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RESPONSES OF RANDOM-ORIENTED-FIBER AND NEOPRENE BEARING PADS UNDER SELECTED LOADING CONDITIONS

by

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The following paper citing performance parameters of R.O.F. (random oriented fiber) and unreinforced neoprene bearing pads began as a life cycle study to confirm the performance claims of MASTICORD™ by JVI, Inc., to be conducted at the request of Dr. Alex Aswad of Stanley Structures, Inc. Interest in the project quickly expanded to include the other members of the Colorado Prestressers Association — namely, Rocky Mountain Prestress and Stresscon Corp. The project also was expanded to include comparative testing of unreinforced neoprene pads.

While this paper is totally unedited by JVI, it must be emphasized that the testing of R.O.F. pads reported upon herein is on MASTICORD™ only and should not be construed as applying to any other R.O.F. construction.

There are vast differences in quality among R.O.F. materials. MASTICORD™ is an engineered product developed to meet specific performance criteria for structural load-bearing application. Other R.O.F. materials may be non-engineered products and as such their performance parameters are unknown.

JVI was invited to contribute financially to support this testing program and enthusiastically accepted the invitation.

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Responses of Random-Oriented-Fiber and Neoprene Bearing Pads under Selected Loading Conditions.

by Alex Aswad and Leonard Tulin.

Synopsis: Random-oriented-fiber (ROF) and Neoprene bearing pads were subjected to cyclic compression and shear loading in an effort to determine their characteristics when used as bearing pads for precast parking decks. The cyclic test program included specimens in the thickness range from 1/4" to 1/2". These specimens were subjected to compressive stress normal to the pad, with both parallel and non-parallel platens, and were cycled up to 5500 times to a maximum shear strain of 70% of their thickness. Apparent shear moduli and coefficients of lateral resistance were determined for these specimens. In addition a few samples were tested in cyclic compression to 1500 psi and in monotonic compression to 8500 psi. The results are tabulated for ready reference.

Quality control information was extracted from the manufacturer's test reports and is summarized in an appendix. Estimates of reaction displacements and rotations due to shrinkage, creep, temperature gradient, and load for a typical twin-tee are also included in an appendix.

Alex Aswad received his Ph.D. degree from the University of Denver. He is currently Staff Consultant with Stanley Structures, Inc., a major precast producer in the Western United States. He has taught structural design in the Denver area while working as a Structural Engineer. Dr. Aswad is active on PCI committees and has written a number of papers in the areas of precast and prestressed structures.

Leonard Tulin received his Ph.D. degree from Iowa State University. He began teaching at the University of Colorado at Boulder in 1950, becoming Professor of Civil Engineering in 1961, and serving a term as departmental chairman from 1972-76. Dr. Tulin has been active in experimental research during his entire academic career. In 1964 he was co-recipient of the ACI Wason Medal for Most Meritorious Paper.

1. INTRODUCTION.

1.1. The general objective of this project was the determination of the behavior of elastomeric bearing pads under monotonic or cyclic compression, cyclic shear, and rotation, or combinations of these loading conditions. Two types of bearing pads were tested, Random-Oriented-Fiber (ROF) pads supplied by JVI, Inc. and Neoprene pads of "AASHTO" grade. A summary of the test reports supplied with these pads has been included in Appendix A. These pads are intended for general use under stemmed members or beams in the precast industry.

1.2. The scope of the project can best be defined by describing the parameters which were considered pertinent.

a. A parameter which has become an index in representing pad geometry, has been termed the Shape Factor. This quantity is related to the tendency of the pad to bulge laterally under compressive loading.

$$\text{Shape Factor: } S = (L \times W) / [2 (L + W) h]$$

The range for S was selected as $2.3 < S < 4.8$. This limitation was established as being consistent with common geometries of pads used in actual practice.

b. The selection of the maximum compressive stress to which the pads would be subjected was based upon a compromise between current practice or usage and manufacturer's claims or established specification limits. The current AASHTO specifications (1) limit compression stress on NEOPRENE pads to a maximum of 800 psi. The level selected in the tests was raised slightly to 850 psi (about 6%) to examine the practicality of the current limitation. While there are presently no prescriptive published criteria limiting the compressive stress on ROF pads, current usage in parking structures employs a maximum value of 1200 psi under full code live loads, while recent industry recommendations (2) and manufacturers allow a permissible value of 1500 psi or more. The value of 1300 psi in these tests was selected as a reasonable compromise.

c. Three types of deformation of the pad were considered significant. They correspond to shear, compressive, and moment loadings as shown in Figure 1.1. Thus the tests were designed to produce such deformations, either separately or in combination. Shear deformations of the order of $\delta \simeq 0.70h$, and rotations, $\theta \simeq 0.03$ radians are recommended values by designers and industry specialists. The probability of reaching all the maximum strains simultaneously is generally quite small in an actual structure. In normal building structures, δ is usually much smaller as shown in APPENDIX B.

d. Creep, aging, or similar long-term effects were not covered in the first phase of the investigation. Limited testing on these effects was done at the end of the program (second phase).

e. Laboratory temperature during the tests varied approximately from 65° to 75°F.

2. CYCLIC SHEAR TESTS WITH SIMULTANEOUS COMPRESSION.

2.1. Load actuators and reaction frames for the "Cyclic Direct Shear Apparatus" are shown schematically in Figures 2.1, 2.2, and 2.3 (with an accompanying legend to identify the various components of the shear box). In addition Figures 2.4 and 2.5 are actual photographs of the test equipment. The vertical actuator has a capacity of 220 kips, while the horizontal actuator has a capacity of 35 kips. Both actuators can be operated in load or displacement control by programming an MTS controller through an IBM-PC microcomputer.

2.2. The top platen was an 8" square concrete member 3" thick faced with a 3/8" thick steel plate. It is shown in Figure 2.6.

2.3. There were two bottom platens. In Series I, the platen was an 8" x 8" x 3" concrete block with a wood float surface finish.

(See Figure 2.7). In Series II, the platen was 8" x 8" x 3" concrete block with a double 3% slope on the top surface which was roughened by acid etching. (See Figure 2.8). The pads were not fixed by gluing or any other method to the upper or lower platens. All platens were cleaned after each test using a steel brush and/or a fluted carborundum stone.

2.4. The pad specimens were placed between the top and bottom platens and subjected to a predetermined compressive load level in the vertical direction while cyclic shear displacements equal to 70% of the pad thickness were applied horizontally. While some pilot tests were run at full cyclic strains, i.e., displacements between $+\delta$ and $-\delta$, the actual tests were operated at half-cycle shear strains (pad displacement between $+\delta$ and 0). The rates of load cycling varied among the various tests and are indicated on each test report. As time progressed, and more familiarity was developed with the response of the pads, the rate was increased to a maximum of about 1000 cycles per hour for the 3/8" thickness and to 1400 cycles per hour for the 1/4" thickness. Some of the tests lasted about 4 hours. It is of interest to interject at this point that no noticeable temperature rise was observed in any of the tests.

2.5. There were two types of specimens as shown below:

a. ROF "Masticord" pads made of random fibers embedded in an elastomeric matrix.

b. AASHTO-Grade "Neoprene" pads.

2.6. The results of the tests are shown in the related force-displacement curves, and the information is summarized in Tables 1 and 2. Copies of the full set of curves and pertinent log sheets may be obtained from the authors or suppliers. These curves were recorded in slow motion at the beginning, half-way through, and at the end of the test. The displacement shown on the graphs measures the lower platen movement.

2.7. Three typical load-displacement curves from Test Series II are shown in Figures 2.9 to 2.11. The lower platen had the 3% slope (see Sec. 2.3 above).

2.8. Typical values for the apparent shear modulus, G and the "coefficient of lateral resistance," μ, (defined as the ratio of the shear to compressive stresses on the pad) are listed in Table 3 for selected sizes and shear strains. All of the specimens, except Pad A5, were smaller than the 8" x 8" platens.

2.9. All listed or calculated stresses are based on the nominal dimensions. The difference between actual and nominal thicknesses are not significant.

3. MONOTONIC AND CYCLIC COMPRESSION.

3.1. A photograph of the MTS servo-controlled mechanical-hydraulic loading frame is shown in Figure 3.1. This testing machine has upper and lower smooth platens which are 8" in diameter. The actuator has a 110 kip capacity and can be operated in either force or displacement mode controlled by an IBM-PC.

3.2. There were three types of tests conducted on the MTS loading frame (see summary in Table 4):

a. Monotonic compression on ROF and NEOPRENE pads: In these tests the 8" x 8" concrete platen, Figure 2.7, was placed over the 8" diameter machine platen and served as the lower platen for the pad. Then a steel plate equal in size to the pad was placed over it before compressive stresses were applied, except for pads C44 and C45, where the upper machine platen was in direct contact with the pad. The objective was to observe the stress-strain curve for various stress levels.

b. Cyclic compression on ROF pad B1: In this test the machine platens were in direct contact with the pad. The compressive stress varied from a minimum of 1000 psi to a maximum of 1550 psi. The cyclic duration was one second.

c. Cyclic concentrated bearing on ROF pads: In the test on D2 (5" x 5" x 3/8") the machine platen served as the lower platen, and a 4" x 5" steel plate was centered over the pad. In test D3 (4" x 4" x 1/4") the 8" x 8" concrete platen was used as the bottom platen, and a 3" x 4" steel plate was placed over the pad. Compressive stresses were applied in a cyclic fashion between a minimum of 1000 psi and a maximum of 1500 psi over the 4" x 5" or 3" x 4" plates, respectively. The cycle duration was one second.

3.3. The results of the tests are summarized in Table 4. The curves were recorded in slow motion (over 6 minutes plus or minus) and, in the case of cyclic compression, were recorded before and after the tests.

3.4. Three stress-strain curves are shown in Figures 3.2 to 3.4.

3.5. Typical values for the compression strain from the monotonic tests are listed in Table 5.

4. SLOW MOTION SHEAR TESTS WITH SIMULTANEOUS COMPRESSION OF ROF PADS.

4.1. The testing equipment and set-up were the same as those described in Section 2. The bottom platen had the double slope as shown in Figure 2.8.

4.2. A single, constant compressive stress level of 1050 psi was used. The maximum shear displacement was set at 0.70h. Two different pairs of pads were tested. In the first test 4" x 3-1/2" x 1/4" pads were used while the second used 4" x 3-1/2" x 3/8" pads.

4.3. Both tests were run at a rate of 4 hours/cycle first, followed by three "fast" cycles at the rate of 1 minute/cycle.

4.4. The load-displacement curves from the second test are shown in Figure 4.1. The dashed line curve is for the slow motion rate.

5. FAST CYCLING IN SHEAR WITH SIMULTANEOUS COMPRESSION OF PRE-OZONIZED ROF PADS.

5.1. Testing proceeded in the same manner as in Section 2 using the double-sloped platen of Figure 2.8.

5.2. Before the mechanical testing, the pads underwent accelerated aging in an ozone chamber at an Ohio laboratory. In this exposure, the pads were placed flat for 96 hours in the chamber at an ozone concentration of 25 pphm. Then they were sent to the University of Colorado for mechanical testing.

5.3. The compressive stress was a constant 1300 psi, and the maximum shear displacement was 0.70h. Two pairs of pads were used: 1/4" and 3/8" thick, both 4" x 3-1/2" in plan.

5.4. Each of the tests lasted two hours, and the pads were cycled approximately 2900 times in shear from zero to maximum displacement, then back to zero.

5.5. The load-displacement curves from the second test are shown in Figure 5.1.

6. CONCLUSIONS.

6.1. Random-oriented-fiber pads were subjected to fast cycles of loading. The behavior of these pads under the tabulated stresses and displacements showed full rebound and no apparent stiffness deterioration at the end of the cycle sequence when the force-displacement curves were compared. Some minor surface abrasion was apparent at the end of the tests, especially at the face in contact with the rough concrete platens. Pads C11 and C33, however, exhibited moderate abrasion and splitting at the lower faces when the maximum compressive stress of 8500 psi was reached. This was to be expected since the stress level was several times greater than the normal range of 1500 psi.

a. The apparent shear modulus, G, and the coefficient of lateral resistance, μ, appear to be a function of the compressive stress, the shear strain, and the platen slope. However, they are not sensitive to the Shape Factor within the test program range ($2.49 < S < 4.80$). For a 1/4" or 3/8" thick pack subjected to compressive stress of 1300 psi, the average values (at 70% shear strain and 3% slope) are $G = 350$ psi and $\mu = 0.19$. It is a known fact that these figures depend on the platen roughness and shear displacement rate. Because of the visco-elastic behavior of elastomers, very slow rates can result in much lower shear moduli and lateral resistance coefficients.

b. The compressive strain in the monotonic or cyclic tests was highly sensitive to the Shape Factor and roughness of the lower platen. A typical value for this strain for a pad with a Shape Factor, $S = 3.43$, tested against a concrete platen under a compressive stress of 1200 psi, was 16%.

6.2. Random-oriented-fiber pads were also subjected to slow-motion shear tests. The purpose of these tests was to simulate the behavior under a double-tee leg in a parking deck roof. These roofs are subject to a daily temperature gradient cycle which could easily reach 45°F on a hot day and cause a horizontal pad displacement of 0.12" over a 6-hour period. The actual equivalent rate would be about 0.02 inches/hour, or 9 to 13 times slower than the test rates. The tests showed that the coefficient, μ, decreases by 47 to 60 percent when the rate was reduced from 1 minute/cycle to 4 hours/cycle. For a compression stress of 1050 psi, a shear strain of 0.70, $\mu = 0.095$ for the 1/4" pad, and $\mu = 0.082$ for the 3/8" pad. It would therefore be safe to assume a coefficient of lateral resistance of no more than 10% for these stress and strain levels when the shear deformation is due to a very slow motion such as temperature gradient effect or creep and shrinkage. It is worthy of note that this value is half the commonly used figure of 20% which has been used by the precasting industry and is more in line with the findings of Reference (3).

6.3. The results of the pre-ozonized, random-oriented-fiber 1/4" pads showed surface abrasion only and about 1/8" permanent "expansion" on one side of the pad. The calculated G and μ values are 14% greater than in the non-ozonized case.

a. The 3/8" pads showed moderate abrasion, residue, and some tear at one corner of the pad (the high end during the tests). In comparing Figures 2.10 and 5.1, it may be observed that G and μ increased by 16%. Otherwise the general functioning of the pads did not seem to be affected.

6.4. AASHTO-Grade NEOPRENE pads were also subjected to fast cycles of loading with a steel upper platen and a concrete lower platen. These pads generally showed satisfactory behavior under the given stresses and displacements without any stiffness deterioration in shear. Only insignificant surface scratching was noticeable at the end of the tests with full rebound except for the two specimens (NE4) which were subjected to non-uniform bearing, an average stress of 850 psi, and 4249 cycles of shear displacement. The permanent "expansion" or "set" of the top surface, however, was about 1/8", which probably would be considered minor.

a. The average value for the shear modulus, G, was approximately 220 psi, while the lateral resistance coefficient, μ, was approximately 0.18 (at 70% shear strain, 3% slope, and 850 psi compressive stress).

b. The compressive strain corresponding to a Shape Factor of 3.33 varied linearly from 16% to 27% when the stress changed from 600 to 1000 psi.

c. The lateral bulging under compressive stresses, however, was significantly greater than for the ROF pads. Under compressive stresses of 1000 psi, the bulging reaching 0.53" each side of the specimen over a concrete platen while under 1200 psi, it was about 0.75". Its vertical deformation was also substantially greater for steel platens (about 50% more).

ACKNOWLEDGEMENT:

The tests described in this report were performed for the Colorado Prestressers Association under an original agreement with Stanley Structures, Inc., of Denver, dated December 1984. The principal investigator for the University of Colorado was Professor Leonard G. Tulin, Ph.D., P.E. The lab technician was Mr. Eric Stauffer.

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NOTATION

G = apparent secant shear modulus

h = pad nominal thickness

L = length of pad

W = width of pad

S = shape factor, ratio of the bearing area to the lateral (unconfined) surface of the pad

δ = horizontal pad displacement

δ_c = uniform vertical pad displacement

θ = pad rotation

μ = coefficient of lateral resistance, defined as the ratio of the shear to compressive stresses on the pad

Table 1: Summary of Test Information on Cyclic Shear of R.O.F. (Masticord) Pads.

TYPE OF TESTS	PAD LABEL	PAD SIZE	SHAPE FACTOR	COMPRESSIVE STRESS (psi)	MAXIMUM NO. OF CYCLES	TOTAL TEST DURATION (minutes)	GENERAL REMARKS
I) Cyclic Shear with	A1	4"x4"x3/8"	2.66	1300, constant	1,019	60 min.	
Compression	A1	4"x4"x3/8"	2.66	700, constant	490	60 min.	
Parallel Platens	A2	5"x5"x3/8"	3.33	1300, constant	840	100 min.	
	A2	5"x5"x3/8"	3.33	1300, constant	338	105 min.	
	A3	4"x4"x1/4"	4.00	1300, constant	570	100 min.	
	A4	4"x6"x1/4"	4.80	1300, constant	600	105 min.	
	A4	4"x6"x1/4"	4.80	700, constant	781	60 min.	
	A5	8"x8"x1/2"	4.00	1300, constant	183	75 min.	
	A6	3-1/2"x4"x3/8"	2.49	1300, constant	430	105 min.	Two pads on platen
	A6	3-1/2"x4"x3/8"	2.49	1300, constant	580	105 min.	Two pads on platen
	A7	3-1/2"x4"x3/8"	2.49	1300, constant	4,033	245 min.	Two pads on platen
	S1	6"x6"x3/8"	4.00	1300, constant	470	61 min.	
	S2	5"x5"x1/2"	2.50	1300, constant	393	62 min.	
II) Cyclic Shear with	E1	3-1/2"x4"x3/8"	2.49	1300, constant	1,024	63 min.	Two pads on platen
Compression, Non-	E5	3-1/2"x4"x1/4"	3.73	1300, constant	5,543	240 min.	Two pads on platen
parallel Platens							

Table 2: Summary of Test Information on AASHTO-Grade Neoprene Pads.

TYPE OF TESTS	PAD LABEL	PAD SIZE	SHAPE FACTOR	COMPRESSIVE STRESS (psi)	MAXIMUM NO. OF CYCLES	TOTAL TEST DURATION (minutes)	GENERAL REMARKS
I) Cyclic Shear with Compression Parallel Platens	NA2	5"x5"x3/8"	3.33	850, constant	540	62 min.	Large side bulging, disappears at load removal
	NA6	3-1/2"x4"x3/8"	2.49	850, constant	520	65 min.	Large side bulging, disappears at load removal
II) Cyclic Shear with Compression, Non-parallel Platens	NE4	3-1/2"x4"x3/8"	2.49	850, constant	4,249	240 min.	Top face expanded permanently 1/8" with respect to bottom. (Two pads on platen)

Table 3: Selected Values for Apparent Shear Modulus, G, and Lateral Resistance Coefficient, μ*.

	PAD TYPE	COMPRESSIVE STRESS (psi)	PAD DESIGNATION	SHAPE FACTOR	SHEAR STRAIN %	SHEAR MODULUS (psi)	COEFFICIENT μ
I) Parallel Platens	R.O.F.	1300	A3(4"x4"x1/4")	4	35	464	0.125
					70	390	0.210
	R.O.F.	1300	A6(3 1/2"x4"x3/8")	2.49	35	469	0.126
					70	383	0.206
	R.O.F.	1300	S1(6"x6"x3/8")	4	35	452	0.122
					70	385	0.207
	R.O.F.	1300	A5(8"x8"x1/2")	4	35	402	0.108
					70	328	0.177
	R.O.F.	700	A1(4"x4"x3/8")	2.66	35	357	0.178
					70	321	0.321
	R.O.F.	700	A4(4"x6"x1/4")	4.80	35	345	0.173
					65	320	0.298
II) Non-parallel Platens (3% slope)	R.O.F.	1300	E1(3 1/2"x4"x3/8")	2.49	35	388	0.104
					70	344	0.185
	R.O.F.	1300	E5(3 1/2"x4"x1/4")	3.73	35	423	0.114
					70	362	0.195
	NEOPRENE	850	NE4(3 1/2"x4"x3/8")	2.49	35	224	0.092
					70	219	0.181

* μ is defined as the ratio of the shear to compressive stresses on the pad.

Table 4: Summary of Information on Compression Tests for "Masticord" and "Neoprene" Pads.

TYPE OF TESTS	PAD LABEL	PAD SIZE	SHAPE FACTOR	COMPRESSIVE STRESS (psi)	MAXIMUM NO. OF CYCLES	TOTAL TEST DURATION (minutes)	GENERAL REMARKS
I)Monotonic Compression on R.O.F. Pads	C11	3"x4"x1/4"	3.43	8,620 max.	1	6	Bottom: moderate abrasion at max. load
	C33	3"x4"x3/8"	2.29	8,500 max.	1	6	Bottom: moderate splitting at the max. load.
	C33	3"x4"x3/8"	2.29	2,500 max.	1	6	No sign of damage
	C44	4"x4"x1/4"	4.00	3,300 max.	1	4	No signs of cracking, splitting, or delamination
	C45	5"x5"x3/8"	3.33	3,300 max.	1	4	No signs of cracking, splitting, or delamination
II)Cyclic Compression on R.O.F. Pads	B1	5"x5"x3/8"	3.33	1,000 min, 1,500 max	1000	17	
III) Cyclic Concentrated Bearing on R.O.F. Pads	D2	5"x5"x3/8"	3.33 2.96*	1,000 min, 1,500 max	3600	60	Top platen: 4"x5" steel steel plate
	D3	4"x4"x1/4"	4.00 3.43*	1,000 min, 1,500 max	1000	17	Top platen: 3" x 4" steel plate
IV)Monotonic Compression on NEOPRENE	NC2	5"x5"x3/8"	3.33	3,800 max.	1	6	

* If portion outside of covered bearing neglected.

Table 5: Selected Values for Compression Strains

PAD DESIGNATION	PAD TYPE	SHAPE FACTOR	TOP PLATEN	BOTTOM PLATEN	COMPRESSIVE STRESS (psi)	COMPRESSIVE STRAIN %	REMARKS
I) Monotonic C11(3"x4"x1/4")	ROF	3.43	3"x4", steel	8"x8", concrete	1200 2000	16 21	
C33(3"x4"x3/8")	ROF	2.29	3"x4", steel	8"x8", concrete	1200 2000	22 29	
C33(3"x4"x3/8")	ROF	2.29	3"x4", steel	8"x8", concrete	1200 2000	26 36	
II) Cyclic B1(5"x5"x3/8")	ROF	3.33	8" dia., steel	8" dia., steel	1000 1200	19 to 20 22.5 to 23.5	Before and after the cyclic test
III) Cyclic with Conc. Bearing D2(5"x5"x3/8")	ROF	3.33/ 2.96*	4"x5", steel	8" dia., steel	1000 1200	18.5 to 21.5 22 to 25	Before and after the cyclic test
IV) Monotonic Compression on NEOPRENE NC2(5"x5"x3/8")	NEOP	3.33	5"x5", steel	8"x8", concrete	600 800 1000	16 21 27	

* If portion outside of covered bearing is neglected.

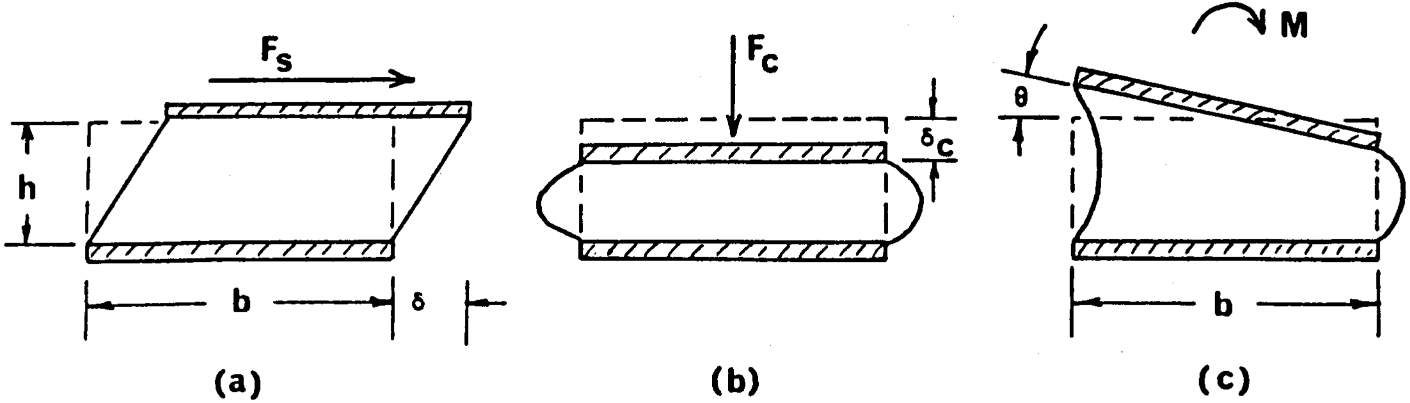


FIGURE 1.1 Three types of Deformation Corresponding to Shear (a), Compression (b), and Rotation (c)

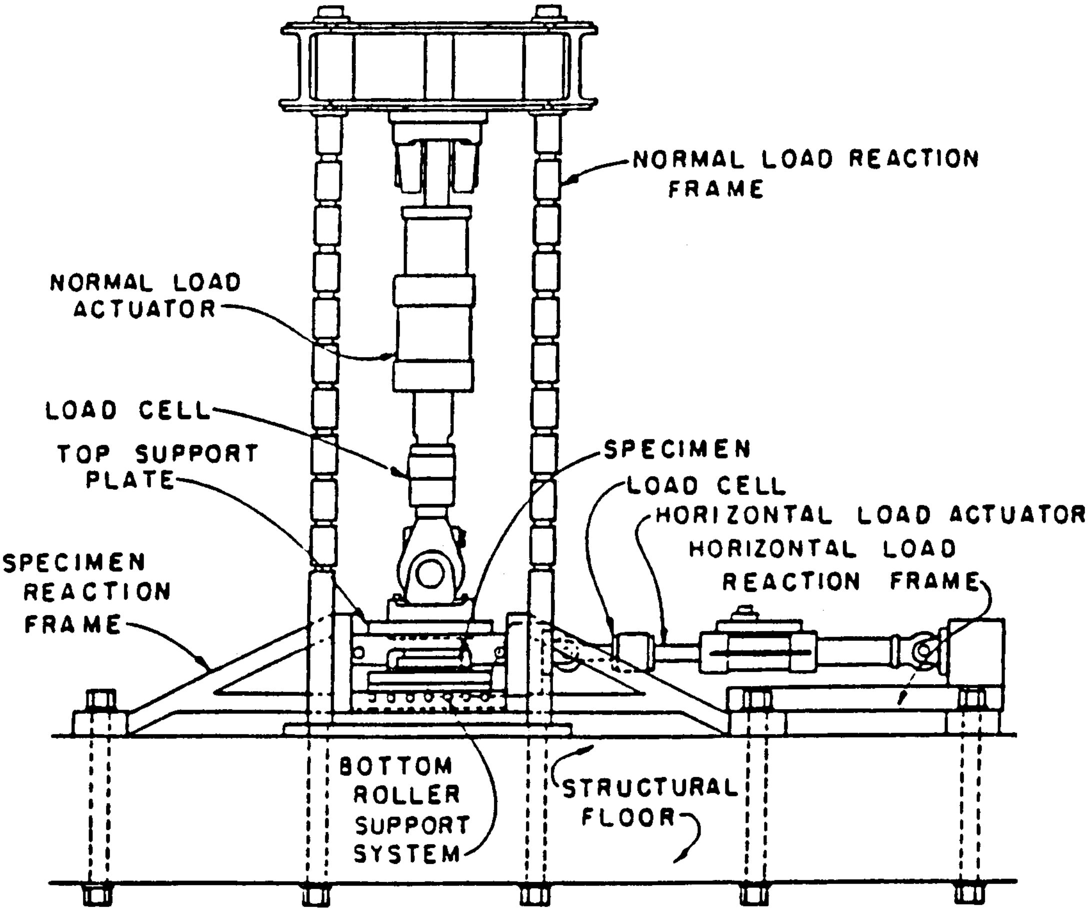


FIGURE 2.1 Cyclic Direct Shear Apparatus (Side View Schematic)

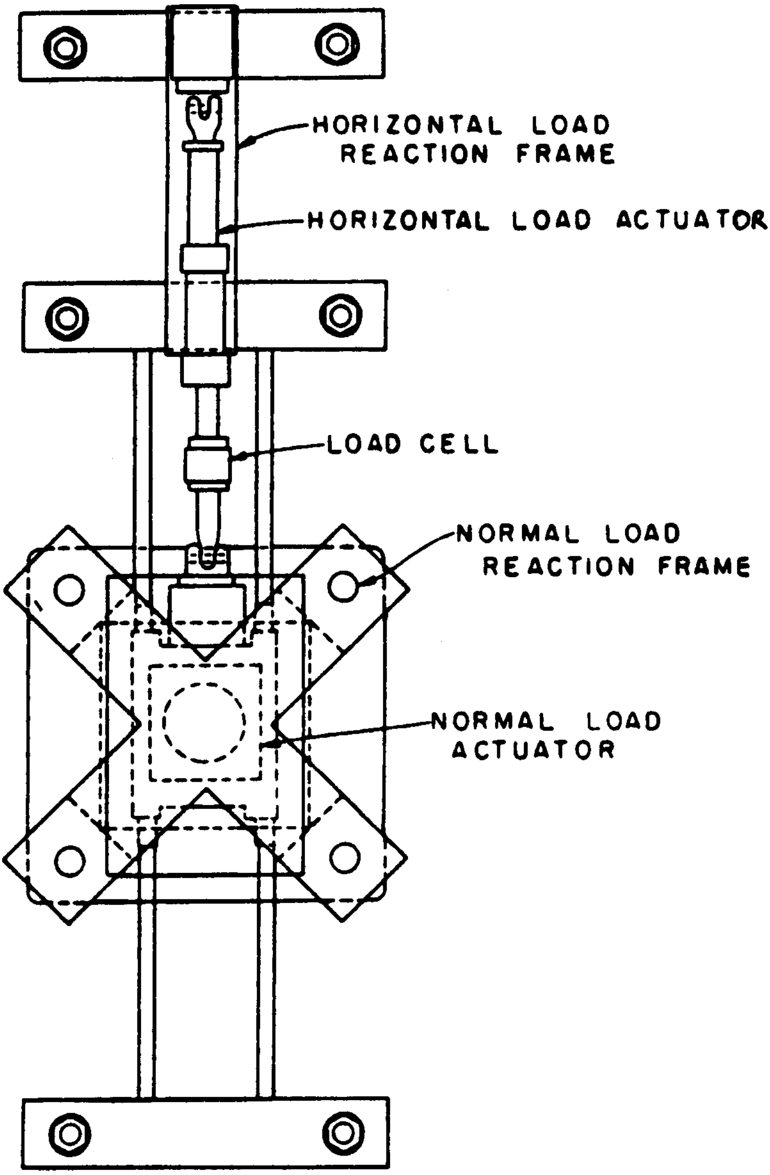
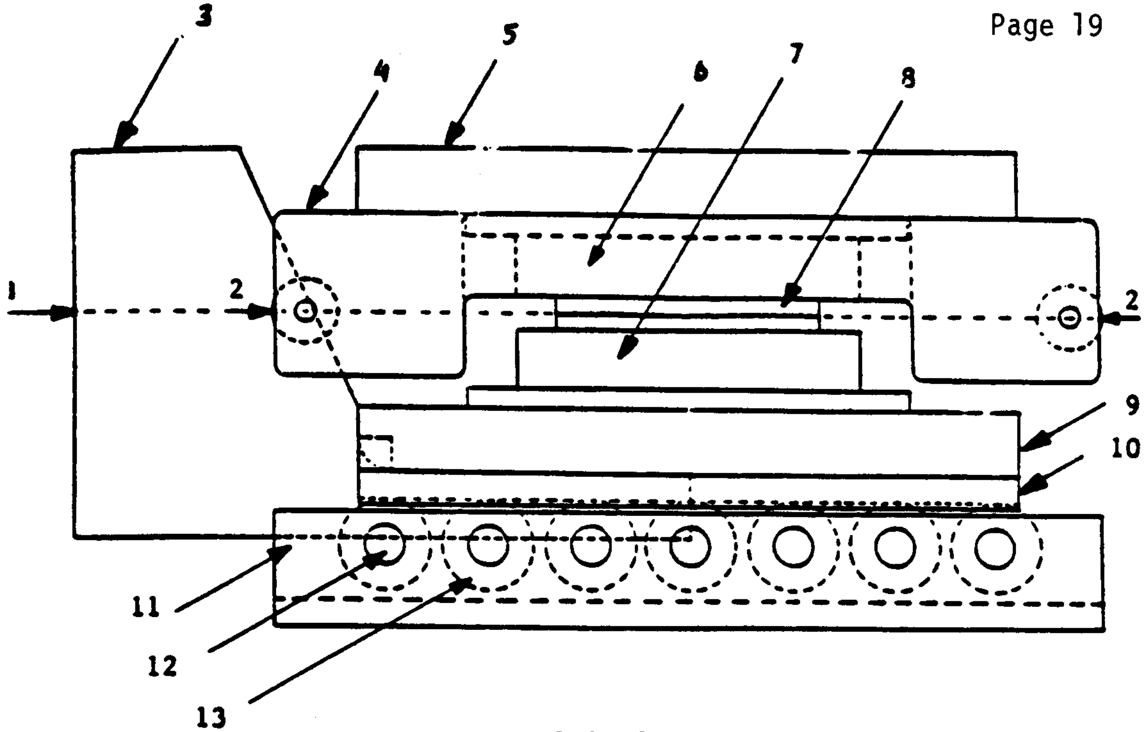
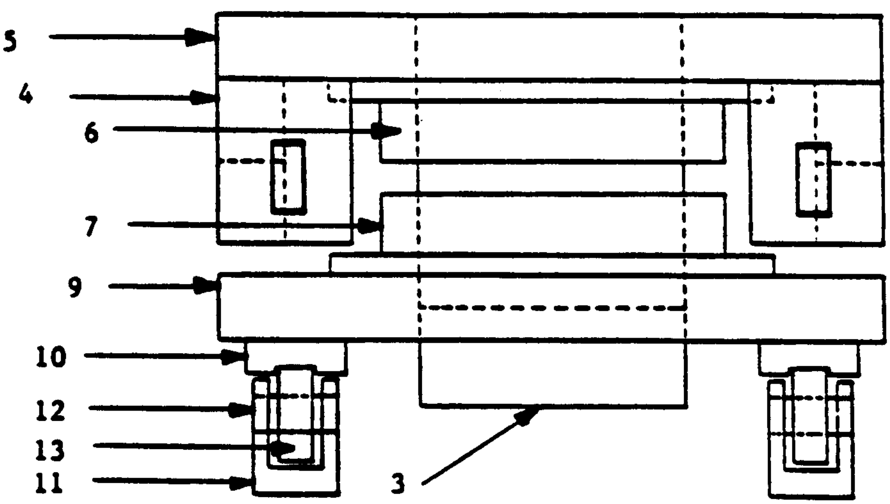


FIGURE 2.2 Cyclic Direct Shear Apparatus
(Top View Schematic)



Side View



Front View

FIGURE 2.3 Specimen Holding Fixtures and Shear Box Compartments

<u>Legend:</u>

1 - Horizontal Force
2 - Reaction Frame Force
3 - Shear Load Transmitting Block
4 - Top Reaction Frame
5 - Top Support Plate
6 - Upper Platen
7 - Lower Platen
8 - Bearing Pad Specimen
9 - Bottom Support Plate
10 - Roller Bearing Support Guides
11 - Channel Housing
12 - Pin
13 - Roller Bearing

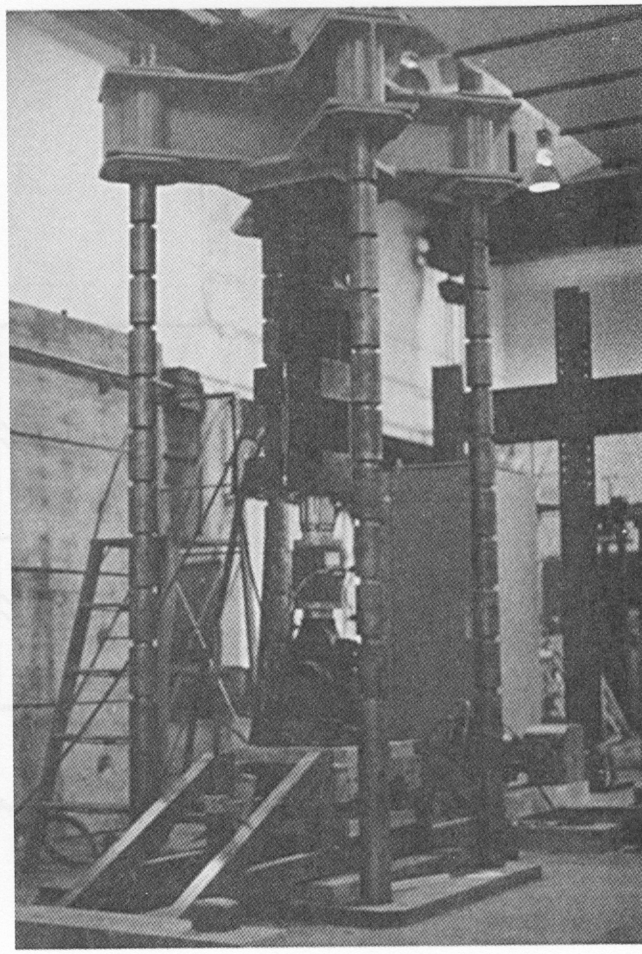


FIGURE 2.4 Cyclic Direct Shear Apparatus

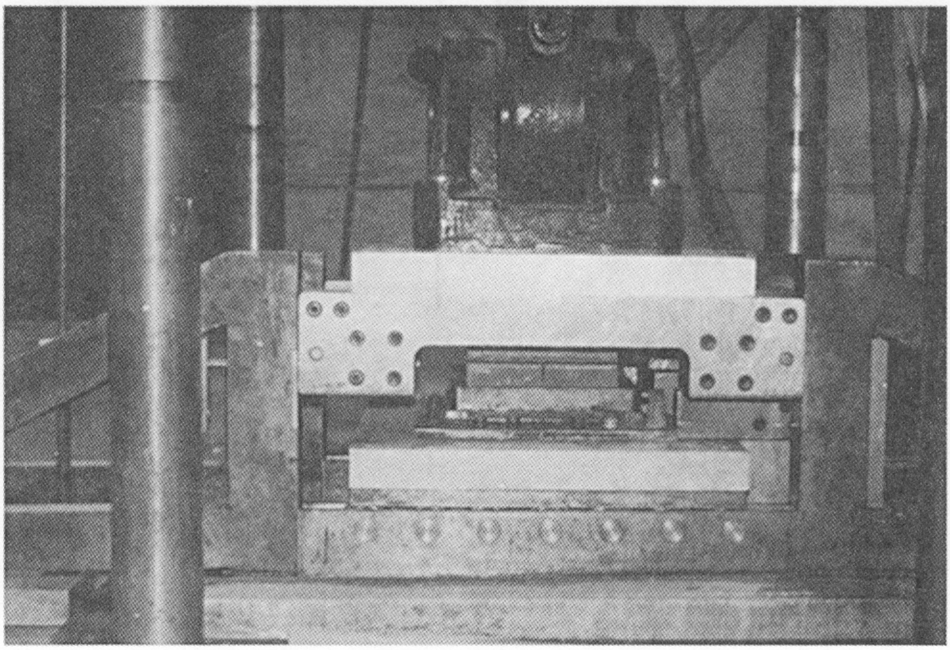


FIGURE 2.5

Close-up View of Platens and Shear Box

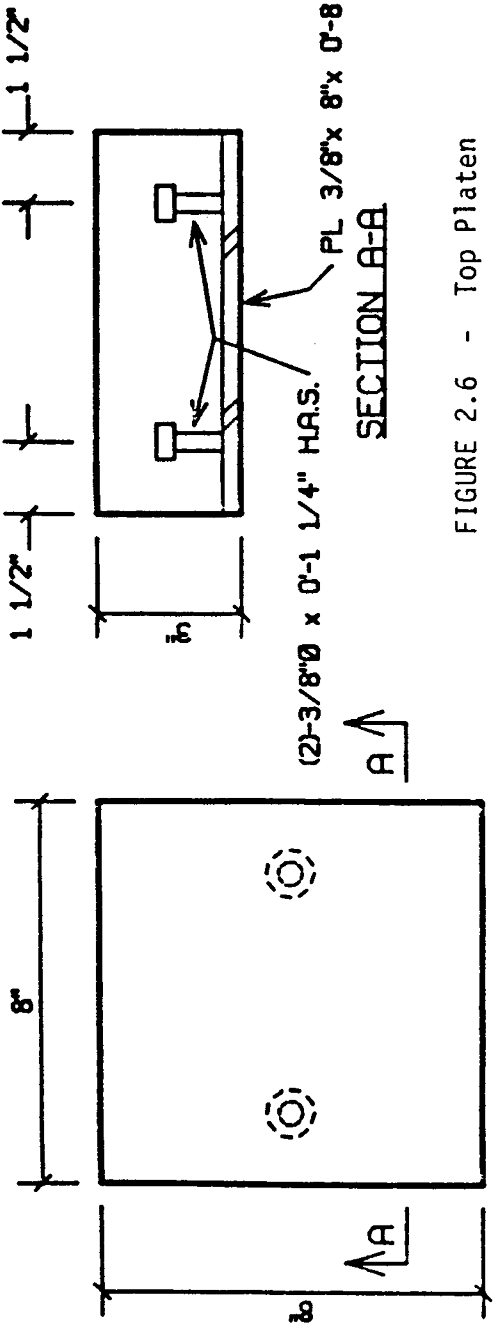


FIGURE 2.6 - Top Platen

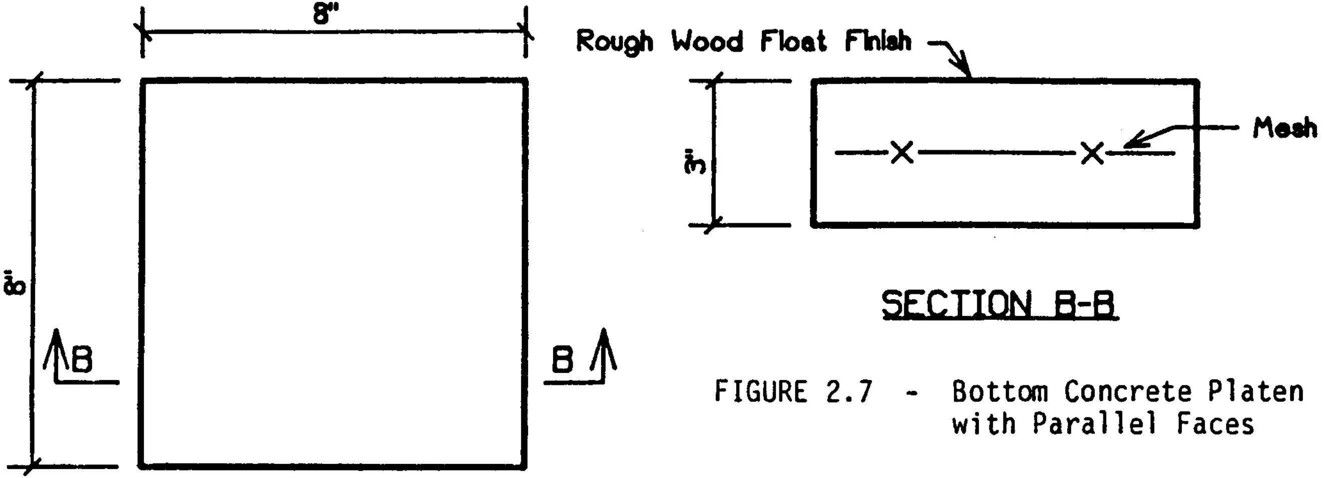


FIGURE 2.7 - Bottom Concrete Platen with Parallel Faces

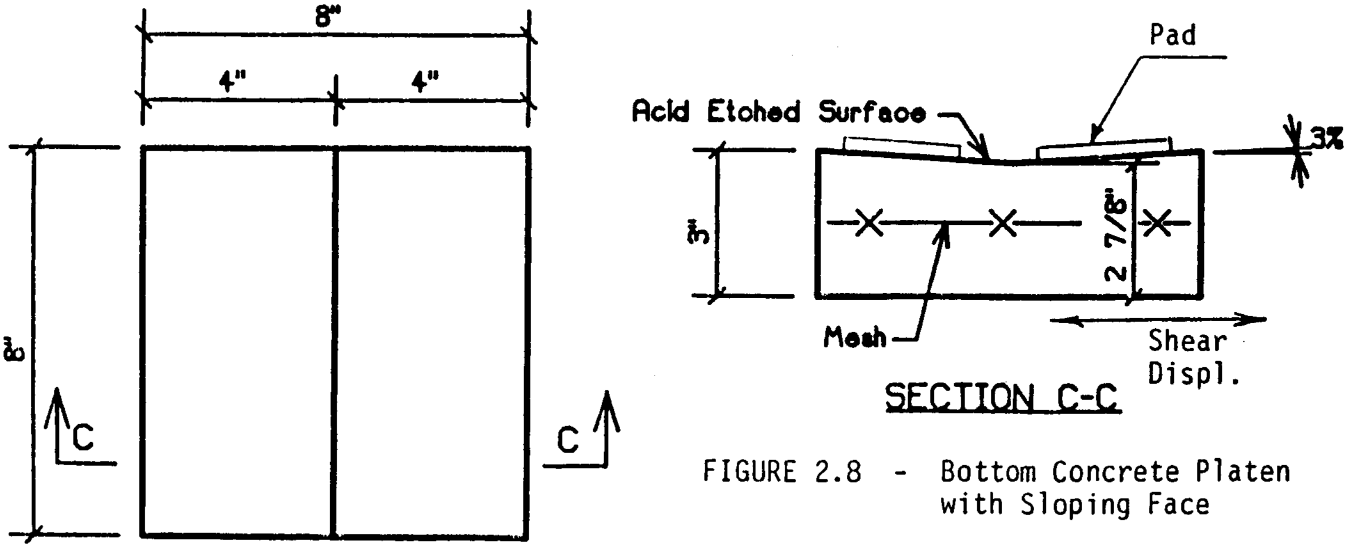


FIGURE 2.8 - Bottom Concrete Platen with Sloping Face

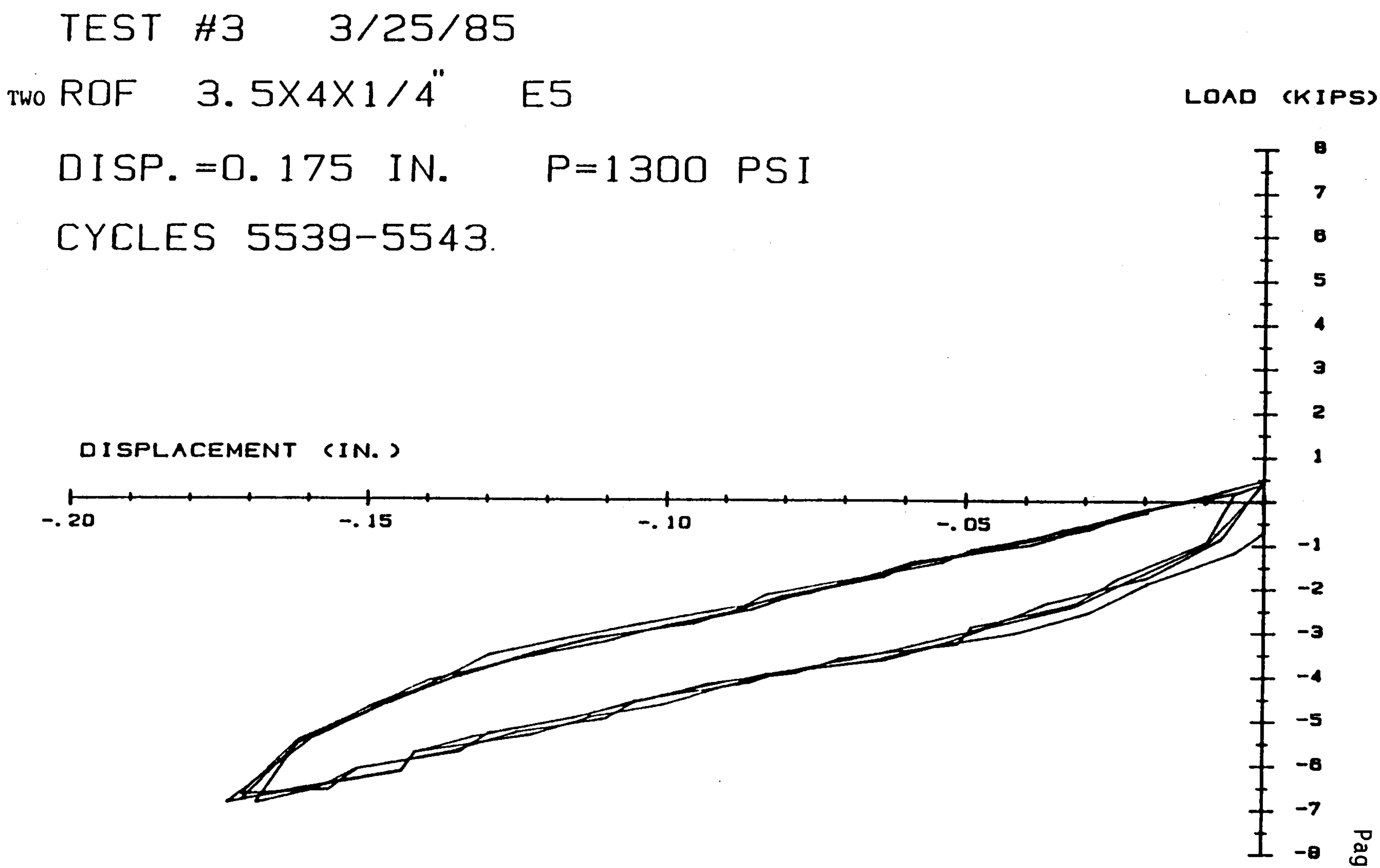


FIGURE 2.9 CYCLIC SHEAR WITH COMPRESSION OF 1300 PSI
(3% Slope on Bottom Platen)

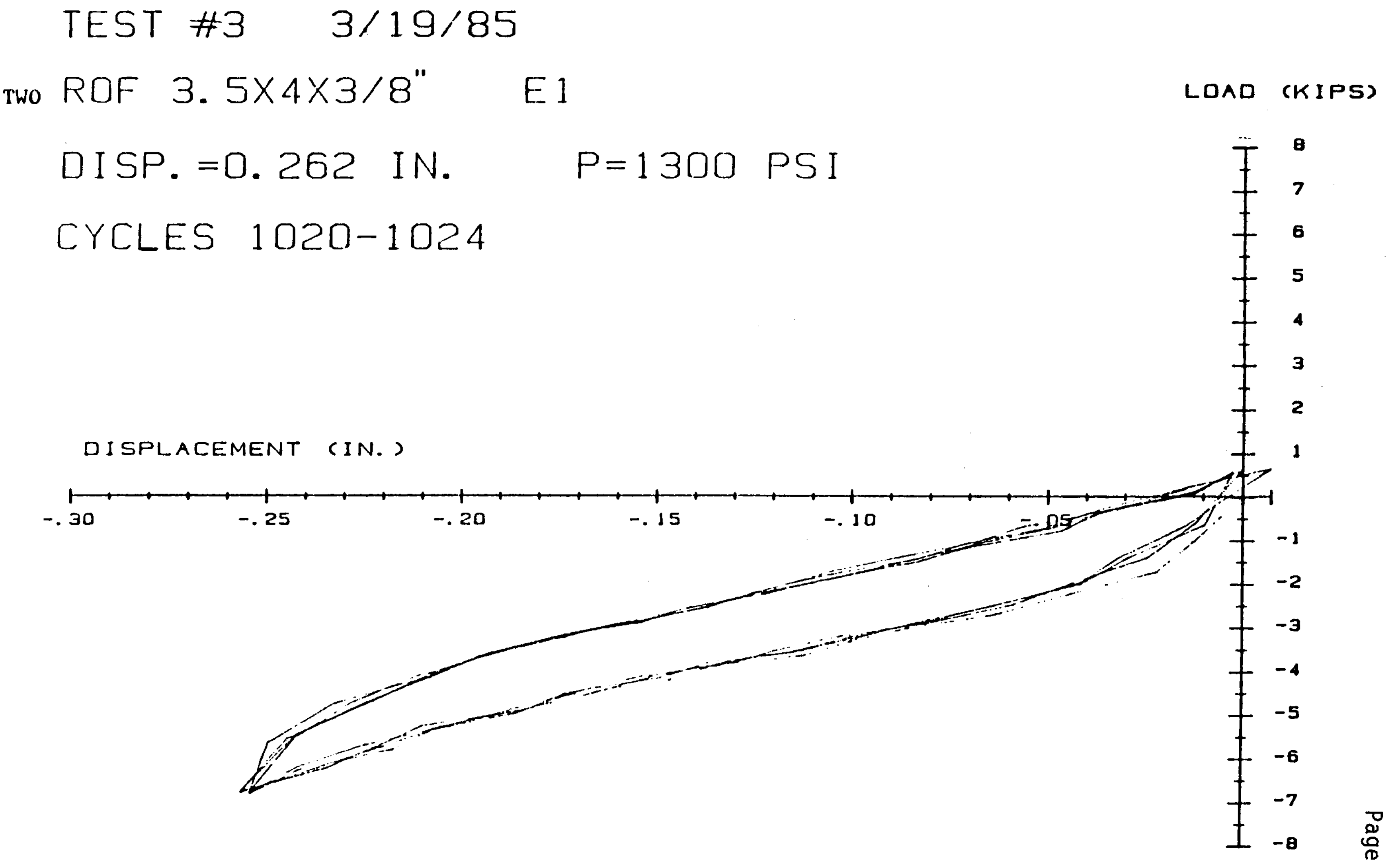


FIGURE 2.10 CYCLIC SHEAR WITH COMPRESSION OF 1300 PSI (3% Slope on Bottom Platen)

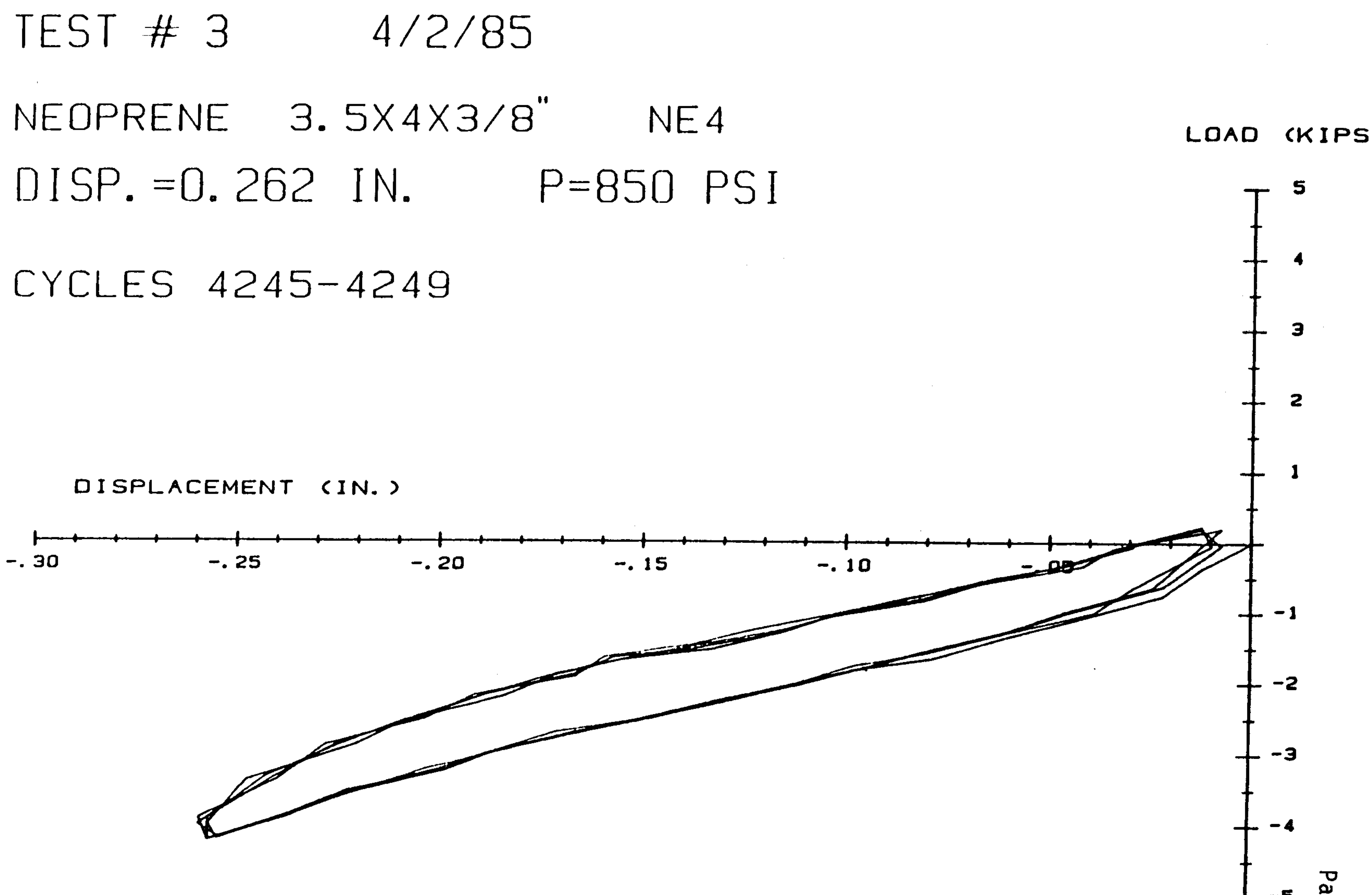


FIGURE 2.11 CYCLIC SHEAR WITH COMPRESSION OF 850 PSI
(3% Slope on Bottom Platten)

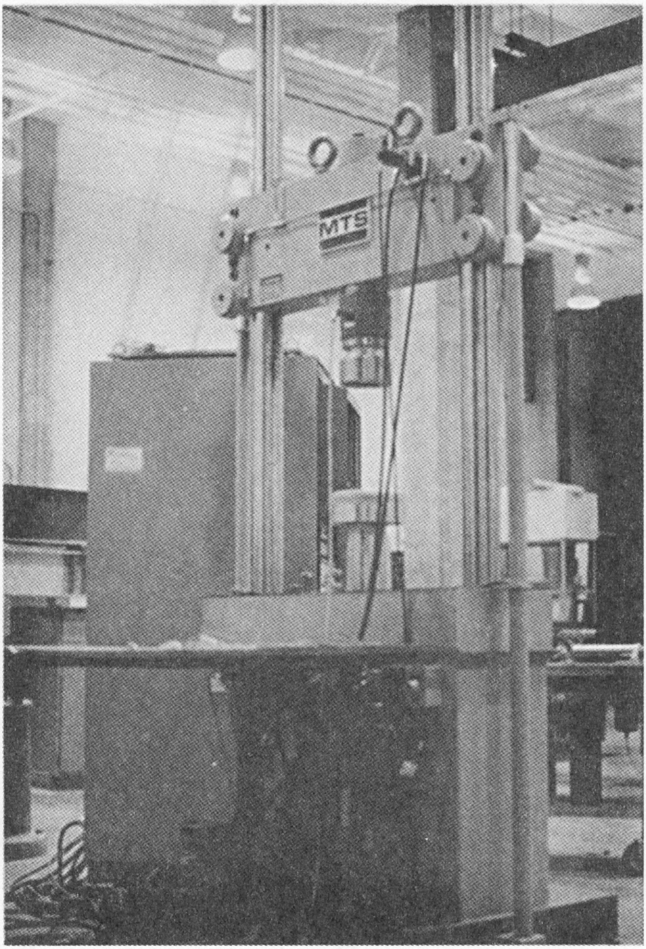


FIGURE 3.1 MTS LOADING FRAME

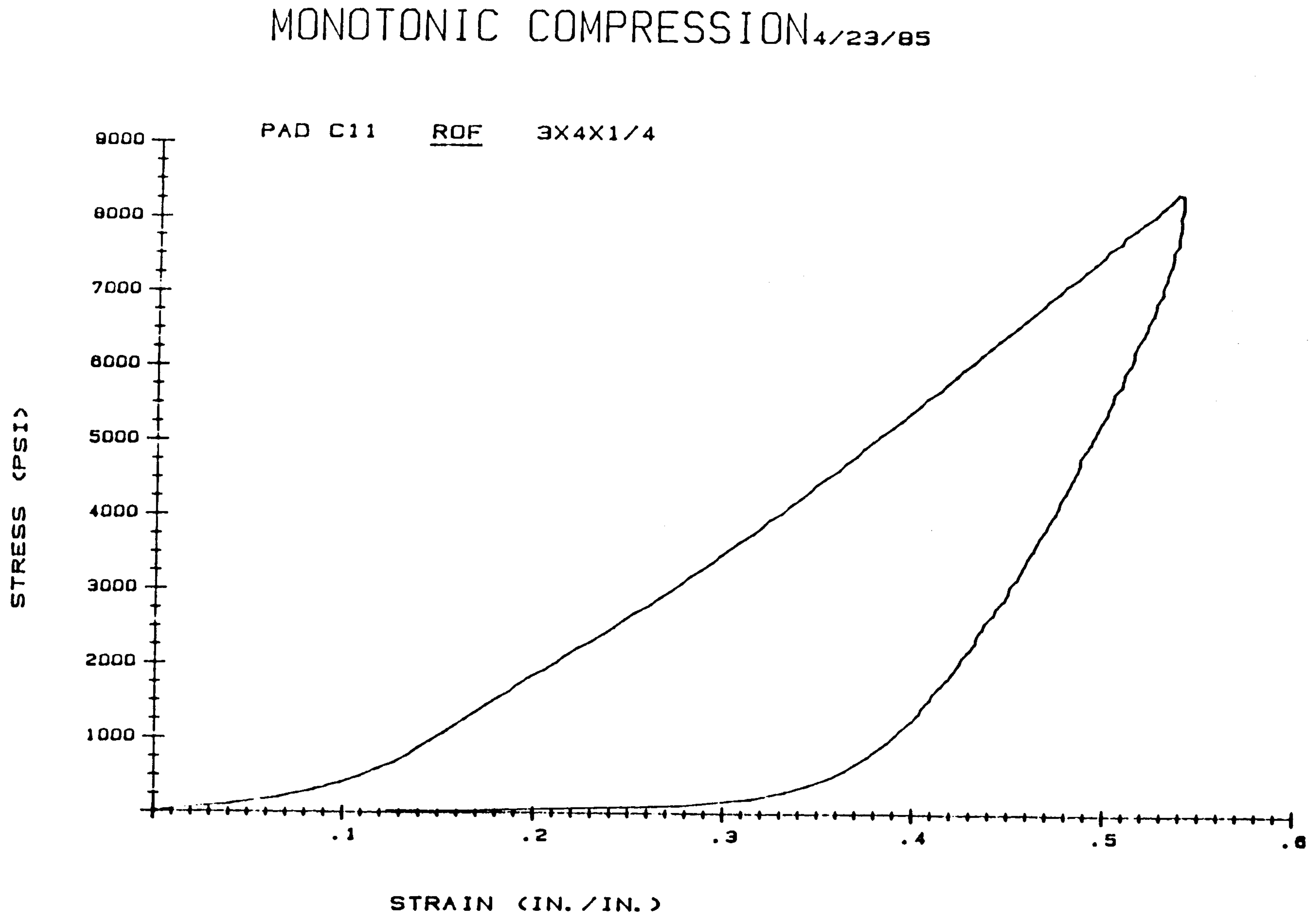


FIGURE 3.2 MONOTONIC COMPRESSION TEST FOR R.O.F. PAD (S = 3.43)

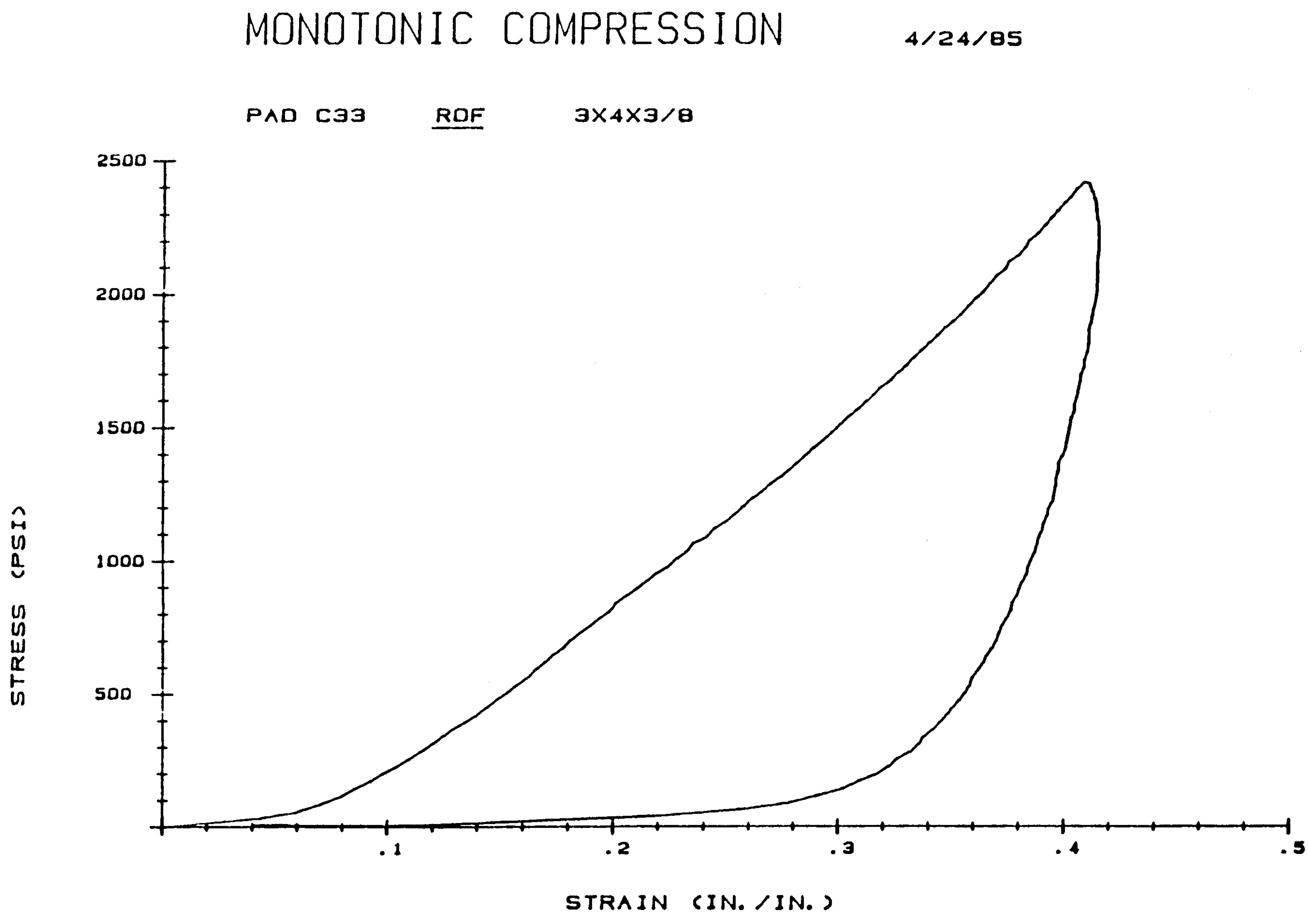


FIGURE 3.3 MONOTONIC COMPRESSION TEST FOR R.O.F. PAD (S = 2.29)

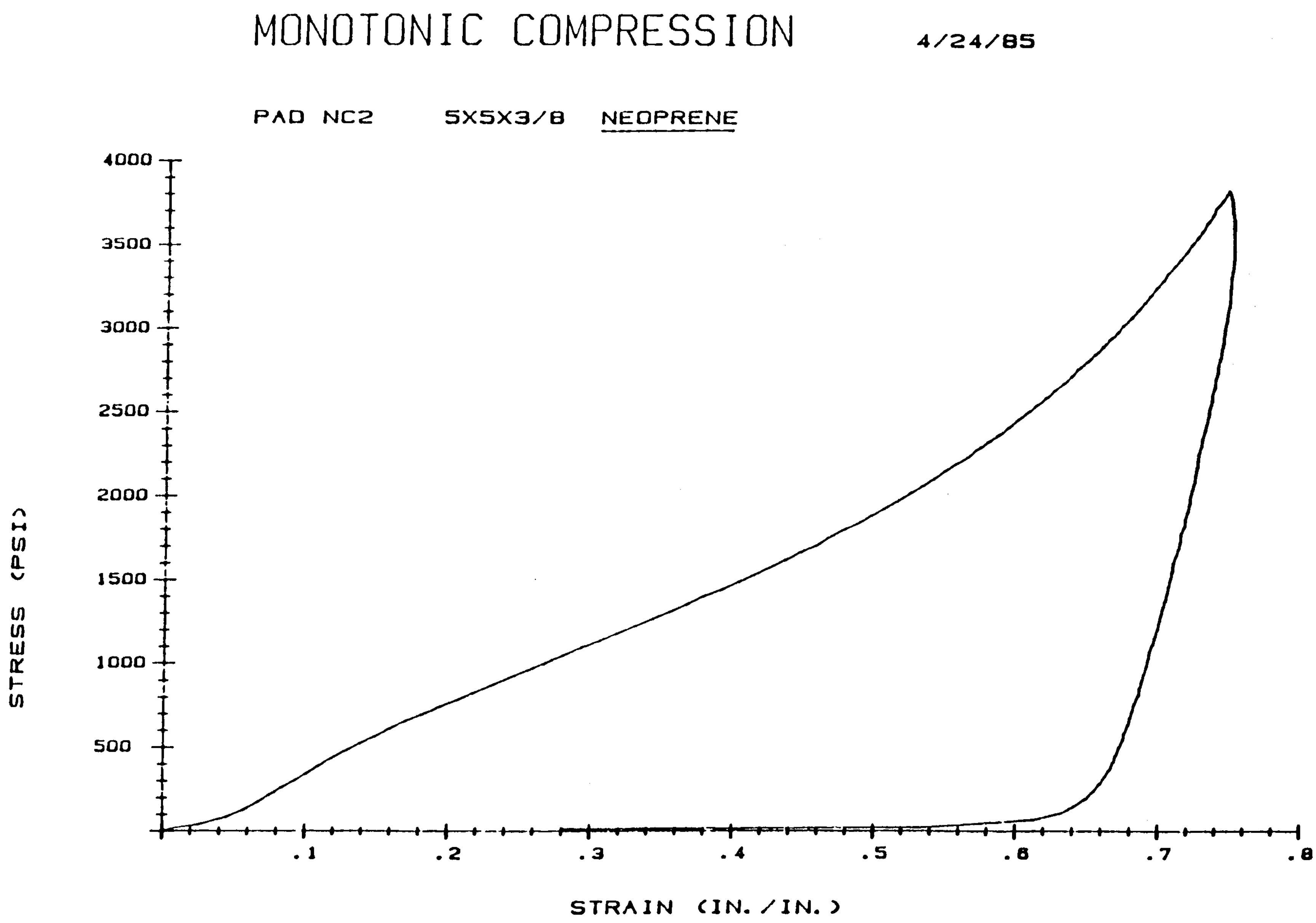


FIGURE 3.4 MONOTONIC COMPRESSION TEST FOR NEOPRENE PAD (S = 3.33)

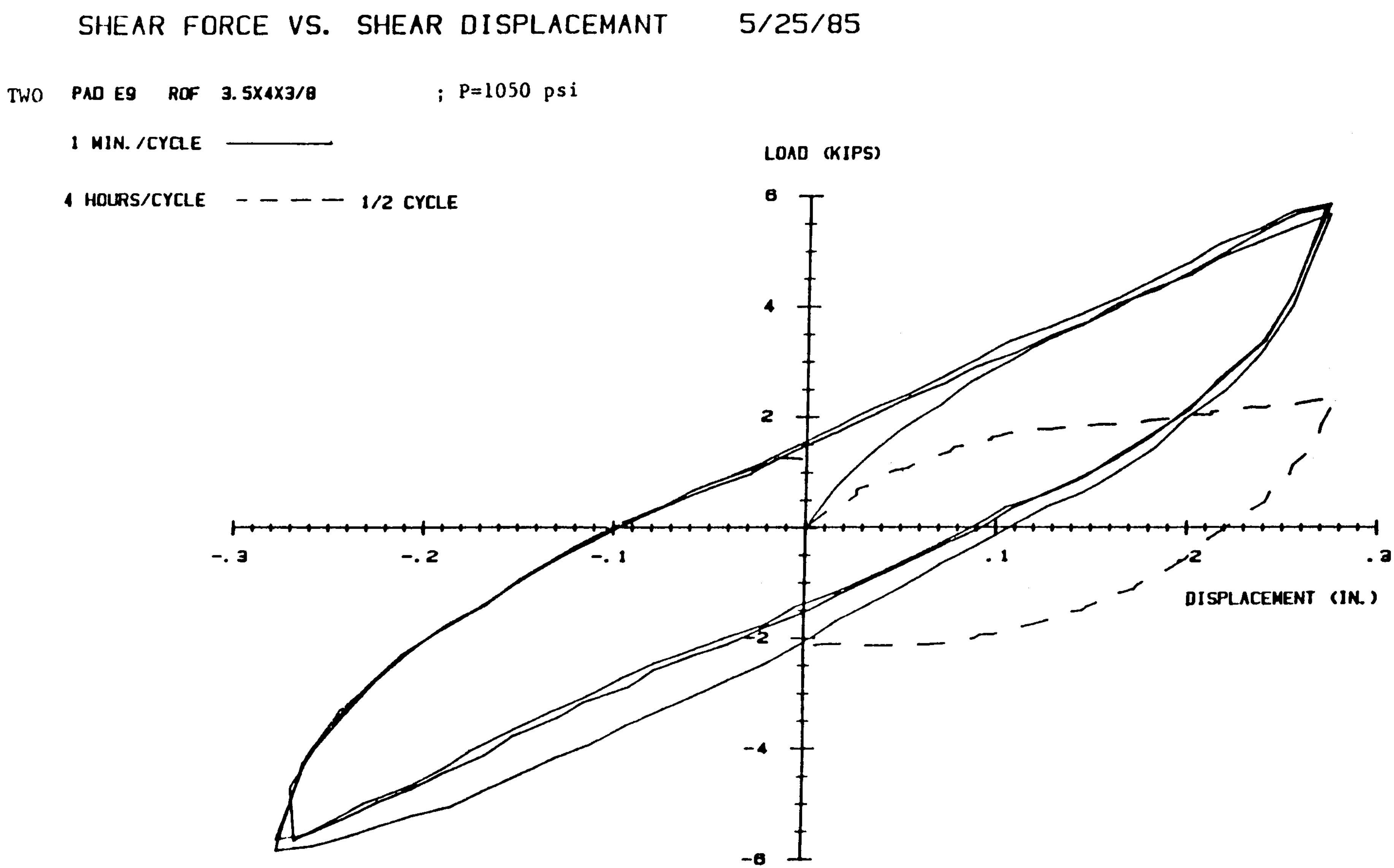


FIGURE 4.1 CYCLIC SHEAR WITH COMPRESSION OF 1050 PSI
(Slow Motion and Fast Cycling of R.O.F. Pads)

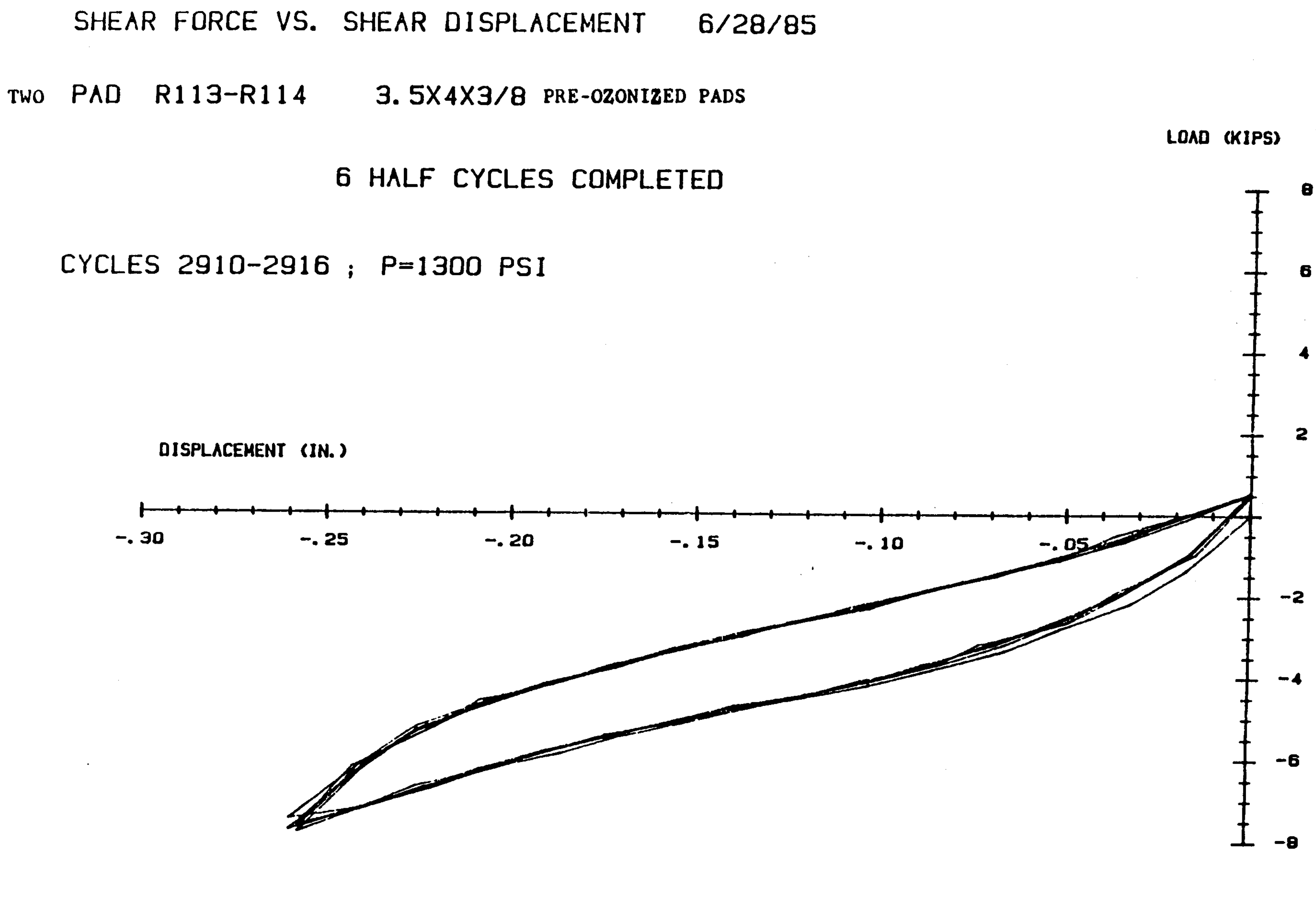


FIGURE 5.1 CYCLIC SHEAR WITH COMPRESSION OF PRE-OZONIZED R.O.F. PADS

APPENDIX A

SUMMARY OF MATERIAL TEST REPORTS

1) Random-Oriented-Fiber Pads by J.V.I. Inc. ("MASTICORD"):

Hardness, Shore A: 76 to 78

Maximum compression: 10,200 to 11,200 psi

Tensile strength, ASTM D412 (Die C): 1053 to 1297 psi
Elongation : 64% to 139%

Tear strength, ASTM D624 (Die B): 385 to 462 lbs/in

Heat aging, ASTM D573:

a. Change in tensile strength: -3 to -18%
b. Change in elongation : -4.5 to -17%
c. Change in hardness : +1 to 2 pts.

Oil Swell, ASTM D471 : 37 to 56%

Shear Modulus: Constant in all directions parallel to the bearing plane.

2) AASHTO-Grade (Table B) NEOPRENE, by Scougal Rubber:

Hardness: 62

Compression set, ASTM D395 (Method B): 19

Tensile strength, ASTM D412 : 3281 psi

Elongation at break, ASTM D412 : 460%

Tear strength, ASTM D624 (Die C) : 321 lbs/in

Heat aging, ASTM D573, 70 hrs./212° F.:

a. Change in tensile strength: 1.08%
b. Charge in elongation : -5.4%
c. Change in hardness : +3 pts.

Ozone test, ASTM D-1149 (100 hrs. @ 100 pphm, 20% strain): Pass.

APPENDIX B

DEFORMATION PREDICTION OF A PARKING ROOF PAD

Assume a typical 60-ft.-span composite, double tee deck consisting of a 24"-deep precast, lightweight section with 3"-thick C.I.P. deck as shown in Figure B-1. Using the analysis shown in Reference (4):

Difference in end rotation between erection and final rotation (at 10 years) : $\theta_2 - \theta_1 = 0.0139$ rad.

Half-span shortening : $\delta_1 = -0.290"$

Displacement due to end rotation change : $\delta_2 = 0.0139\ (21.13") = 0.294"$

Instantaneous end rotation under a realistic 18 psf passenger car loading : $\theta_3 = 0.0021$ rad.

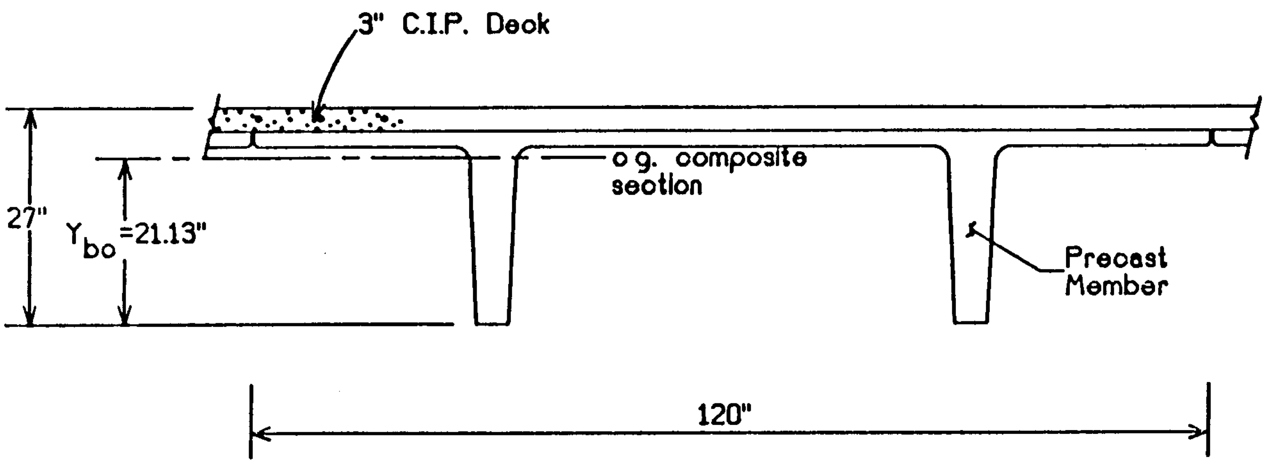
Displacement change due to θ_3: $\delta_3 = 0.0021\ (21.13) = 0.045"$

To estimate the temperature effects assume the the members were erected at 60°F and that the temperature profile on a hot summer day is as shown in Figure B-1. Then, using standard methods of mechanics, the following values are derived for a 45°F gradient:

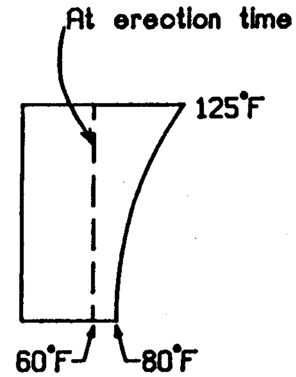
End rotation change over 5 hours : $\theta_4 = 0.007$ radians

Net displacement at leg bottom due to temperature increase and gradient : $\delta_4 = -0.095"$

In conclusion, it appears that creep and shrinkage net effect ($\delta_2 + \delta_1$) is almost nil for this case while the daily summer temperature swing emerges as the dominant effect with a displacement of about 0.10". Due to variations in material properties a value $\delta_4 \simeq 0.12"$ should be considered for daily cycling. The displacement δ_3 under an 18 psf live load is opposite to δ_4 but much smaller in magnitude.



Roof Cross Section



Temperature Profile

Figure B-1 Roof cross section and temperature profile.