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Static Tests of One-Third Scale Impact Limiters

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U.S. DEPARTMENT OF COMMERCE
Robert Mosbacher, Secretary

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Raymond G. Kammer, Acting Director

ABSTRACT

The National Institute of Standards and Technology carried out four tests of one-third scale impact limiters for Transnuclear, Inc. The impact limiters were tested under static load in a 12-million pound capacity universal testing machine. Energy absorbed by the impact limiters, as indicated by the area under the load-deformation curve, was computed and compared with the required value which was specified for each specimen by Transnuclear, Inc. The testing was terminated when the absorbed energy value exceeded the required value.

Keywords: energy absorption; impact limiters; static load tests.

ACKNOWLEDGEMENTS

The authors would like to extend special appreciation to Mr. Mike Williams, Larry Cass, and Don Nolan of Transnuclear, Inc. for their participation and guidance in testing the impact limiters and for providing valuable comments for this report.

We also wish to thank Mr. Frank Rankin, Eric Anderson, and Steve Johnson of the Center for Building Technology whose hard work made these tests possible.

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1. INTRODUCTION

Impact limiters are devices that are attached to the ends of cylindrical casks, used for the transportation of spent nuclear fuel, to absorb accidental impact. The National Institute of Standards and Technology (NIST) conducted four static load tests of one-third scale impact limiters for Transnuclear, Inc. (TN), Hawthorne, New York (Transnuclear Project No. 3024). The impact limiters were loaded to simulate impact at various angles with respect to the axis of the cylindrical cask. Prior to testing, NIST prepared and submitted for TN's approval a quality assurance (QA) plan and a test procedure. Throughout the testing, the QA plan and the test procedure were followed. The tests were conducted in accordance with TN Specification 3024-6, Rev. 1, with the following exceptions per instructions from TN. A cold test was not run and instrumented bolts were not used. This report presents the results of the tests.

All test specimens, test fixtures and the information necessary to prepare the test set-up were supplied by TN. NIST made necessary modifications to the test fixtures in order to fasten them to the test bed. All tests were performed by NIST personnel, and were observed by TN's representatives.

Section 2 describes in detail the test specimens and test set-up. Section 3 presents instrumentation used to record the test data. Section 4 describes the procedure that was followed for each test. Section 5 presents the results of the tests. Supporting documents for the tests and other relevant data are presented in Appendices.

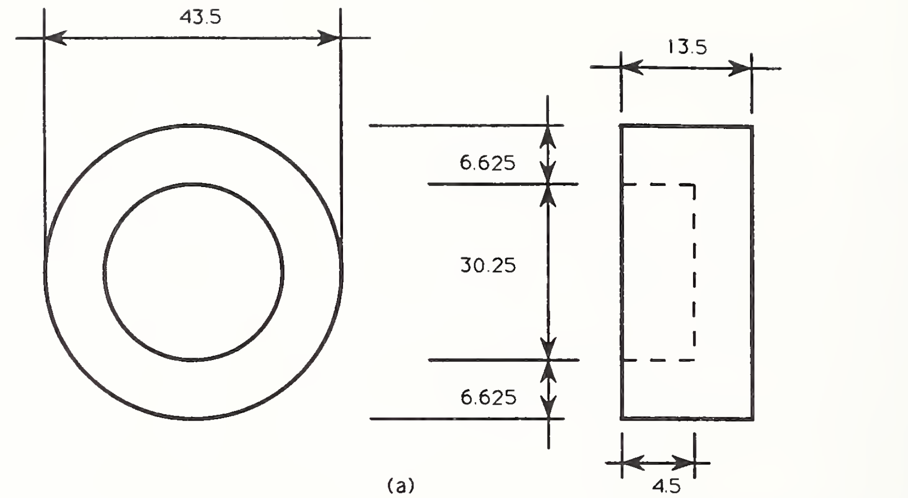
2. SPECIMEN DESCRIPTION AND TEST SET-UP

2.1 Specimen Description

The one-third scale impact limiters consisted of a radially stiffened steel housing with wood blocks inserted between stiffeners. All specimens were circular in shape; one was a front impact limiter and two were rear impact limiters. The overall approximate dimensions of the front and rear specimens are shown in Figure 2.1.

The four tests were designated as S-1, S-2, S-3 and S-4. The specimens were positioned so that the front face of the specimen was oriented at an angle of 0°, 30°, 60°, and 90° with respect to the direction of loading. Figure 2.2 illustrates these four orientations. The designation of each test is also shown in the figure.

For tests S-1 (30°) and S-3 (90°), new specimens were tested, a rear specimen for S-1 (30°) and a front specimen for S-3 (90°). For test S-2 (60°), the undamaged side of the rear specimen used for test S-1 was tested. For test S-4 (0°), the undamaged side of a rear specimen previously used for a vertical drop test was tested. The vertical drop test was carried out by Sandia National Laboratories. Thus, three specimens were used for four tests.



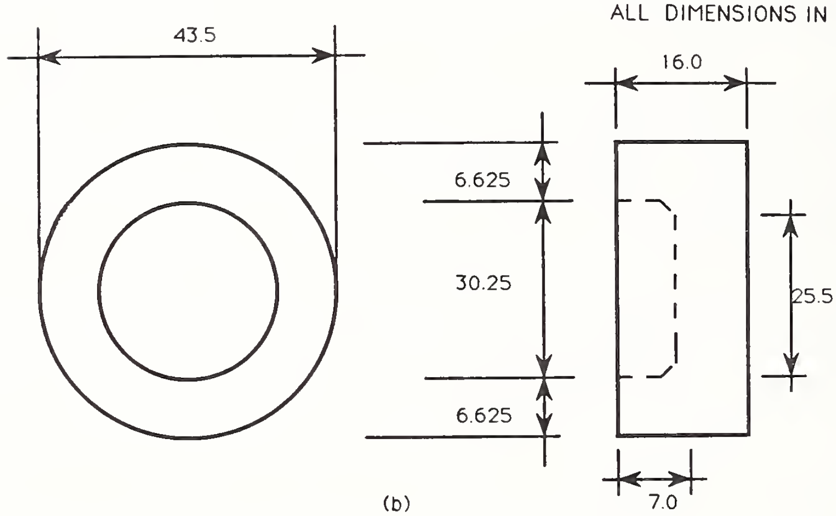


Figure 2.1 Impact Limiter Specimens
(a) Front Specimen
(b) Rear Specimen

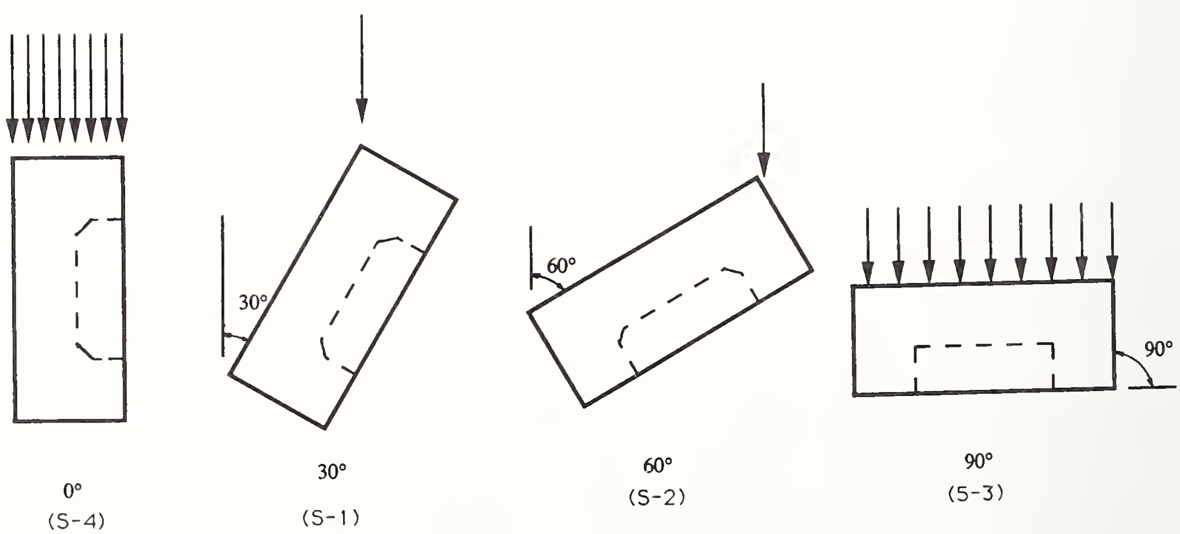


Figure 2.2 Direction of Loading on Test Specimens

2.2 Test Set-up

All parts necessary to assemble the test set-up including the test fixtures, the ring adapters, and bolts were supplied by TN. A steel pedestal to which the test fixture was fastened was provided by NIST.

For each test, the test fixture was fastened to a circular steel pedestal using four 1-inch (2.54 cm) diameter, A325 bolts. The pedestal was 12 inches (30.5 cm) thick and 84 inches (213 cm) in diameter. A thin layer of fast-setting plaster was placed between the test fixture and the pedestal prior to bolting to ensure accurate angular orientation of the test fixture. The inclination angles of the test fixture were checked by an inclinometer. In all cases, the inclination was achieved within 1° of deviation from the specified angle.

A ring adapter, provided by TN, was fastened to the test fixture using 5/8-inch (16 mm) diameter cap screws. Each cap screw was torqued to the specified value of 30 ft-lb using a calibrated torque wrench. A test fixture with and without the adapter are shown in Figure 2.3. Except for test S-3, all test specimens were mounted on the adapter using four 3/4-inch (19 mm) diameter cap screws which were torqued to 50 ft-lb each. This was a change to the original requirement which called for using four 5/8-inch diameter cap screws. To adapt the 3/4-inch diameter cap screws, both the test specimens and the fixtures were modified according to the drawings provided by Transnuclear. For test S-3, the specimen was not fastened to the adapter.

The specimen was placed directly under the 48-in (122 cm) dia. circular steel platen of the NIST 12 million lb (53,380-kN) universal testing machine (UTM). The initial contact point of the specimen with the platen was specified by TN. Figures 2.4, 2.5, 2.6, and 2.7 show the detailed test set-up for tests S-1, S-2, S-3, and S-4, respectively. A calibration report of the NIST 12 million pound UTM is given in Appendix F.

3. INSTRUMENTATION

Vertical deformation of the test specimens was measured using two string-potentiometers for tests S-1, S-2 and S-4, and two linear variable differential transformers (LVDTs) for test S-3. The string-potentiometers had a maximum stroke of 25 inches (63.5 cm) and LVDTs had a maximum stroke of 12 inches (30.5 cm). These instruments were placed between the platen of the testing machine and the pedestal which supported the test fixture. To measure any possible rotation of the platen relative to the pedestal, the instruments were positioned 180° apart on either side of the test specimen.

To measure possible movement of the test fixture relative to the pedestal, two LVDTs of 3-inch (7.62 cm) stroke were used to measure both the horizontal and vertical movements. The locations of the string-potentiometers and LVDTs are shown in Figures 2.4, 2.5, 2.6 and 2.7.

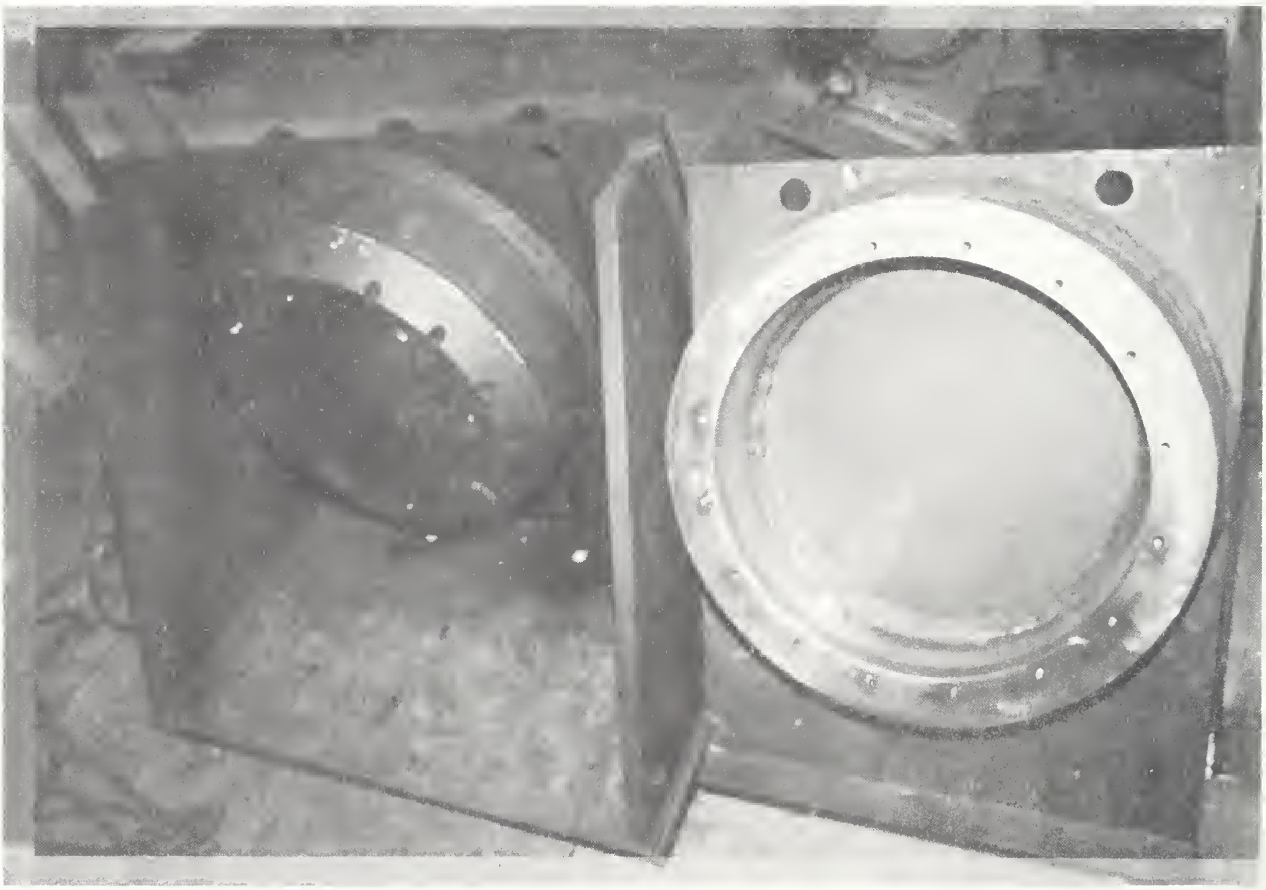


Figure 2.3 Test Fixture with Adapter for Test S-4 (left) and Test Fixture without Adapter for Test S-1 (right)

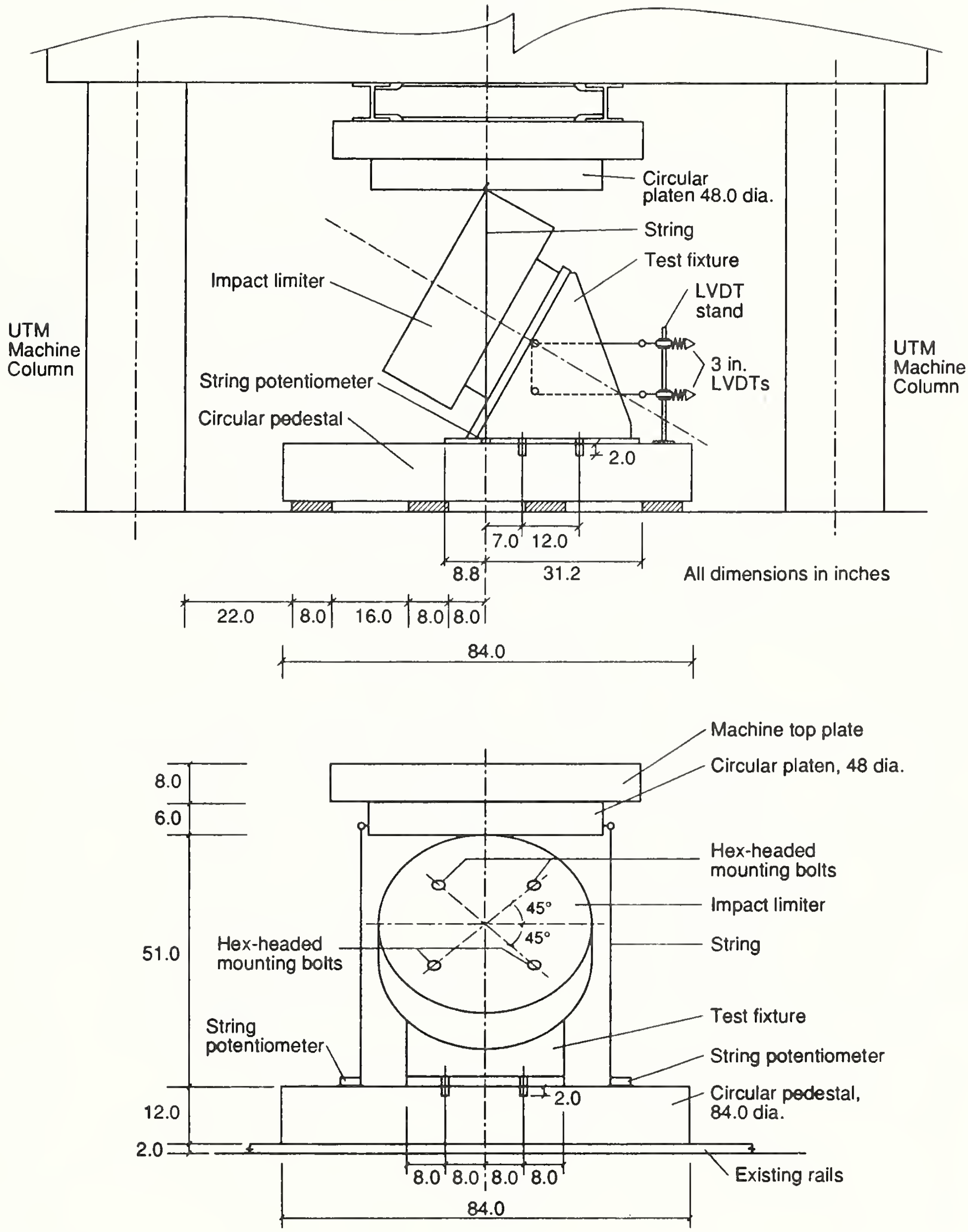
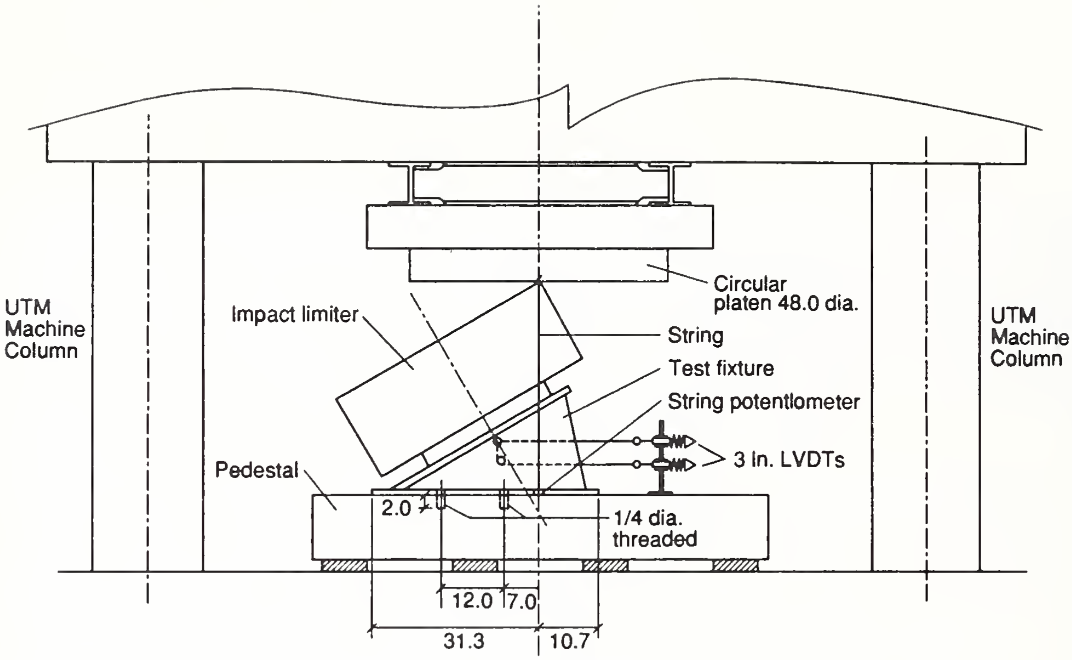


Figure 2.4 Test S-1



All dimensions in inches

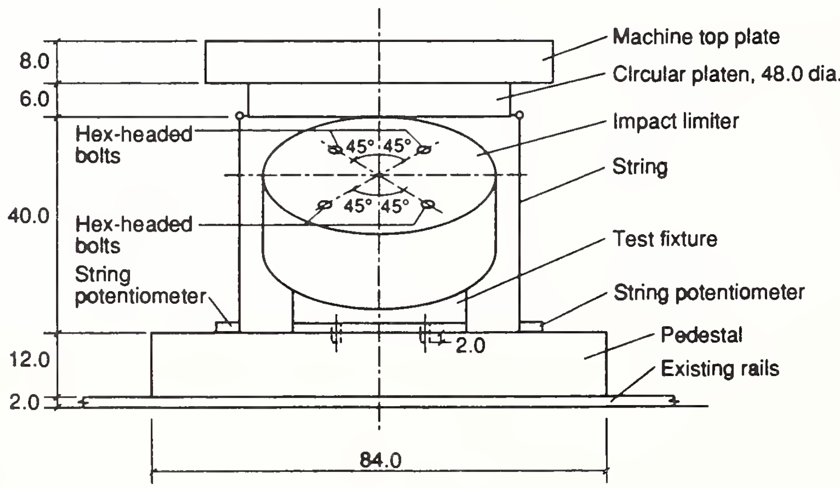


Figure 2.5 Test S-2

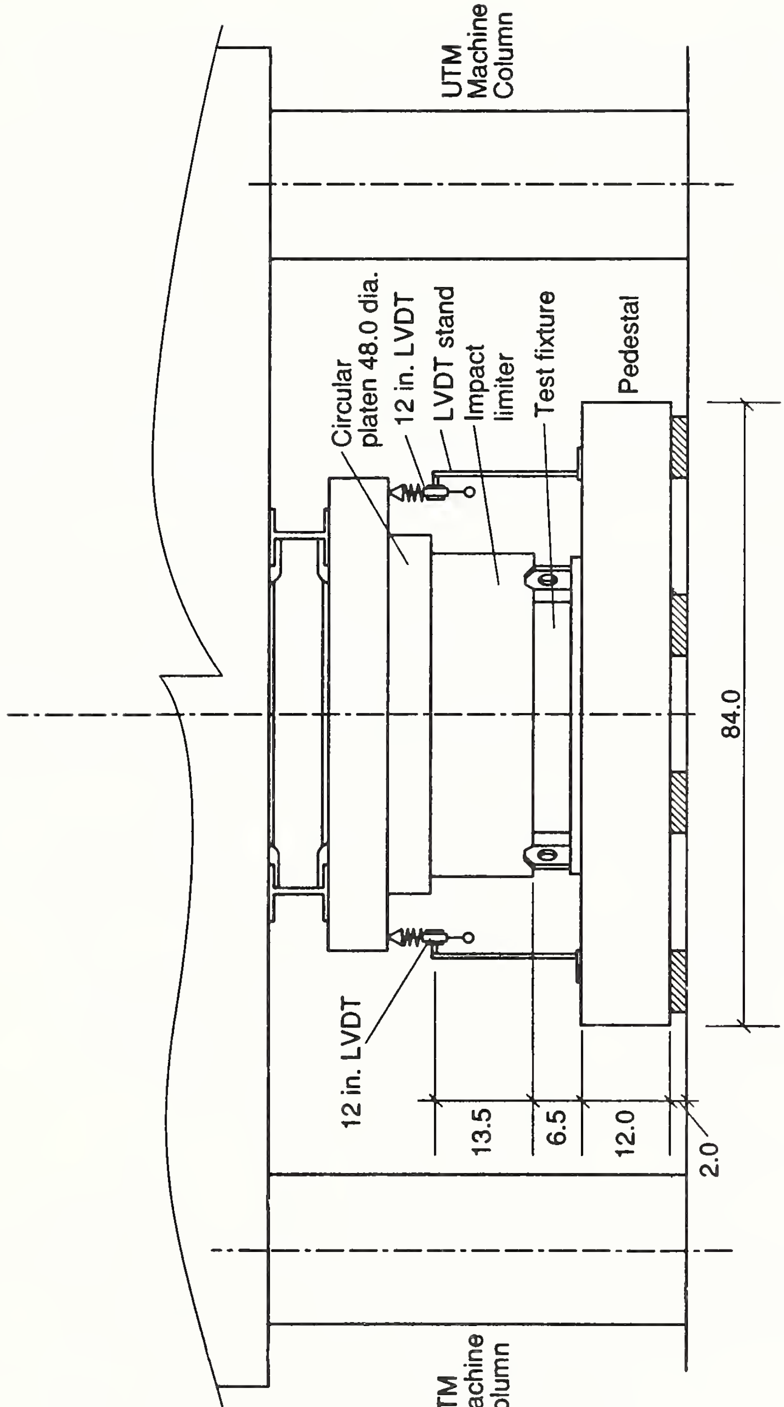


Figure 2.6 Test S-3

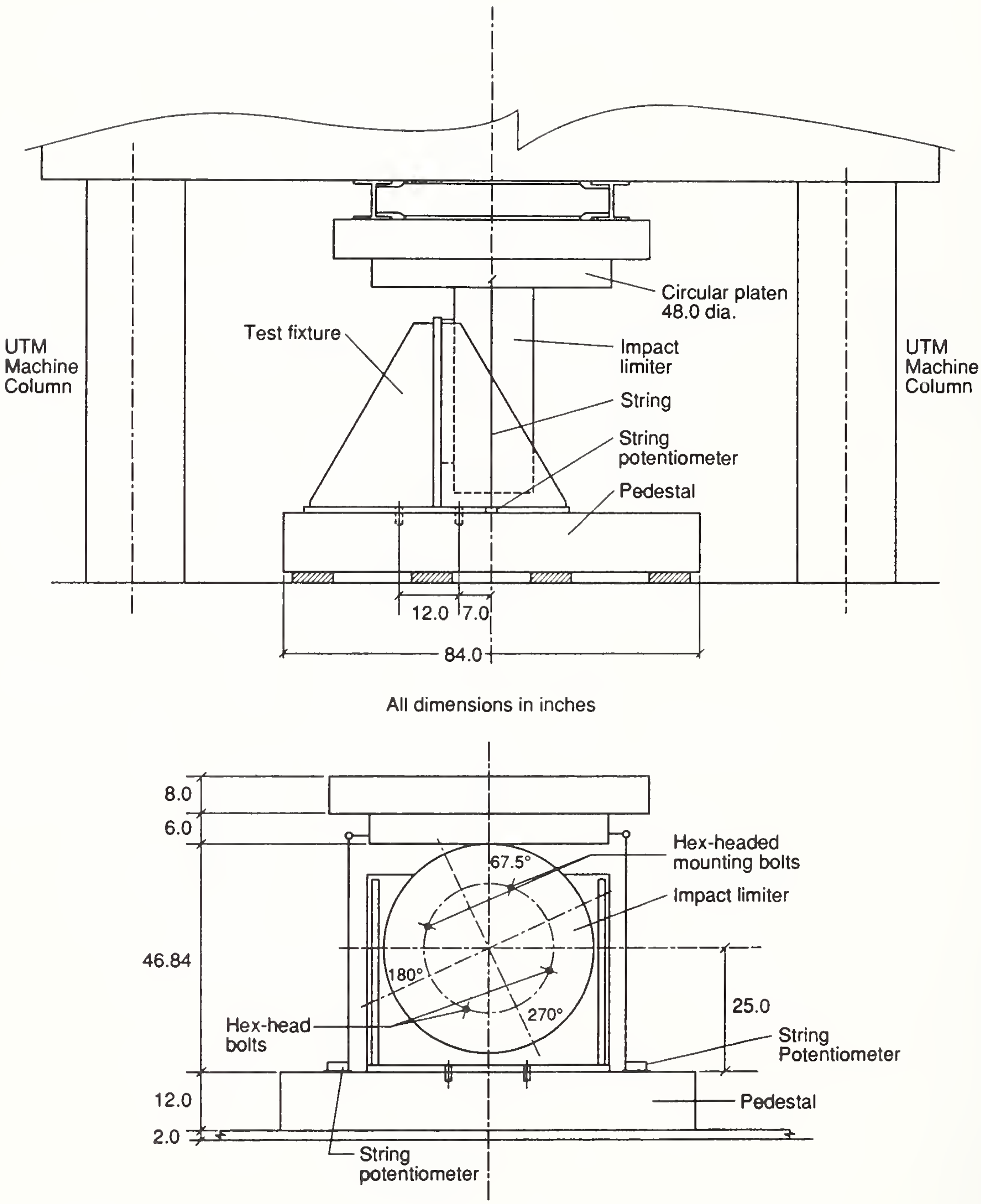


Figure 2.7 Test S-4

Electrical signals from the string potentiometers and LVDTs were recorded continuously during the test at a scanning rate of 8 data samples per second. These signals were also used to plot the load-deformation curves on two separate X-Y recorders. One of the load-deformation plots was used to monitor the amount of energy absorbed in the specimen.

All string-potentiometers and LVDTs were calibrated prior to testing. The calibration curves are given in Appendix E.

4. TEST PROCEDURE

After positioning the test specimen on the pedestal and installing the required instrumentation, a trial run of the data acquisition system was made prior to loading to ensure that all instruments and recording systems were functioning properly. Photographs of the test set-up were also taken prior to loading the specimen.

Load was then applied continuously at a constant deformation rate of approximately 1.5 inches (3.8 cm) per minute. Testing was terminated when the energy absorbed in the specimen, as calculated by the area under the load-deformation curve, exceeded the required value specified by TN. The test energy absorption specified by TN for each test is listed below. The test energy was specified to be at least 110% of the energy required.

Test	Specified Absorbed Energy (in-lbs x 10^6)
S - 1	3.19
S - 2	3.58
S - 3	3.63
S - 4	2.08

The load was applied continuously until the end of testing for tests S-1, S-3, and S-4. For test S-2, however, the loading was temporarily discontinued. The load was removed from the specimen at 520 kips (2,313 KN) when it was noted that the loading platen was not large enough to cover the enlarging deformed area of the specimen under increasing load. A 2-inch (5.1 cm)-thick steel plate was inserted between the specimen and the platen, and the testing was resumed.

After unloading, the specimen was removed from the test fixture for visual inspection, and damage was photographed.

5. TEST RESULTS

Test S - 1: 30° Test

Figures 5.1 and 5.2 show the load vs. deformation curve and the load vs. absorbed energy curve for test S-1, respectively. Loading was stopped at 1,678 kips (7,464 kN) with corresponding deformation of 10.6 inches (27 cm). The computed total absorbed energy at this load was 4.105×10^6 in-lbs (463,802 joule). The required energy absorption was reached at 1,080 kips (4,804 kN) with a corresponding deformation of 10.1 inches (25.7 cm). The 3-in stroke LVDTs used to monitor the vertical and horizontal displacements of the test fixture showed no movement.

Figures 5.3a and 5.3b show the front and side views, respectively, of the test S-1 specimen before testing. Figure 5.3c shows the deformed specimen after testing. Figure 5.3d shows local damage on the bottom and inner surfaces of the specimen.

Test S - 2: 60° Test

Figures 5.4 and 5.5 show the load vs. deformation curve and the load vs. absorbed energy curve, respectively, for test S-2. Photographs taken before and after testing are shown in Figures 5.6a through 5.6e. As can be seen in Figures 5.6, the undamaged side of the specimen used for test S-1 was retested. The maximum applied load was 689 kips (3,065 kN) with a corresponding deformation of 10.48 inches (26.6 cm). The total absorbed energy at the maximum applied load was 3.3×10^6 in-lbs (372,849 joule) which was less than the required absorbed energy value of 3.6×10^6 in-lbs (406,745 joule). Testing was stopped before reaching this required absorbed energy value because the bottom of the specimen came in contact with the test fixture (see Figure 5.6c). This figure also shows the 2-inch (5.08-cm) steel plate which was inserted between the specimen and the platen to cover the entire deformed surface at the top of the specimen. The damaged inner surface of the specimen is shown in Figure 5.6e.

Test S - 3: 90° Test

Figures 5.7 and 5.8 show the load vs. deformation curve and the load vs. absorbed energy curve, respectively, for test S-3. Photographs taken before and after testing are shown in Figures 5.9a through 5.9d. The maximum applied load, which was also the ultimate load, was 985 kips (4,382 kN) with a corresponding deformation of 1.02 inches (2.59 cm). Because the specimen was tested in the horizontal position, a large surface area was in contact with the loading platen. Thus the vertical deformation was small. Because the specimen did not reach the required absorbed energy level of 3.63×10^6 in-lbs (410,135 joule) at the ultimate load, loading was continued. The absorbed energy of 3.905×10^6 in-lbs (441,206 joule) was attained when the specimen deformed 5.42 inches (13.8 cm) and testing was stopped at this point.

Test S - 4: 0° Test

The specimen used for test S-4 had been used in a free-fall drop test. As a result, part of the specimen was deformed. The specimen was positioned in the test fixture such that the undamaged part was in contact with the platen, see Figure 5.12a. Figures 5.10 and 5.11 show the load vs. deformation curve and the load vs. absorbed energy curve, respectively. Photographs taken before and after testing are shown in Figures 5.12a through 5.12e. The maximum applied load was 793.4 kips (3,529 kN) with a corresponding deformation of 5.29 inches (13.4 cm). The absorbed energy at the maximum load was 2.5 x 10^6 in-lbs (282,462 joule) which was greater than the required absorbed energy value of 2.08 x 10^6 in-lbs (235,008 joule). This required absorbed energy value was reached at the vertical deformation of 4.87 inches (12.4 cm).

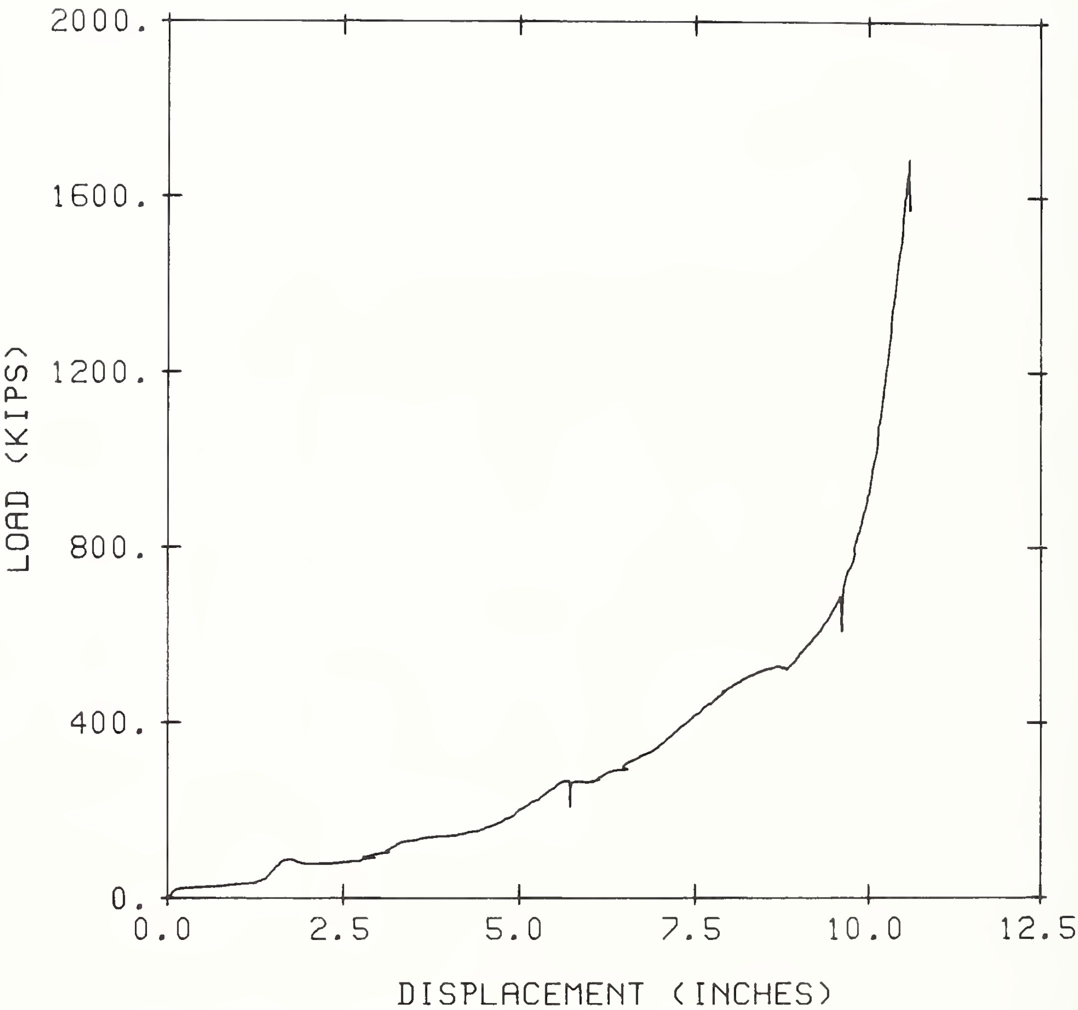


Figure 5.1 Load vs. Displacement for Test S-1

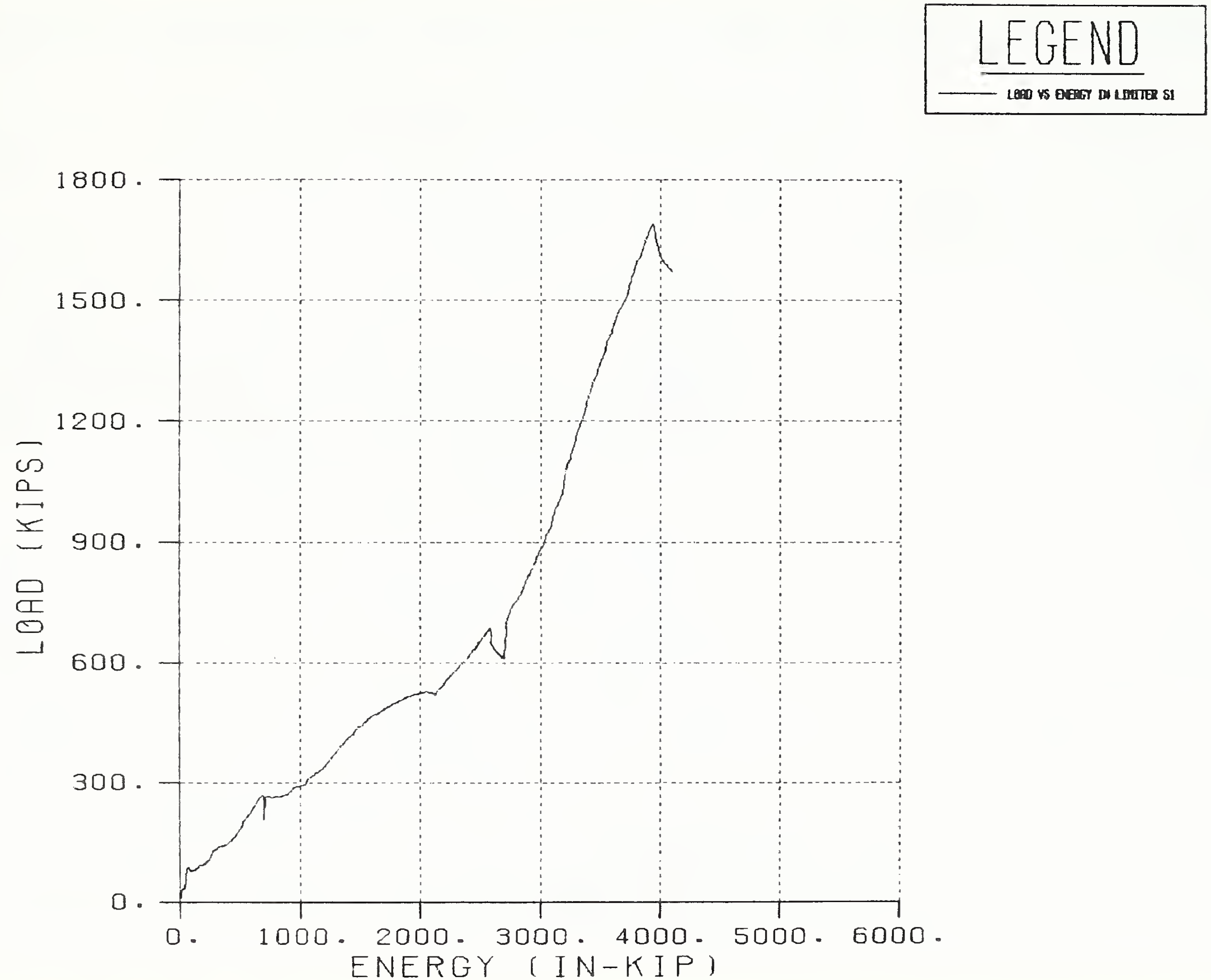


Figure 5.2 Load vs. Accumulated Energy for Test S-1.

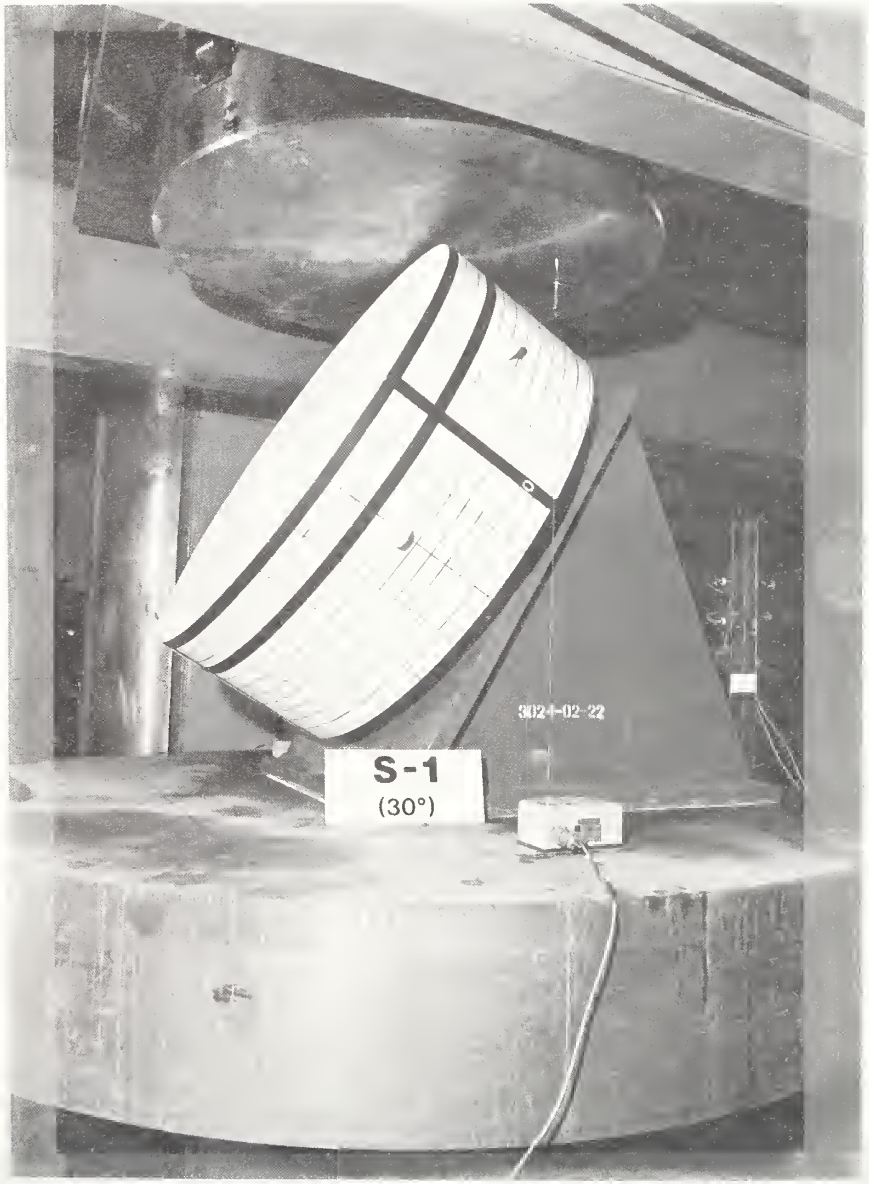


Figure 5.3 (a) Front View of Test S-1 before Test.

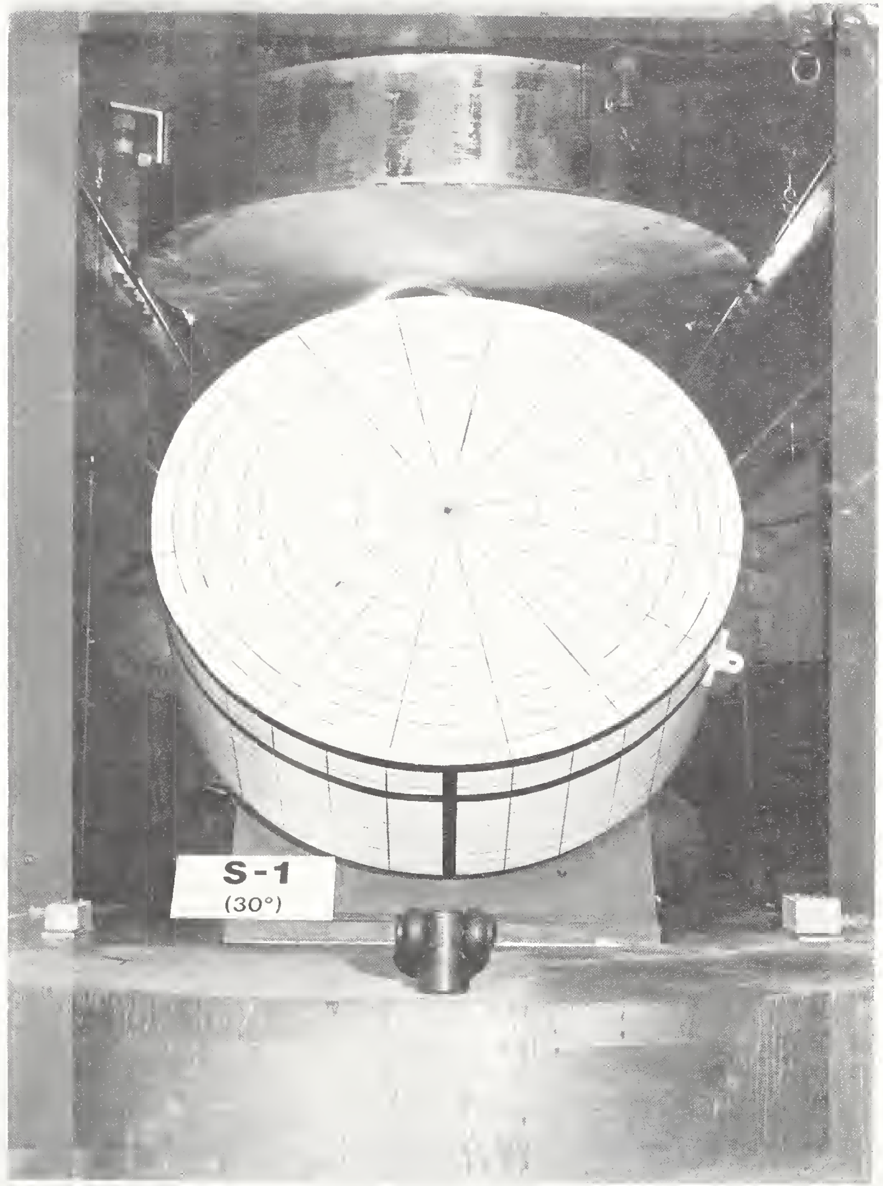


Figure 5.3 (b) Side View of Test S-1 before Test.

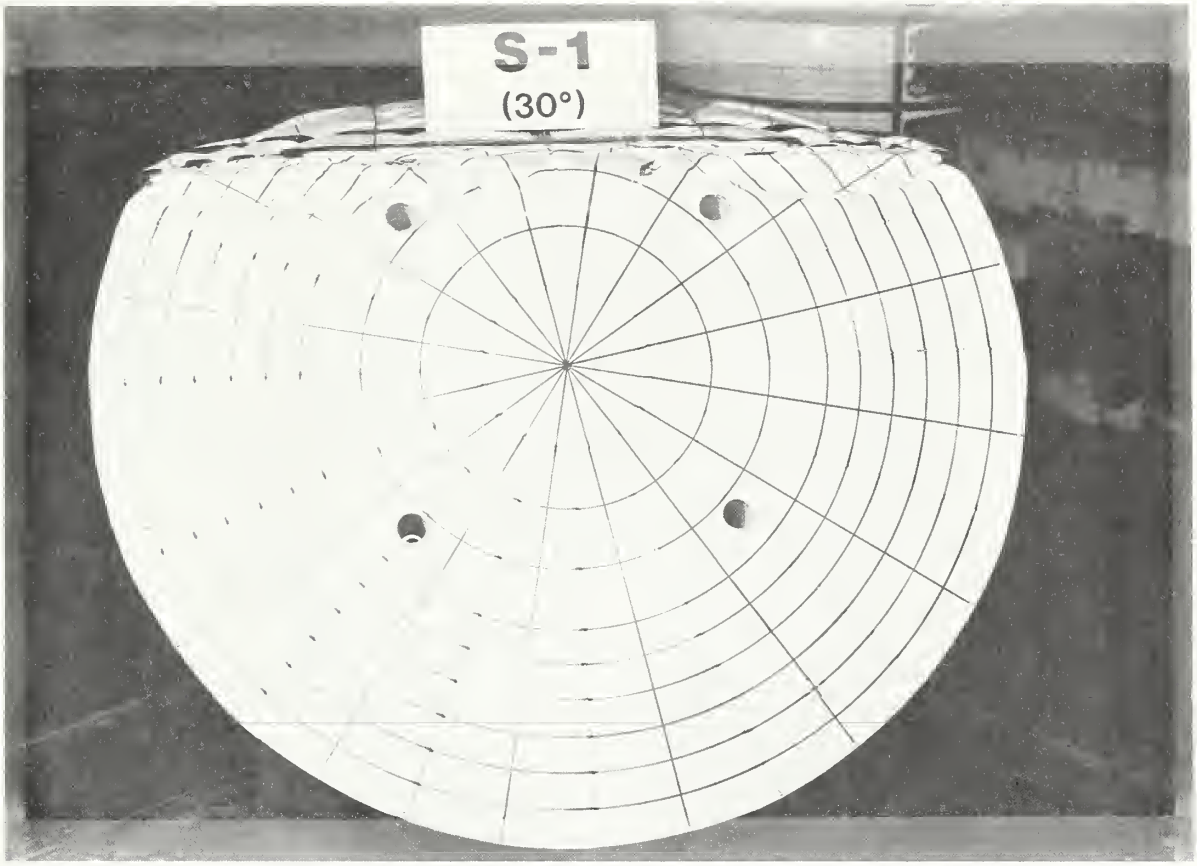


Figure 5.3 (c) Deformation of Impact Limiter in Test S-1 after Loading.

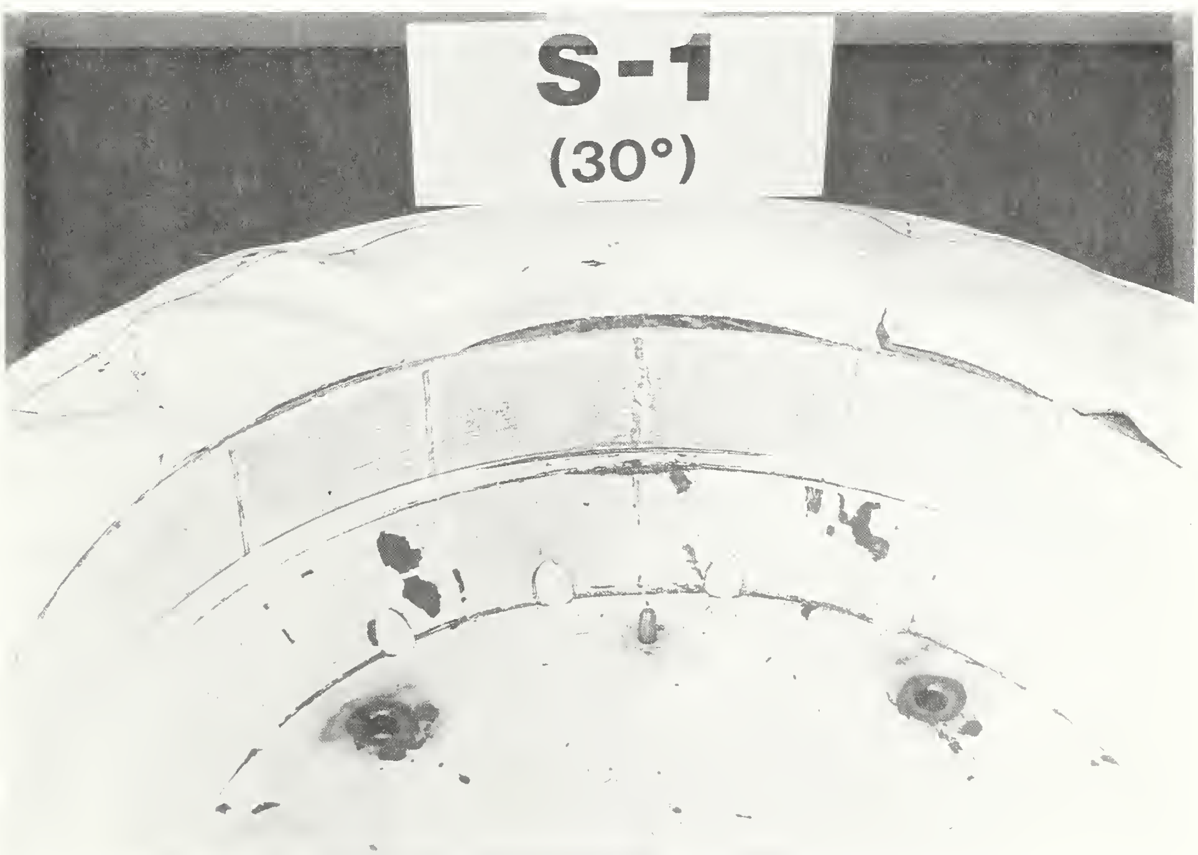


Figure 5.3 (d) Local Damages, Including Weld Fracture on the Inner Surface of S-1

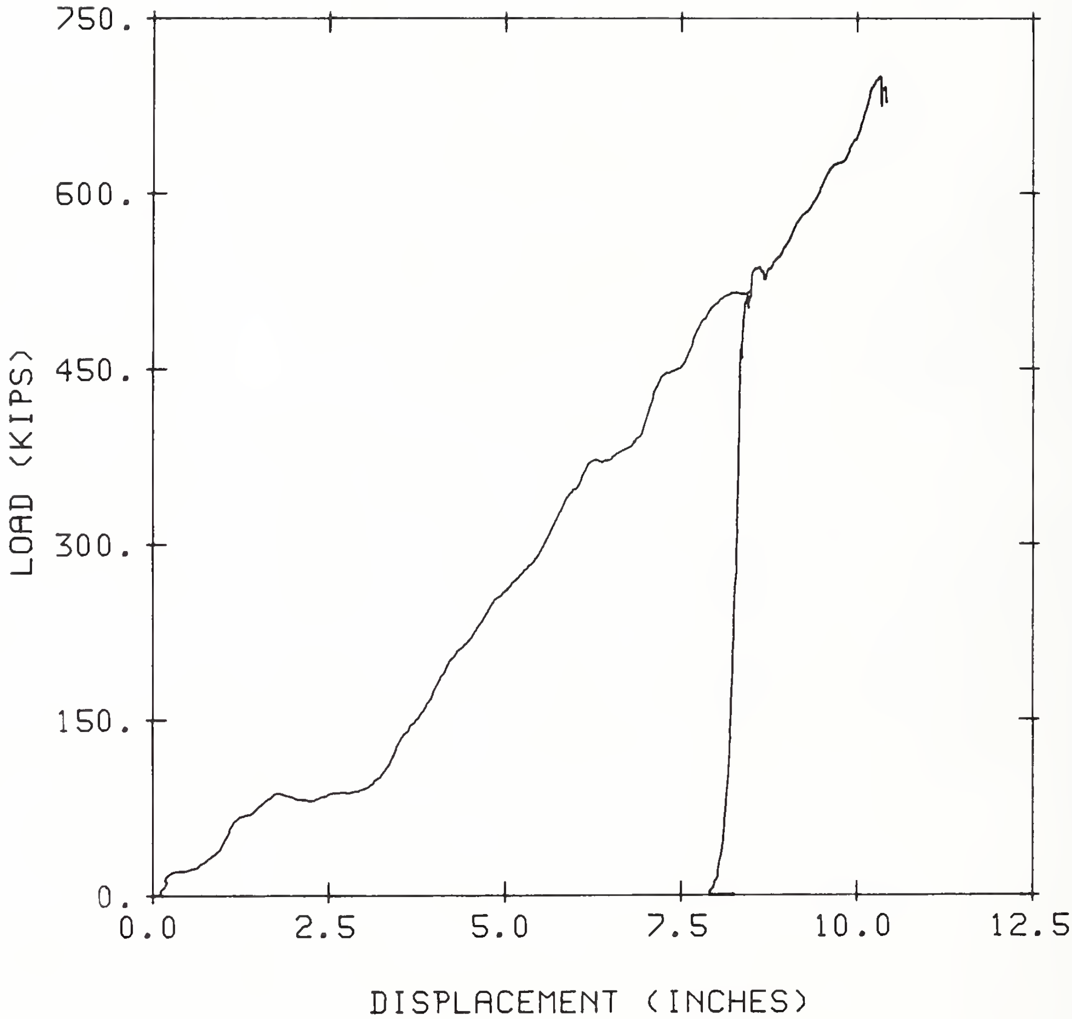


Figure 5.4 Load vs. Displacement for Test S-2

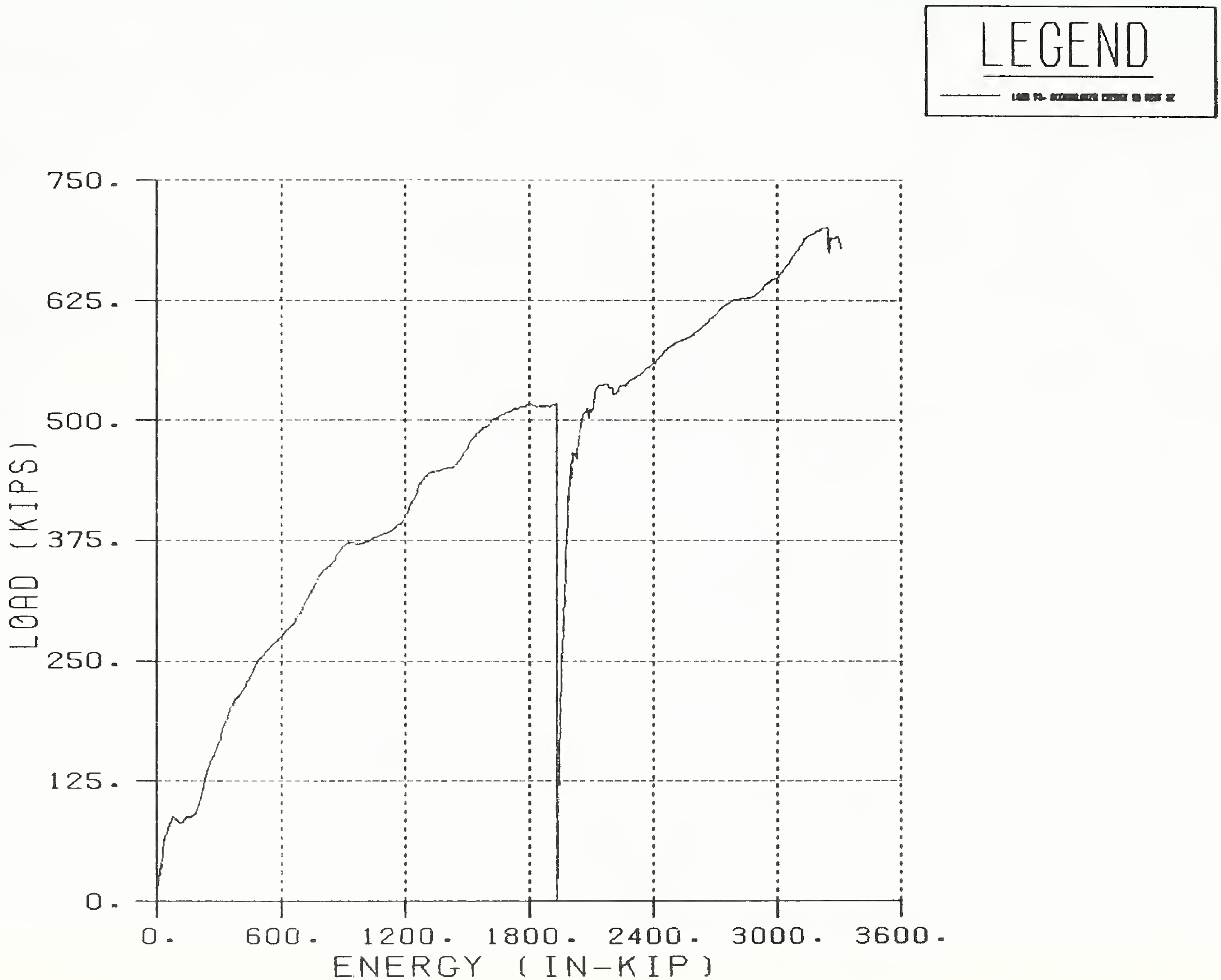


Figure 5.5 Load vs. Accumulated Energy for Test S-2.

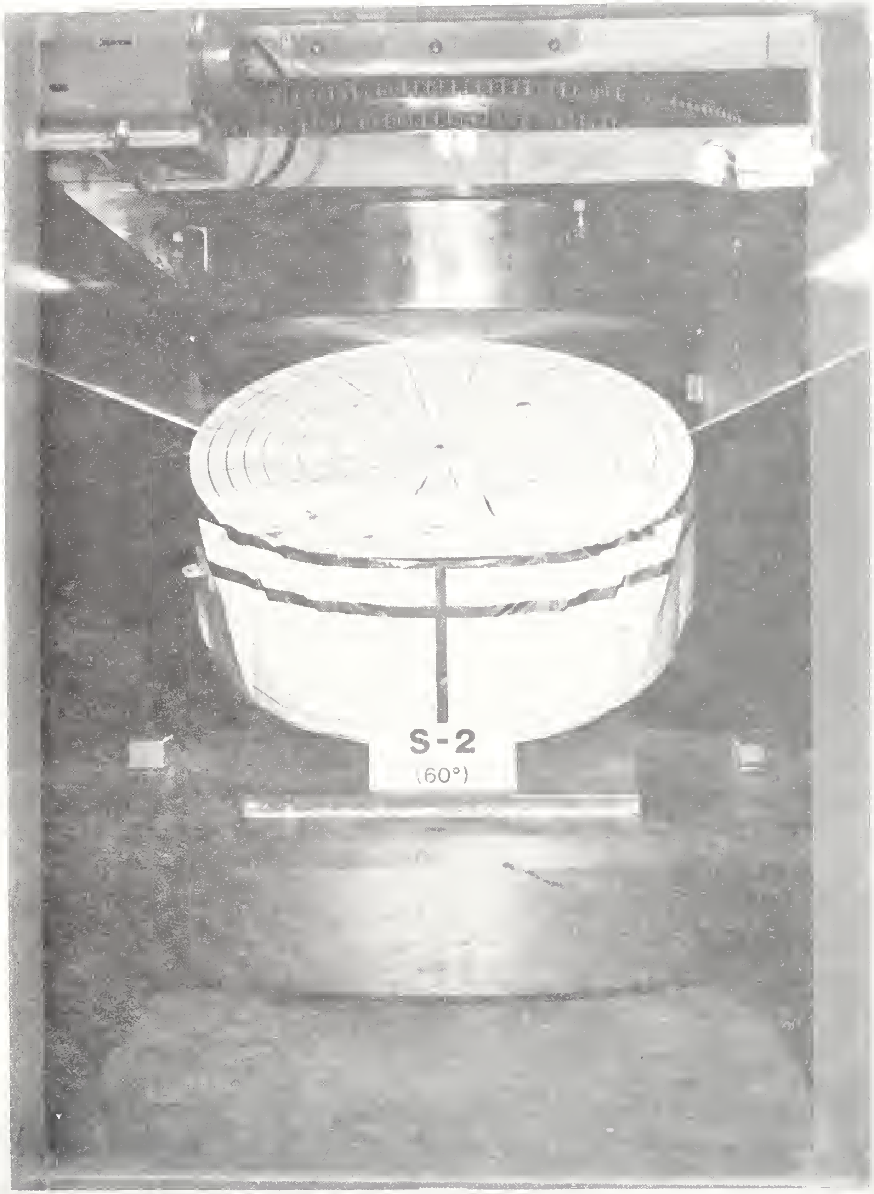


Figure 5.6 (a) Front View of Test S-2 before Test.

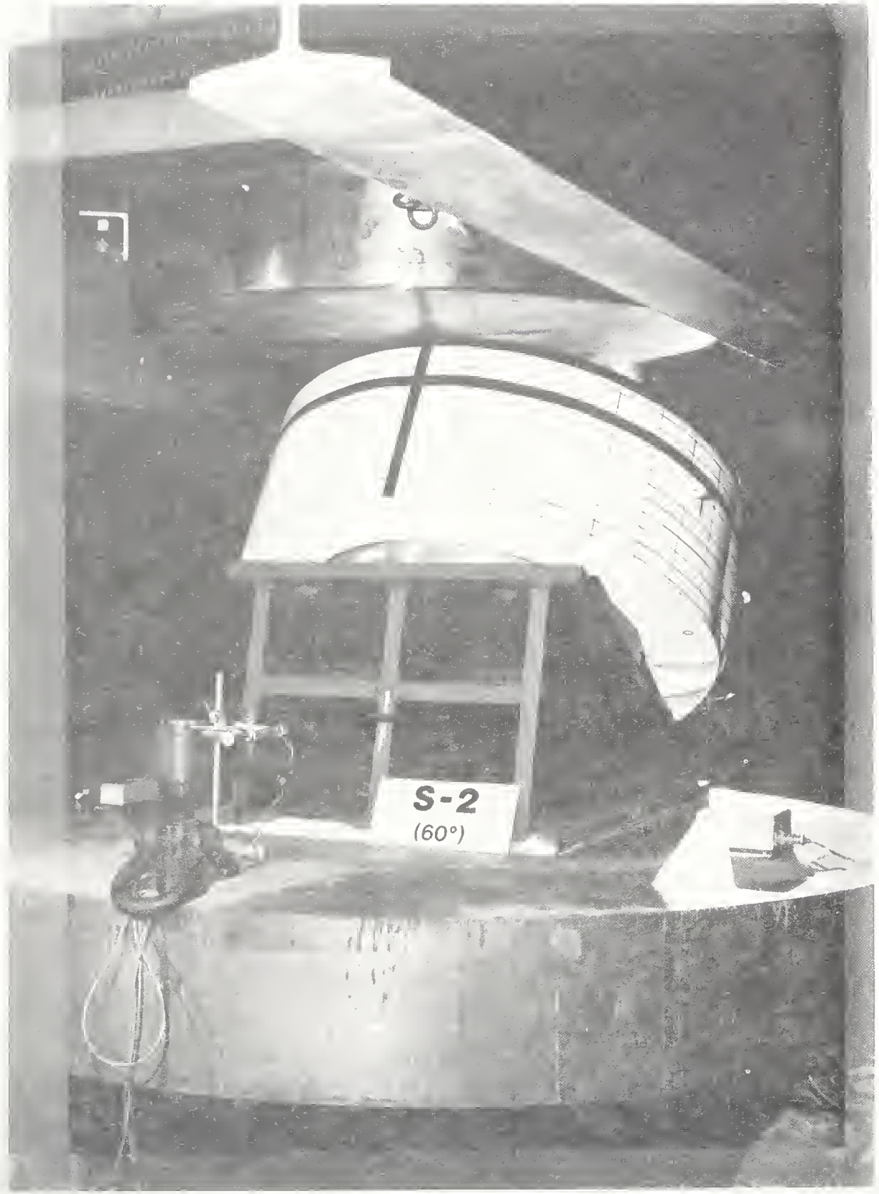


Figure 5.6 (b) Rear View of Test S-2 before Test

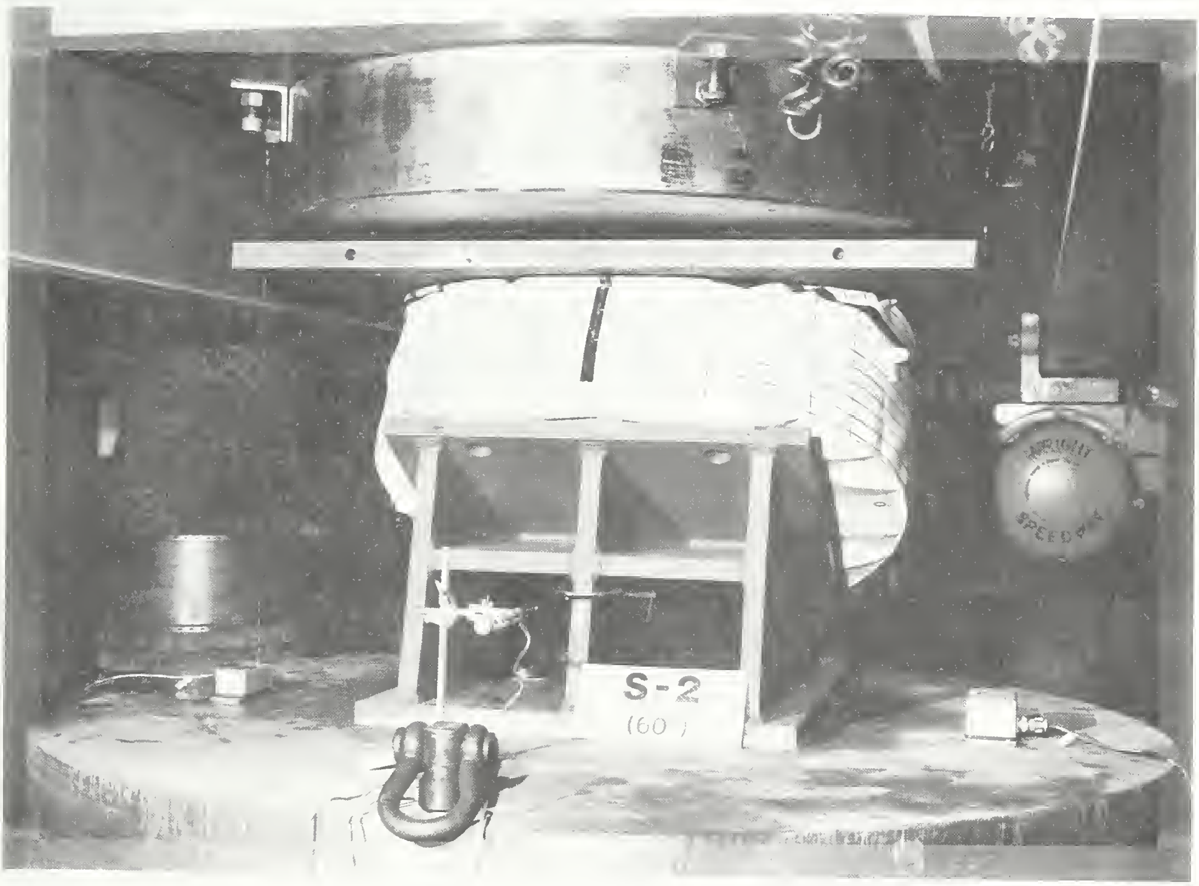


Figure 5.6 (c) Rear View of Test S-2 after Test

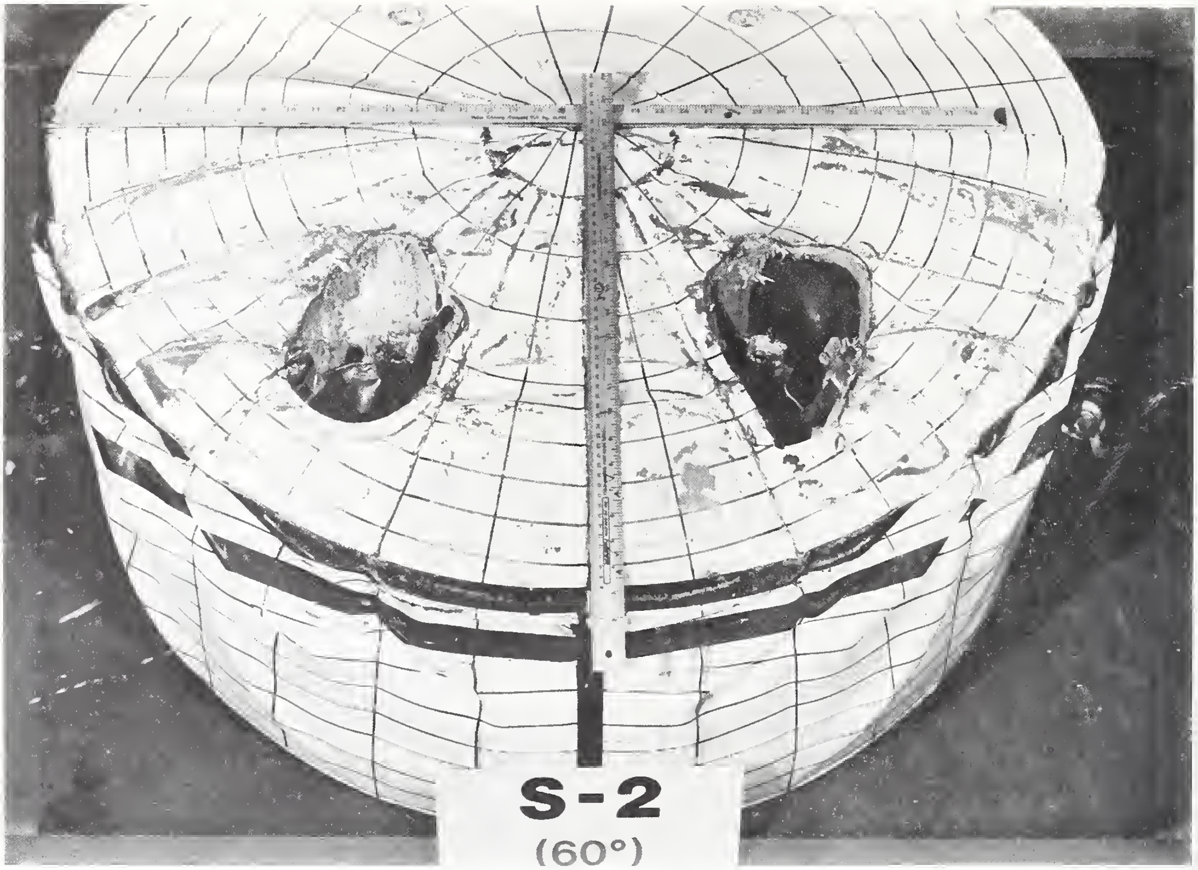


Figure 5.6 (d) Damaged Area of Impact Limiter in Test S-2.

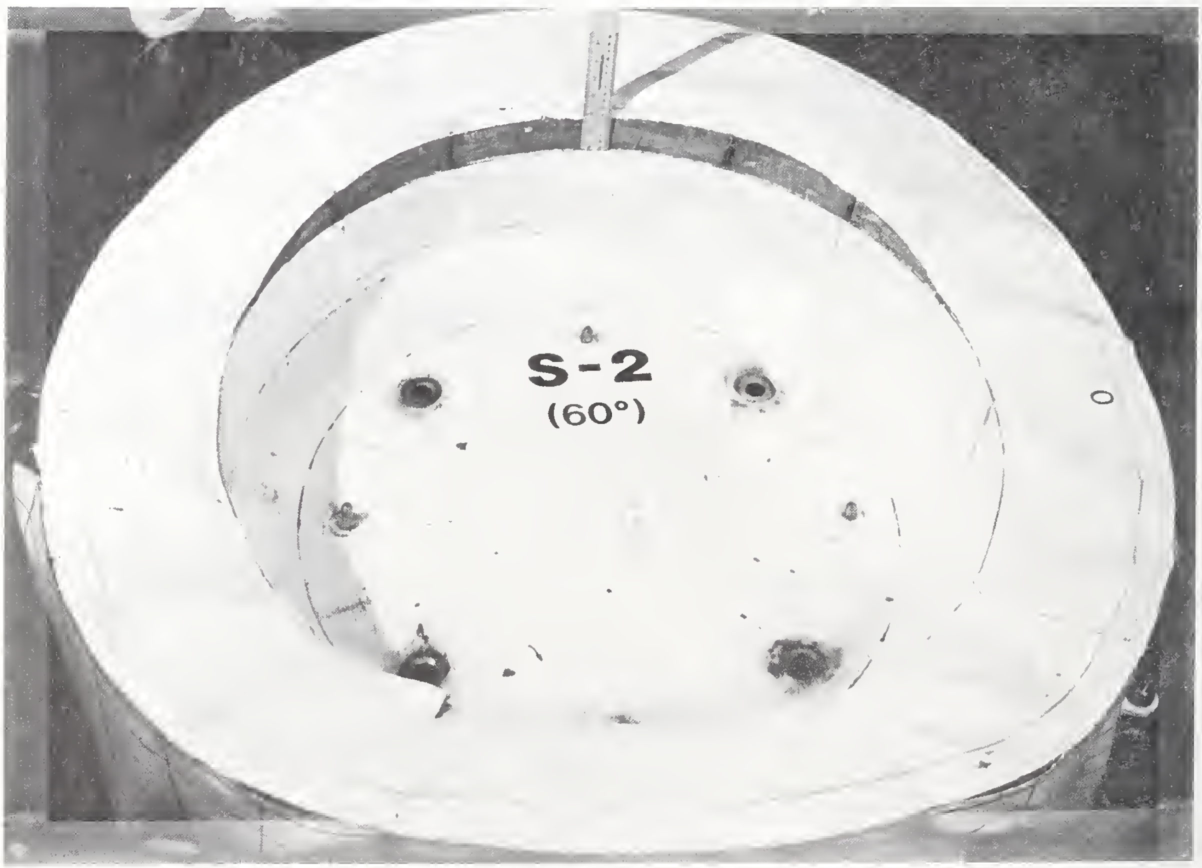


Figure 5.6 (e) Damages on Inner Surface of S-2.

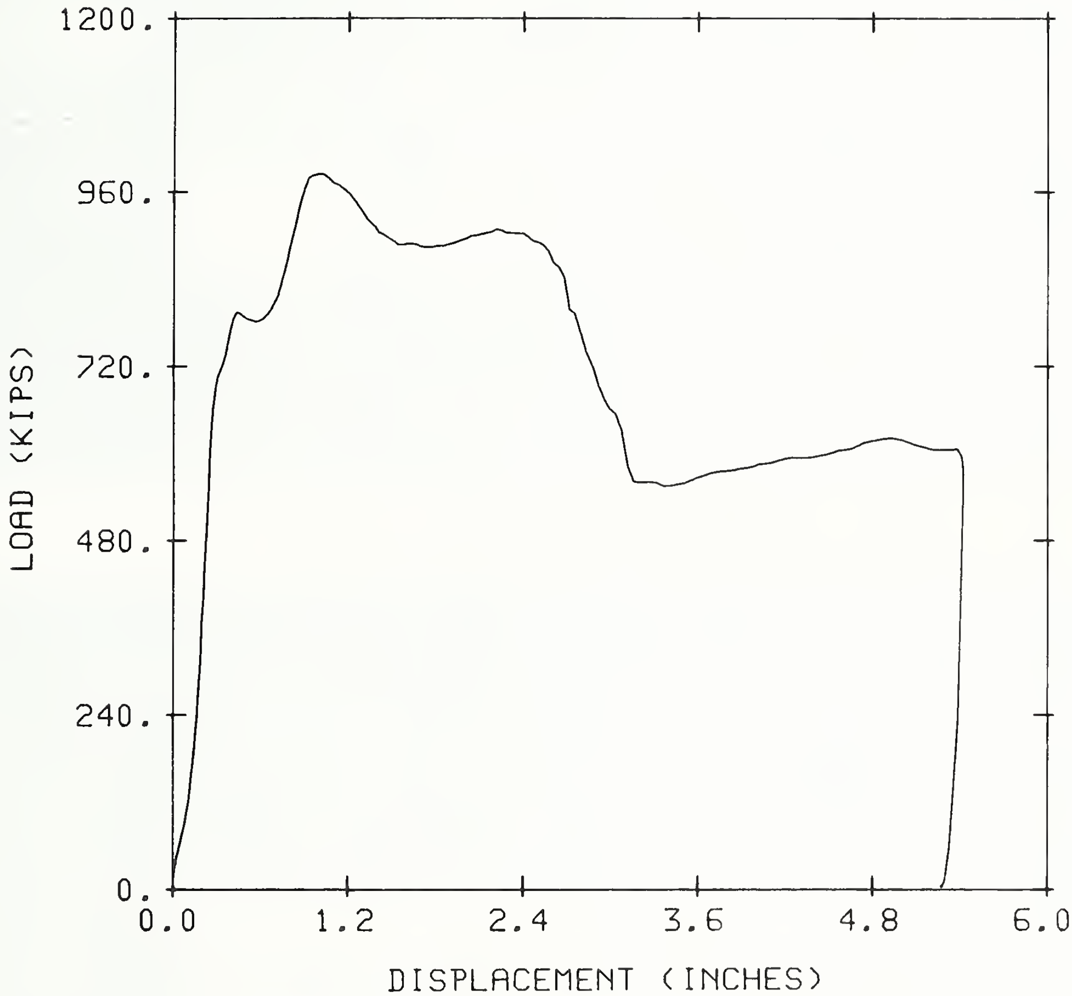


Figure 5.7 Load vs. Displacement for Test S-3

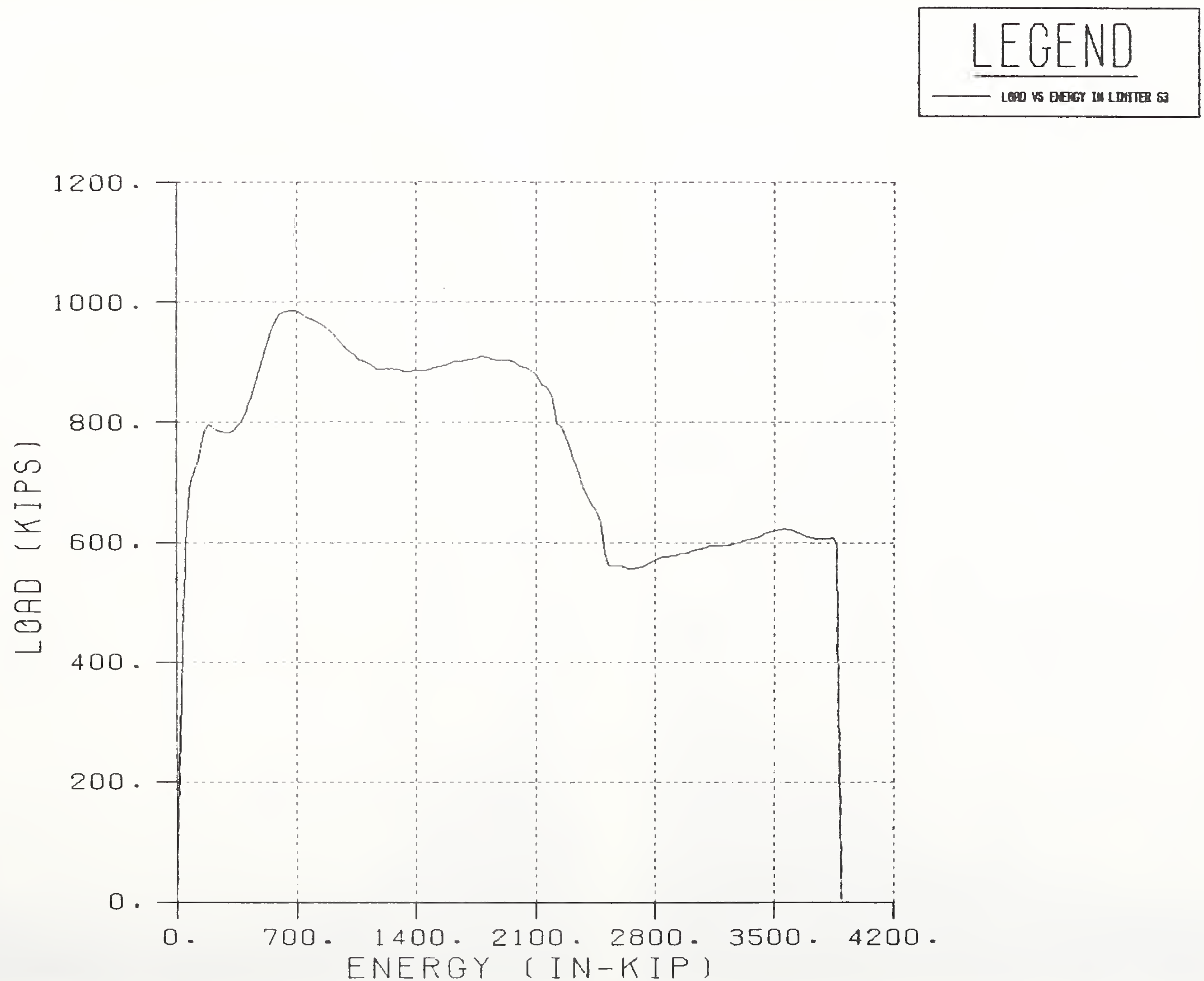


Figure 5.8 Load vs. Accumulated Energy for Test S-3.

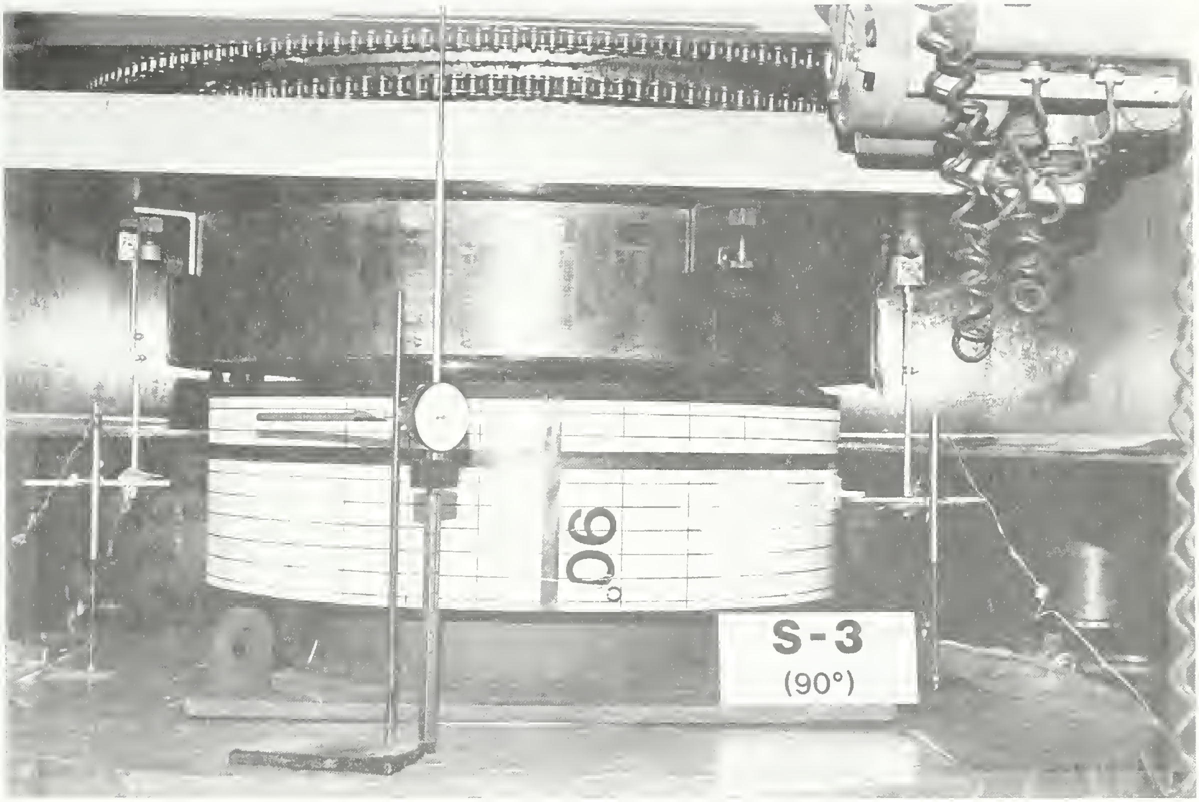


Figure 5.9 (a) Impact Limiter S-3 before Test.

Figure 5.9 (b) Impact Limiter S-3 after Test.

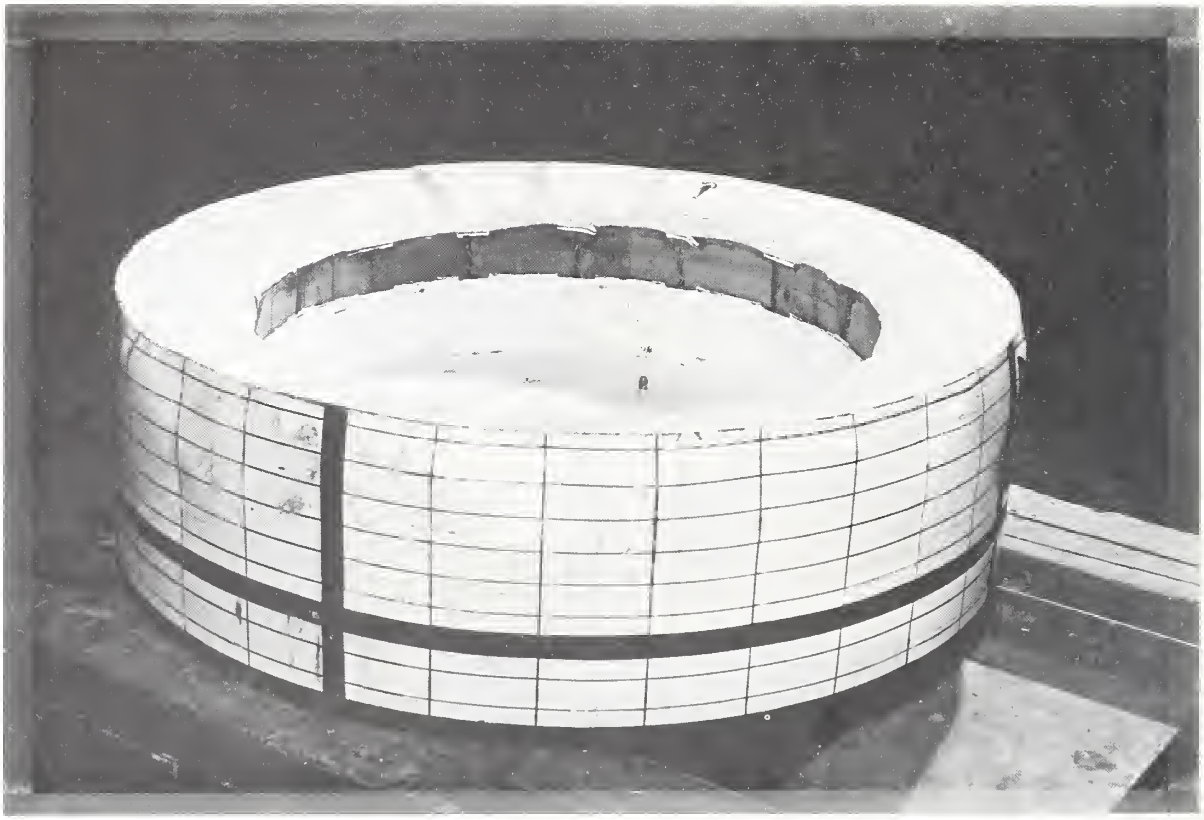


Figure 5.9 (c) Damages on Inner Surface of S-3

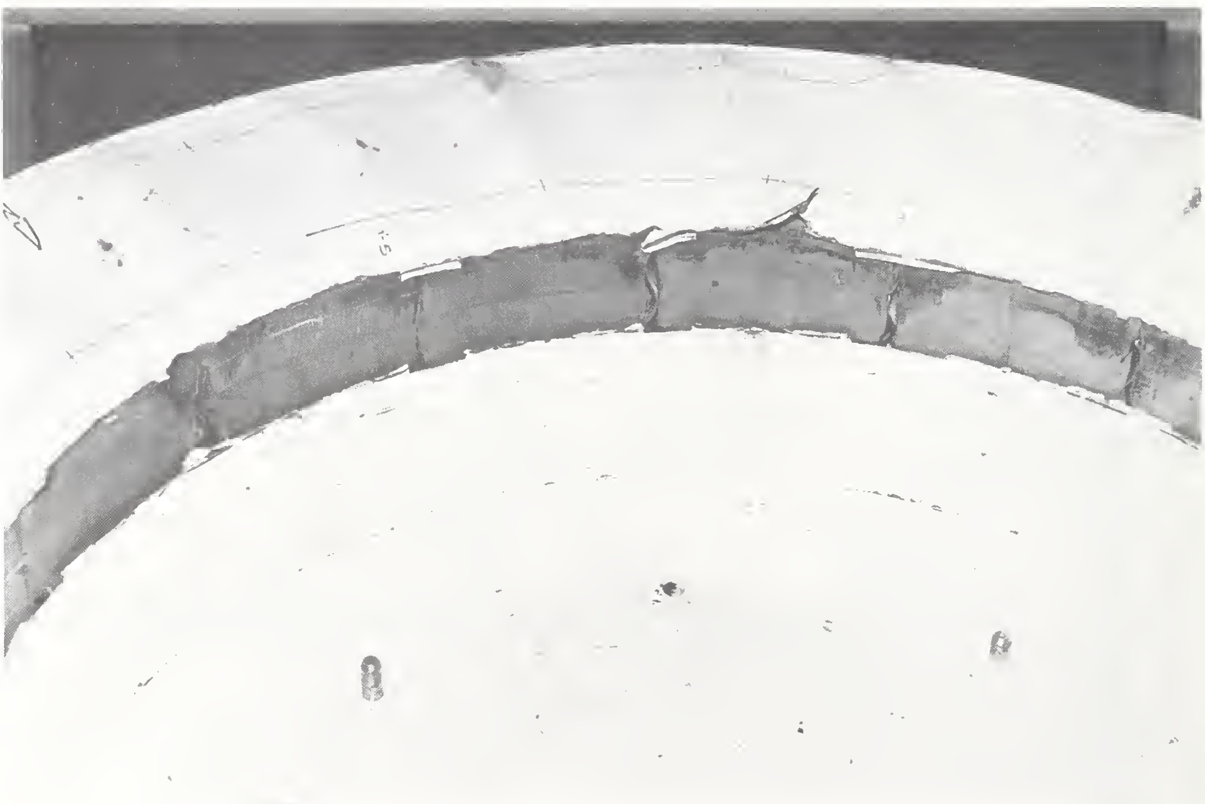


Figure 5.9 (d) Close-up of Damages on Inner Surface of S-3.

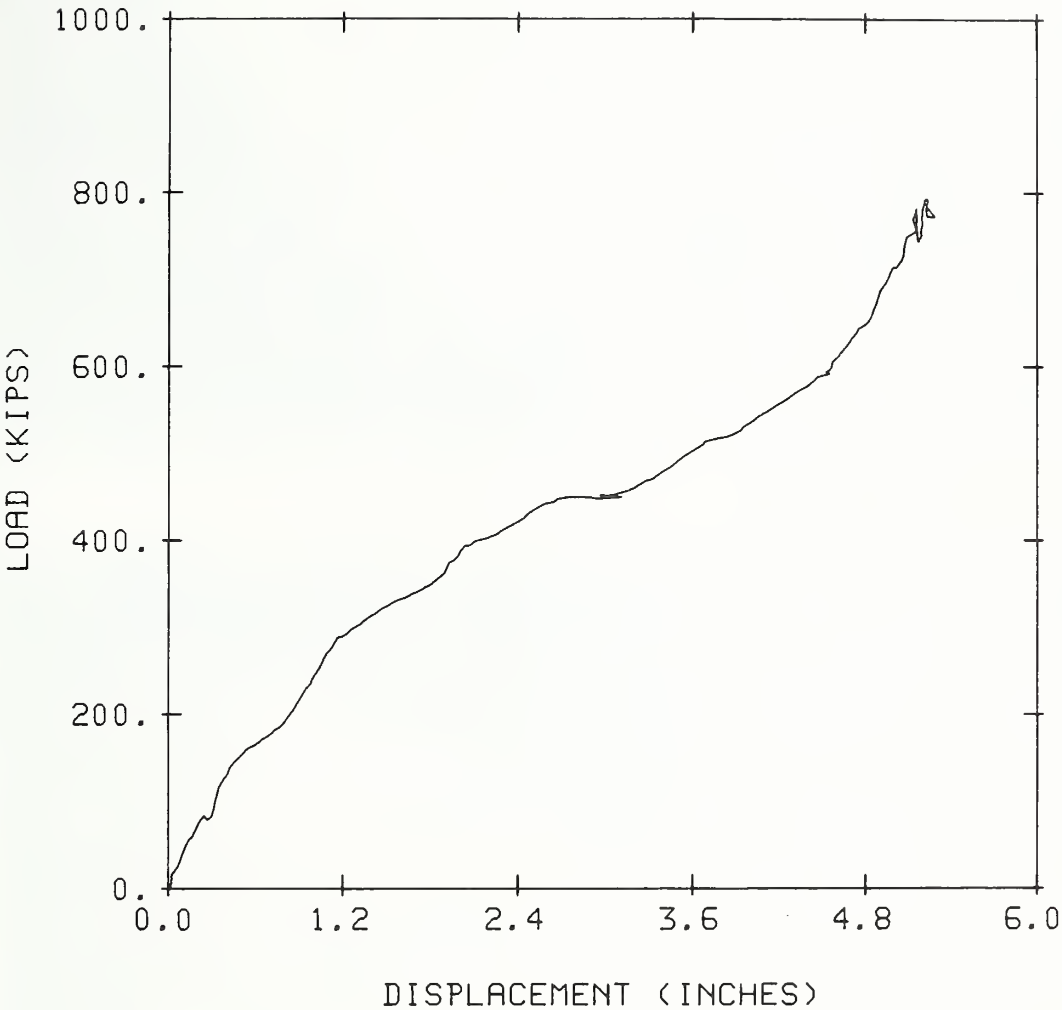


Figure 5.10 Load vs. Displacement for Test S-4

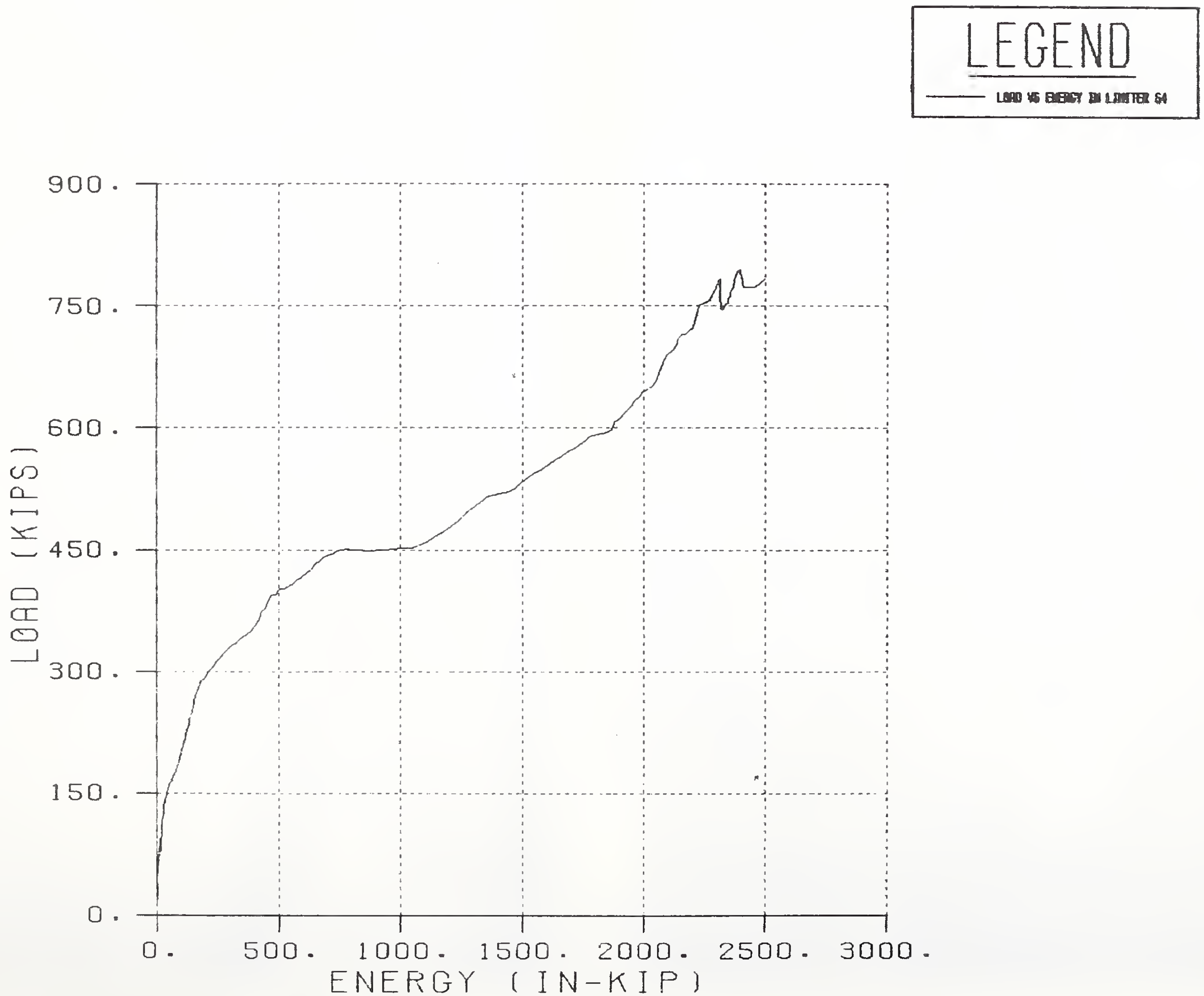


Figure 5.11 Load vs. Accumulated Energy for Test S-4.

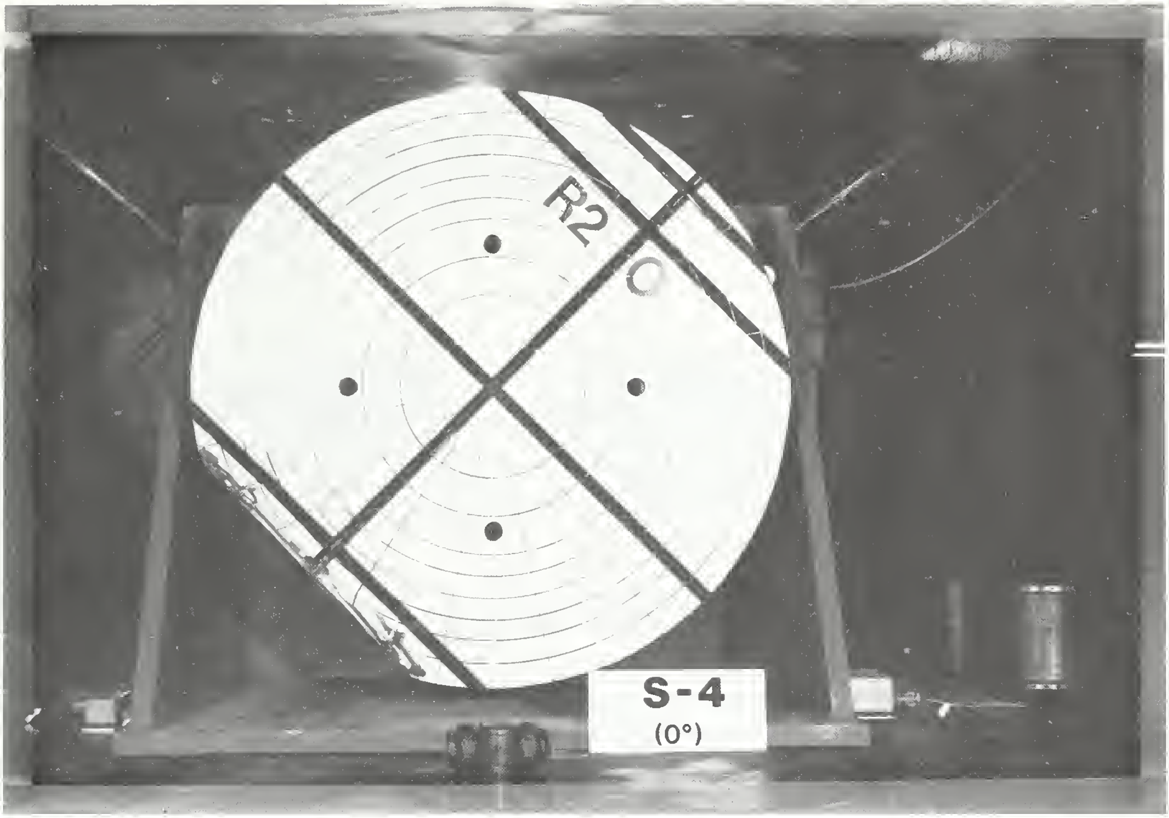


Figure 5.12 (a) Front View of Test S-4 before Test.

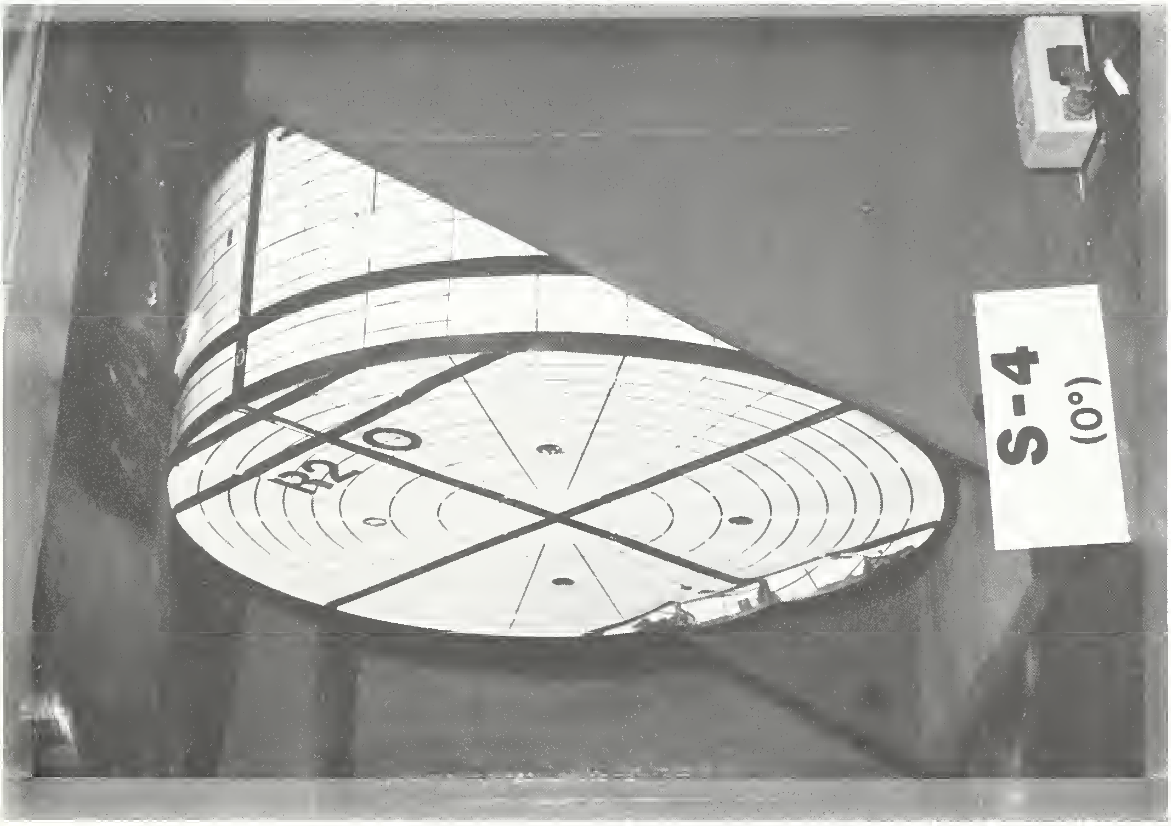


Figure 5.12 (b) Side View of Test S-4 before Test.

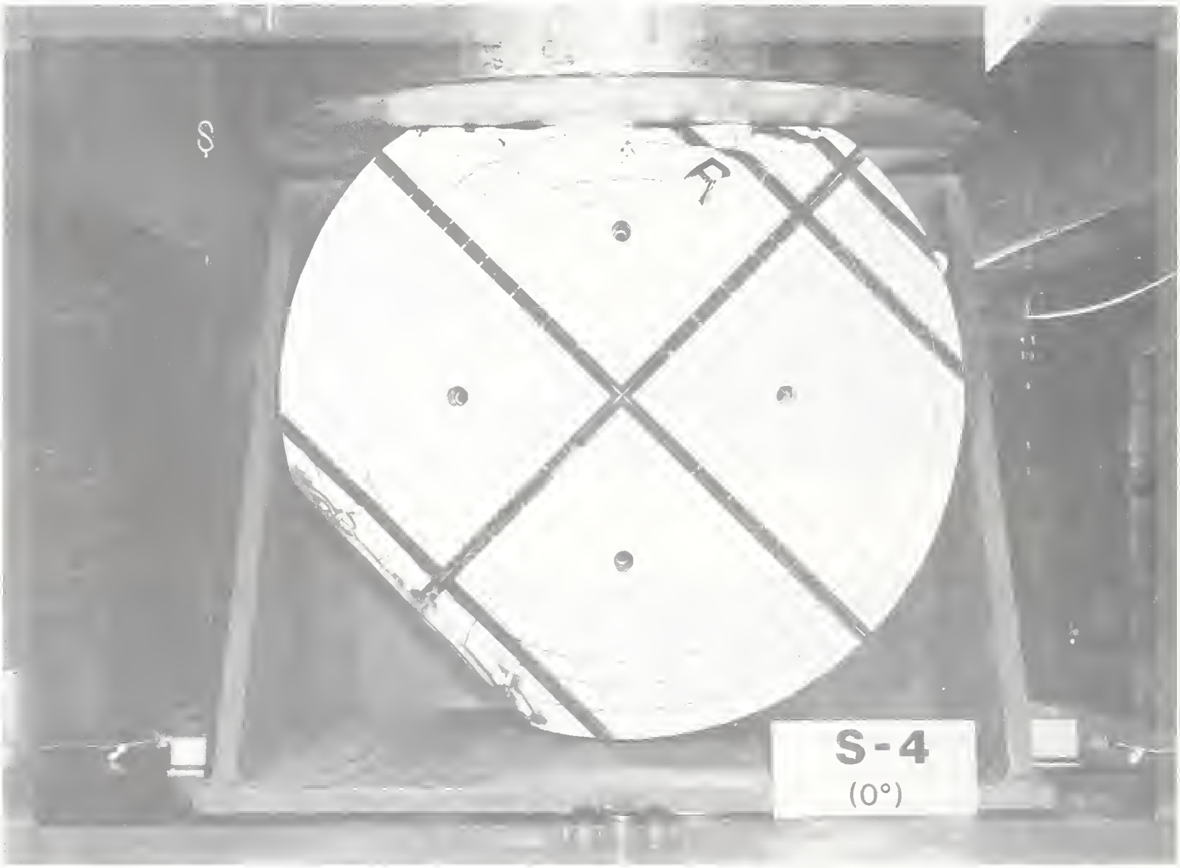


Figure 5.12 (c) Front View of Test S-4 during Loading.

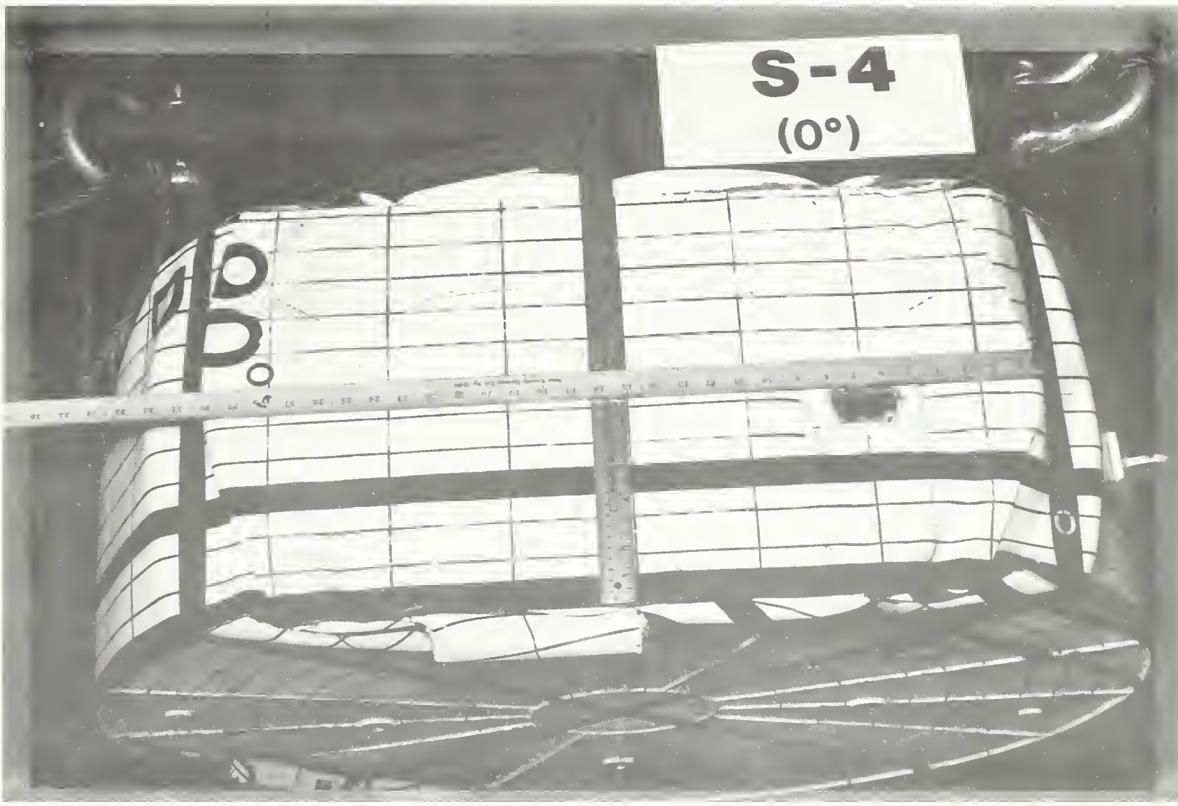


Figure 5.12 (d) Top View of Damaged Area in Test S-4

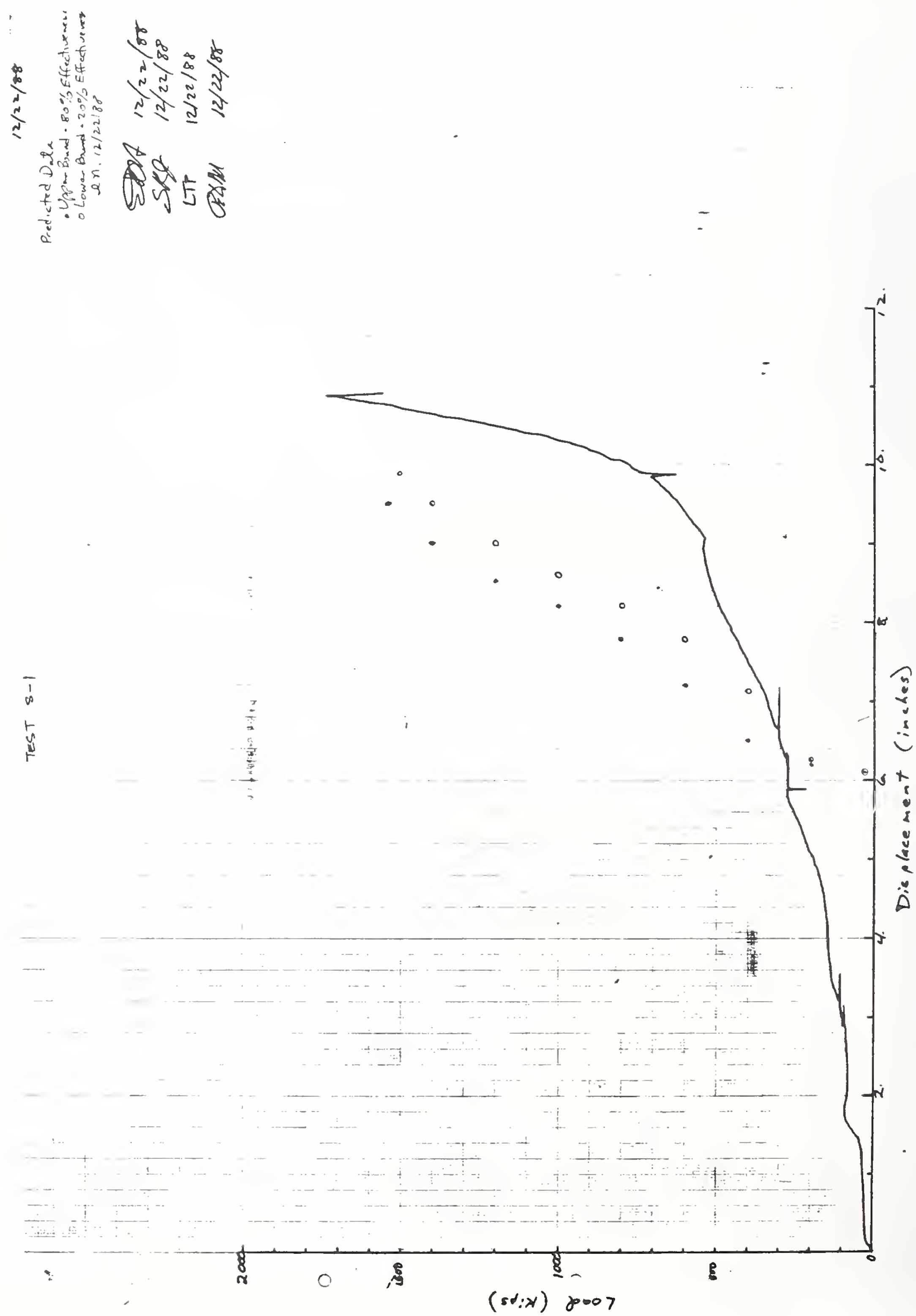
Figure 5.12 (e) Side View of Damaged Area in Test S-4

6. APPENDICES

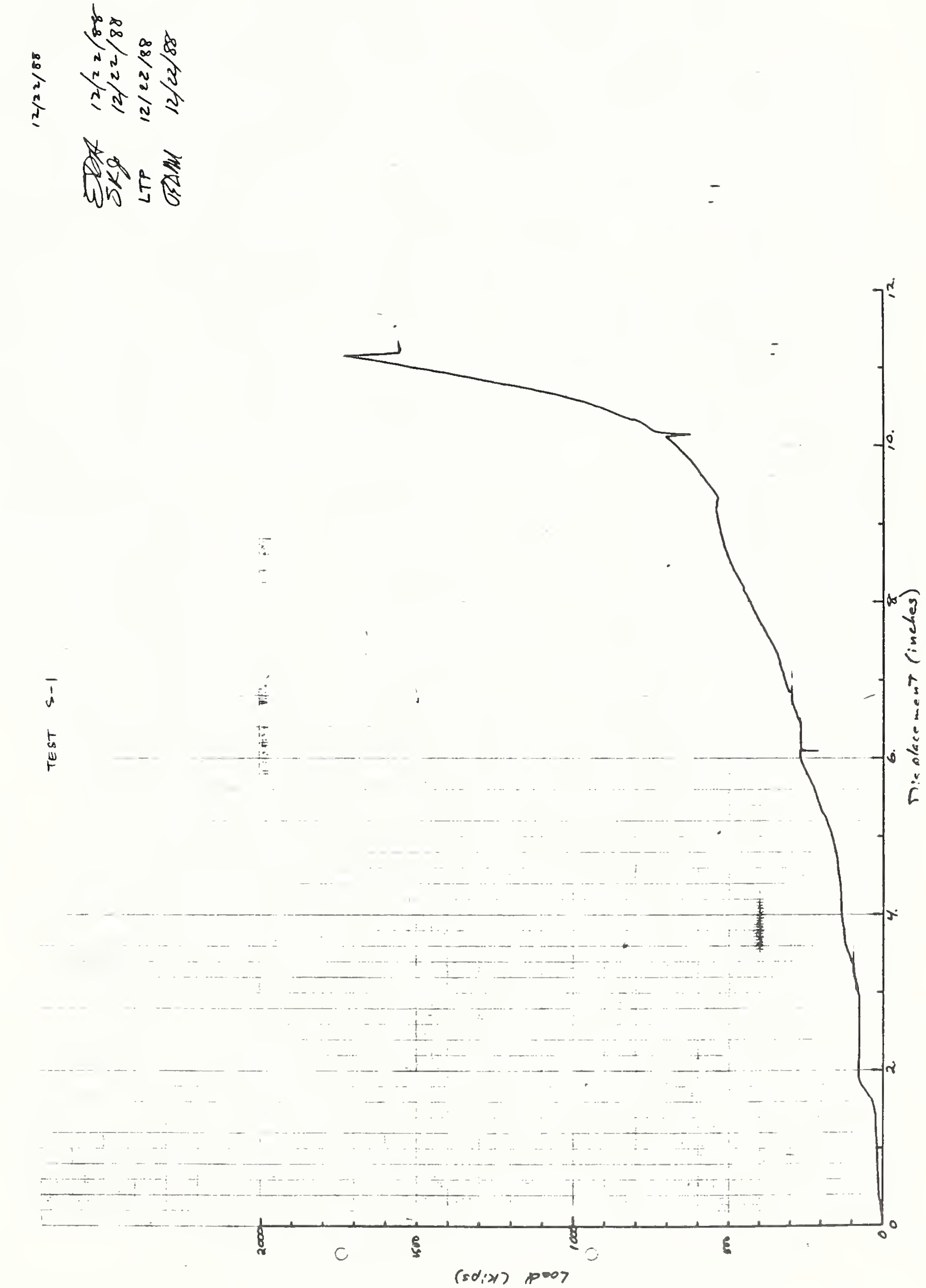
APPENDIX A

Load-Deflection Curves for Test S-1 from X-Y Plotter.

A.1 North-side



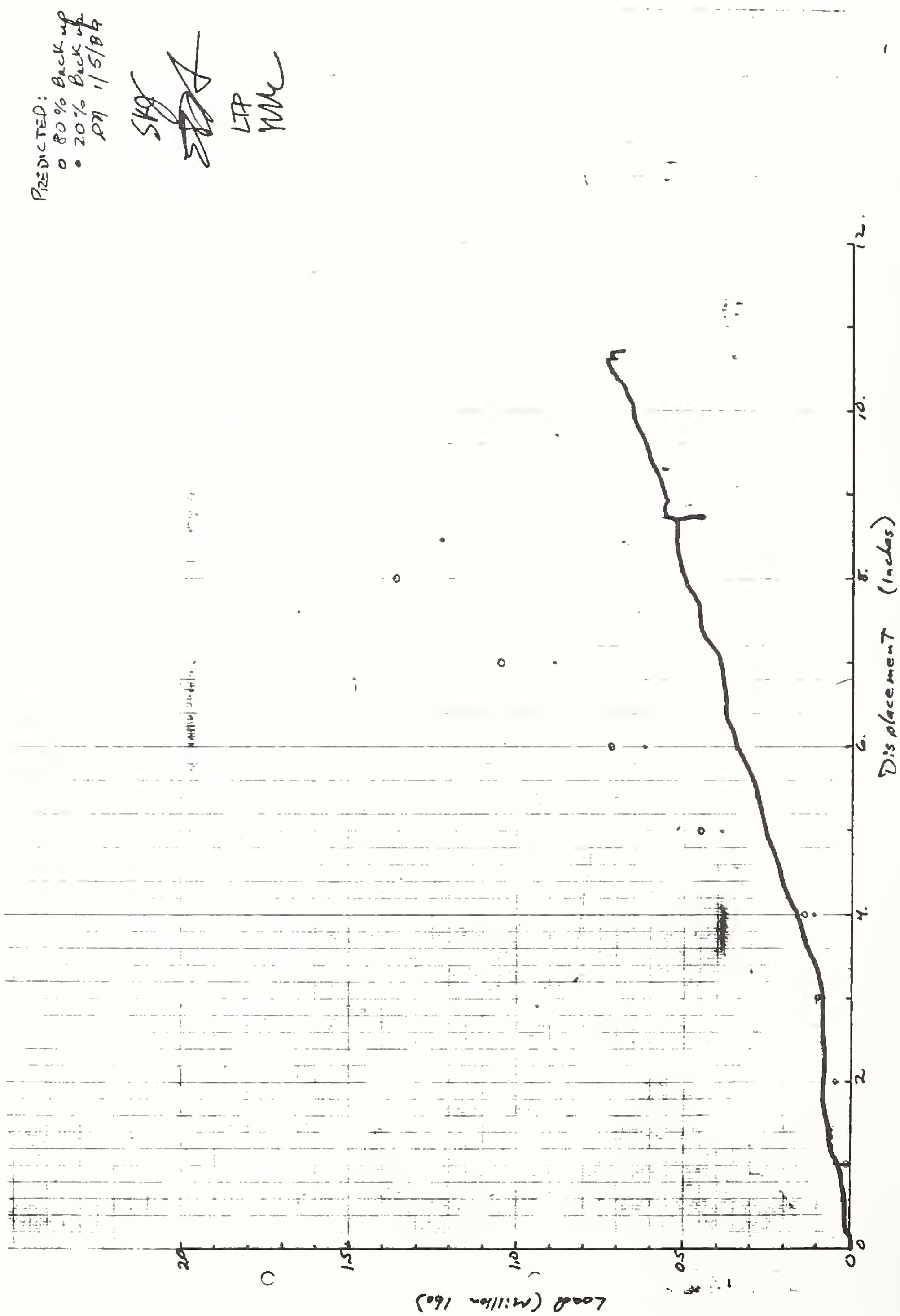
A.2 South-side



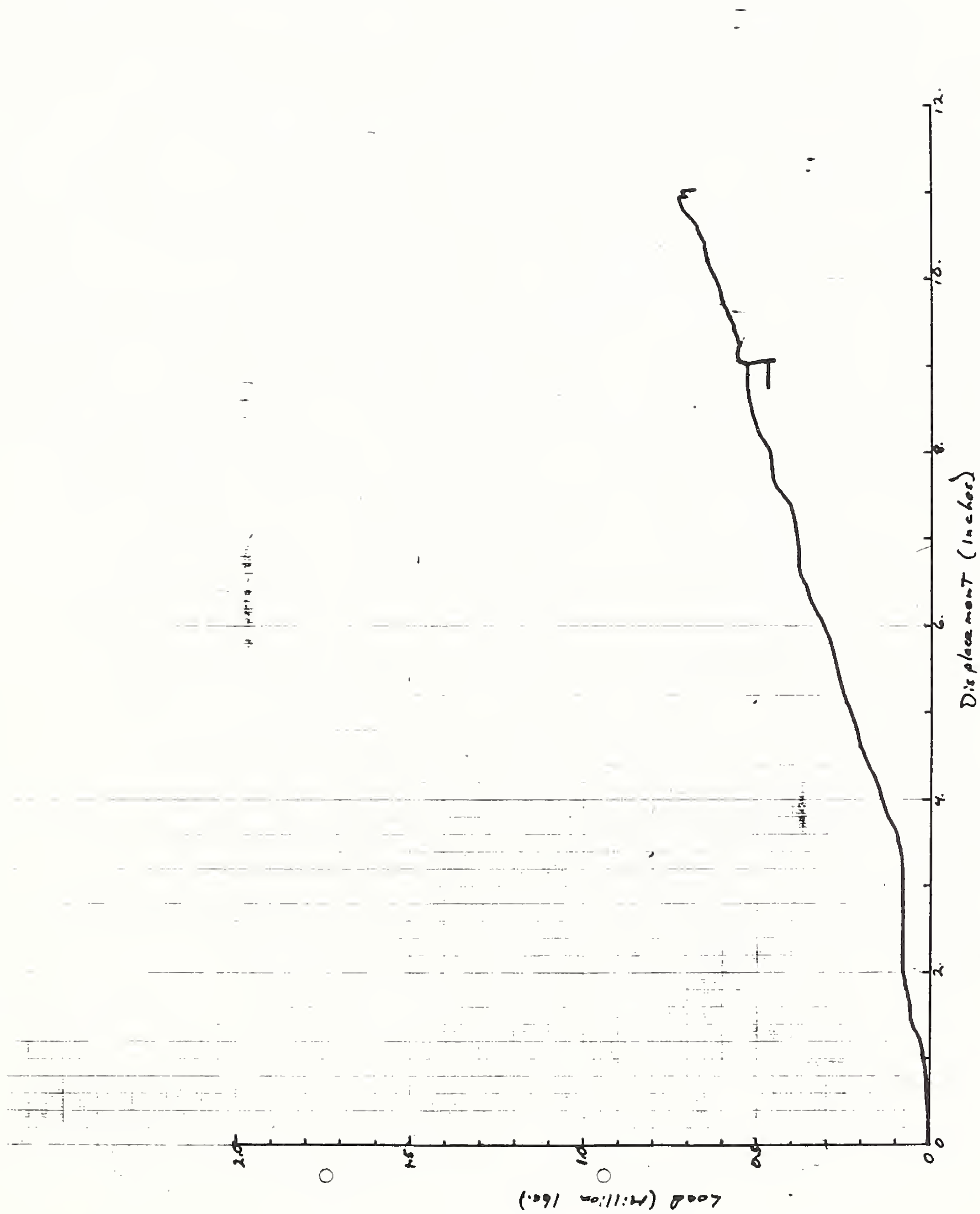
APPENDIX B

Load-Deflection Curves for Test S-2 from X-Y Plotter.

B.1 North-Side



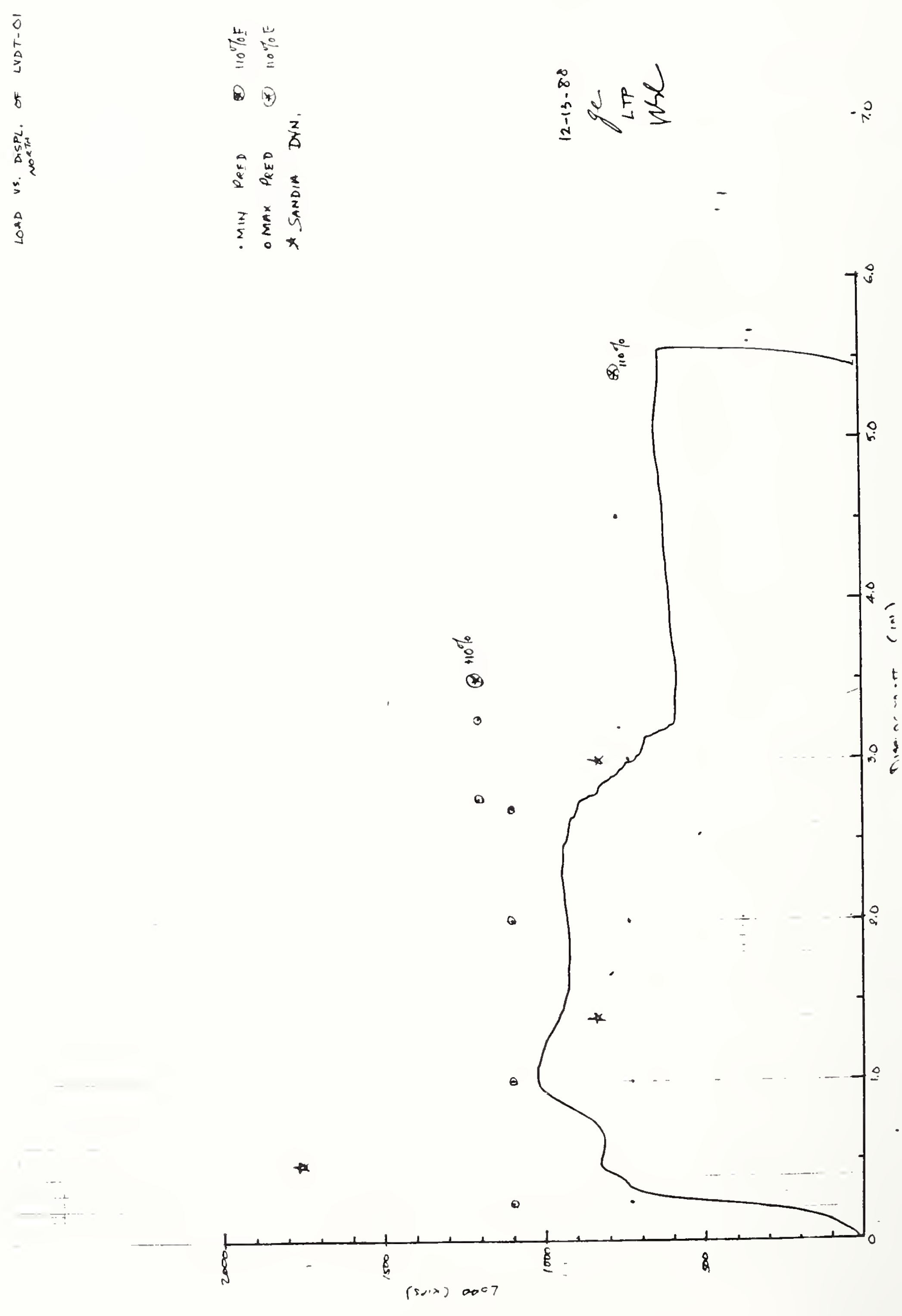
B.2 South-Side



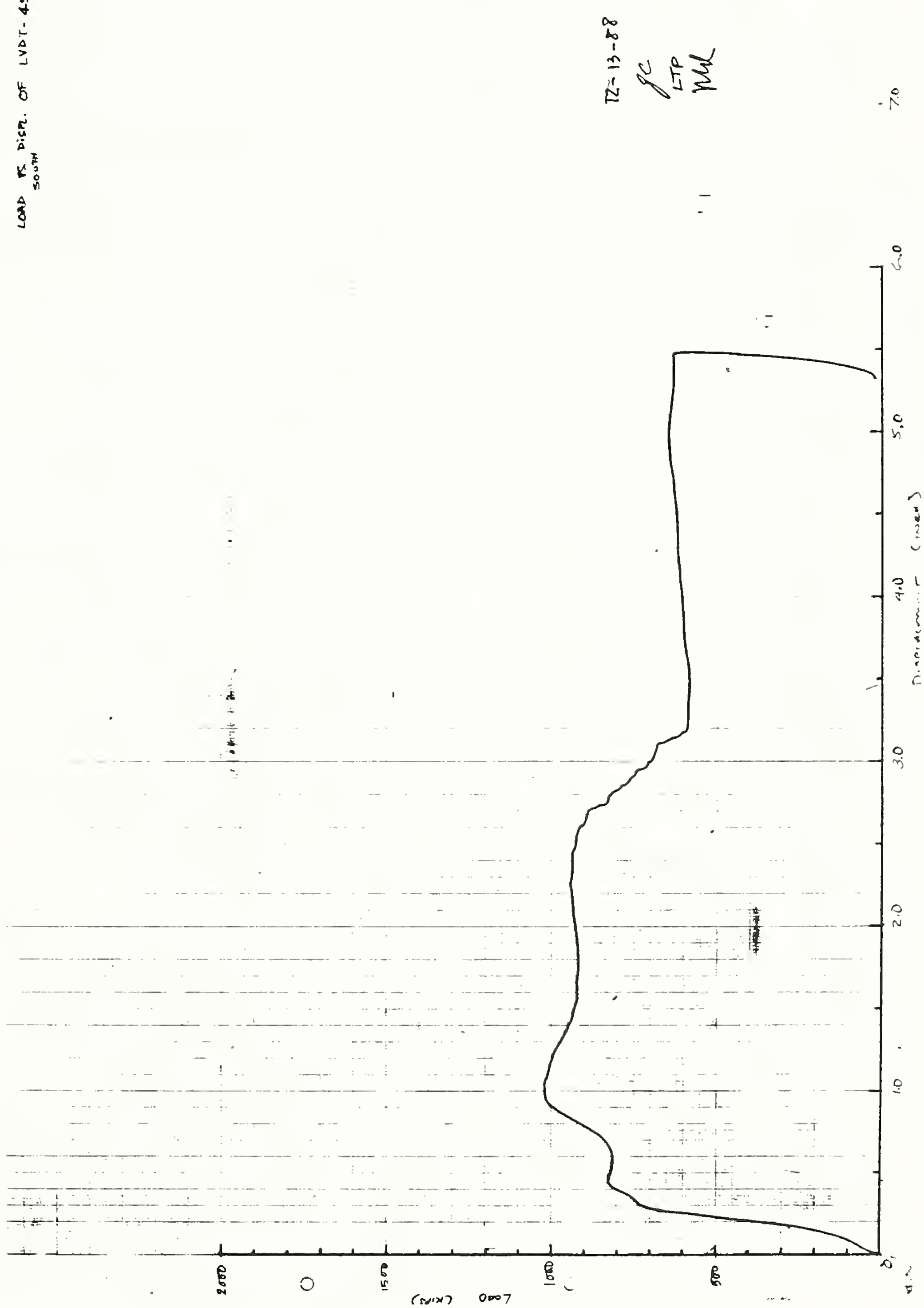
APPENDIX C

Load-Deflection Curves for Test S-3 from X-Y Plotter.

C.1 North-Side



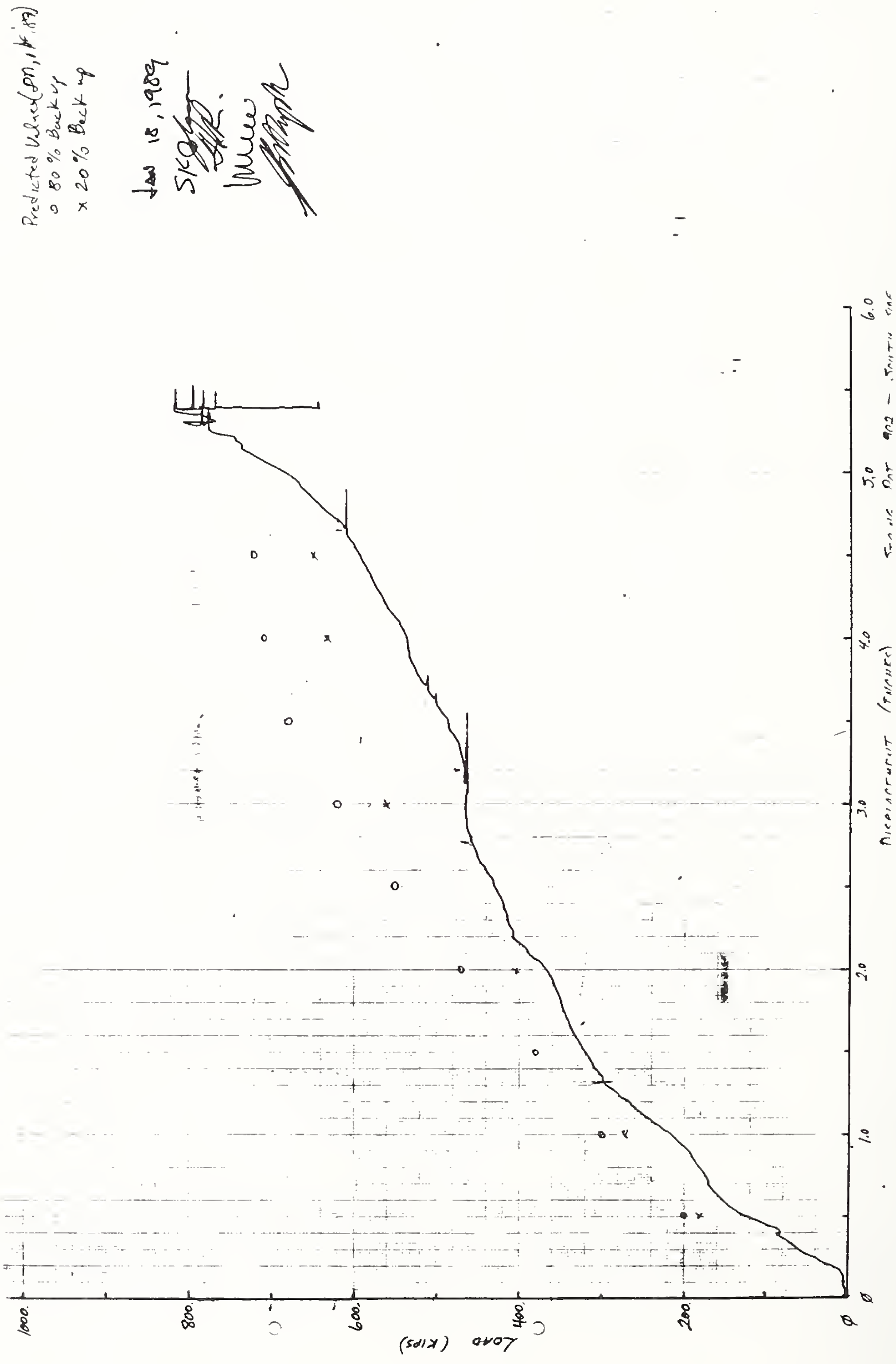
C.2 South-Side



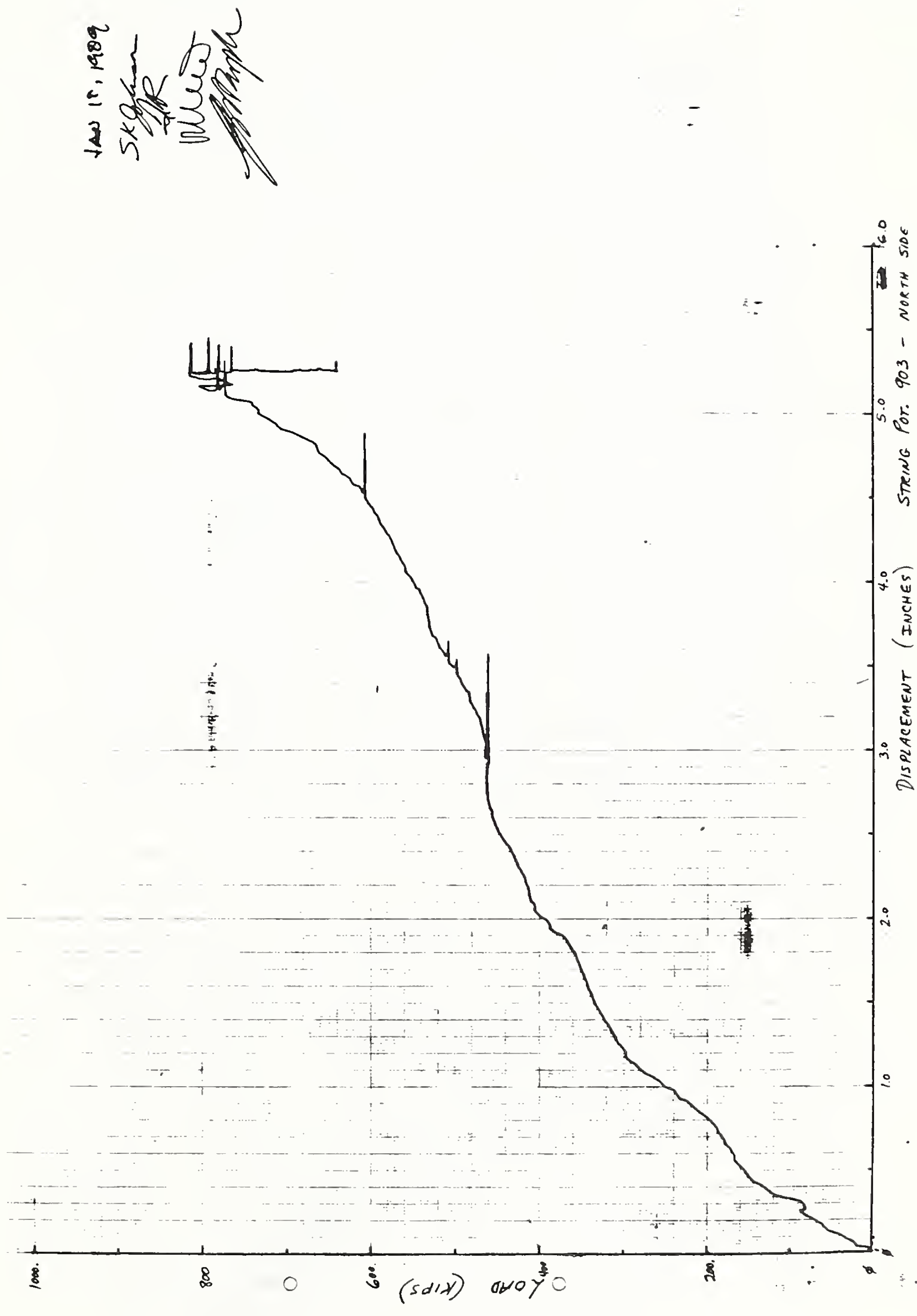
APPENDIX D

Load-Deflection Curves for Test S-4 from X-Y Plotter.

D.1 North-Side



D.2 South-Side



APPENDIX E

Calibration Curves for Electrical Devices.

E.1 Calibration Curve for North-Side String-Potentiometer

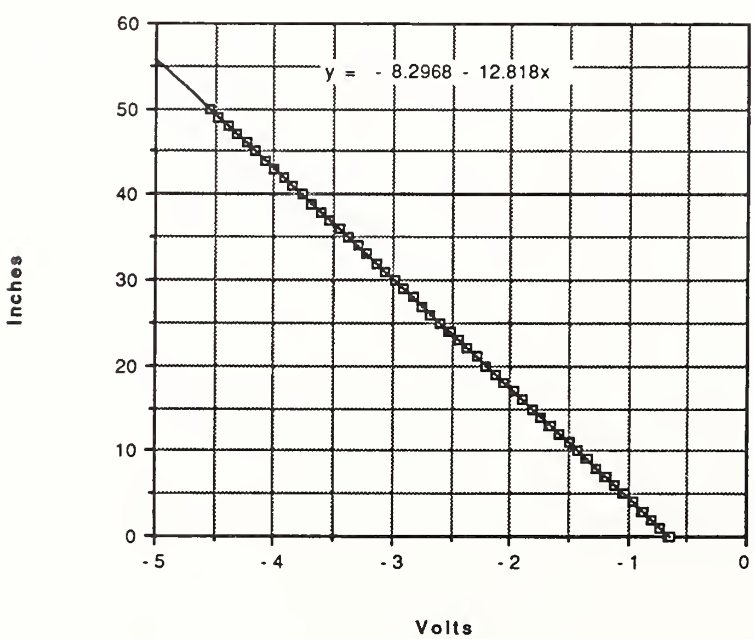
```
... CALIBRATION REPORT FOR DEVICE (ST-POT-903)...
... PERFORMED AT: 17:22:27  ON: 20-DEC-88  BY: S.K. JOHNSON

...REGRESSION ANALYSIS
... FIRST ORDER                        ... SECOND ORDER
INTERCEPT: 0.79528809E-01              INTERCEPT: 0.49396515E-01
XAA1 COEF:-0.12818408E+02              XAA1 COEF:-0.12865180E+02
                                       XAA2 COEF:-0.12035546E-01
CORR COEF:1.00                         CORR COEF:1.[illegible]
STD ERROR: 0.35434172E-01              STD ERROR: 0.29424790E-01
TOT ERROR: 0.12304687E+00              TOT ERROR: 0.83984375E-01

NOTE: XAA1 COEF: IS READ AS REFERENCE UNITS PER VOLT.
```

REFERENCE VALUE	ASSOCIATED VOLTAGE	REFERENCE VALUE	ASSOCIATED VOLTAGE	REFERENCE VALUE	ASSOCIATED VOLTAGE
0.000E+00	-0.653458	0.000E+00	-0.644302	0.100E+01	-0.730667
0.200E+01	-0.801697	0.200E+01	-0.808029	0.300E+01	-0.886612
0.300E+01	-0.878830	0.400E+01	-0.965271	0.400E+01	-0.957642
0.500E+01	-1.041794	0.500E+01	-1.035309	0.600E+01	-1.119766
0.600E+01	-1.112366	0.700E+01	-1.196213	0.700E+01	-1.187744
0.800E+01	-1.276398	0.800E+01	-1.267700	0.900E+01	-1.354065
0.900E+01	-1.344604	0.100E+02	-1.432190	0.100E+02	-1.422424
0.110E+02	-1.506958	0.110E+02	-1.499023	0.120E+02	-1.585999
0.120E+02	-1.578217	0.130E+02	-1.665039	0.130E+02	-1.658478
0.140E+02	-1.740417	0.140E+02	-1.737976	0.150E+02	-1.819305
0.150E+02	-1.816559	0.160E+02	-1.896057	0.160E+02	-1.894836
0.170E+02	-1.976166	0.170E+02	-1.974030	0.180E+02	-2.053680
0.180E+02	-2.052612	0.190E+02	-2.130737	0.190E+02	-2.129822
0.200E+02	-2.207336	0.200E+02	-2.207794	0.210E+02	-2.283325
0.210E+02	-2.284088	0.220E+02	-2.361450	0.220E+02	-2.361450
0.230E+02	-2.438354	0.230E+02	-2.437592	0.240E+02	-2.517700
0.240E+02	-2.516174	0.250E+02	-2.596130	0.250E+02	-2.595215
0.260E+02	-2.676086	0.260E+02	-2.674255	0.270E+02	-2.752380
0.270E+02	-2.752380	0.280E+02	-2.829285	0.280E+02	-2.829285
0.290E+02	-2.908630	0.290E+02	-2.908020	0.300E+02	-2.986145
0.300E+02	-2.986145	0.310E+02	-3.063049	0.310E+02	-3.064575
0.320E+02	-3.140869	0.320E+02	-3.141479	0.330E+02	-3.219910
0.330E+02	-3.220215	0.340E+02	-3.299255	0.340E+02	-3.299255
0.350E+02	-3.377075	0.350E+02	-3.378601	0.360E+02	-3.457336
0.360E+02	-3.455200	0.370E+02	-3.533020	0.370E+02	-3.534851
0.380E+02	-3.612366	0.380E+02	-3.611755	0.390E+02	-3.688965
0.390E+02	-3.689575	0.400E+02	-3.767700	0.400E+02	-3.768311
0.410E+02	-3.846436	0.410E+02	-3.846436	0.420E+02	-3.925171
0.420E+02	-3.925781	0.430E+02	-4.003906	0.430E+02	-4.002686
0.440E+02	-4.081726	0.440E+02	-4.080811	0.450E+02	-4.159546
0.450E+02	-4.158630	0.460E+02	-4.236755	0.460E+02	-4.236755
0.470E+02	-4.313660	0.470E+02	-4.313965	0.480E+02	-4.393616
0.480E+02	-4.394226	0.490E+02	-4.472656	0.490E+02	-4.471436
0.500E+02	-4.549561				

String Pot 903 Calibration



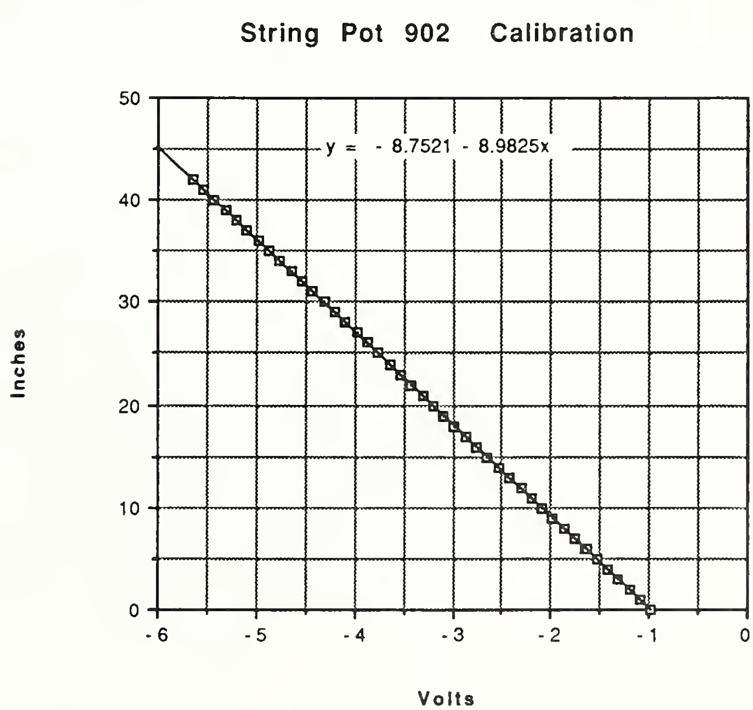
E.2 Calibration Curve for South-Side String-Potentiometer

```
... CALIBRATION REPORT FOR DEVICE (ST-POT-902)...
... PERFORMED AT: 17:44:42  ON: 20-DEC-88  BY: S.K. JOHNSON

...REGRESSION ANALYSIS
... FIRST ORDER                    ... SECOND ORDER
INTERCEPT: 0.20576477E-01          INTERCEPT: 0.74424744E-02
X**1 COEF:-0.89825315E+01          X**1 COEF:-0.89997997E+01
                                   X**2 COEF:-0.36936370E-02
CORR COEF:1.00                     CORR COEF:1.00
STD ERROR: 0.22872658E-01          STD ERROR: 0.19098174E-01
TOT ERROR: 0.43945312E-01          TOT ERROR: 0.30273437E-01

NOTE: X**1 COEF: IS READ AS REFERENCE UNITS PER VOLT.
```

REFERENCE VALUE	ASSOCIATED VOLTAGE	REFERENCE VALUE	ASSOCIATED VOLTAGE	REFERENCE VALUE	ASSOCIATED VOLTAGE
0.000E+00	-0.976639	0.000E+00	-0.975952	0.100E+01	-1.085587
0.100E+01	-1.087265	0.200E+01	-1.198349	0.200E+01	-1.200790
0.300E+01	-1.310577	0.300E+01	-1.311951	0.400E+01	-1.422272
0.400E+01	-1.423035	0.500E+01	-1.531525	0.500E+01	-1.531830
0.600E+01	-1.640472	0.600E+01	-1.641693	0.700E+01	-1.752319
0.700E+01	-1.753845	0.800E+01	-1.865082	0.800E+01	-1.864777
0.900E+01	-1.976471	0.900E+01	-1.976929	0.100E+02	-2.084198
0.100E+02	-2.085571	0.110E+02	-2.190399	0.110E+02	-2.190704
0.120E+02	-2.305145	0.120E+02	-2.304687	0.130E+02	-2.420502
0.130E+02	-2.418060	0.140E+02	-2.533875	0.140E+02	-2.533569
0.150E+02	-2.648010	0.150E+02	-2.647400	0.160E+02	-2.757568
0.160E+02	-2.758484	0.170E+02	-2.869263	0.170E+02	-2.869568
0.180E+02	-2.979736	0.180E+02	-2.979431	0.190E+02	-3.090515
0.190E+02	-3.091431	0.200E+02	-3.201904	0.200E+02	-3.204041
0.210E+02	-3.311157	0.210E+02	-3.312378	0.220E+02	-3.420715
0.220E+02	-3.421326	0.230E+02	-3.530884	0.230E+02	-3.531799
0.240E+02	-3.644104	0.240E+02	-3.645935	0.250E+02	-3.757629
0.250E+02	-3.757935	0.260E+02	-3.867493	0.260E+02	-3.869629
0.270E+02	-3.977966	0.270E+02	-3.979187	0.280E+02	-4.089050
0.280E+02	-4.090576	0.290E+02	-4.201355	0.290E+02	-4.201355
0.300E+02	-4.313660	0.300E+02	-4.315186	0.310E+02	-4.425964
0.310E+02	-4.425354	0.320E+02	-4.537964	0.320E+02	-4.538269
0.330E+02	-4.647217	0.330E+02	-4.646912	0.340E+02	-4.760437
0.340E+02	-4.759521	0.350E+02	-4.869385	0.350E+02	-4.870300
0.360E+02	-4.984436	0.360E+02	-4.985352	0.370E+02	-5.093384
0.370E+02	-5.093384	0.380E+02	-5.205688	0.380E+02	-5.204468
0.390E+02	-5.313721	0.390E+02	-5.314331	0.400E+02	-5.430908
0.400E+02	-5.429687	0.410E+02	-5.541382	0.410E+02	-5.540161
0.420E+02	-5.650635	0.420E+02	-5.651245		



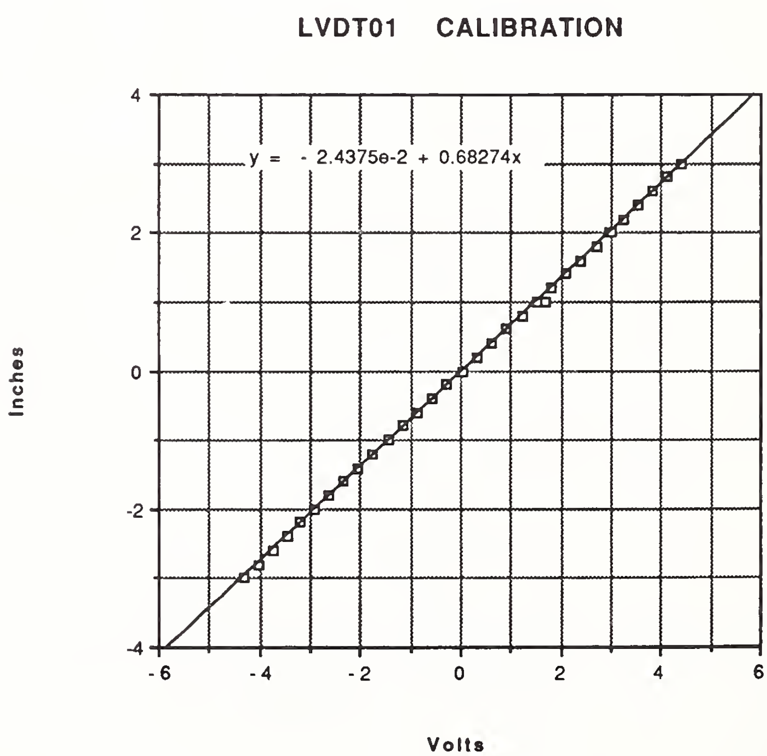
E.3 Calibration Curve for North-Side 12-in LVDT

```
... CALIBRA.ION REPORT FOR DEVICE (LVDT-01    )...
... PERFORMED AT: 17:30:32  ON: 12-DEC-88  BY: SK JOHNSON

...REGRESSION ANALYSIS
... FIRST ORDER                      ... SECOND ORDER
INTERCEPT: 0.29478073E-01            INTERCEPT: 0.31932354E-01
XAA1 COEF: 0.68273926E+00            XAA1 COEF: 0.68104112E+00
                                     XAA2 COEF: 0.19522131E-03
CORR COEF:1.00                       CORR COEF:1.00
STD ERROR: 0.21623861E-01            STD ERROR: 0.21815509E-01
TOT ERROR: 0.27587891E-01            TOT ERROR: 0.27603149E-01

NOTE: XAA1 COEF: IS READ AS REFERENCE UNITS PER VOLT.
```

REFERENCE VALUE	ASSOCIATED VOLTAGE	REFERENCE VALUE	ASSOCIATED VOLTAGE	REFERENCE VALUE	ASSOCIATED VOLTAGE
-0.300E+01	-4.315186	-0.280E+01	-4.026794	-0.280E+01	-4.026489
-0.260E+01	-3.746643	-0.260E+01	-3.746033	-0.240E+01	-3.468323
-0.240E+01	-3.468628	-0.220E+01	-3.192444	-0.220E+01	-3.193054
-0.200E+01	-2.918396	-0.200E+01	-2.918396	-0.180E+01	-2.629089
-0.180E+01	-2.630615	-0.160E+01	-2.335358	-0.160E+01	-2.336731
-0.140E+01	-2.045441	-0.140E+01	-2.046661	-0.120E+01	-1.746826
-0.120E+01	-1.747589	-0.100E+01	-1.444397	-0.100E+01	-1.445618
-0.800E+00	-1.150589	-0.800E+00	-1.151733	-0.600E+00	-0.852051
-0.600E+00	-0.853729	-0.400E+00	-0.557480	-0.400E+00	-0.559044
-0.200E+00	-0.269909	-0.200E+00	-0.270329	0.000E+00	0.030975
0.000E+00	0.030422	0.000E+00	0.030499	0.200E+00	0.330734
0.200E+00	0.330849	0.400E+00	0.621872	0.400E+00	0.622292
0.600E+00	0.920410	0.600E+00	0.920410	0.800E+00	1.222687
0.800E+00	1.222839	0.100E+01	1.669769	0.100E+01	1.520081
0.120E+01	1.820679	0.120E+01	1.820831	0.140E+01	2.115173
0.140E+01	2.115326	0.160E+01	2.401581	0.160E+01	2.400970
0.180E+01	2.693176	0.180E+01	2.693481	0.200E+01	2.979431
0.200E+01	2.980347	0.220E+01	3.253174	0.220E+01	3.253174
0.240E+01	3.533936	0.240E+01	3.533630	0.260E+01	3.814697
0.260E+01	3.813782	0.280E+01	4.093323	0.280E+01	4.093323
0.300E+01	4.387512				



E.4 Calibration Curve for South-Side 12-in LVDT

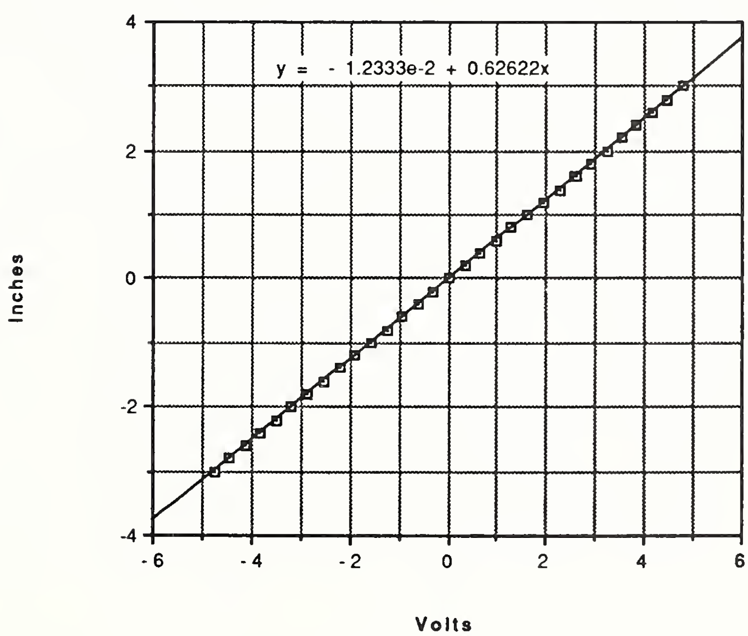
```
... CALIBRATION REPORT FOR DEVICE (LVDT-45    )...
... PERFORMED AT: 18:00:20  ON: 12-DEC-88  BY:

...REGRESSION ANALYSIS
... FIRST ORDER                      ... SECOND ORDER
INTERCEPT: 0.11540413E-01            INTERCEPT: 0.18333673E-01
XAA1 COEF: 0.62622291E+00            XAA1 COEF: 0.62195390E+00
                                     XAA2 COEF: 0.44794235E-03
CORR COEF:1.00                       CORR COEF:1.00
STD ERROR: 0.79600736E-02            STD ERROR: 0.72899028E-02
TOT ERROR: 0.37384033E-02            TOT ERROR: 0.30822754E-02

NOTE: XAA1 COEF: IS READ AS REFERENCE UNITS PER VOLT.
```

REFERENCE VALUE	ASSOCIATED VOLTAGE	REFERENCE VALUE	ASSOCIATED VOLTAGE	REFERENCE VALUE	ASSOCIATED VOLTAGE
-0.300E+01	-4.752502	-0.280E+01	-4.438782	-0.280E+01	-4.438782
-0.260E+01	-4.137268	-0.260E+01	-4.136658	-0.240E+01	-3.827209
-0.240E+01	-3.826294	-0.220E+01	-3.509827	-0.220E+01	-3.509521
-0.200E+01	-3.193970	-0.200E+01	-3.195190	-0.180E+01	-2.866821
-0.180E+01	-2.868347	-0.160E+01	-2.534485	-0.160E+01	-2.536011
-0.140E+01	-2.213898	-0.140E+01	-2.215729	-0.120E+01	-1.890259
-0.120E+01	-1.897583	-0.100E+01	-1.565704	-0.100E+01	-1.572418
-0.800E+00	-1.250916	-0.800E+00	-1.250916	-0.600E+00	-0.932312
-0.600E+00	-0.932770	-0.400E+00	-0.613213	-0.400E+00	-0.614128
-0.200E+00	-0.298138	-0.200E+00	-0.298271	0.000E+00	0.026321
0.000E+00	0.025082	0.000E+00	0.024548	0.200E+00	0.345612
0.200E+00	0.347633	0.400E+00	0.655746	0.400E+00	0.657043
0.600E+00	0.971909	0.600E+00	0.974045	0.800E+00	1.291809
0.800E+00	1.293640	0.100E+01	1.611328	0.100E+01	1.613007
0.120E+01	1.943512	0.120E+01	1.945496	0.140E+01	2.272186
0.140E+01	2.274475	0.160E+01	2.590942	0.160E+01	2.593079
0.180E+01	2.913818	0.180E+01	2.915649	0.200E+01	3.230286
0.200E+01	3.230896	0.220E+01	3.535156	0.220E+01	3.534851
0.240E+01	3.843689	0.240E+01	3.843384	0.260E+01	4.154358
0.260E+01	4.155273	0.280E+01	4.462891	0.280E+01	4.463806
0.300E+01	4.777832				

LVDT45 Calibration



E.5 Calibration Curve for Vertical 3-in LVDT

... CALIBRATION REPORT FOR DEVICE (LVDT-1008)...
... PERFORMED AT: 12:33:45 ON: 21-DEC-88 BY: SK JOHNSON

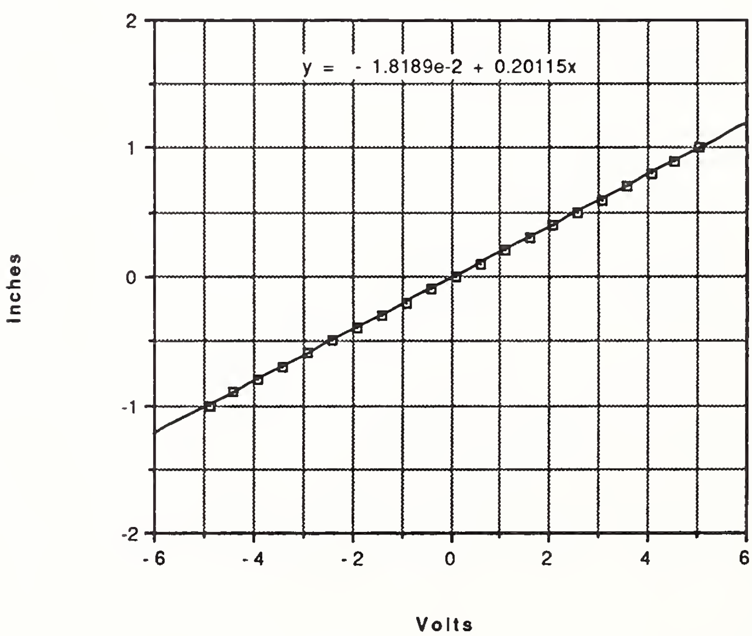
...REGRESSION ANALYSIS

... FIRST ORDER	... SECOND ORDER
INTERCEPT: 0.26493001E+00	INTERCEPT: 0.26449811E+00
X**1 COEF: 0.21998958E+00	X**1 COEF: 0.22025307E+00
	X**2 COEF:-0.21686807E-04
CORR COEF:1.00	CORR COEF:1.00
STD ERROR: 0.84452897E-01	STD ERROR: 0.85120164E-01
TOT ERROR: 0.45646667E+00	TOT ERROR: 0.45646286E+00

NOTE: X**1 COEF: IS READ AS REFERENCE UNITS PER VOLT.

REFERENCE VALUE	ASSOCIATED VOLTAGE	REFERENCE VALUE	ASSOCIATED VOLTAGE	REFERENCE VALUE	ASSOCIATED VOLTAGE
-0.160E+01	-5.971680	-0.150E+01	-5.916748	-0.150E+01	-5.917358
-0.140E+01	-5.829468	-0.140E+01	-5.830688	-0.130E+01	-5.708618
-0.130E+01	-5.709229	-0.120E+01	-5.546875	-0.120E+01	-5.548096
-0.110E+01	-5.285034	-0.110E+01	-5.288086	-0.100E+01	-4.868469
-0.100E+01	-4.871521	-0.900E+00	-4.391479	-0.900E+00	-4.394226
-0.800E+00	-3.903198	-0.800E+00	-3.904419	-0.700E+00	-3.405457
-0.700E+00	-3.406067	-0.600E+00	-2.902832	-0.600E+00	-2.904358
-0.500E+00	-2.405548	-0.500E+00	-2.406769	-0.400E+00	-1.901855
-0.400E+00	-1.901398	-0.300E+00	-1.402435	-0.300E+00	-1.399689
-0.200E+00	-0.905685	-0.200E+00	-0.903854	-0.100E+00	-0.405579
-0.100E+00	-0.403366	0.000E+00	0.091667	0.000E+00	0.094547
0.000E+00	0.110493	0.000E+00	0.119152	0.100E+00	0.612183
0.100E+00	0.610695	0.200E+00	1.106720	0.200E+00	1.112289
0.300E+00	1.596680	0.300E+00	1.602631	0.400E+00	2.089233
0.400E+00	2.089691	0.500E+00	2.585144	0.500E+00	2.586975
0.600E+00	3.076782	0.600E+00	3.079834	0.700E+00	3.571777
0.700E+00	3.573608	0.800E+00	4.063110	0.800E+00	4.065552
0.900E+00	4.544373	0.900E+00	4.545898	0.100E+01	5.018311
0.100E+01	5.019531	0.110E+01	5.453491	0.110E+01	5.452271
0.120E+01	5.754395	0.120E+01	5.755615	0.130E+01	5.940552
0.130E+01	5.941162	0.140E+01	6.071167	0.140E+01	6.074829
0.150E+01	6.164551	0.150E+01	6.159668	0.160E+01	6.214600

LVDT1008 Calibration



E.6 Calibration Curve for Horizontal 3-in LVDT

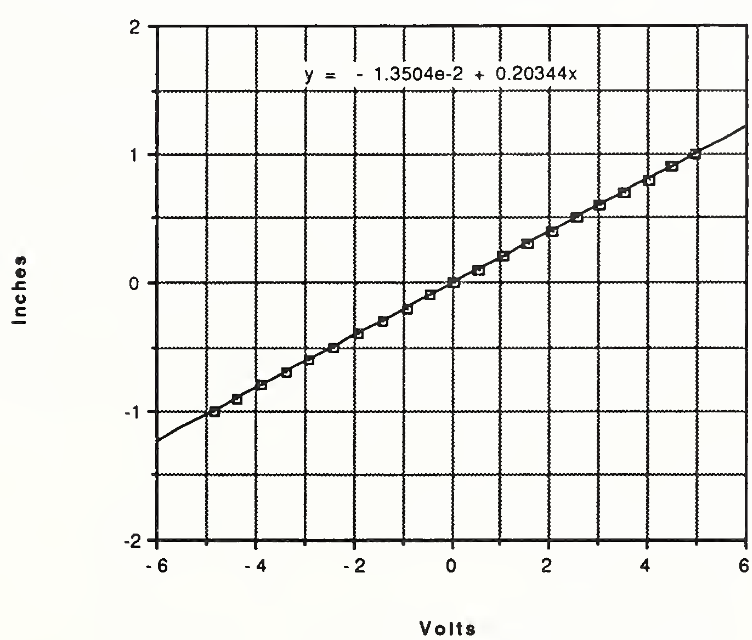
```
... CALIBRATION REPORT FOR DEVICE (LVDT-1003 )...
... PERFORMED AT: 12:00:26  ON: 21-DEC-88  BY: SK JOHNSON

...REGRESSION ANALYSIS
... FIRST ORDER                      ... SECOND ORDER
INTERCEPT: 0.25875282E+00            INTERCEPT: 0.27397764E+00
XAA1 COEF: 0.22580911E+00            XAA1 COEF: 0.21651725E+00
                                     XAA2 COEF: 0.76295331E-03
CORR COEF:0.99                       CORR COEF:0.99
STD ERROR: 0.98812990E-01            STD ERROR: 0.99018149E-01
TOT ERROR: 0.64442444E+00            TOT ERROR: 0.63729858E+00

NOTE: XAA1 COEF: IS READ AS REFERENCE UNITS PER VOLT.
```

REFERENCE VALUE	ASSOCIATED VOLTAGE	REFERENCE VALUE	ASSOCIATED VOLTAGE	REFERENCE VALUE	ASSOCIATED VOLTAGE
-0.160E+01	-5.902100	-0.150E+01	-5.859375	-0.150E+01	-5.859375
-0.140E+01	-5.775757	-0.140E+01	-5.776367	-0.130E+01	-5.652466
-0.130E+01	-5.652466	-0.120E+01	-5.488892	-0.120E+01	-5.488892
-0.110E+01	-5.232544	-0.110E+01	-5.233154	-0.100E+01	-4.826660
-0.100E+01	-4.826965	-0.900E+00	-4.358521	-0.900E+00	-4.358215
-0.800E+00	-3.877869	-0.800E+00	-3.878174	-0.700E+00	-3.385925
-0.700E+00	-3.386230	-0.600E+00	-2.889709	-0.600E+00	-2.890015
-0.500E+00	-2.396545	-0.500E+00	-2.397003	-0.400E+00	-1.897430
-0.400E+00	-1.898499	-0.300E+00	-1.403961	-0.300E+00	-1.404724
-0.200E+00	-0.916290	-0.200E+00	-0.916595	-0.100E+00	-0.423355
-0.100E+00	-0.424271	0.000E+00	0.037708	0.000E+00	0.073032
0.000E+00	0.073967	0.000E+00	0.073109	0.100E+00	0.570793
0.100E+00	0.535088	0.200E+00	1.031494	0.200E+00	1.066208
0.300E+00	1.558380	0.300E+00	1.524200	0.400E+00	2.053070
0.400E+00	2.018280	0.500E+00	2.551575	0.500E+00	2.516479
0.600E+00	3.045654	0.600E+00	3.010254	0.700E+00	3.538208
0.700E+00	3.504333	0.800E+00	4.028625	0.800E+00	3.993530
0.900E+00	4.469299	0.900E+00	4.504395	0.100E+01	4.965820
0.100E+01	4.934082	0.110E+01	5.354004	0.110E+01	5.385132
0.120E+01	5.680542	0.120E+01	5.665283	0.130E+01	5.861816
0.130E+01	5.852051	0.140E+01	5.978394	0.140E+01	5.983887
0.150E+01	6.058350	0.150E+01	6.062012	0.160E+01	6.097412
0.160E+01	6.096802	0.170E+01	6.098633		

LVDT1003 Calibration



APPENDIX F

Calibration Report of the NIST's 12 Million Pound
Universal Testing Machine

Cost Center No. 8/7413576
Div. Req. No. 741-8-3501
Calibrated October 21-24, 1988

U. S. Department of Commerce
National Institute of Standards and Technology
Gaithersburg, MD 20899

REPORT OF CALIBRATION

Bliss Testing Machine (No Serial Number)
Capacity 12,000,000 lbf, Compression
6,000,000 lbf, Tension
4,000,000 lbf, Flexure

Located in Room 130
Engineering Mechanics Building
Center for Building Technology
National Institute of Standards and Technology
Gaithersburg, MD 20899

This hydraulically-powered machine uses the same force-sensing system for measuring compression, tension, and flexural loads. Hydraulic pressure within the force-measuring cell is sensed by pressure transducers and is transformed into an electrical signal which is converted to load indication by both digital and analog indicating systems.

The analog ranges of the testing machine were calibrated to range-capacity or 3-million lbf, whichever was less, on October 21-24, 1988, according to the current ASTM method E4, using the following load calibration devices.

Device No.	Capacity	Calibrated	Class A Minimum Working Load
NBS Load Cell No. CD-12	1,000,000 lbf	October 1988	40460 lbf
NBS Load Cell No. CD-13	1,000,000 lbf	October 1988	35371 lbf
NBS Load Cell No. CD-14	1,000,000 lbf	October 1988	30803 lbf

The results of the testing machine calibration are given in Table 1. Table 2 shows the loading ranges, as defined in ASTM Method E4 for errors not exceeding 1 percent.

For the Director
National Institute of Standards and Technology

Donald S. Blomquist, Chief
Automated Production Technology Division
Center for Manufacturing Engineering

Attachment

U. S. Department of Commerce
National Institute of Standards and Technology
Gaithersburg, MD 20899

Table 1 - Calibration of Bliss 12,000,000 lbf Universal Testing Machine
Analog Ranges (Ascending-Loads and Descending-Loads as Implied Below
Calibrated October 21-24, 1988

0 - 600,000 lbf Scale Range		0 - 1,200,000 lbf Scale Range		0 - 3,000,000 lbf Scale Range		0 - 6,000,000 lbf Scale Range		0 - 12,000,000 lbf Scale Range	
Machine Reading (lbf)	Machine Error (%)	Machine Reading (lbf)	Machine Error (%)	Machine Reading (lbf)	Machine Error (%)	Machine Reading (lbf)	Machine Error (%)	Machine Reading (lbf)	Machine Error (%)
50 000	-2.45	100 000	-0.95	250 000	-2.26	250 000	-2.21	500 000	+0.20
100 000	-1.53	200 000	-0.95	500 000	-0.84	500 000	-0.55	1 000 000	-0.16
150 000	-1.00	300 000	-0.70	750 000	-0.45	750 000	-0.41	1 500 000	+0.12
200 000	-0.44	400 000	-0.31	1 000 000	-0.19	1 000 000	-0.08	2 000 000	+0.14
250 000	+0.02	500 000	-0.12	1 250 000	+0.12	1 250 000	-0.14	2 500 000	+0.03
300 000	+0.32	600 000	-0.02	1 500 000	+0.22	1 500 000	+0.04	3 000 000	+0.23
350 000	+0.47	700 000	+0.10	1 750 000	+0.22	1 750 000	+0.21	2 500 000	+0.28
400 000	+0.56	800 000	+0.16	2 000 000	+0.16	2 000 000	+0.24	2 000 000	+0.27
450 000	+0.58	900 000	+0.13	2 250 000	+0.11	2 250 000	+0.34	1 500 000	0.00
500 000	+0.64	1 000 000	+0.19	2 500 000	+0.04	2 500 000	+0.36	1 000 000	-0.05
550 000	+0.62	1 100 000	+0.15	2 750 000	-0.14	2 750 000	+0.22	500 000	-1.00
600 000	+0.60	1 200 000	+0.16	3 000 000	-0.25	3 000 000	+0.34		
550 000	+0.69	1 100 000	+0.51	2 750 000	+0.01	2 750 000	+0.51		
500 000	+0.76	1 000 000	+0.54	2 500 000	+0.13	2 500 000	+0.51		
450 000	+0.77	900 000	+0.62	2 250 000	+0.22	2 250 000	+0.49		
400 000	+0.79	800 000	+0.66	2 000 000	+0.24	2 000 000	+0.31		
350 000	+0.79	700 000	+0.64	1 750 000	+0.42	1 750 000	+0.26		
300 000	+0.87	600 000	+0.63	1 500 000	+0.38	1 500 000	+0.08		
250 000	+0.70	500 000	+0.43	1 250 000	+0.27	1 250 000	-0.05		
200 000	+0.59	400 000	0.00	1 000 000	+0.21	1 000 000	-0.16		
150 000	+0.43	300 000	0.00	750 000	-0.10	750 000	-0.19		
100 000	+0.32	200 000	0.00	500 000	-0.65	500 000	-0.74		
50 000	+0.03	100 000	+0.05	250 000	-1.23	250 000	-0.98		

U. S. Department of Commerce
National Institute of Standards and Technology
Gaithersburg, MD 20899

TABLE 2 - Loading Ranges
Bliss 12,000,000 lbf Universal Testing Machine
for errors not exceeding one percent

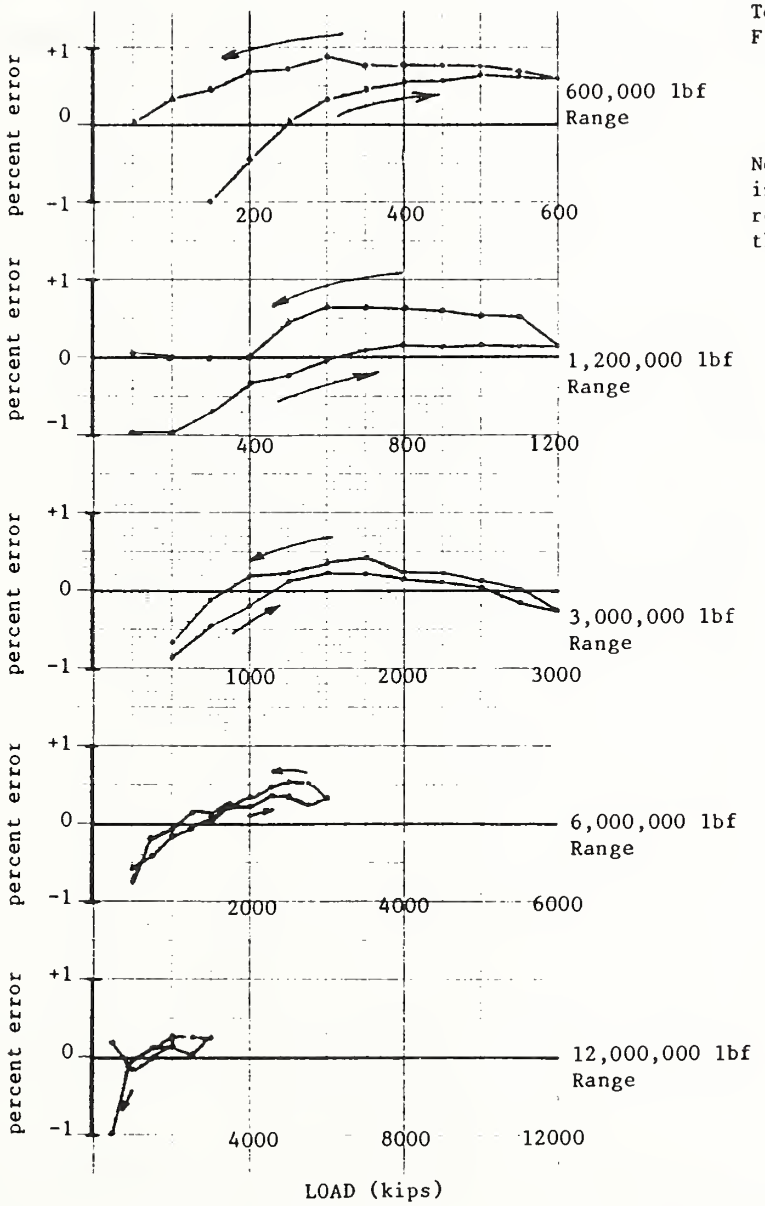
Calibrated October 21-24, 1988

Analog Scale Range (lbf)	Ascending Loading Range (lbf)	Descending Loading Range (lbf)
0 - 600 000	150 000 - 600 000	600 000 - 50 000
0 - 1 200 000	100 000 - 1 200 000	1 200 000 - 100 000
0 - 3 000 000	500 000 - 3 000 000	3 000 000 - 500 000
0 - 6 000 000	500 000 - 3 000 000	3 000 000 - 250 000
0 - 12 000 000	500 000 - 3 000 000	3 000 000 - 500 000

Bliss Testing Machine

Calibrated October 21-24, 1988
By: National Institute of Science and Technology
In Accordance with ASTM Method E-4

Capacity: 12,000,000 lbf
Compression: 6,000,000 lbf
Tension: 4,000,000 lbf
Flexure



Note - A positive error indicates that the machine reading is greater than the applied load.

E-4 Loading Range (for Errors Not Exceeding One Percent)

Scale Range lbf	Ascending Loading Range lbf	Descending Loading Range lbf
600,000	150,000 - 600,000	600,000 - 50,000
1,200,000	100,000 - 1,200,000	1,200,000 - 100,000
3,000,000	500,000 - 3,000,000	3,000,000 - 500,000
6,000,000	500,000 - 3,000,000	3,000,000 - 250,000
12,000,000	500,000 - 3,000,000	3,000,000 - 500,000

Donald S. Blomquist, Chief
Automated Production Technology Div.
Center for Manufacturing Engineering

NBS-114A (REV. 2-80)

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5. AUTHOR(S)

Long T. Phan and H. S. Lew

6. PERFORMING ORGANIZATION *(If joint or other than NBS, see instructions)*

NATIONAL BUREAU OF STANDARDS
U.S. DEPARTMENT OF COMMERCE
GAITHERSBURG, MD 20899

7. Contract/Grant No.

8. Type of Report & Period Covered

9. SPONSORING ORGANIZATION NAME AND COMPLETE ADDRESS *(Street, City, State, ZIP)*

10. SUPPLEMENTARY NOTES

☐ Document describes a computer program; SF-185, FIPS Software Summary, is attached.

11. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here)*

The National Institute of Standards and Technology carried out four tests of one-third scale impact limiters for Transnuclear, Inc. The impact limiters were tested under static load in a 12-million pound capacity universal testing machine. Energy absorbed by the impact limiters, as indicated by the area under the load-deformation curve, was computed and compared with the required value which was specified for each specimen by Transnuclear, Inc. The testing was terminated when the absorbed energy value exceeded the required value.

12. KEY WORDS *(Six to twelve entries; alphabetical order; capitalize only proper names; and separate key words by semicolons)*

energy absorption; impact limiters; static load tests

13. AVAILABILITY

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