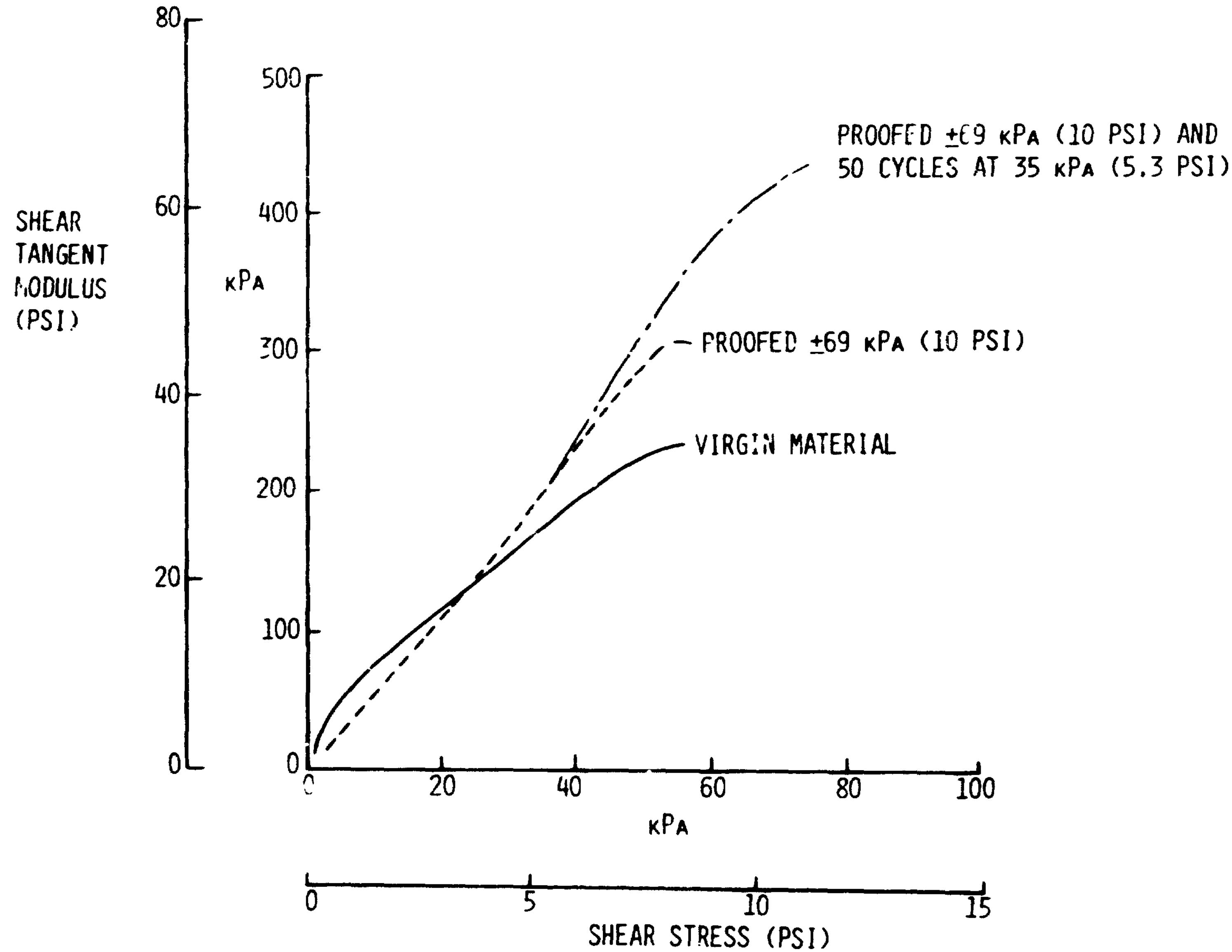
(b) Tangent modulus behavior

Figure 7.- Concluded.



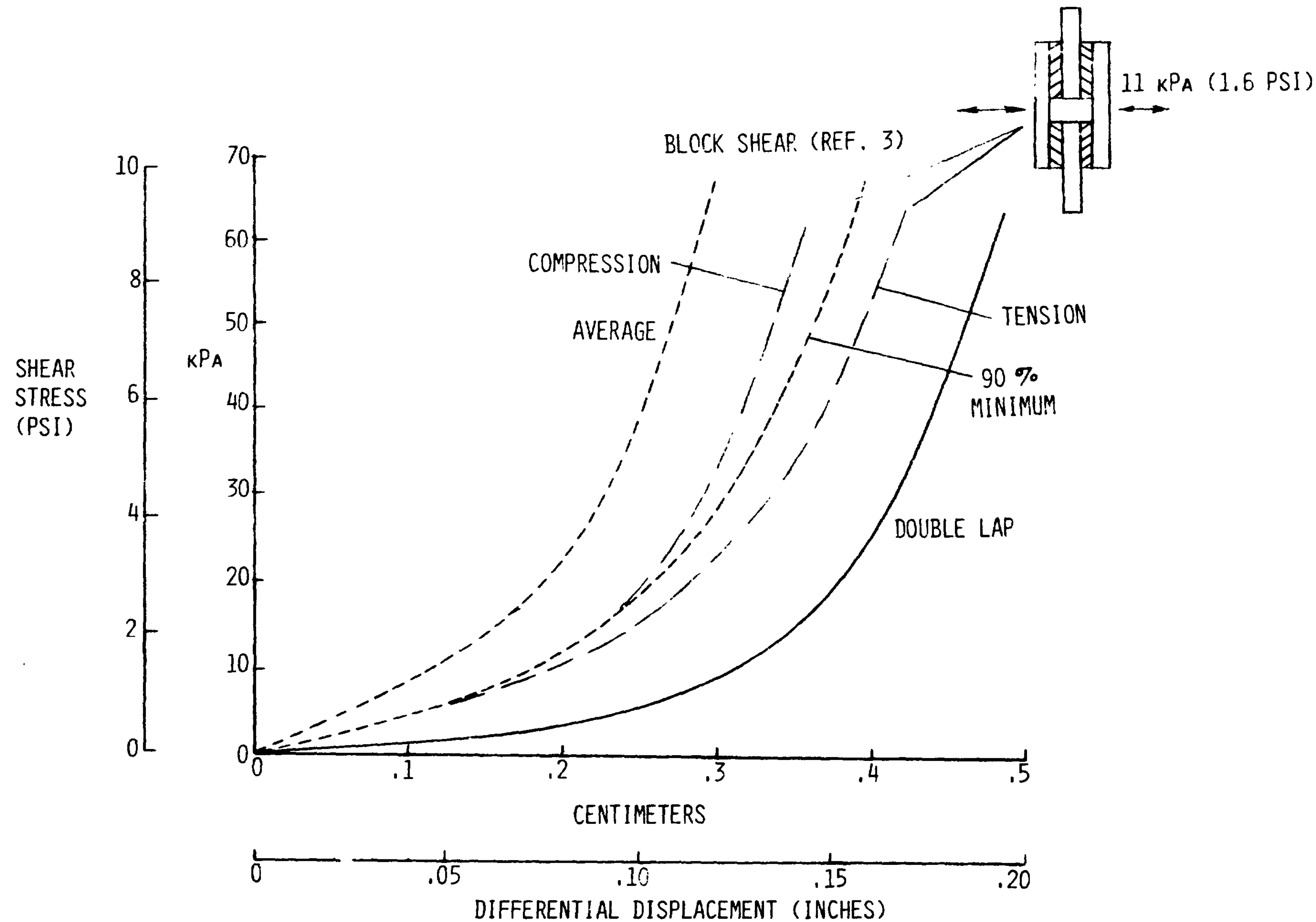
(a) Shear-differential displacement behavior

Figure 8.- Effect of normal proof and cycling on shear behavior of .41 cm (.160 inch) thick SIP. Material stressed in cross-roll direction.



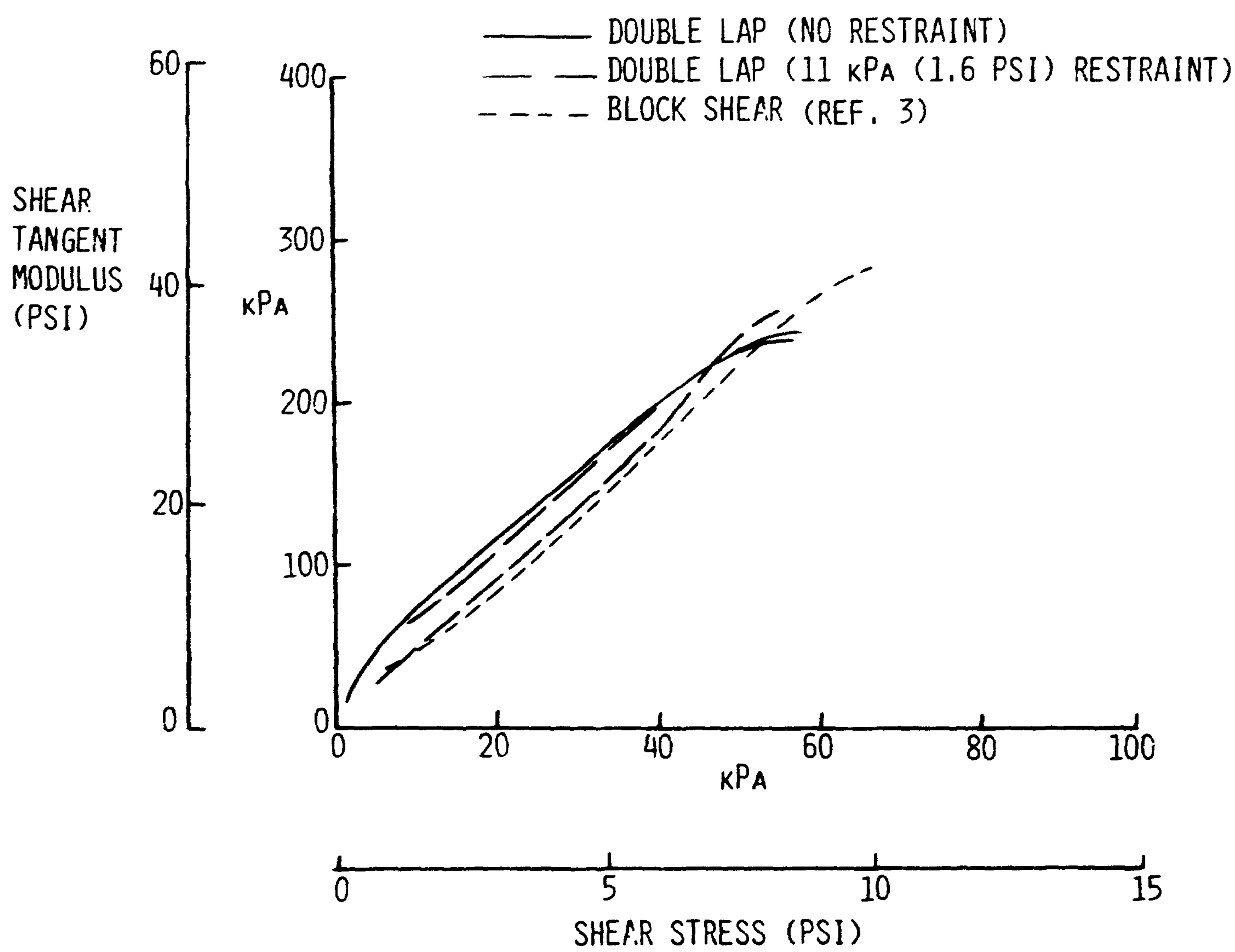
(b) Tangent modulus behavior

Figure 8.- Concluded.



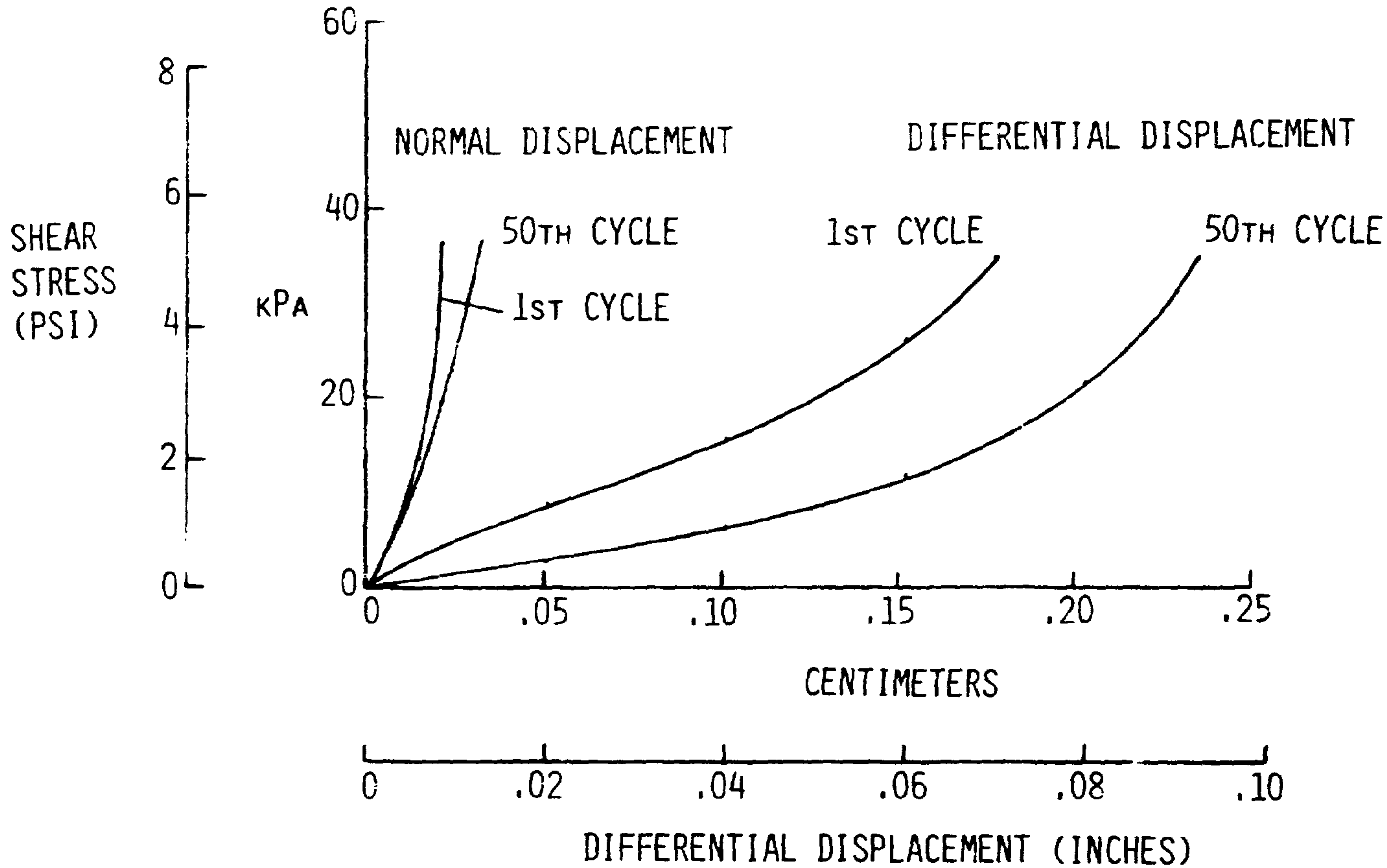
(a) Shear-differential displacement behavior.

Figure 9.- Effect of normal force on shear behavior of .41 cm (.160 inch) thick SIP. Material stressed in cross-roll direction.



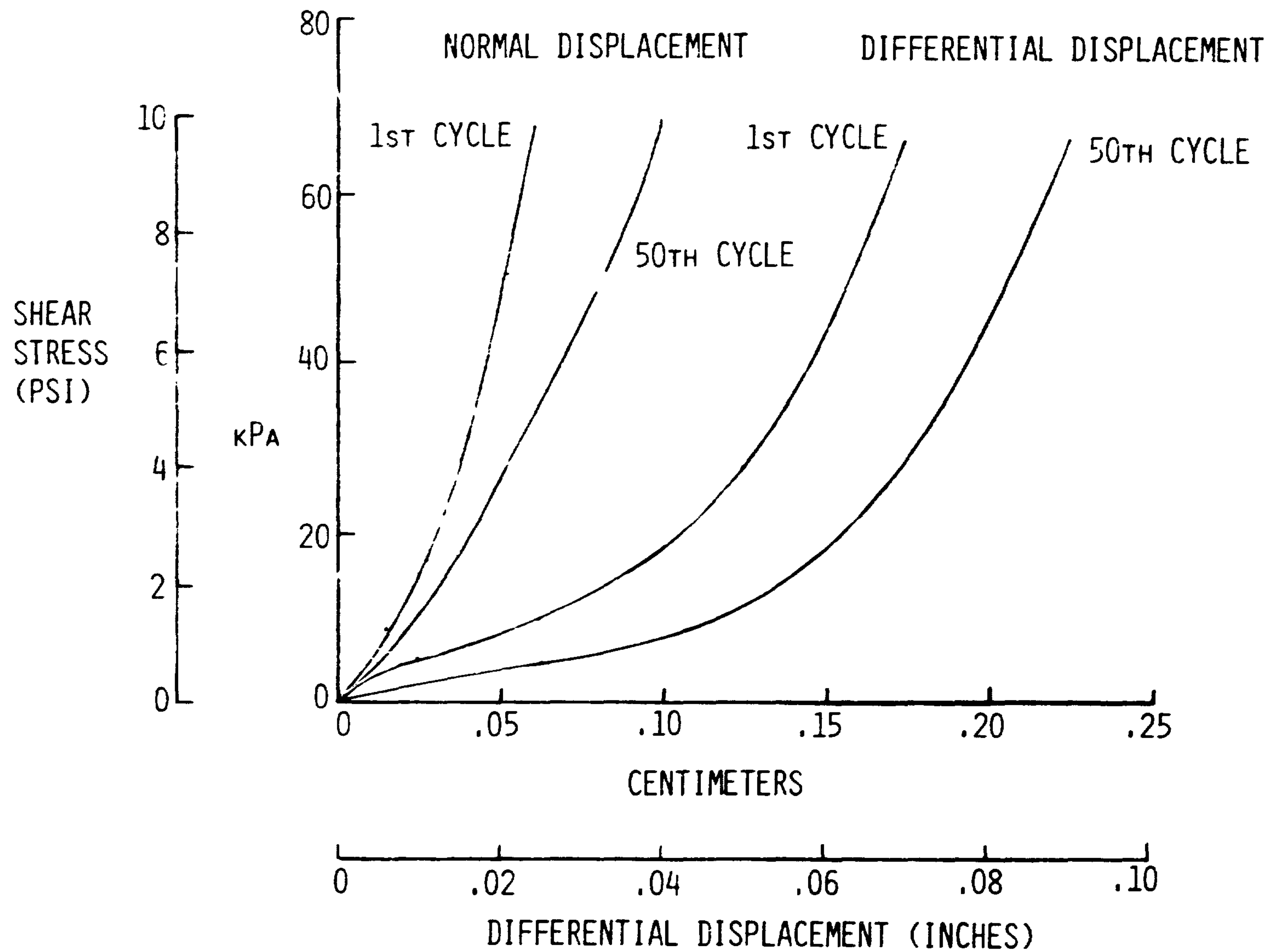
(b) Tangent modulus behavior

Figure 9.- Concluded.



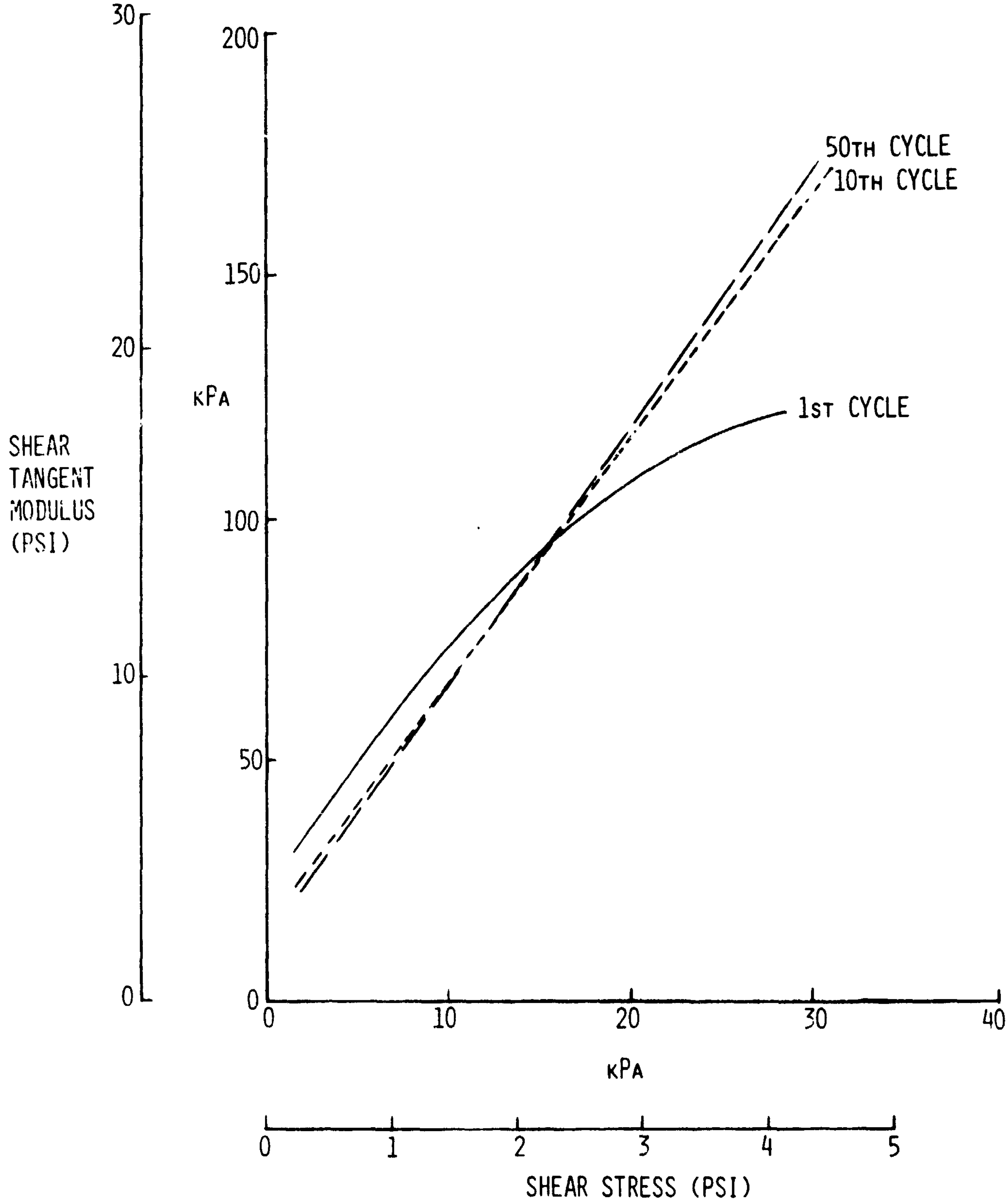
(a) Cyclic Load Level - 34.5 kPa (5 psi)

Figure 10.- Shear stress-differential displacement behavior for virgin and load conditioned .23 cm (.090 inch) thick SIP. Material stressed in cross-roll direction.



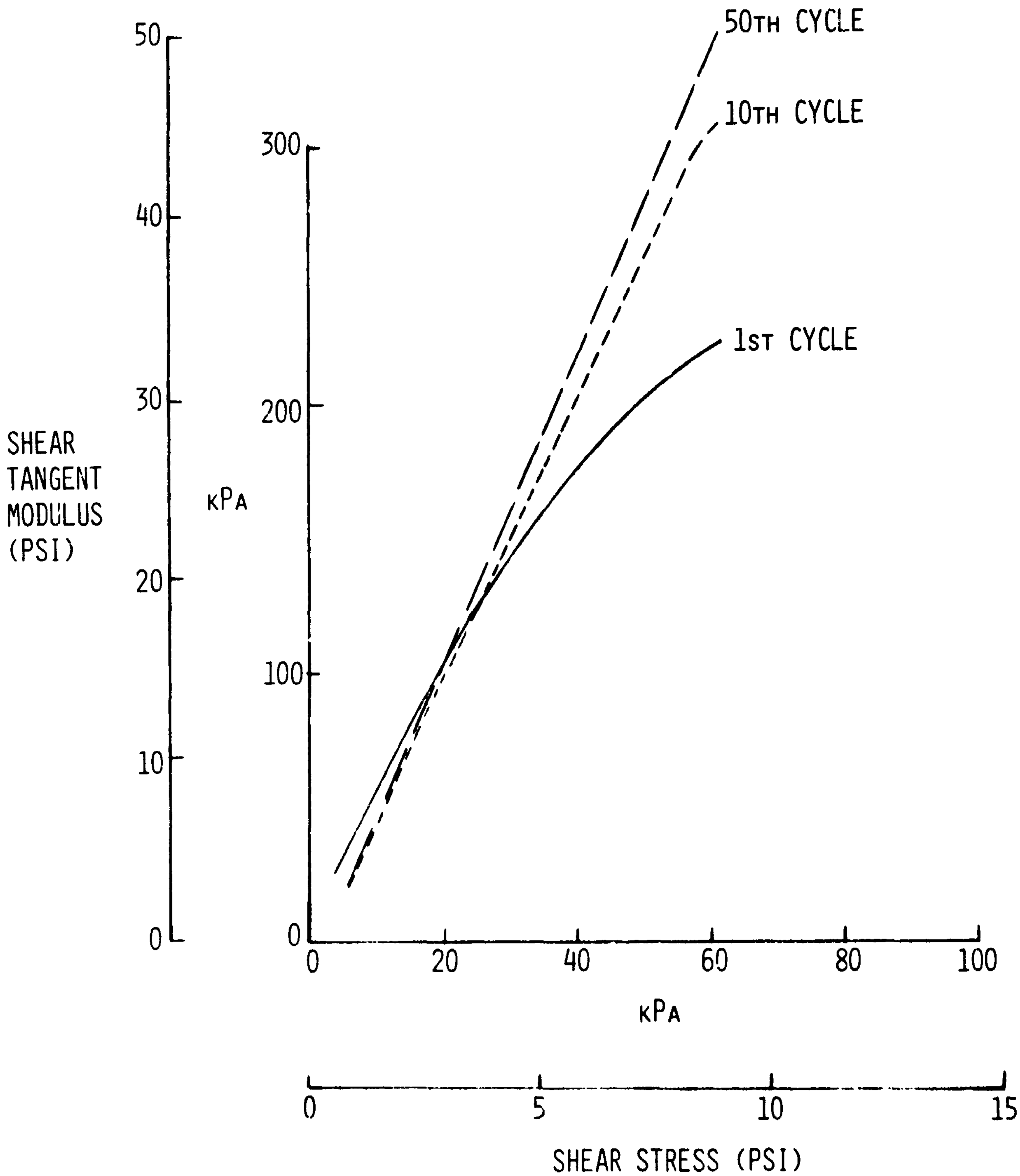
(b) Cyclic Load Level - 69.0 kPa (10 psi)

Figure 10.- Concluded.



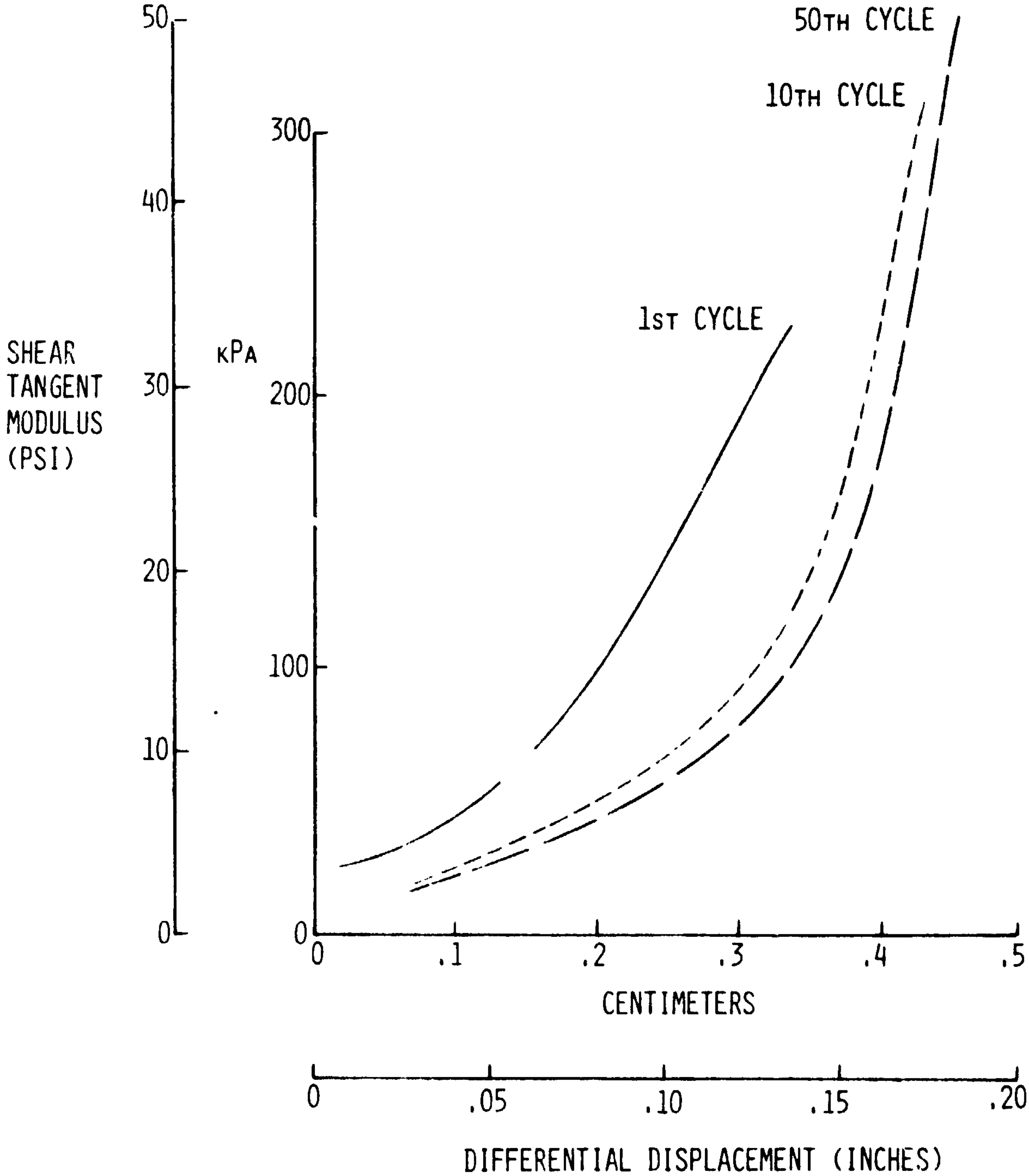
(a) CYCLIC LOAD LEVEL - 34.5 kPa (5 PSI)

Figure 11.- Shear tangent modulus as function of shear stress for virgin and load conditioned .23 cm (.090 inch) thick SIP. Material stressed in cross-roll direction.



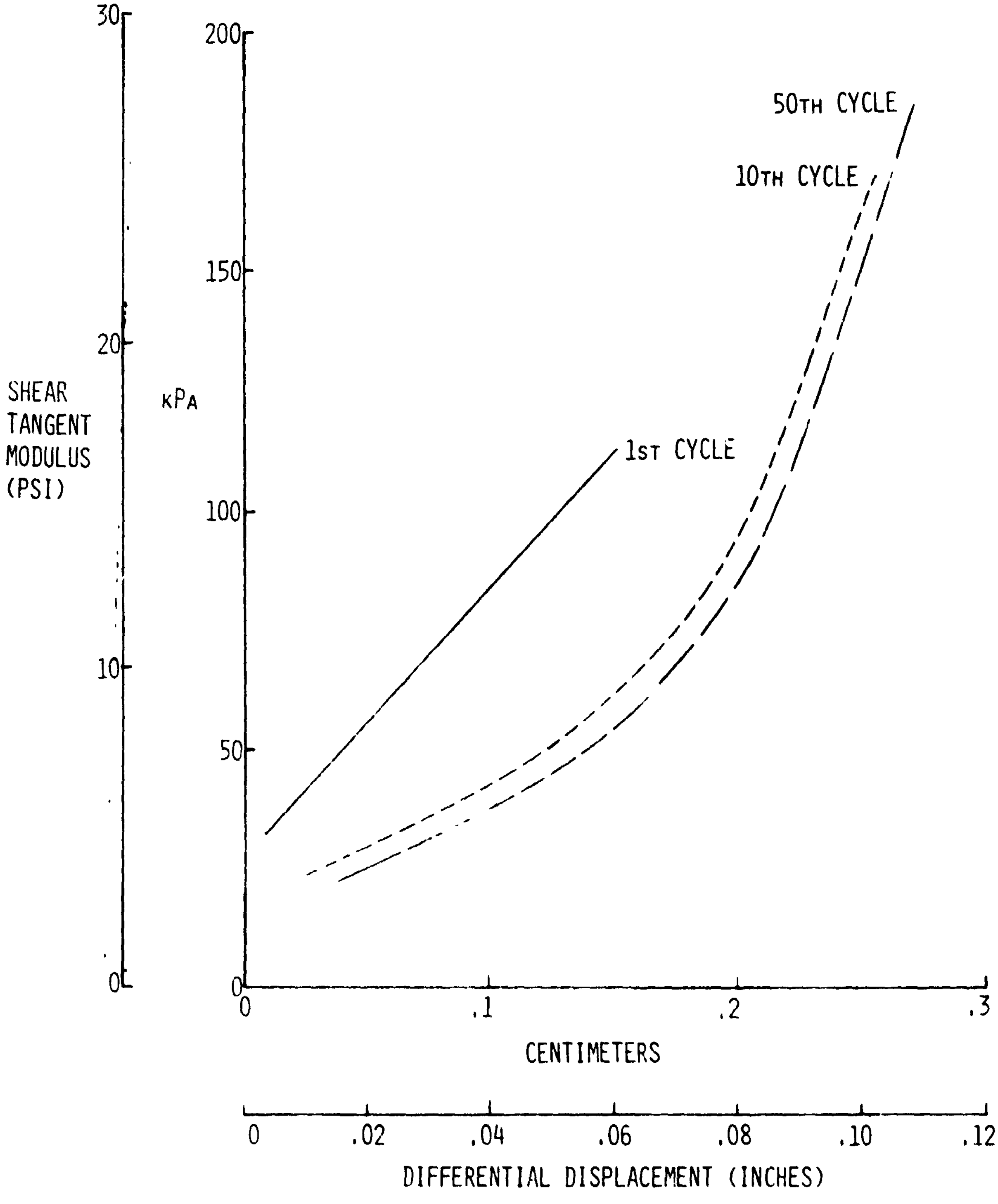
(b) CYCLIC LOAD LEVEL - 69.0 kPa (10 PSI)

Figure 11.- Concluded.



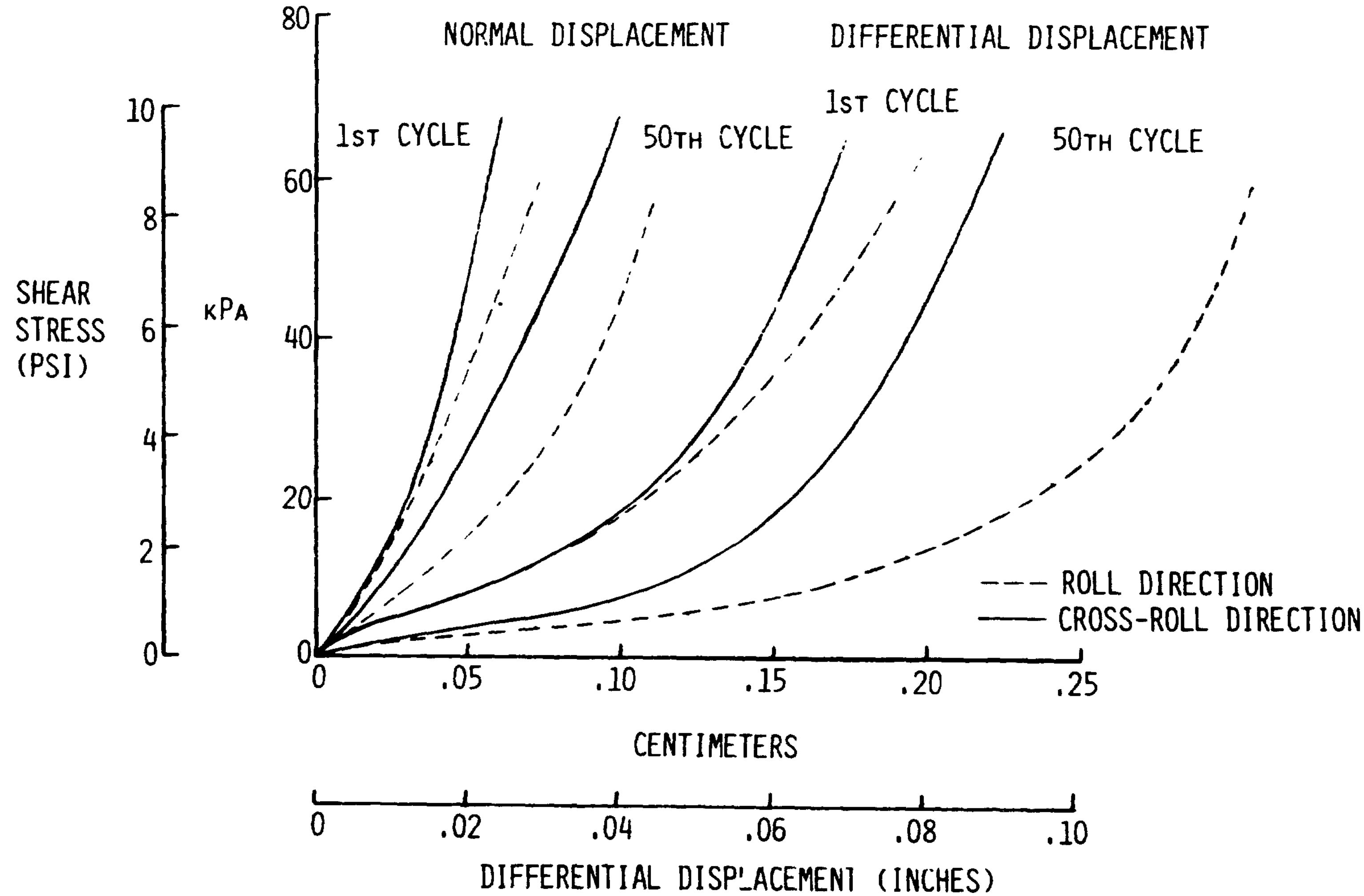
(b) Cyclic Stress Level - 69.0 kPa (10 psi)

Figure 12.- Concluded.



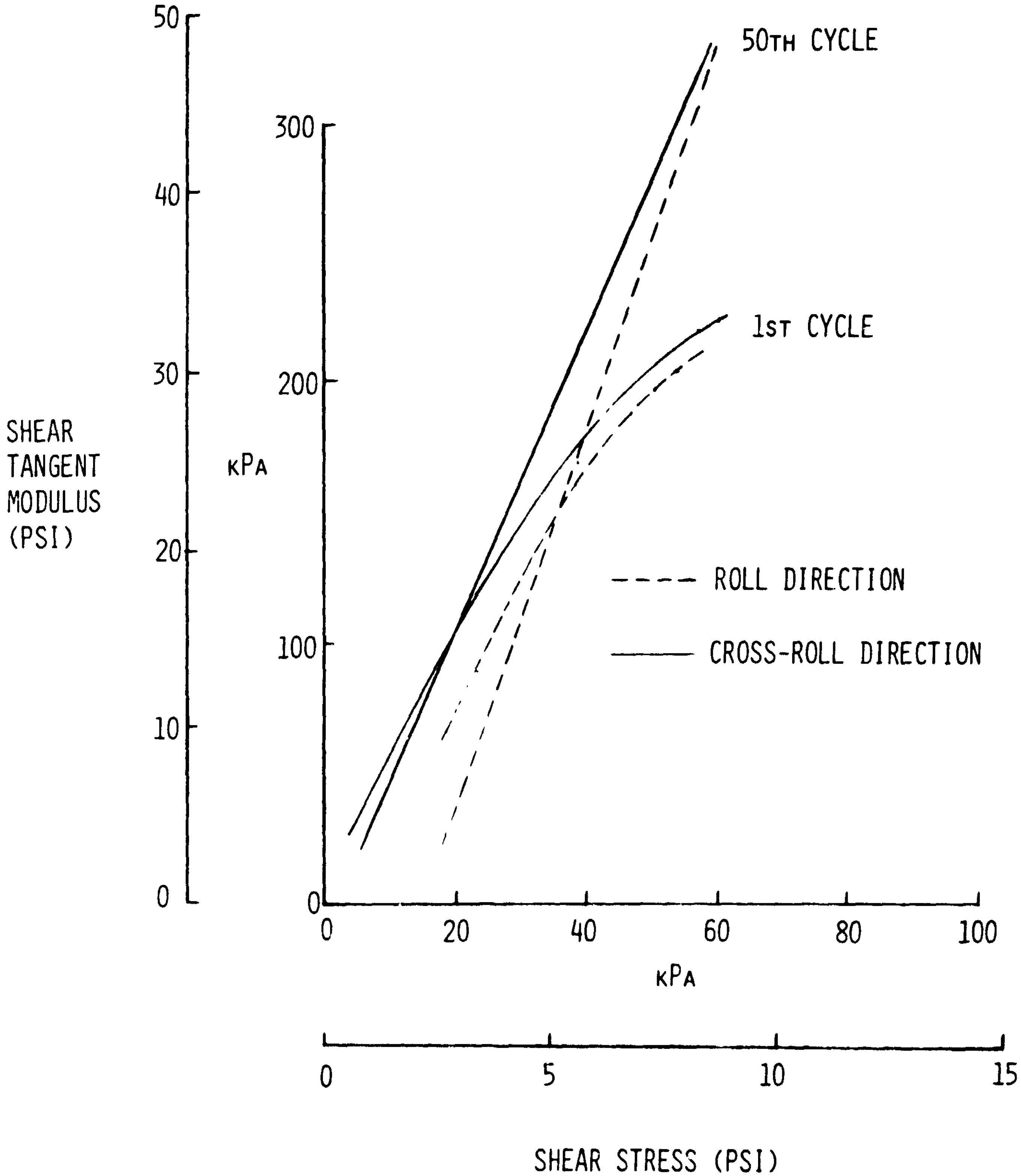
(a) Cyclic Load Level - 34.5 kPa (5 psi)

Figure 12.- Shear tangent modulus as function of differential displacement for virgin and load conditioned .23 cm (.090 inch) thick SIP. Material stressed in cross-roll direction.



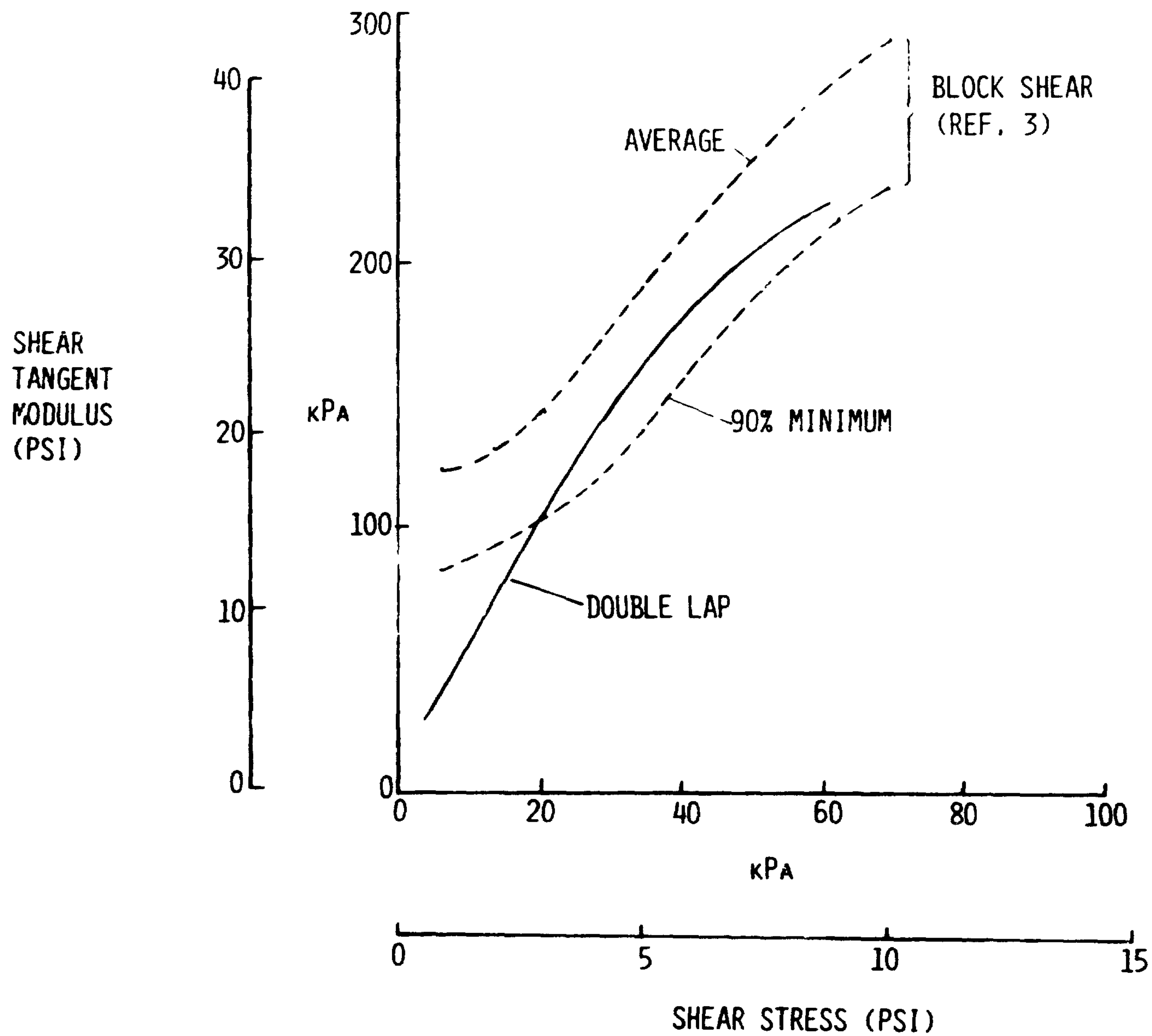
(a) Shear-differential displacement behavior.

Figure 13.- Effect of material orientation on shear behavior of .23 cm (.090 inch) thick SIP. Cyclic load level - 69.0 kPa (10 psi).



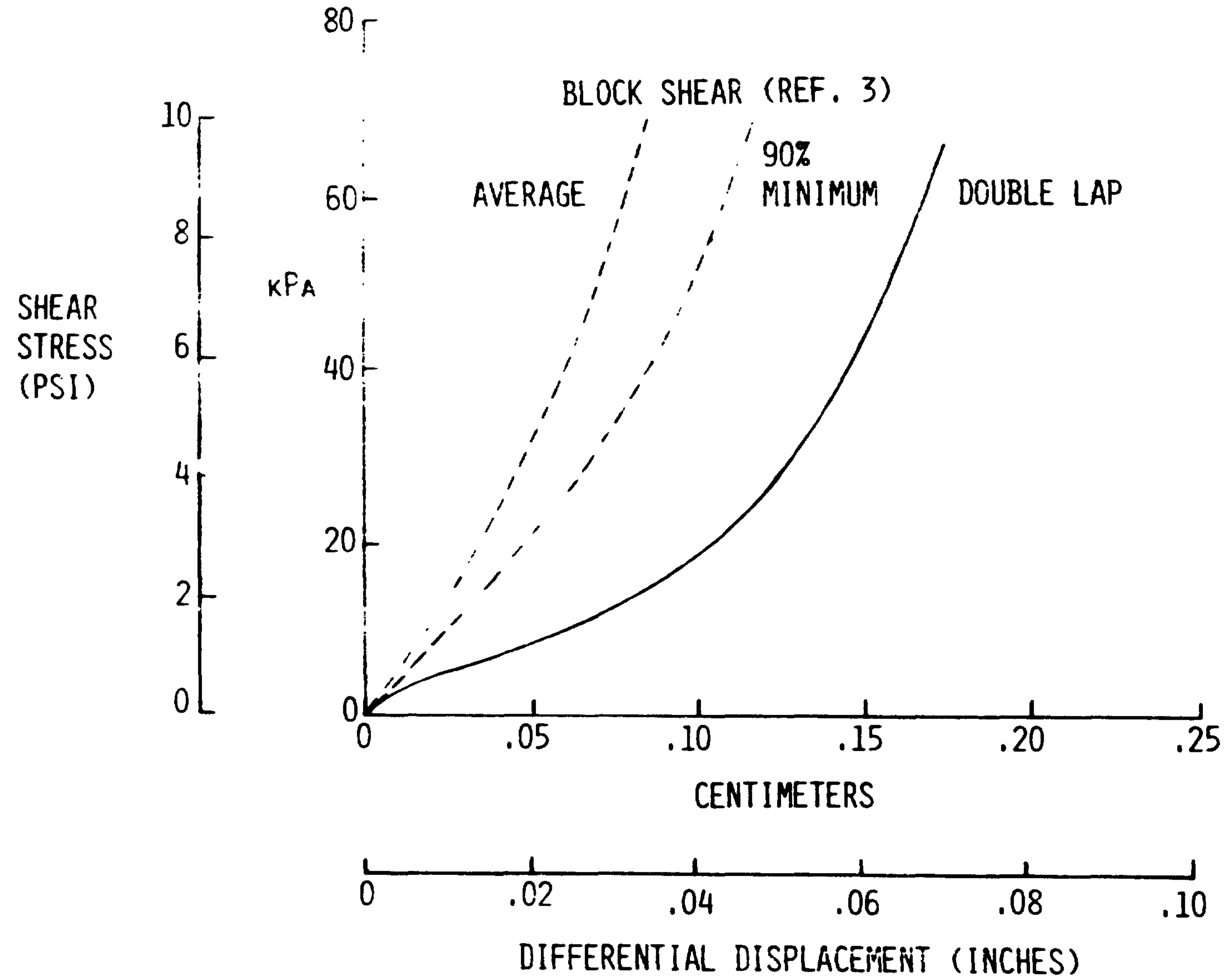
(b) Tangent modulus behavior

Figure 13.- Concluded.



(b) Tangent modulus behavior

Figure 14.- Concluded.



(a) Shear-differential displacement behavior.

Figure 14.- Comparison of the shear behavior of .23 cm (.090 inch) thick SIP obtained using block shear and double lap joint test specimens. Material stressed in cross-roll direction.