

Summary of Experimental Tests of Elastomeric
Seismic Isolation Bearings for Use in
Nuclear Reactor Plants

by

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Abstract

This paper describes an experimental test program for isolator bearings which was developed to help establish the viability of using laminated elastomer bearings for base isolation of nuclear reactor plants. The goal of the test program is to determine the performance characteristics of laminated seismic isolation bearings under a wide range of loadings. Tests were performed on scale-size laminated seismic isolators both within the design shear strain range to determine the response of the bearing under expected earthquake loading conditions, and beyond the design range to determine failure modes and to establish safety margins. The test program was funded by the U.S. Department of Energy (DOE) and the National Science Foundation (NSF).

Three types of bearings, each procured from a different manufacturer, have been tested: (1) high shape factor-high damping-high shear modulus bearings; (2) medium shape factor-high damping-high shear modulus bearings; and (3) medium shape factor-high damping-low shear modulus bearings. These bearings were designed by ANL and made according to ANL specifications. All of these tests described in this report were performed at the Earthquake Engineering Research Center (EERC) at the University of California, Berkeley, with technical assistance from ANL. In addition, tests were performed by ETEC on two of the type (1) bearings cited above. Those tests will be reported by others at this workshop.

The tests performed on the three types of bearings have confirmed the high performance characteristics of the high damping-high and low shear modulus elastomeric bearings. The bearings have shown that they are capable of having extremely large shear strains before failure occurs. The most common failure mechanism was the debonding of the top steel plate from the isolators. This failure mechanism can be virtually eliminated by improved manufacturing quality control.

The most important result of the failure test of the isolators is the fact that bearings can sustain large horizontal displacement, several times larger than the design value, without failure. The results of these test programs should give the designer confidence that base isolated structures

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can be designed and built with more than adequate safety margins. Their performance in moderate and strong earthquakes will be far superior to conventional structures.

I. Introduction and Scope

This paper presents an overview of the results of a number of tests of elastomeric seismic isolation bearings conducted over the last three years. These tests were conducted as part of the U.S. Department of Energy (DOE) program to develop seismic isolation technology for use in nuclear facilities, and also as part of a joint U.S./Japanese program to study seismic isolation. The joint program was conducted by Argonne National Laboratory (ANL) and the Shimizu Corporation of Japan. The ANL work on this joint program was funded by the National Science Foundation (NSF).

The goals of these tests are to determine the performance characteristics of isolator bearings under a wide range of loadings, to determine failure modes and to establish safety margins. During the course of conducting these tests, three types of elastomeric bearings were tested. The results of these tests are presented along with conclusions relating to bearing design and manufacture, acceptance testing and margins of safety against failure.

II. Background

ANL has been deeply involved in the development of seismic isolation for use in nuclear facilities for the past decade. Under funding and direction of DOE, ANL has participated in the development of the methodology needed to design and evaluate usefulness and effectiveness of seismic isolation for advanced liquid metal-cooled reactors (LMRs). As part of that program, tests were conducted on elastomeric bearings for DOE by the Earthquake Engineering Research Center (EERC) at the University of California, Berkeley, California and at the Energy Technology and Engineering Center (ETEC) near Los Angeles, California. The results of those tests are reported in other papers at this workshop and elsewhere.

More recently, ANL had a major role in evaluating the use of seismic isolation for the DOE New Production Reactors (NPR), and also worked with Shimizu Corporation on the joint U.S./Japanese program to study seismic isolation of a full size test building facility in Sendai, Japan.

As part of these programs, ANL procured over fifty elastomeric isolation bearings for use both in the Sendai test building facility and for individual bearing tests. The results of these individual bearing tests are summarized in this paper.

Three types of high-damping rubber bearings, each procured from a different manufacturer, have been tested: (1) high shape factor-high shear modulus bearings; (2) medium shape factor-high shear modulus bearings; and (3) medium shape factor-low shear modulus

bearings. The bearings were designed by ANL and made according to ANL specifications. All tests described in this report were performed at the EERC with technical oversight by ANL. The tests at EERC were conducted on either the Single Bearing Test Machine, or the Large Scale Test Machine. Descriptions of these test facilities are given in Refs. (1) and (2). The bearing configurations, test plans, and test results are described in the following sections. This material is based on detailed test reports prepared by EERC.

III. High Shape Factor-High Shear Modulus Bearings

A. Background Information

The high shape factor-high shear modulus bearings are made of a high damping-high shear modulus rubber compound. They have a high shape factor value of 24. The bearings were designed and constructed as "dowelled" bearings to avoid tension in the rubber.

ANL purchased sixteen (16) bearings for the joint ANL/Shimizu program. Eight bearings were shipped to Japan for installation at the Sendai test facility and for performance of laboratory tests at Shimizu Corporation; four bearings were sent to EERC for testing to determine their static and dynamic characteristics; two bearings were sent to ETEC for dynamic tests; and two bearings were retained by ANL for archival purposes.

B. Description of Bearings

Figure 1 shows the configuration of the Sendai bearing. The overall diameter of the bearing, including a 3/4 inch protective cover layer, is 20 inches. The bearing has 1 inch thick end plates located at its top and bottom with four drilled holes in the top plate used for dowel pins.

C. Test Plan

The ANL test program at EERC was specifically designed to replicate insitu field tests conducted in Japan on the full size building after the bearings were installed. The bearings were tested in the Large Scale Bearing Test Machine at EERC.

The Sendai seismically-isolated test building weighs a total of 255.4 metric tons and is supported by six bearings. It is estimated that the four corner bearings carry a load of 37.8 metric tons each, and the two middle bearings carry 52.3 tons each. These loads correspond to 83.2 kips and 115.1 kips, respectively.

The four bearings were placed in the test machine with the vertical load set to 83.2 kips. Each horizontal displacement cycle ($\pm 3.15\%$, $\pm 6.25\%$, $\pm 12.5\%$, $\pm 25\%$, $\pm 50\%$, $+75\%$ - 50% shear strain) was repeated three times and data collected for all three cycles. The vertical load was increased to 115.1 kips and the test sequence repeated. The bearings were then deformed to

displacement cycles of $\pm 100\%$ and $\pm 125\%$ at the larger vertical load. It was observed that one bearing was showing signs of distress at this point. This bearing and its partner on that side of the test machine were immobilized by a strong-back, and the testing was continued with displacement cycles corresponding to $\pm 150\%$, $\pm 200\%$ shear strain. No further evidence of damage was visible, and it was concluded that the two tested bearings performed satisfactorily to $\pm 200\%$ strain. (The distressed bearing was cut in half after the test and it was found that the bond between the rubber and the top end plate had failed.)

D. Test Results

Test results are given in detail in ANL/Shimizu report, ANL-002 [Ref. 1]. Figures in this section are taken directly from Ref. 1. Major test results are force-displacement loops and damping values. The force-displacement (hysteresis) loops were recorded for the bearings at the two vertical loads, 83.2 kips and 115.1 kips. The results for the 115.1 kip vertical load is shown in Fig. 2. Figure 3 shows shear modulus as a function of strain obtained from the third cycle of the bearing tests and from the 0.75 Hz coupon tests provided by the elastomer compound supplier. The damping values obtained from the bearing and coupon tests are given in Fig. 4.

As can be seen from Fig. 3, at 50% shear strain the shear modulus of the rubber is about 120 psi. With a building weight of 255.4 metric tons, the bearing's frequency at 50% shear strain is 0.79 Hz. This is higher than the design frequency of 0.75 Hz. In fact, the frequency of 0.75 Hz would not be achieved for the Sendai bearings until the shear strain reached around 100%.

E. Conclusions

The results indicate that the bearings are somewhat stiffer than anticipated in the design. The system frequency at 50% strain is 0.79 Hz. For small displacements generated by minor earthquakes, the frequency will be even higher. For example, at around 10% strain, the response will be of the order of 1.2 Hz. The damping in the bearings is also consistently high. Over the range of strains, from 3% to 50%, the average damping is 15.5%. Thus, for small to moderate earthquakes, structures using these high-shape factor bearings will not experience significant reductions in horizontal seismic loads.

The bearing that showed early signs of distress experienced a bond failure that occurred at the top end plate. While observations of the type of failure show that the failure is not sudden, they also highlighted the difficulty of detecting a poor bond in bearings. The testing procedure of 50% shear strain (at 100% of design vertical compressive load) as an acceptance test did not reveal the presence of a poor bond. The test procedure was modified for later procurements to require the test to subject the bearings to large horizontal displacements while the vertical load on the bearing is reduced to essentially zero, thus eliminating the frictional effect which may mask defects in the bonding.

IV. Medium Shape Factor-High Shear Modulus Bearings

A. Background Information

The motivation to design and test medium (or moderate) shape factor bearings include a desire to achieve a bearing design that facilitates fabrication to high quality standards and has the highly predictable behavior needed for nuclear applications. Also, this particular test program was very important to the DOE's seismic isolation program, because it provided data on a range of shape factors lying between the earlier bearings of GE's PRISM and Rockwell International's SAFR reactors tested at EERC, which were high and low shape factor bearings, respectively.

Four types of rubber bearings were manufactured. The bearings were designed as "bolted"-type bearings (i.e., the bearing is able to develop tensile stresses in the rubber during horizontal deformations). The four types of isolators have two different rubber compounds and two different shape factors, 9 and 18.

Each type of bearing was subjected to seven different types of tests, making a total of 28 bearings tested. Each type of isolator was subjected to five different failure tests in which combinations of the axial and the shear loads were varied in order to obtain an insight into effects of axial-shear load interaction. Fatigue tests were carried out at two different shear strain levels: one at 100% and the other at 150%.

B. Description of Bearings

The four types of bearings used in this test series were designated as types 1, 2, 5 and 6. The dimensions and overall arrangement of bearing type 1 is shown in Fig. 5. (Details of the other bearing types are similar.) A summary of the dimensions and properties of the four types of bearings is given in Table I. As shown in Table I, two different rubber compounds were used (designated here as A and B), and two different shape factors were used, 9 and 18. The overall height of the bearings varied slightly to maintain the overall rubber thickness at 3.75 inches.

The compound used in types 1 and 2 bearings, designated A, has a nominal shear modulus of 120 psi at 100% shear strain; the compound used in types 5 and 6 bearings, designated as B, has a shear modulus of 150 psi at 100% shear strain. The nominal design vertical load for the bearings was 62.5 tons. These isolators were designed to provide a horizontal frequency of 0.50 Hz at 100% shear strain.

C. Test Plan

The seven tests performed on each type of bearing were fatigue and combination failure tests. The purpose of the fatigue tests was to study (1) the resistance of the isolators to a long time duration of cyclic dynamic loads, (2) the loss of stiffness under cyclic loading, and

(3) the failure mechanisms. The purpose of the combination failure tests was to gain insight into an axial-shear load interactions.

There were five combination shear-axial load failure tests performed on each type of bearing for a total of 20 tests. The five tests are: (1) pure compression failure, (2) shear failure with a compressive design vertical load, (3) shear failure with no axial load, (4) shear failure with a tensile design vertical load, and (5) pure tension failure.

The original test program for the fatigue tests was to test each type of bearing to a cyclic displacement corresponding to 50% and 100% shear strains until failure while carrying the design load of 62.5 tons (125 kips). However, after the first fatigue test was performed, bearing type 5 resisted 2880 cycles without a sign of failure. A decision was made to modify the test program to shear strain levels of 100% and 150% and only bearing types 1 and 5 were tested. Thus, there were a total of five fatigue tests.

D. Test Results

Test results important to establish dynamic characteristics and failure mechanisms of the bearings are summarized below.

1. Fatigue Tests

During the five tests, only the two bearings subjected to cycles at 150% shear strain failed. One bearing tested in fatigue at 150% shear strain sustained up to 1120 cycles before failing. Another bearing sustained 515 cycles due to a fissure caused by the expulsion of an air bubble entrapped in the bearing. Figures 6 and 7 are photographs of the two bearings after failure. (Note that Fig. 7 shows only the lower portion of the failed bearing after removal from the test machine.)

The shape factor has no apparent influence on the mechanical behavior of the isolators when subjected to cyclic loading. Similarly, the type of rubber compound had no apparent influence on the mechanical behavior of the isolators when subjected to a fatigue test.

2. Combination Failure Tests

The combination failure tests gave a variety of results which depended to a large extent on the quality of the bond between the steel plates and shims and the rubber layers. For example, some of the isolators carrying high compressive load and tested in shear did not fail, but when the axial load was removed and tested again in shear, they did fail. This suggests that weak bonding was the cause of the failure.

In general, for tests of shear failure with compressive vertical load, the maximum shear strain reached by the isolators surpassed 250% shear strain, and all tests surpassed 175% shear strain.

As expected, bearings with higher shape factor resisted higher compression loads than those with low shape factor bearings, since bearings with higher shape factor require more layers and consequently more steel shims which resist most of the vertical load. The compression tests gave consistent results.

It was possible to test all bearings to failure during the test of shear failure with no axial load. This test was useful in determining the quality of the bonding between the steel shims and plates with the rubber layers.

The results of the tension failure tests were varied, with the tensile strength ranging from 111 psi up to 586 psi. The variability in tensile strength is due to variability in bond strength between the steel plates and shims and rubber layers.

E. Conclusions

These bearings performed well during the fatigue tests. The bearings tested in fatigue at 150% shear strain sustained up to 1120 cycles before failing (equivalent to 30 minutes of very severe ground shaking). These results are more than satisfactory when considering that no earthquake will generate so many cycles all with large displacements. For example, an earthquake of two (2) minutes duration (which is very high) would have about 200 cycles, only a fraction of which cycles would be of the higher displacement motion.

The compression tests revealed that the mechanism of failure is yielding and tearing of the reinforcing steel plates. The plates are loaded by surface shear stresses as they act to prevent barrelling of the bearing under the vertical load. It was demonstrated that the elastomer and the rubber steel bond are able to sustain shear stresses that are large enough to yield the steel in a type of all around tension. The vertical pressure on the bearing, at which the steel reinforcing plates failed, depended on the shape factor but was in every case many times larger than the design vertical pressure.

The program has shown that adequate bond can be achieved if correct quality assurance procedures are followed during the molding and vulcanizing of the bearings. It has also been shown that bonding cannot be determined by tests with a horizontal shear strain of 100% under the presence of any vertical compressive load. One must test under zero axial load or under a slight tension load (to minimize pseudo-beneficial effects of friction).

V. Medium Shape Factor-Low Shear Modulus Bearings

A. Background Information

After experiencing 37 minor to moderate earthquakes in 1-1/2 years, ANL and Shimizu Corporation decided that the high shape factor-high damping isolation bearings installed in the Sendai test facility should be replaced by a set of medium shape factor-low shear modulus

- high damping isolation bearings. This was done to achieve improved response of the building over a wide range of small to moderate earthquakes.

A new compound had been developed which had a shear modulus about half that of the shear modulus of the high damping rubber used in the original test bearings. In July 1990, ANL purchased ten bearings using the newly developed compound. Eight bearings were shipped to Japan in October 1990: six for installation in the Sendai test building and two for laboratory tests in Japan. The two remaining were sent to EERC for laboratory testing.

B. Bearing Configuration

These bearings are characterized as having medium shape factor-high damping-low shear modulus. These bearings have a diameter of 14.75 inches and are 8.1 inches in height. They have 12 layers of 0.394 inch thick rubber and 11 steel shims which are 0.128 inches thick. Details of these bearings are described elsewhere at this workshop (see paper by R. F. Kulak, "Technical Specifications for the Successful Fabrication of Laminated Seismic Isolation Bearings"). With a nominal vertical load of 92.6 kips corresponding to 621 psi vertical pressure, these bearings provide a horizontal frequency of 0.40 Hz at 100% shear strain.

C. Test Plan

The test plan consists of three types of tests: (1) horizontal tests, (2) vertical tests, and (3) failure tests. All tests were carried out on the Single Bearing Test Machine at the Earthquake Simulator Laboratory of EERC.

In the horizontal tests, the bearing was subjected to two sequences of horizontal displacement cycles. Each sequence included three cycles of displacement of the strain levels:

Sequence 1: $\pm 5\%$, $\pm 10\%$, $\pm 25\%$, $\pm 50\%$, $\pm 75\%$, $\pm 100\%$

Sequence 2: $\pm 125\%$, $\pm 150\%$, $\pm 175\%$, $\pm 200\%$

In the vertical tests, the bearing was subjected to five cycles of vertical loading centered around 500, 625, 1000, and 1500 psi of vertical pressure. The variation in the vertical load in each of these tests corresponded to about ± 100 psi. This particular test series is close to the limits of the test system capability at EERC.

The horizontal tests in Sequence 1 were carried out at frequencies of 0.1 Hz and 0.5 Hz. The horizontal tests in Sequence 2 and the vertical tests were carried out only at a frequency of 0.1 Hz.

After the completion of the horizontal and vertical tests a failure test was performed. In the failure test, the bearing was loaded monotonically in shear at a rate of 2.5 in/min.

D. Test Results

Test results are discussed in detail in Ref. [2]. Tables II gives the effective stiffness and equivalent viscous damping for tests performed at a frequency of 0.5 Hz. The force displacement plot for Sequence 1 tests at frequency of 0.5 Hz with 1000 psi vertical pressure is shown in Fig. 8.

Table III gives the stiffness values of the bearing for five cycles around 500 psi, 621 psi, 1000 psi, and 1500 psi. The variation of pressures is ± 100 psi. The hysteresis loops are shown in Fig. 9 where they are superimposed on the monotonic loading curve. As can be seen from Table III, the stiffness value varies with the pressure level around which the cycles are centered. The stiffness values are higher at high pressure levels. Figure 9 shows that the slopes of the hysteresis loops due to pressure variation are much higher than the tangent stiffness of the monotonic loading curve.

In the failure test the bearing was loaded monotonically at a rate of 2.5 in/min. In all three trials, the bearing did not fail when the actuator reached its maximum displacement. Figures 10 and 11 show the deformation of the bearing at shear strain of 200% and 300%, respectively. The maximum shear strain obtained in the test was 415%, with a maximum shear stress of 355 psi. This is equivalent to a maximum displacement of 19.6 inches with a maximum shear load of 52.9 kips.

E. Conclusions

The results of horizontal shear tests show that the shape of hysteresis loops change with the magnitude of vertical pressure loads. The loops change from narrow-elongated to wide-elliptical as vertical pressure increases. The results of vertical tests show that the bearing stiffness varies with the pressure level around which the cycles are centered and they are much higher than the tangent stiffness of the monotonic loading curve. The most important results of the failure test is the fact that the bearing was able to sustain very high horizontal shear displacements while under the design vertical load.

V. Summary

The three test programs summarized in this paper have confirmed the high performance characteristics of the high damping-high and low shear modulus elastomeric bearings. The tests have shown that these bearings are capable of experiencing extremely large shear strains (several times the design shear strain level) before failure occurs. Failure mechanisms of these bearings are strongly influenced by the quality of the bond between the steel plates and shims and rubber layers. Bearings tested in fatigue at 150% shear strain sustained up to 1120 cycles before failing. This is roughly equivalent to about 30 minutes of extremely strong ground shaking. These results are more than satisfactory when considering that no earthquake will generate so many cycles with such large displacements.

VI. Acknowledgments

The authors wish to thank Professor James M. Kelly, Dr. Ian D. Aiken, and Messrs. Wes Neighbors, Donald Clyde, Edgardo Quiroz, and Ivo Van Asten of the Earthquake Engineering Research Center (EERC) for performing and analyzing the bearing tests and preparing test reports. These tests were performed as part of work in the Engineering Mechanics Program of the Reactor Engineering Division of Argonne National Laboratory under the auspices of the U.S. Department of Energy, Contract No. W-31-109-Eng-38. The funding of the experimental tests was partially provided by the National Science Foundation under NSF Agreement No. CES-8800871.

VII. References

1. James M. Kelly, Ian D. Aiken, and Donald Clyde, "Performance Evaluation of ANL Sendai Bearings," ANL/Shimizu, ANL-002, September 1989.
2. James M. Kelly, "Mechanical Characteristics of Low Modulus High Damping Natural Rubber Isolators for a Base Isolated Demonstration Building," ANL/Shimizu, ANL-004, June 1991.

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Table I. Dimensions and Properties of Medium Shape Factor Bearings

MEDIUM SHAPE FACTOR BEARING TEST BEARINGS DIMENSIONS AND COMPOUNDS									
TOTAL RUBBER THICKNESS: 3.75" SINGLE STEEL SHIM THICKNESS: 1/16"									
BEARING TYPE	STEEL SHIM		RUBBER			SHAPE FACTOR	COMPOUND TYPE		
	DIAMETER	AREA (IN ²)	LAYERS	THICKNESS	LAYERS				
1	14"	153.94	9	3/8"	10	9	A		
2	14"	153.94	19	3/16"	20	18	A		
5	12"	113.10	11	5/16"	12	9	B		
6	12"	113.10	23	5/32"	24	18	B		

Table II. Equivalent Stiffness and Viscous Damping of Low Shear Modulus Bearing for Tests Performed at 0.5 Hz Frequency

HORIZONTAL SHEAR TEST FREQUENCY: 0.5 Hz									
PRESSURE ¹ PSI	FILENAME (5-100%)	DYNAMIC PROPERTIES	SHEAR STRAIN						
			5%	10%	25%	50%	75%	100%	
0	910325.10	$K_{(em)}$ (Kips in)	3.64	3.14	2.61	2.21	1.97	1.83	
		β (%)	13.69	11.72	9.66	8.82	8.27	8.02	
500	910325.11	$K_{(em)}$ (Kips in)	4.39	3.37	2.45	1.93	1.66	1.53	
		β (%)	18.35	17.84	16.29	14.57	13.75	13.25	
621	910325.12	$K_{(em)}$ (Kips in)	139	107	78	61	53	48	
		G (psi)	4.69	3.47	2.41	1.85	1.58	1.46	
1000	910325.13	$K_{(em)}$ (Kips in)	18.31	20.71	19.27	17.39	16.17	15.23	
		β (%)	149	110	76	59	50	46	
1500	910325.14	$K_{(em)}$ (Kips in)	5.39	3.82	2.29	1.56	1.28	1.16	
		β (%)	17.81	23.03	27.77	27.49	26.68	25.54	
		G (psi)	171	121	72	49	41	37	
		$K_{(em)}$ (Kips in)	6.35	4.44	2.49	1.52	1.1	0.92	
		β (%)	15.51	21.65	31.04	36.96	42.39	42.52	
		G (psi)	201	141	79	48	35	29	

¹These pressures are the target pressures, actual values are indicated in the plots.

Table III. Stiffness of Low Shear Modulus Bearing at Various Pressure Loadings

SENDAI - BEARING TEST COMPRESSION TEST					
FILENAME	PRESSURE ¹ PSI	ΔP PSI	STIFFNESS (Kips in)		f_v HERTZ
			1ST CYCLE	5TH CYCLE	
910325.15	500	± 100	1114.11	1114.12	12.10
910404.04	500	± 100	916.88	914.16	10.99
910325.16	621	± 100	1151.32	1149.26	10.84
910404.05	621	± 100	1059.80	1054.51	10.56
910325.17	1000	± 100	1697.81	1657.7	10.47
910404.06	1000	± 100	1621.35	1588.43	10.21
910325.18	1500	± 100	3878.29	3820.09	13.03
910404.07	1500	± 100	2545.18	2635.64	10.56

¹These pressures are the target pressures, actual values are indicated in the plots.

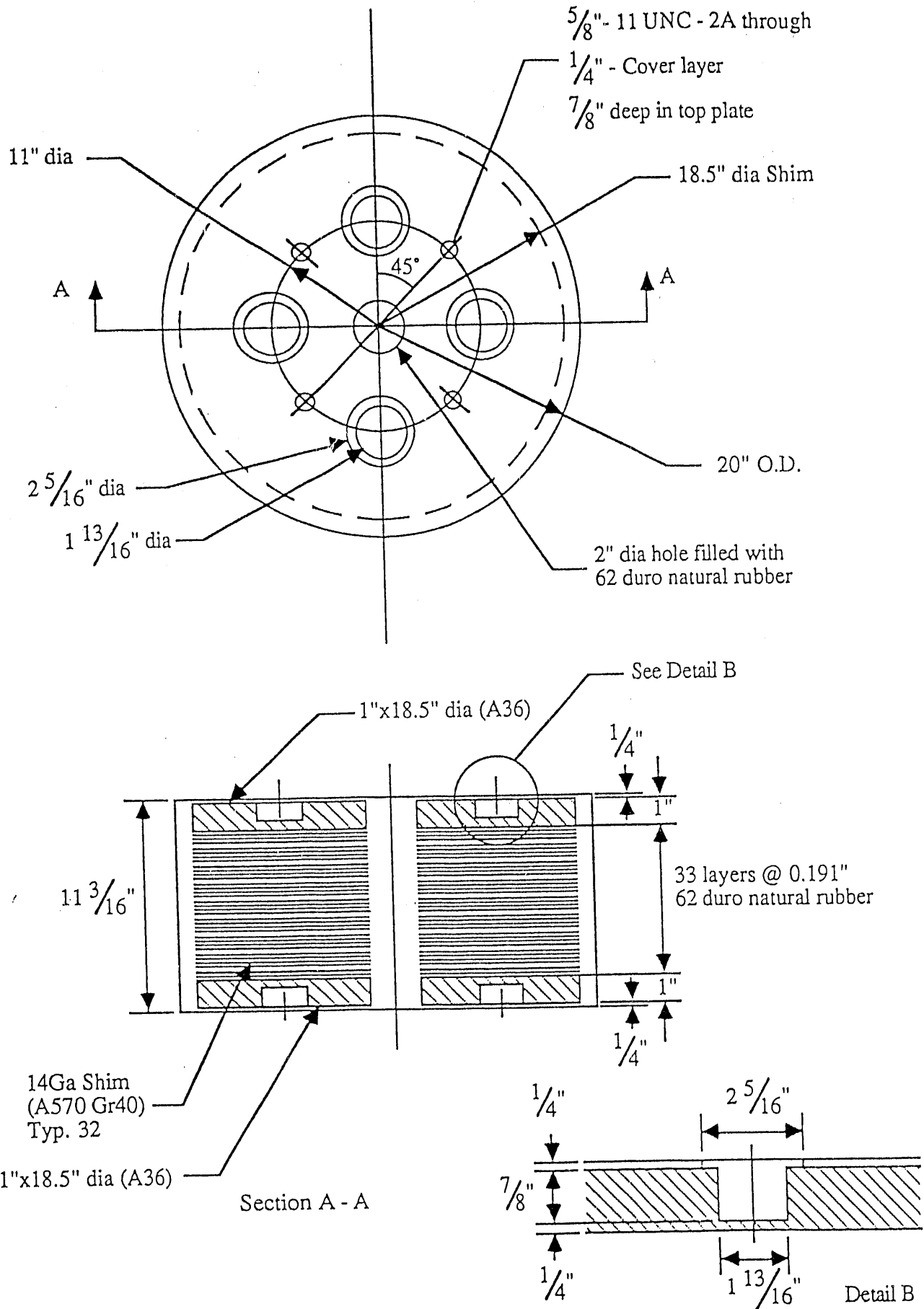


Fig. 1. Design Detail for Sendai Bearing

SEHDAI - ISOLATION BEARINGS

static vertical load = 115.11 kips/bearing

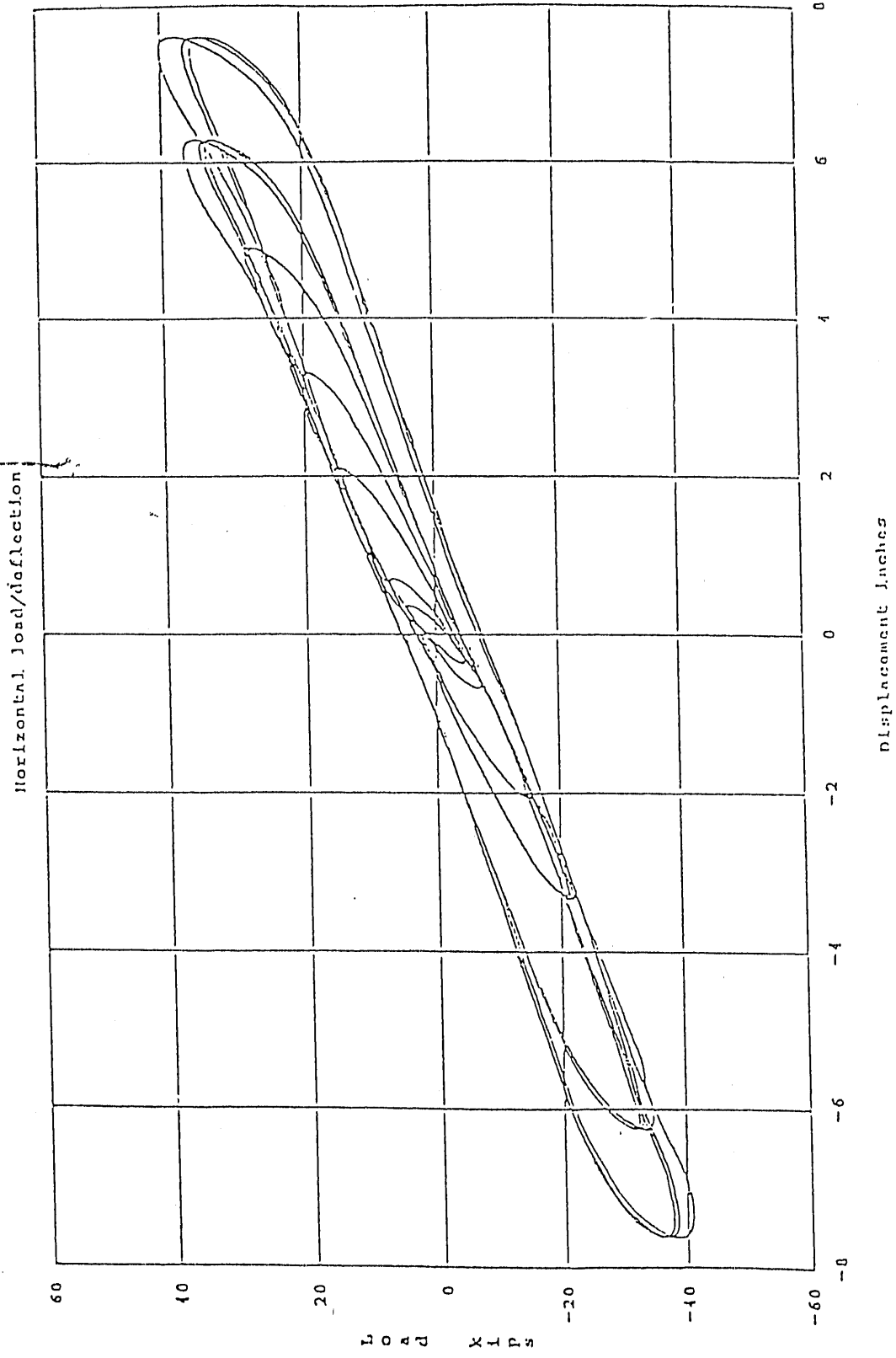


Fig. 2. Force-Displacement Loops for Bearing, Vertical Load = 115.1 kips

ANL-SENDAI BEARING TESTS

SHEAR MODULUS vs. SHEAR STRAIN
Bearing (3rd Cycle) and Coupon Tests

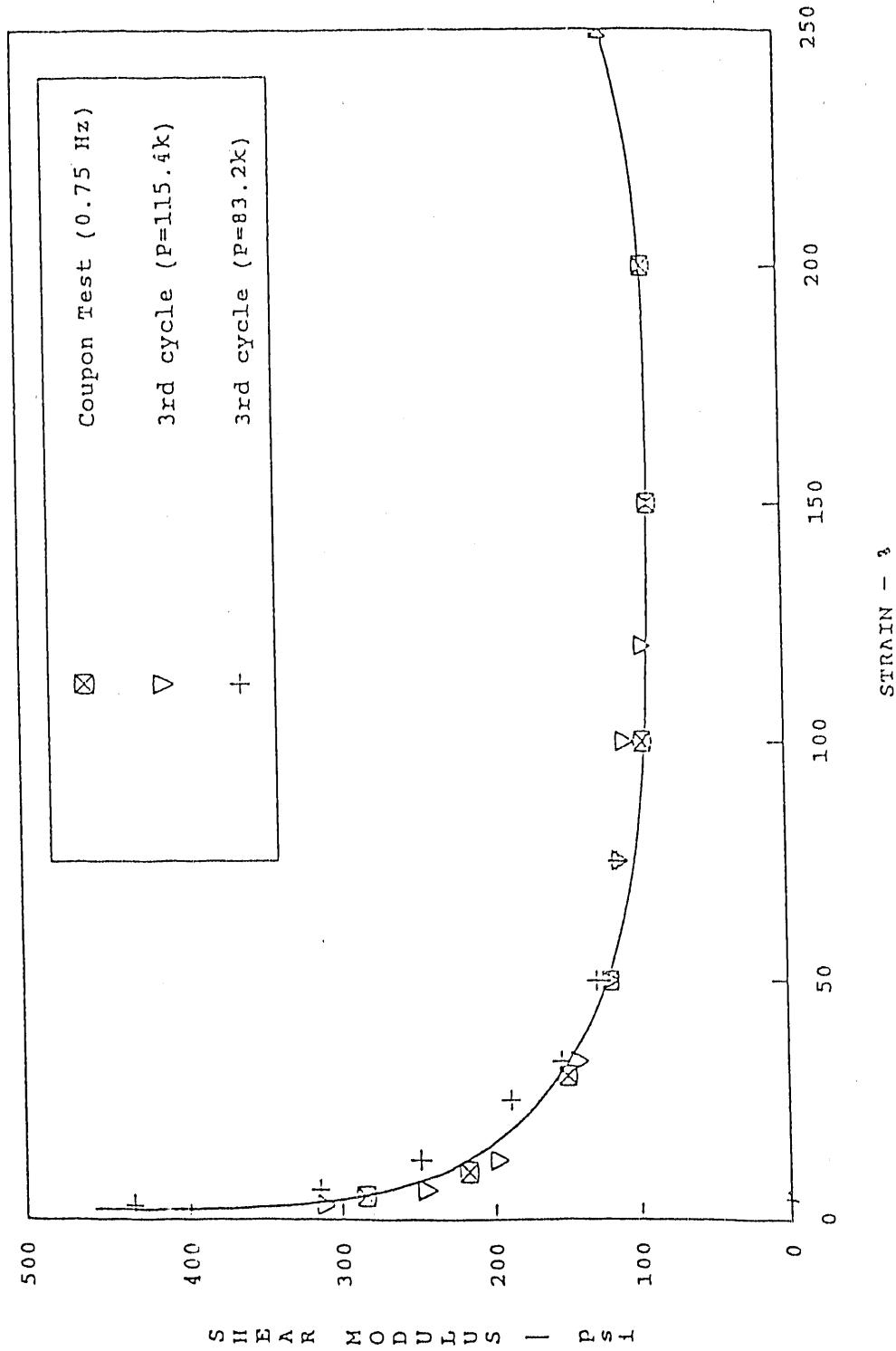


Fig. 3. Shear Modulus vs. Shear Strain for Bearing and Coupon Tests

ANL-SENDAI BEARING TESTS

DAMPING FACTOR VS. SHEAR STRAIN

Bearing and Coupon Tests

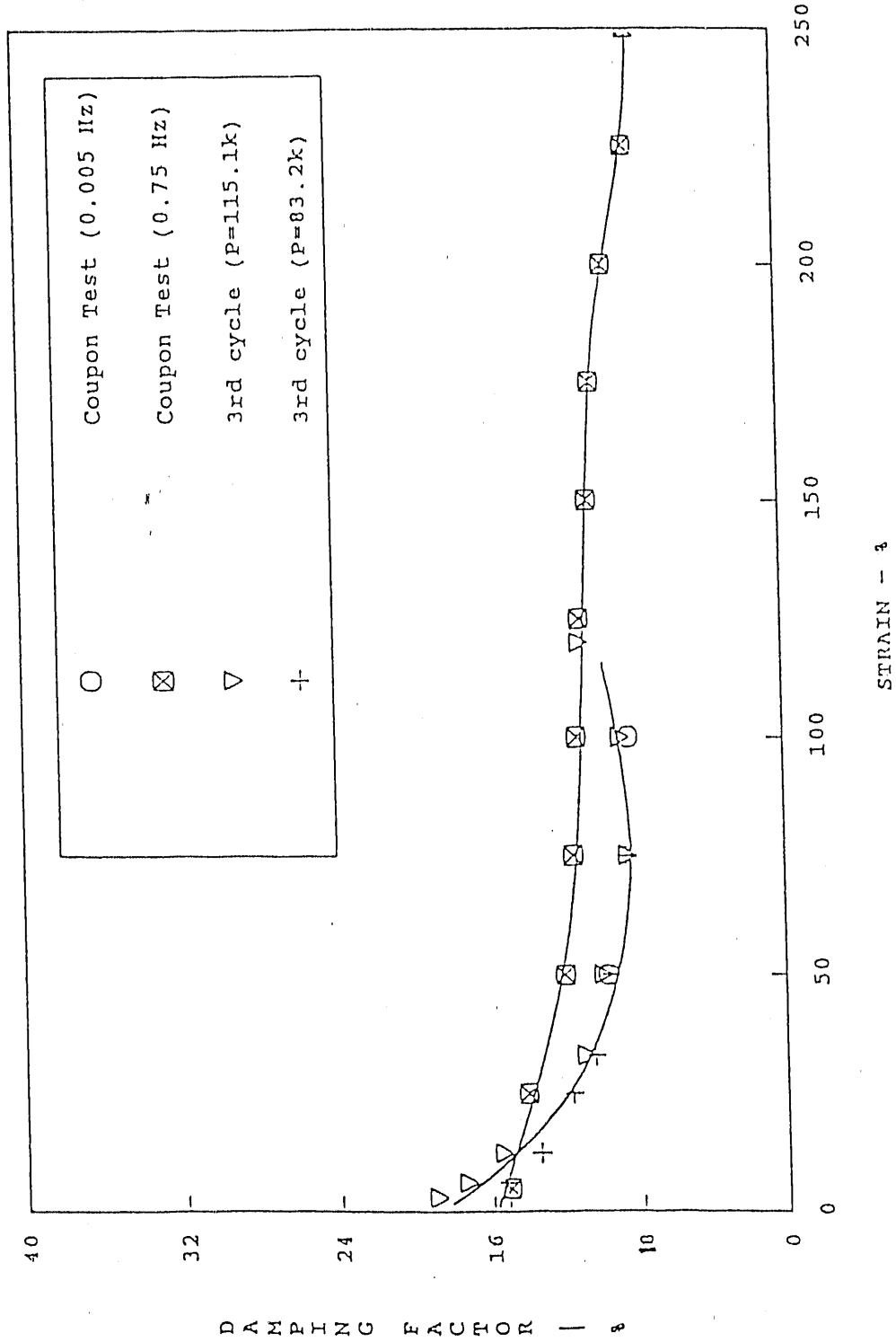
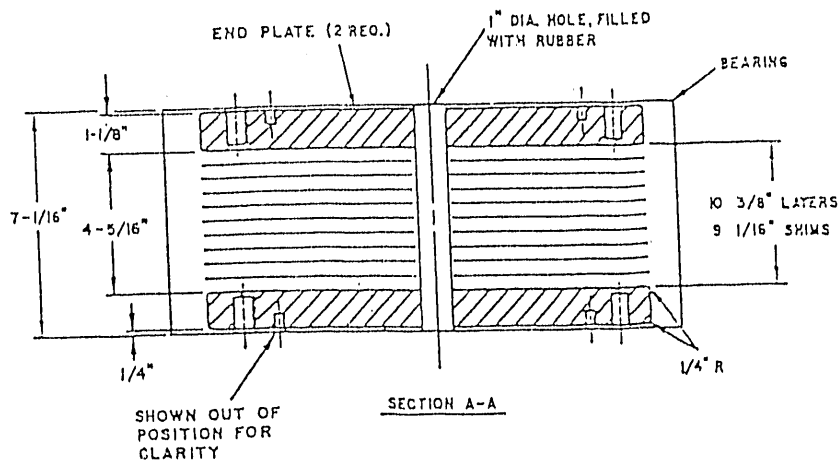
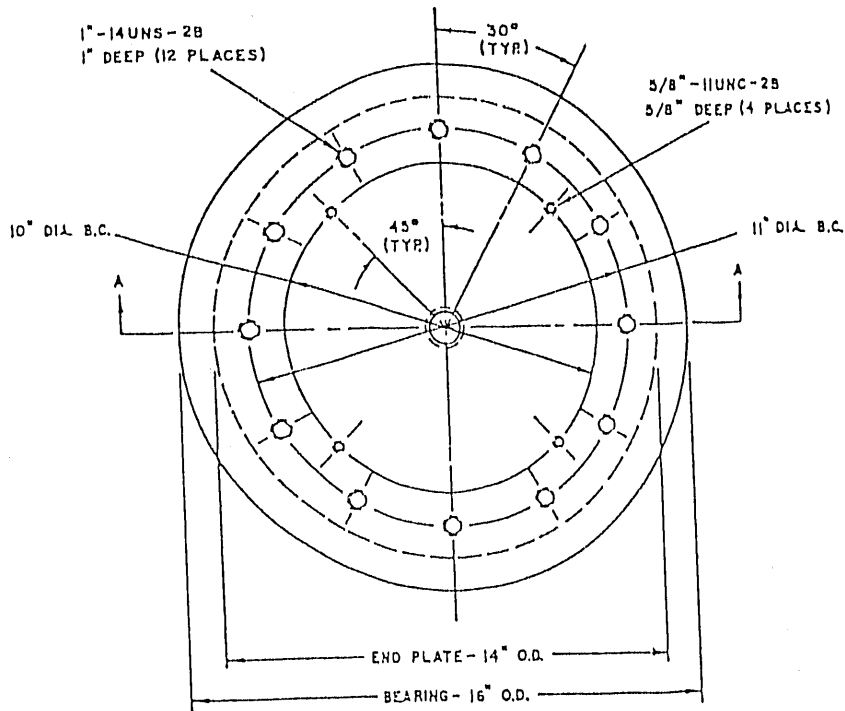


Fig. 4. Damping Factor vs. Shear Strain for Bearing and Coupon Tests



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Fig. 5. Design Details for Test Bearing Type 1

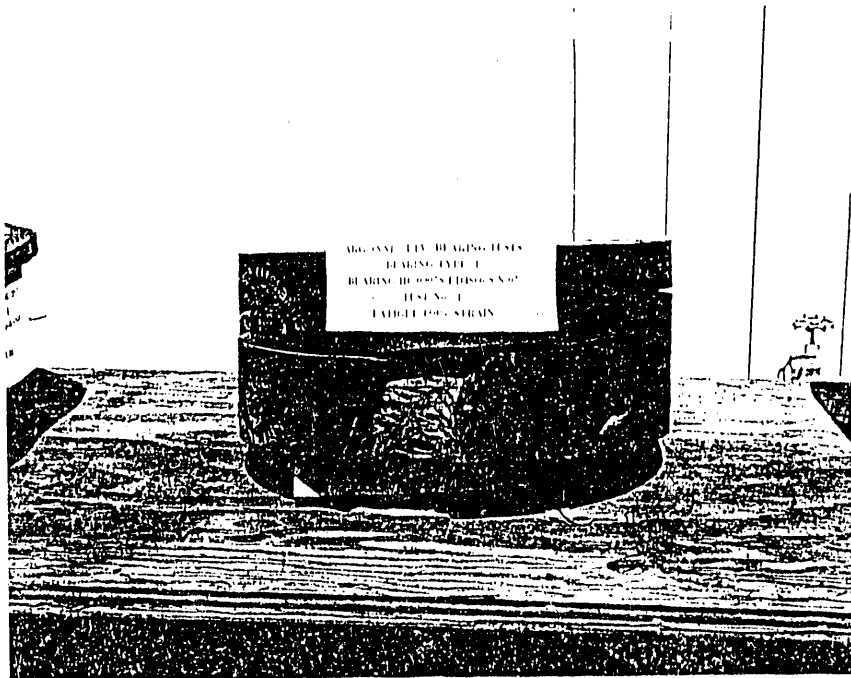


Fig. 6. Bearing Type 1.07 - Fatigue Test at 150% Shear Strain - Test No. 1



Fig. 7. Bearing Type 5.07 - Fatigue Test at 150% Shear Strain - Test No. 2

SENDAY-DEARING TEST
 SHEAR DIAGNOSTIC TEST 5A - 100A STRAIN

Strain	Stiffness	Shear Modulus	Damping
5%	5.39 Kips/in	171 psi	17.81 %
10%	3.82	121	23.03
25%	2.29	72	27.77
50%	1.56	49	27.49
75%	1.28	41	26.68
100%	1.16	37	25.54

FILENAME: 910325.13
 VERT PRESSURE: 1000 PSI
 FREQUENCY: 0.5 HERTZ

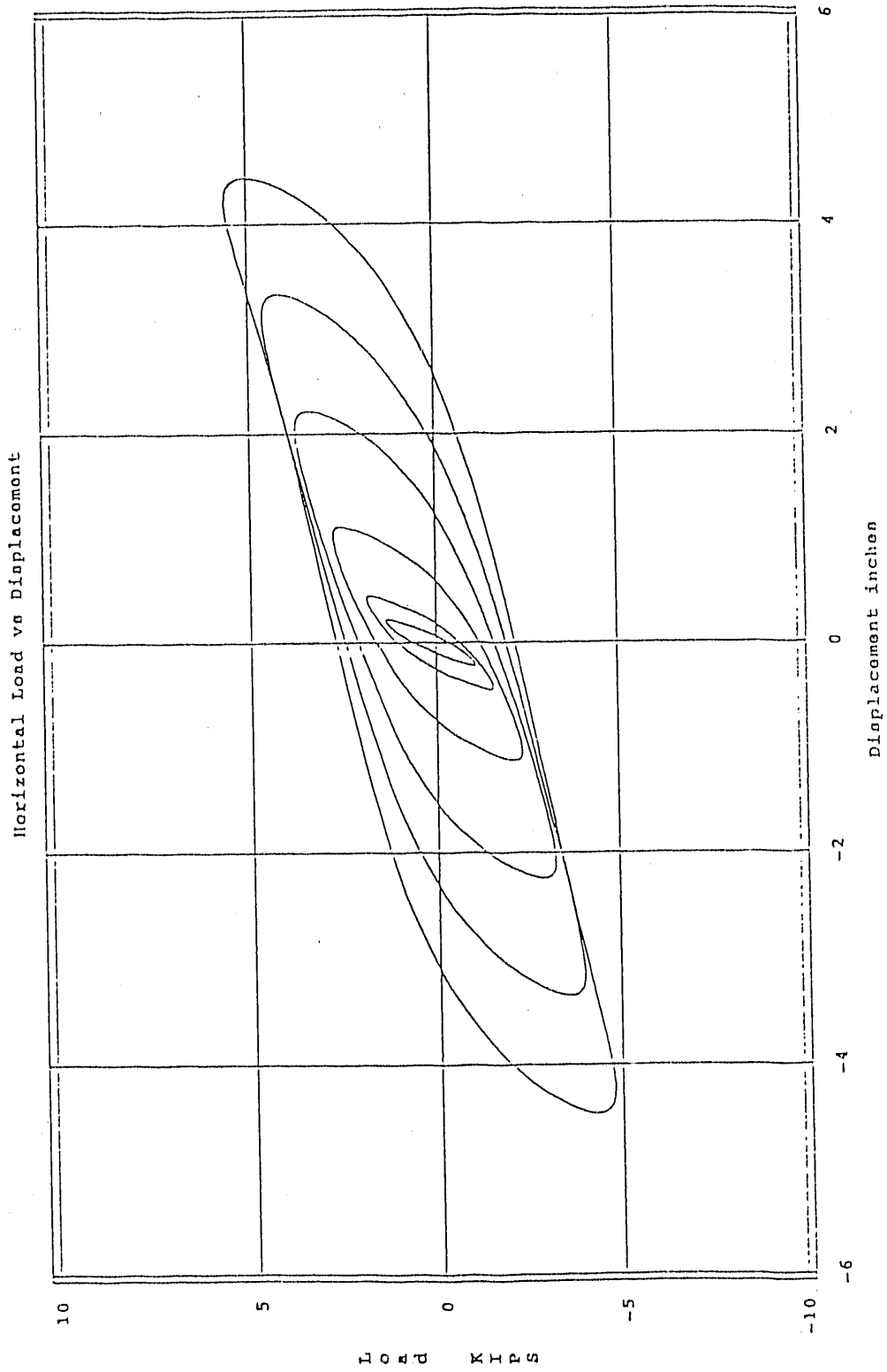


Fig. 8. Force Displacement Plots for Sequence I - 1000 psi Vertical Pressure at Frequency 0.5 Hz

SENDAI - BEARING TEST
COMPRESSION TEST

Filename: 910404.03

Max. Vert. Load: 232.36 Kips

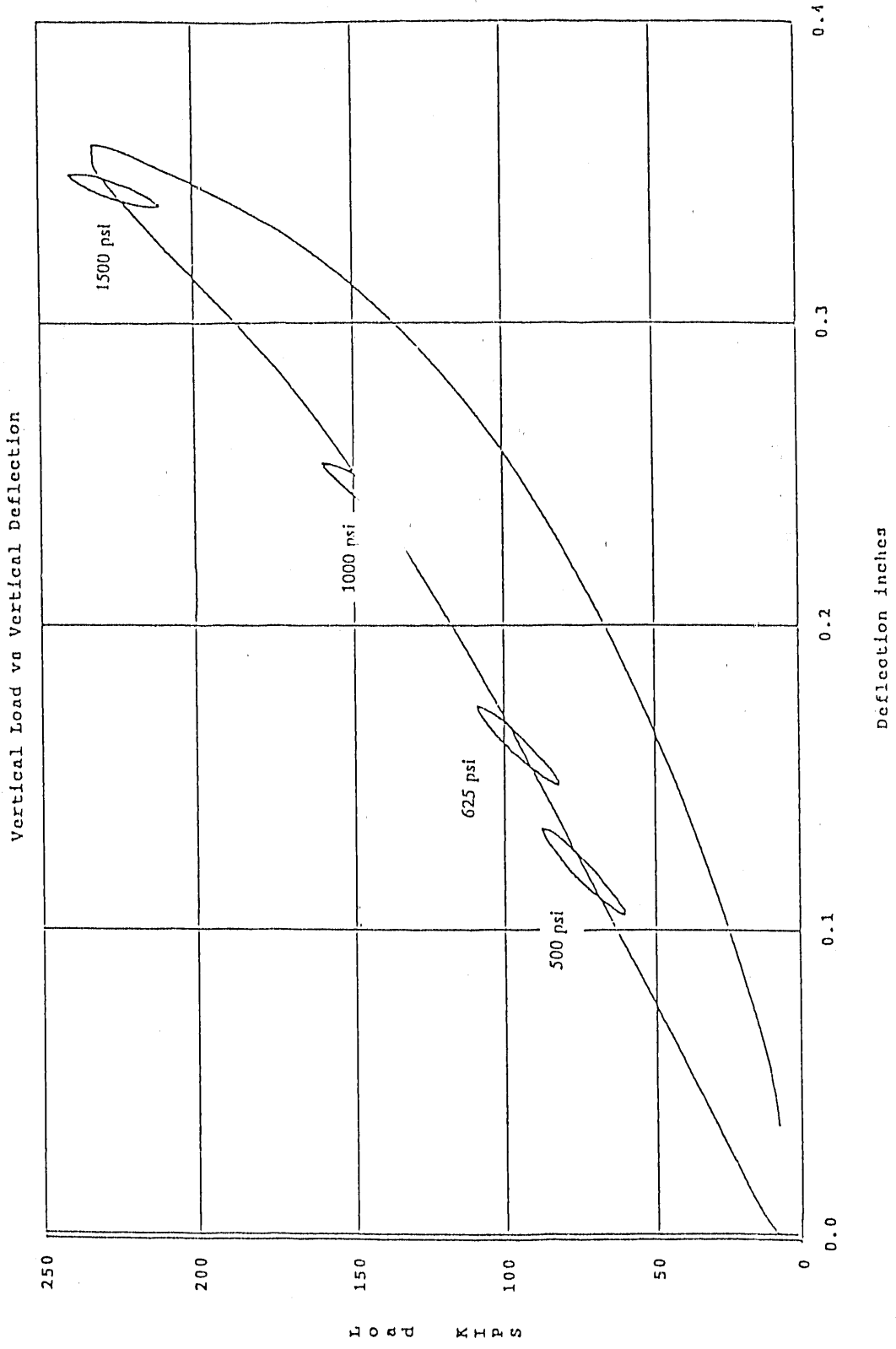


Fig. 9. Superimposition of Cyclic Vertical Tests on Monotonic Vertical Compression Test - for Low Shear Modulus Bearings



Fig. 10. Bearing Appearance at 200% Strain

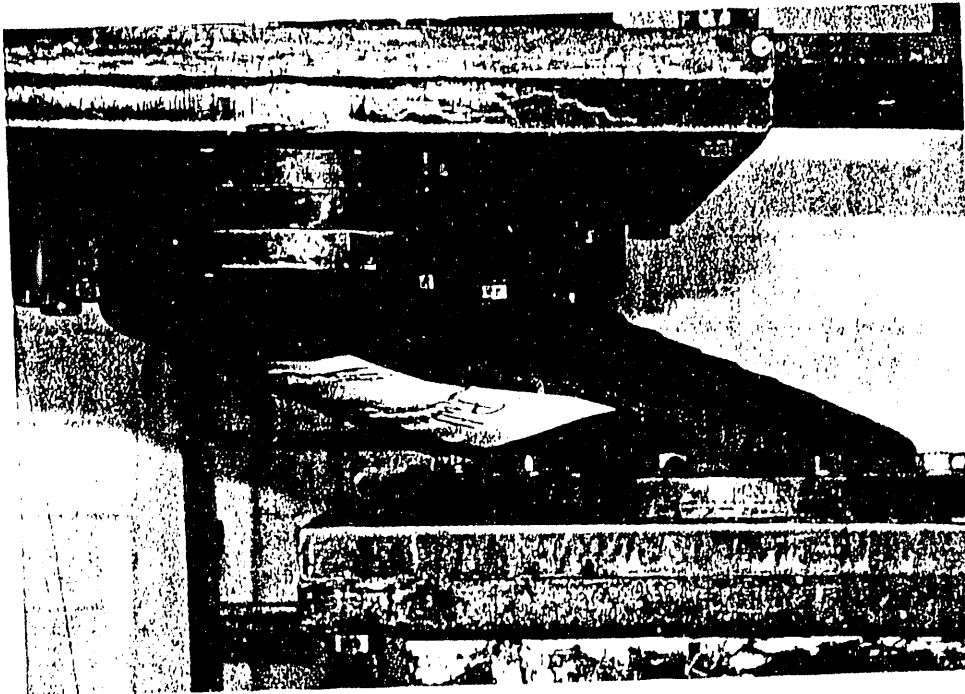


Fig. 11. Bearing Appearance at 300% Strain

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