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STRUCTURAL ENGINEERING
MECHANICS AND MATERIALS

CYCLIC TESTING OF THREE FULL-SCALE STEEL BEAM-COLUMN CONNECTIONS

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INTRODUCTION

This report summarizes the results of seismic-type cyclic testing of three full scale beam-column connection specimens. The specimens were designed by ADP Fluor Daniel, and tested in the Structural Testing Laboratory of the Department of Civil and Environmental Engineering of University of California at Berkeley. The test program was conducted under Service to Industry Project No. ES-2076. The Principal Investigator was Professor Egor P. Popov.

TEST SPECIMEN

Three identical beam/column connection specimens were fabricated by Bostrom-Bergen of California. The beams were fabricated from a W36x245 section of A36 steel, the columns were fabricated from a W14x398 section of A572-Gr50 steel. Figure 1a shows the specimen dimensions and geometry. Figure 1b gives some important welding details.

TEST SETUP AND INSTRUMENTATION

The test setup was designed to test specimens in a horizontal position, as shown in Figure 2. The support system consisted of three reinforced concrete reaction blocks fixed on the floor with high strength rods. The column was tightened to the reaction blocks at the ends by prestressed steel rods. The "bottom" end support restrained column displacement in two directions and simulated a hinged connection. The column "top" end support simulated a roller support.

Load was applied to the cantilever beam end by a hydraulic actuator through a clevis bolted to the beam end plate. The actuator has a displacement range of ± 6 inches and a capacity of ± 350 kips when controlled via a 3,000 psi servovalve, and a capacity of ± 500 kips with a manually operated pump. To prevent out of plane motion of the beam, a horizontal bracing system was provided near the beam end. The photograph in Figure 3 shows the test setup.

Instrumentation consisted of a load cell to measure the applied load, linear potentiometers to capture the global displacement response of the specimen, and strain gages and rosettes to measure the strain in critical zones. Figures 4a and 4b show the location of measuring instruments. The channel list is presented in Table 1.

LOADING HISTORY

The testing program was based on the ATC-24 document "Guidelines for Cyclic Seismic Testing of Steel Structures". The specimens were tested under displacement control, following a loading history consisting of stepwise increasing deformation cycles. Each loading step was defined by the peak deformation (actuator displacement) and by the number of cycles, as shown in Figure 5.

DATA PROCESSING

The specimen behavior was characterized by the following parameters: applied load, beam end displacement, plastic rotation, column deformation, panel zone shear deformation, and beam deflection. A test specimen layout, corresponding measurements, and chosen positive directions of applied load, measured displacements, and rotations are shown in Figure 6a.

Total displacement of the beam end (δ_{total}) is caused by the deformations of beam itself, column, and panel zone. As a result of the column and panel zone deformations, the panel zone rotates on a certain angle (Θ_c) and changes its initial configuration. The panel zone position and configuration for a deformed specimen are shown in Figure 6b. Four displacement measurements (δ_1, δ_2, δ_3, and δ_4) were used to compute the connection rotation (Θ_c) and panel zone shear deformation (γ). The total displacement of the beam end (δ_{total}) can be separated into three components: displacement due to deformation of the beam itself (δ_b), displacement caused by rigid connection rotation (δ_c), and the contribution from the panel zone shear (δ_γ) as shown in Figure 6c. These values were determined as follows:

- Beam end displacement: δ_{total}
- Total rotation: $\theta_{total} = \dfrac{\delta_{total}}{L}$

  where L is the "clear length" of the beam. For the ADP specimens this value was calculated with respect to the bottom cover plate face ($L = L_b - L_{cp}$).

- Connection rotation: $\theta_c = \dfrac{\delta_1 - \delta_2}{d_{12}}$

- Panel zone shear deformation: $\gamma = \dfrac{\sqrt{a^2 + b^2}}{2ab}(\delta_3 - \delta_4)$

  where a and b are the dimensions of the rectangular panel zone area used for measuring the panel zone shear deformation.

- Beam deflection: $\delta_b = \delta_{total} - \theta_c \cdot \left(L_b + \frac{d_c}{2} \right) + \gamma \frac{d_c}{2}$
- Total plastic rotation: $\left(\theta_{total} \right)_{pl} = \theta_{total} - \frac{M}{K_\theta}$

  where $M = Q(L_{act} - L_{cp})$ is the moment at the bottom cover plate edge and K_θ is the elastic stiffness determined from the M - θ_{total} curve. The unloading path of one of the elastic cycles below the reverse point was used to estimate stiffness, to avoid the influence of initial imperfections, clearances, hysteresis, etc. The range from $0.8M_{peak}$ to $0.2M_{peak}$ was fit in a least-squares sense to determine the slope of the elastic curve.

A set of programs for the MATLAB 4.0 environment was created to process data and to plot results in accordance with the procedure described above.

TEST RESULTS

SPECIMEN 1

Testing of the first specimen was started on November 21, 1995. Test execution was interrupted when the servocontrolled capacity was reached (327 kips), and resumed after switching the actuator to a manually operated pump. The specimen sustained all loading steps up to and including the 5" actuator displacement cycles without significant damage. Testing was stopped a second time during the execution of the first 6" cycle due to failure in the clevis connecting the beam end to the actuator. A new clevis was designed and fabricated. On December 12 the test was continued starting from the point were the first test was interrupted to complete three full 6" actuator displacement cycles.

The imposed actuator displacement history is shown in Figure 7. The last cycles were asymmetrical due to some initial offset of the beam end (~ 1.5"). The specimen behaved elastically during the 1" actuator displacement cycles. First yielding was noticed during the first 2" cycle. Some tearing in the corner of bottom cover plate-beam flange weld was noted during the 3" cycles. Small buckling of both beam flanges occurred during 4" cycles. A tear in the corner of the top cover plate-beam flange weld appeared after the first 5" cycle.

Plots of applied load versus beam end displacement response and moment versus plastic rotation are presented in Figures 8 and 9, respectively. Moment and plastic rotation were calculated with respect to the bottom cover plate edge. A graph showing the energy dissipated by the specimen versus cumulative actuator displacement is presented in Figure 10. Panel zone shear deformation is shown in Figure 11. Beam deflection (total beam end displacement minus column and panel zone contributions) is shown in Figure 12. Plots of local strains in selected points (measured by strain gages) are presented in Figures 13 - 26. Photographs in Figures 27 - 32 show deformation of the beam flanges and weld cracks during the test. Key parameters characterizing the specimen performance are given in Table 2.

SPECIMEN 2

Testing was performed during three days (December 13, 14, and 17, 1995). The imposed actuator displacement history is shown in Figure 33. The cycles starting from 5" actuator displacement were asymmetrical due to some initial offset of the beam end (~ 1.5"). Plots of applied load versus beam end displacement response and moment versus plastic rotation are presented in Figures 34 and 35, respectively. A graph showing the energy dissipated by the specimen during this test versus cumulative actuator displacement is presented in Figure 36. Panel zone shear deformation is shown in Figure 37. Beam deflection is shown in Figure 38. Plots of local strains in selected points are presented in Figures 39 - 52.

The specimen failed suddenly during the negative excursion of the first 6" cycle. The top cover plate, both column flanges, and the column web were fractured. Photographs in Figures 53 - 58 show fracture of the specimen ADP2.

Key parameters characterizing the specimen performance are given in Table 2.

SPECIMEN 3

The test was performed in two days (December 20 and 21, 1995).

The imposed actuator displacement history is shown in Figure 59. Plots of applied load versus beam end displacement response and moment versus plastic rotation are presented in Figures 60 and 61, respectively. A graph showing the energy dissipated by the specimen during this test versus cumulative actuator displacement is presented in Figure 62. Panel zone shear deformation is shown in Figure 63. Beam deflection is shown in Figure 64. Plots of local strains in selected points are presented in Figures 65 - 78.

The specimen failed suddenly during the negative excursion of the first 4" cycle. The column flange was fractured completely starting from the junction of top beam flange - cover plate - column flange. Fracture was very similar to that for the specimen 2 but a crack in the column web developed outside the panel zone and the top cover plate was not fractured. Photographs in Figures 79 -82 show fracture of the specimen ADP3.

Key parameters characterizing the specimen performance are given in Table 2.

COMMENTS

Inspection of the damaged specimens after the tests seems to indicate that some of the specimens were not fabricated following the welding specifications shown in Figure 1b. This might explain the specimen behavior differences observed during the tests.

TABLE 1: CHANNEL - INSTRUMENT LIST

Box 17 (I/O Connector 1)

channel	cont. #	label	device	description	miscellaneous
1	1	KTEMPA	tempo	temposonic	
2	2	KLC	l.cell	load cell	
3	3	KEMP3		spare	
4	4	KEMP4		spare	
5	5	KEMP5		spare	
6	6	KEMP6		spare	
7	7	KEMP7		spare	
8	8	KEMP8		spare	
9	9	KEMP9		spare	
10	10	KEMP10		spare	
11	11	KEMP11		spare	
12	12	KEMP12		spare	
13	13	KEMP13		spare	
14	14	KEMP14		spare	
15	15	KEMP15		spare	
16	16	KP1B17	trafo	power supply	

Box 18 (I/O Connector 10)

channel	cont. #	label	device	description	miscellaneous
17	1	KSGTF1	sg 120	top flange 1 (edge)	
18	2	KSGTF2	sg 120	top flange 2	
19	3	KSGTF3	sg 120	top flange 3	
20	4	KSGTF4	sg 120	top flange 4 (axis)	
21	5	KSGTF5	sg 120	top flange 5 (control)	
22	6	KSGTP1	sg 120	top plate 1(edge)	
23	7	KSGTP2	sg 120	top plate 2	
24	8	KSGTP3	sg 120	top plate3 (axis)	
25	9	KSGTP4	sg 120	top plate 4 (control)	
26	10	KSGTFP	sg 120	top flange - plate	
27	11	KSGCF1	sg 120	col fl top front top	
28	12	KSGCF2	sg 120	col fl top front bot	
29	13	KSGCF3	sg 120	col fl top back top	
30	14	KSGCF4	sg 120	col fl top back bot	
31	15	KEMP31		spare	
32	16	KP1B18	trafo	power supply	

Box 19 (I/O Connector 11)

channel	cont. #	label	device	description	miscellaneous
33	1	KSGBF1	sg 120	bot flange 1 (edge)	
34	2	KSGBF2	sg 120	bot flange 2	
35	3	KSGBF3	sg 120	bot flange 3	
36	4	KSGBF4	sg 120	bot flange 4 (axis)	
37	5	KSGBF5	sg 120	bot flange 5 (control)	
38	6	KSGBP1	sg 120	bot plate 1 (edge)	
39	7	KSGBP2	sg 120	bot plate 2	
40	8	KSGBP3	sg 120	bot plate 3	
41	9	KSGBP4	sg 120	bot plate 4	
42	10	KSGBP5	sg 120	bot plate 5 (control)	
43	11	KSGCF5	sg 120	col fl bot front top	
44	12	KSGCF6	sg 120	col fl bot front bot	
45	13	KSGCF7	sg 120	col fl bot back top	
46	14	KSGCF8	sg 120	col fl bot back bot	
47	15	KEMP47		spare	
48	16	KP1B29	trafo	power supply	

Box 20 (I/O Connector 12)

channel	cont. #	label	device	description	miscellaneous
49	1	KRPZCV	sg 120	panel zone center ver	
50	2	KRPZCD	sg 120	panel zone center dia	
51	3	KRPZCH	sg 120	panel zone center hor	
52	4	KRCATV	sg 120	col fl axis top ver	
53	5	KRCATD	sg 120	col fl axis top dia	
54	6	KRCATH	sg 120	col fl axis top hor	
55	7	KRCABV	sg 120	col fl axis bot ver	
56	8	KRCABD	sg 120	col fl axis bot dia	
57	9	KRCABH	sg 120	col fl axis bot hor	
58	10	KSGWT1		beam web top E	
59	11	KSGWT2		beam web top W	
60	12	KSGWB1		beam web bottom E	
61	13	KSGWB2		beam web bot W	
62	14	KEMP62		spare	
63	15	KEMP63		spare	
64	16	KP1B20	trafo	power supply	

Box 29 (I/O Connector 13)

channel	cont. #	label	device	description	miscellaneous
129	1	KEM129		spare	
130	2	KEM130		spare	
131	3	KPCNRT	spot 4"	cnct. rotation top	
132	4	KPCNRB	spot 4"	cnct. rotation bot	
133	5	KPWBST	spot 2"	web shear NE to SW	
134	6	KPWBSB	spot 2"	web shear SE to NW	
135	7	KEM135		spare	
136	8	KEM136		spare	
137	9	KPNSTT	spot 2"	north seat top	
138	10	KPNSTB	spot 2"	north seat bot	
139	11	KPNSTA	spot 2"	north seat axial	
140	12	KPSSTT	spot 2"	south seat top	
141	13	KPSSTB	spot 2"	south seat bot	
142	14	KWPTA	wpot 15"	control act displ	
143	15	KWPTD	wpot 15"	control tip dipl.	
144	16	KP2B29	trafo	power supply	

sg 120: 120 Ω strain gage
wpot 15": wire pot with 15" stroke
spot 2": stick pot with 2" stroke
spot 4": stick pot with 4" stroke

TABLE 2: SUMMARY OF TEST RESULTS

	ADP1	ADP2	ADP3
Yield Load, [kips]	256	267	267
Beam End Displacement @Yield, [inch]	0.9	0.97	0.93
Max Measured Actuator Displacement, [inch]	+6.38 -4.42	+6.62 -4.12	+3.7 -3.9
Max Beam End Displacement, [inch]	+5.83 -4.11	+6.06 -3.8	+3.4 -3.64
Beam End Displacement @Failure, [inch]	-	-1.6	-3.2
Maximum Load, [kips]	+495 -492	+495 -486	+450 -459
Load @Max Displacement, [kips]	468	487	450
Load @Failure, [kips]	-	-459	-459
Max Plastic Rotation, [rad]	0.043	0.044	0.019
Plastic Rotation Range, [rad]	+0.043 -0.025	+0.044 -0.022	+0.019 -0.017
Beam End Displacement @ 3% Plastic Rotation	4.67	4.72	-
Dissipated Energy, [kip-inch]	35, 000	24, 000	8, 500

FIGURE 1A: SPECIMEN GEOMETRY

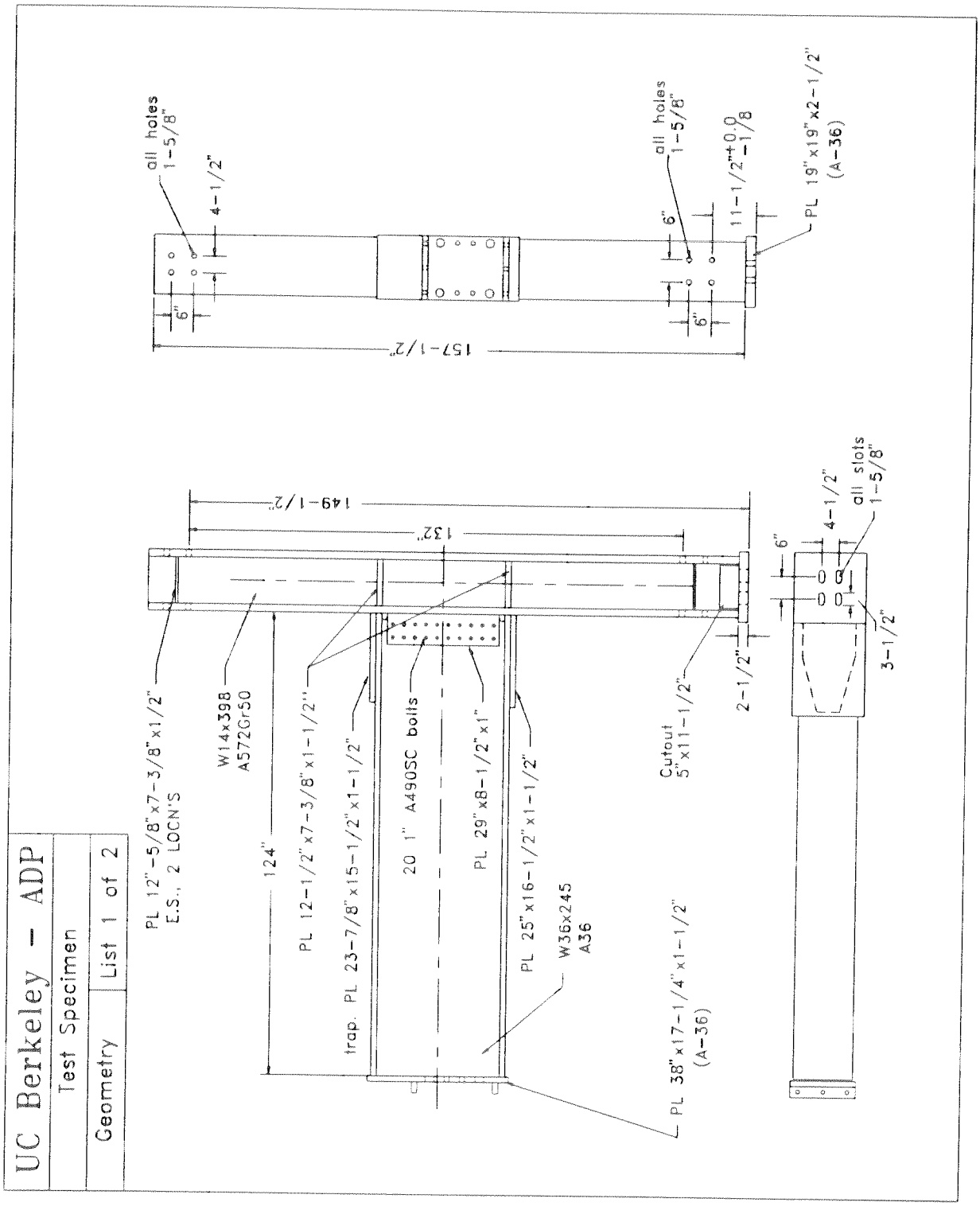


FIGURE 1B: WELDING DETAILS

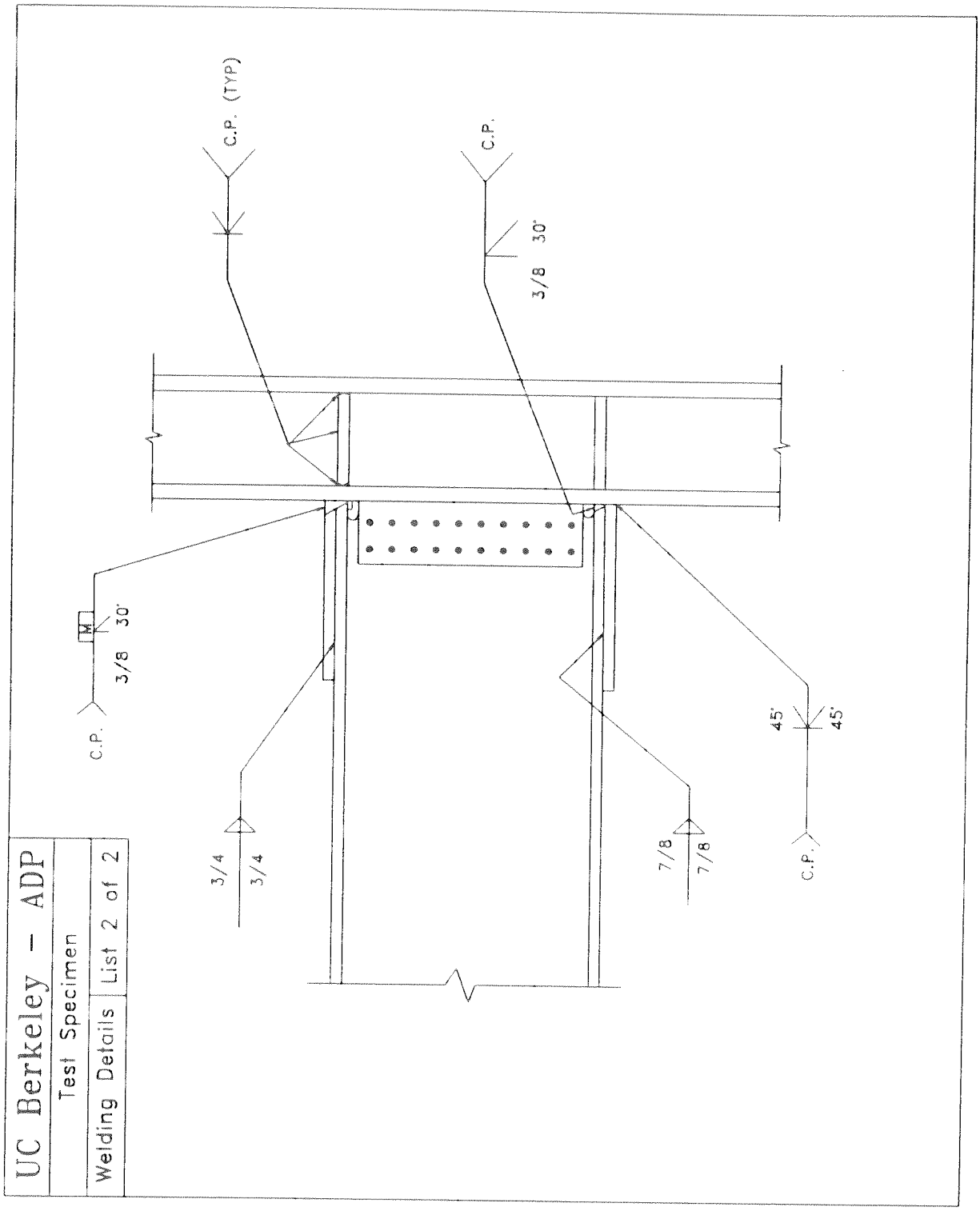


FIGURE 2: TEST SETUP -- FLOOR PLAN

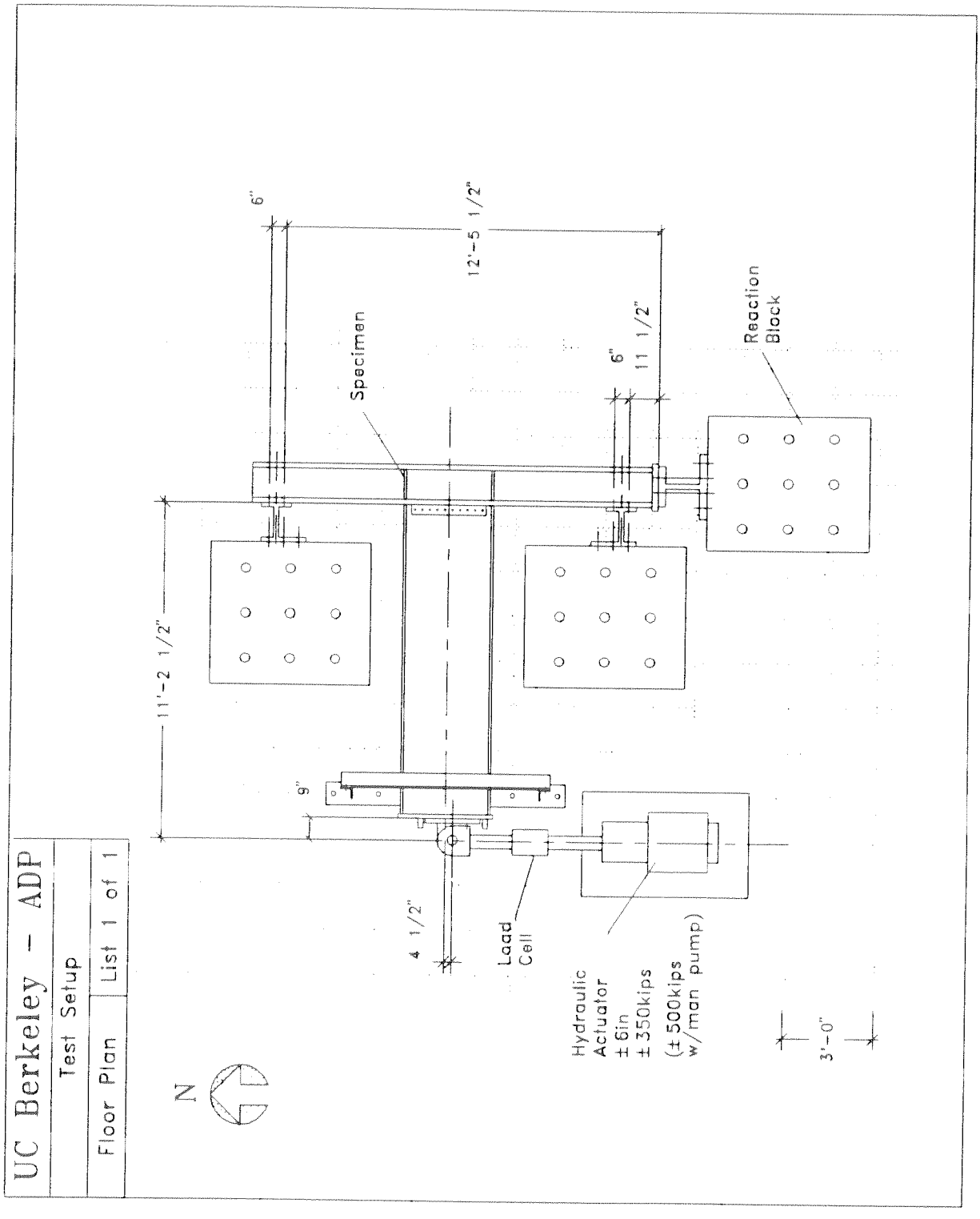


FIGURE 3: PHOTOGRAPH SHOWING A SPECIMEN TESTING

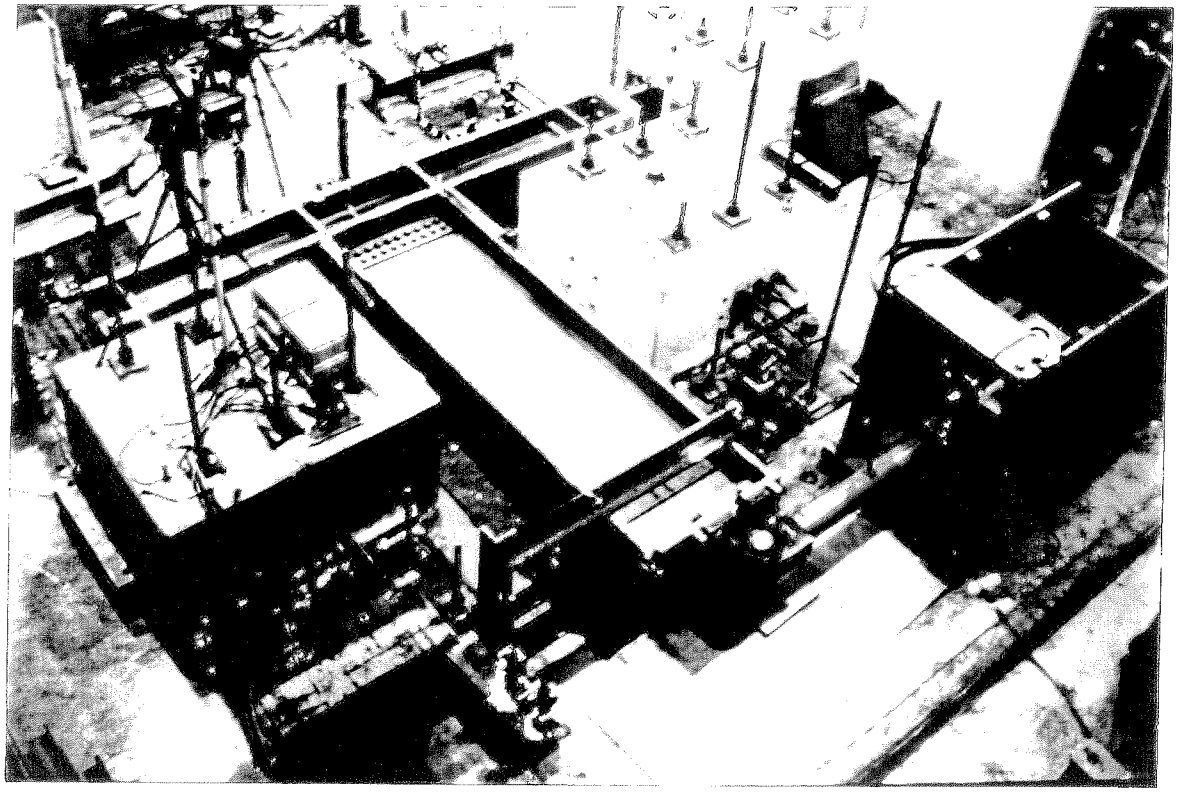


FIGURE 4A: SPECIMEN INSTRUMENTATION -- POTENTIOMETERS

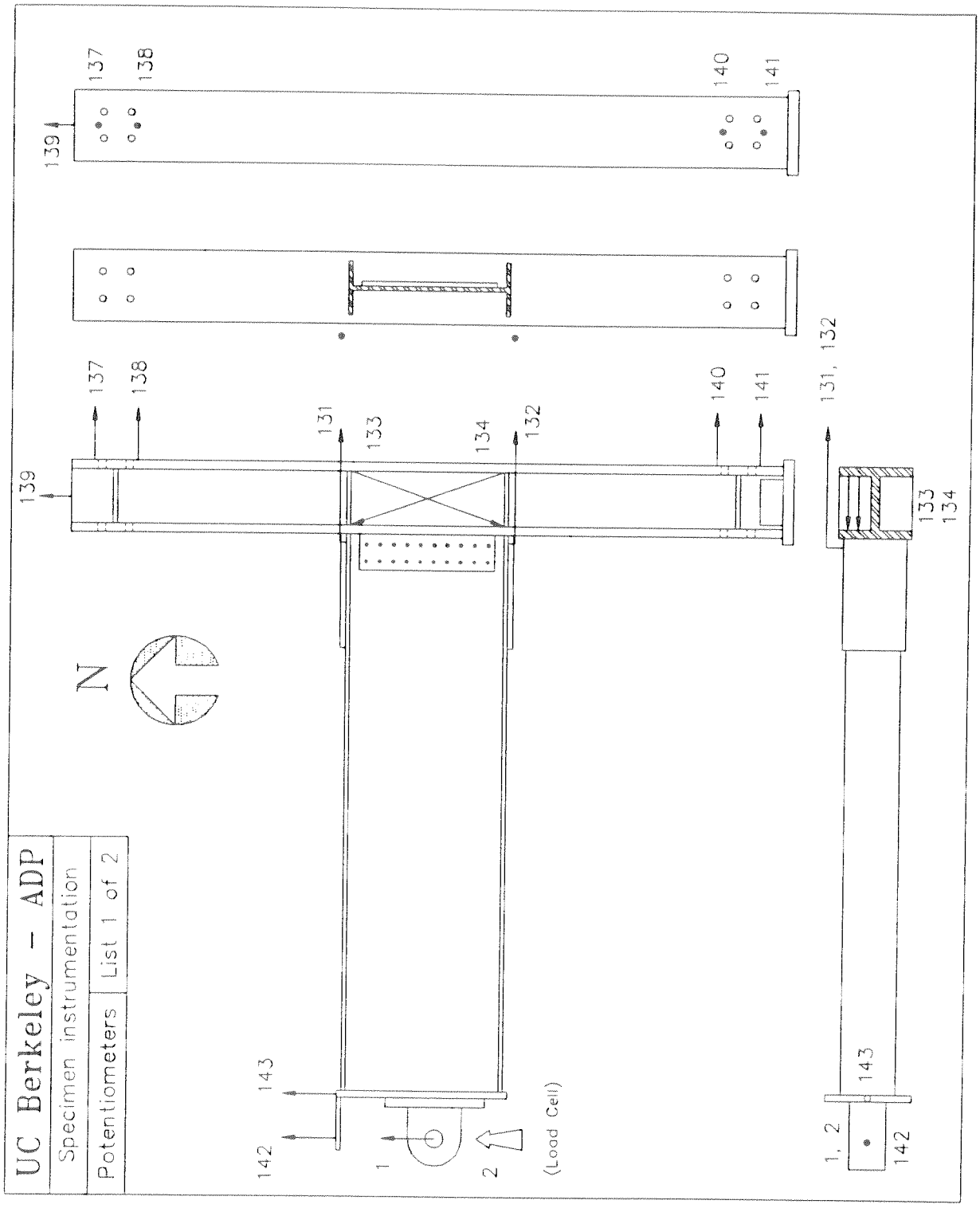


FIGURE 4B: SPECIMEN INSTRUMENTATION -- STRAIN GAGES

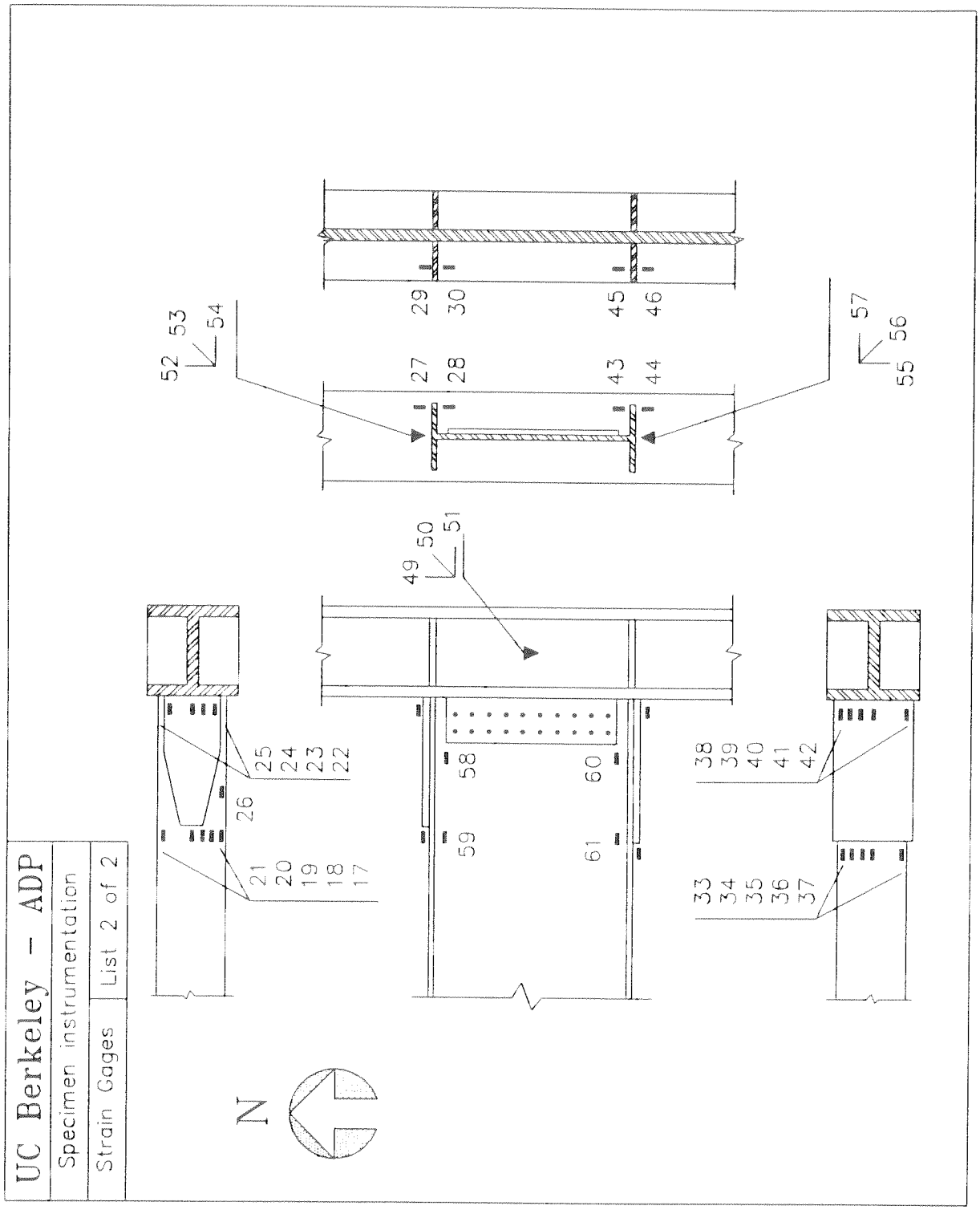
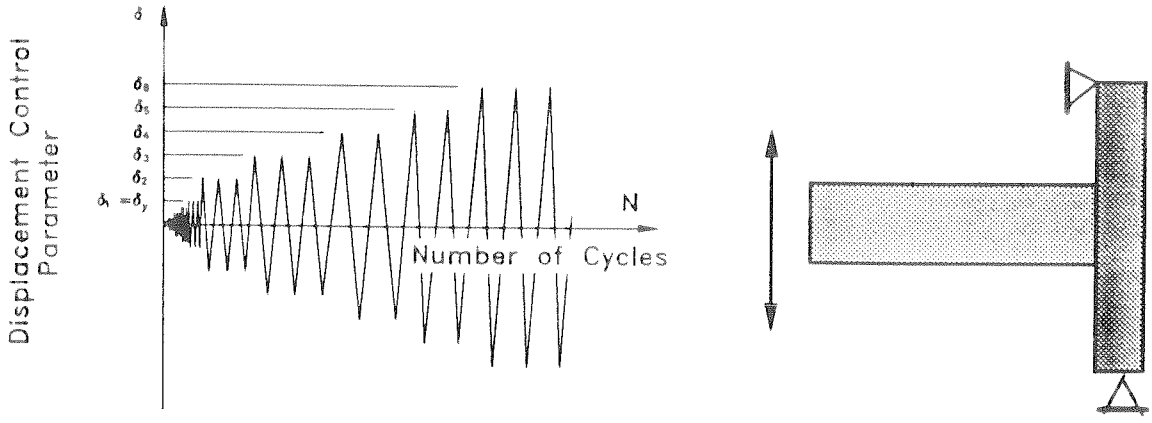


FIGURE 5: TEST PROGRAM



LOAD STEP	PEAK DISPLACEMENT [inch]	NUMBER OF CYCLES	COMMENTS
1	0.10	2	Equipment Test
2	0.25	3	
3	0.50	3	
4	0.75	3	
5	1.00	3	Reference Point
6	2.00	3	
7	3.00	3	
8	4.00	2	
9	5.00	2	
10	6.00	n	To Failure

FIGURE 6A: TEST SPECIMEN -- REFERENCE DIMENSIONS AND MEASUREMENTS

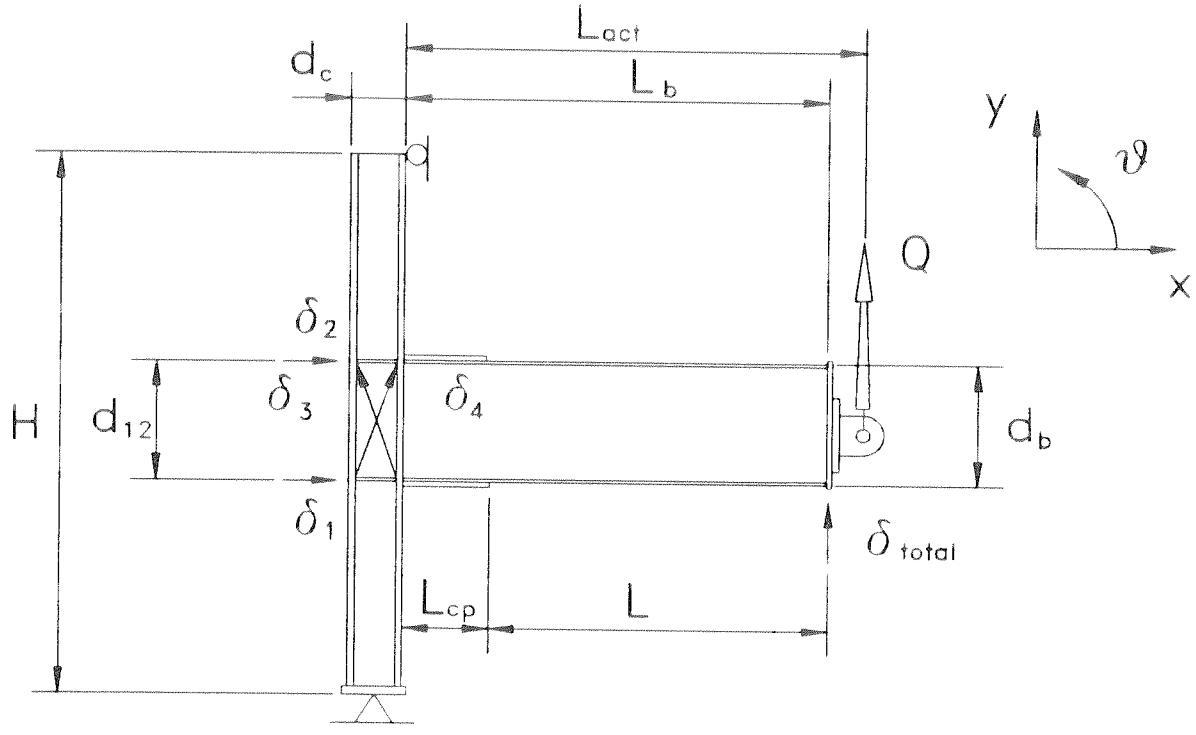


FIGURE 6B: PANEL ZONE DEFORMATION

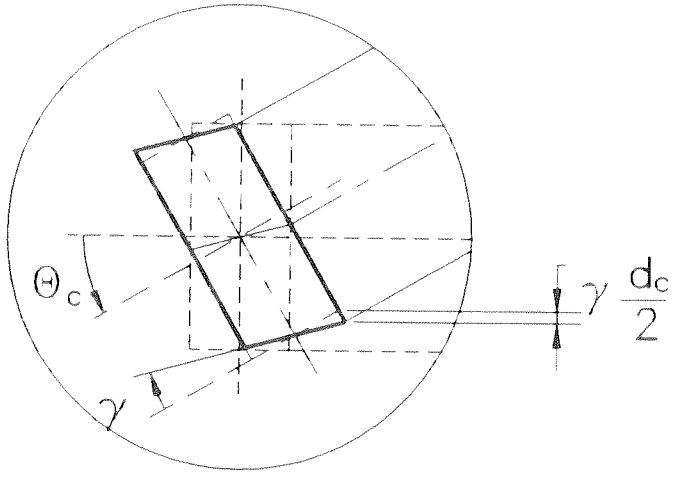


FIGURE 6C: CONTRIBUTIONS IN TOTAL BEAM END DISPLACEMENT

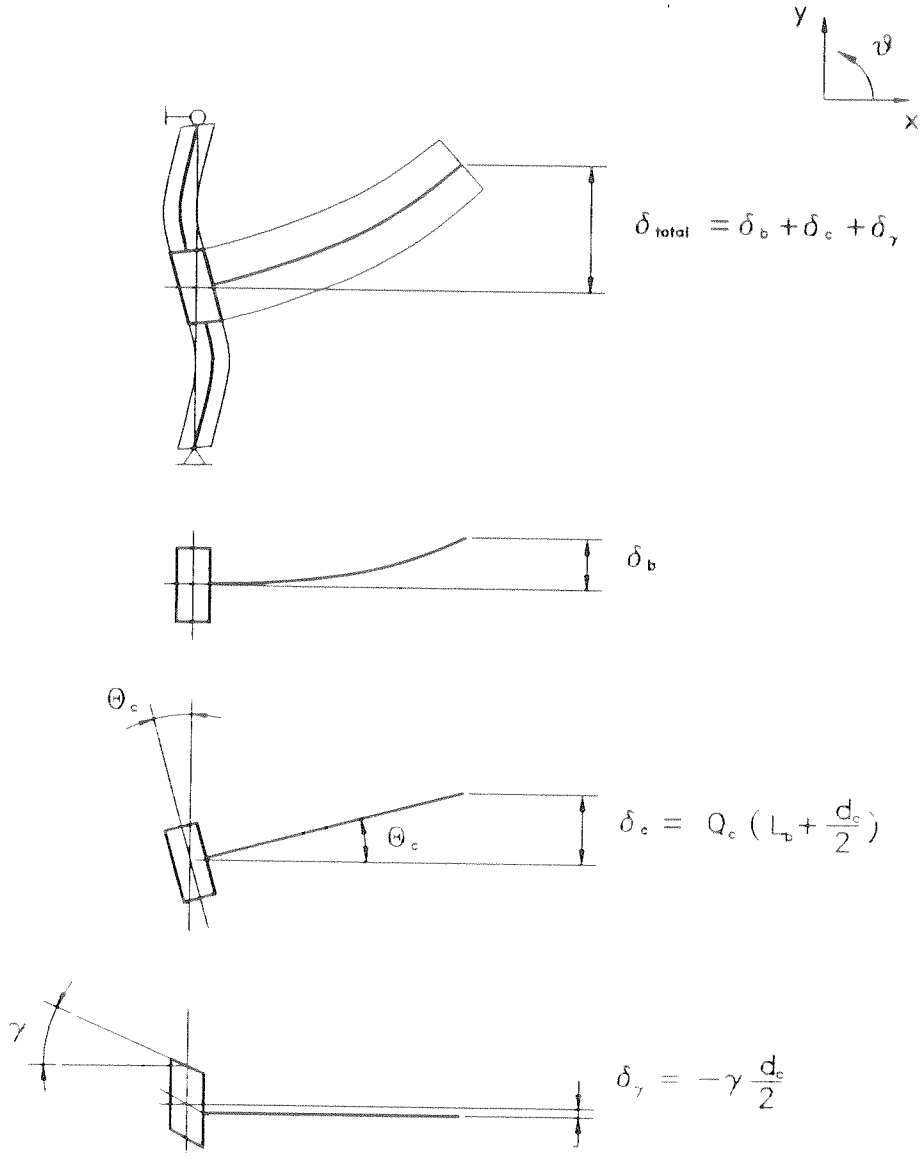


FIGURE 7: IMPOSED LOADING HISTORY -- ACTUATOR DISPLACEMENT

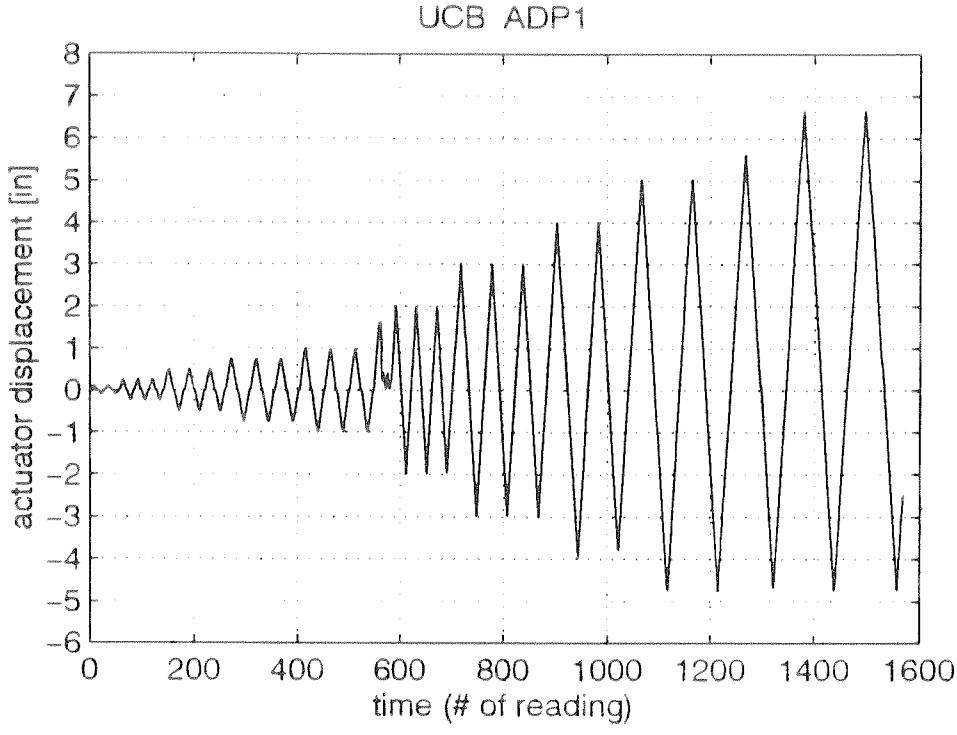


FIGURE 8: APPLIED LOAD / BEAM END DISPLACEMENT RESPONSE

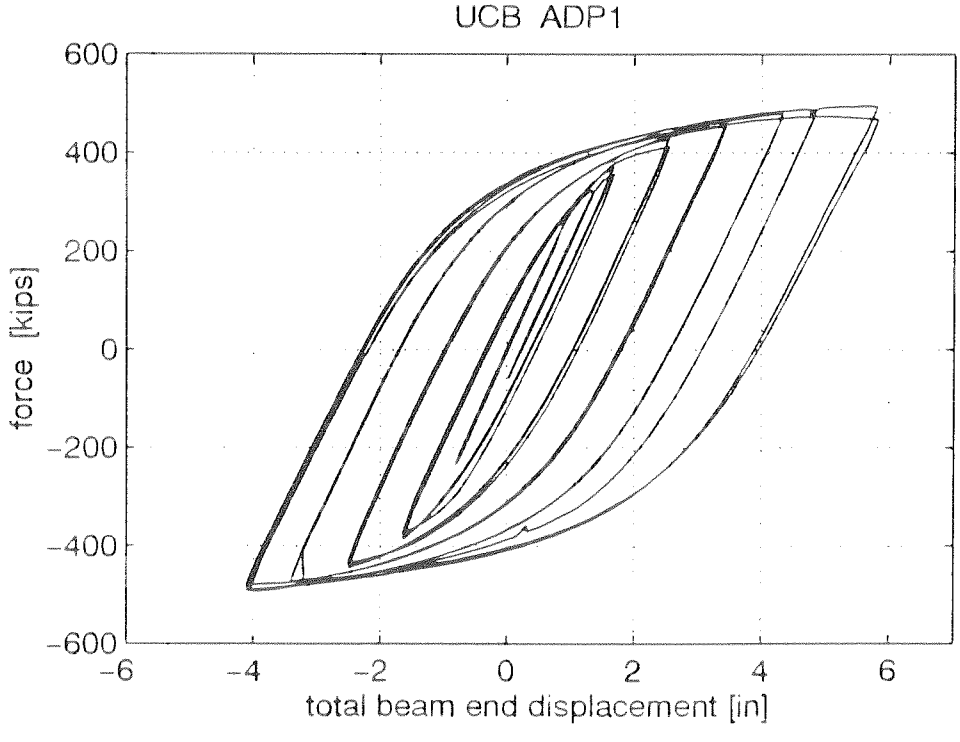


FIGURE 9: PLASTIC ROTATION VERSUS MOMENT @ COVER PLATE EDGE

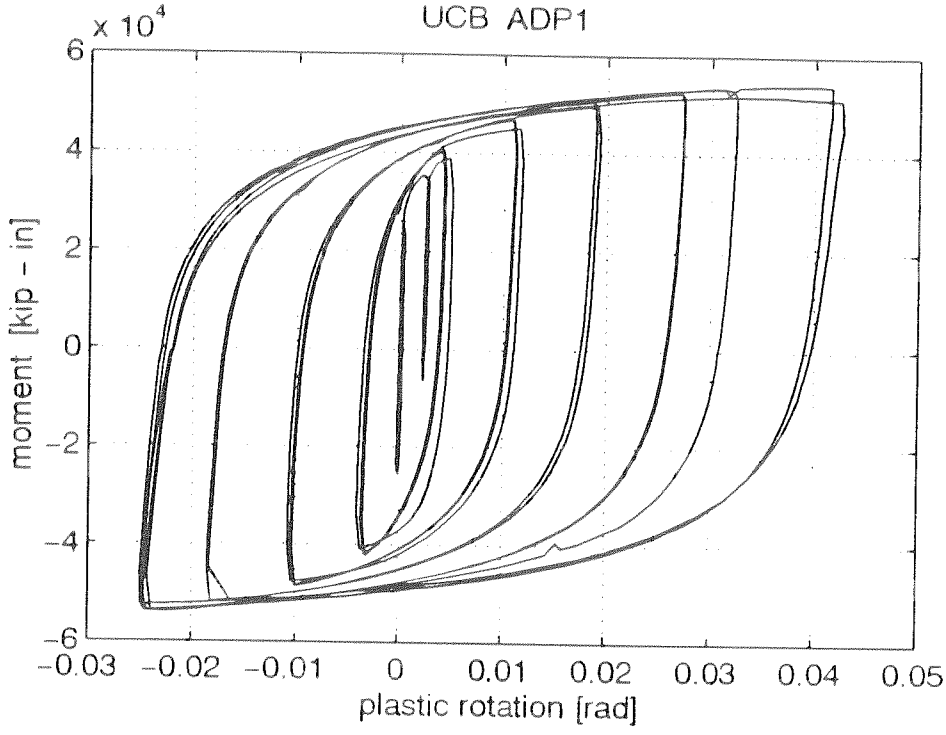


FIGURE 10: DISSIPATED ENERGY

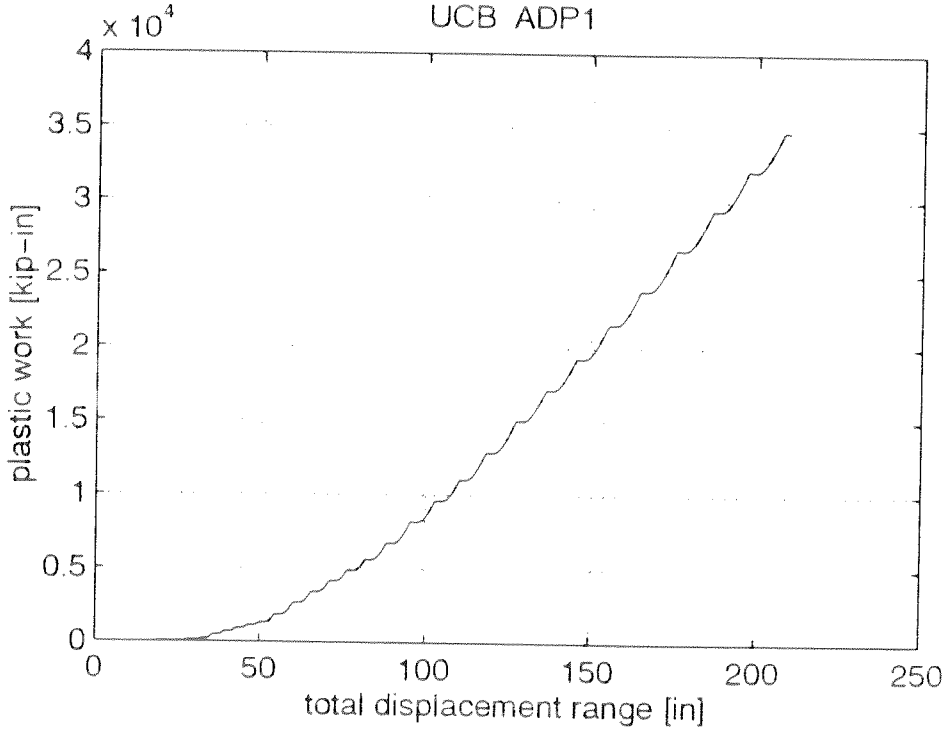


FIGURE 11: PANEL ZONE SHEAR DEFORMATION

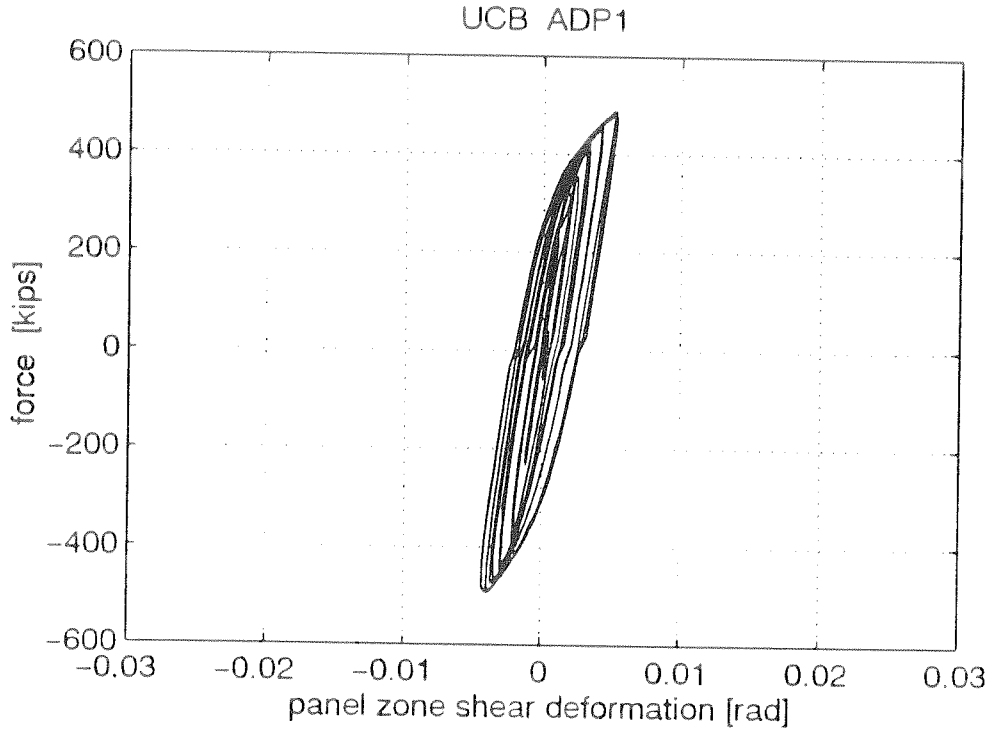


FIGURE 12: BEAM CONTRIBUTION IN TOTAL DISPLACEMENT

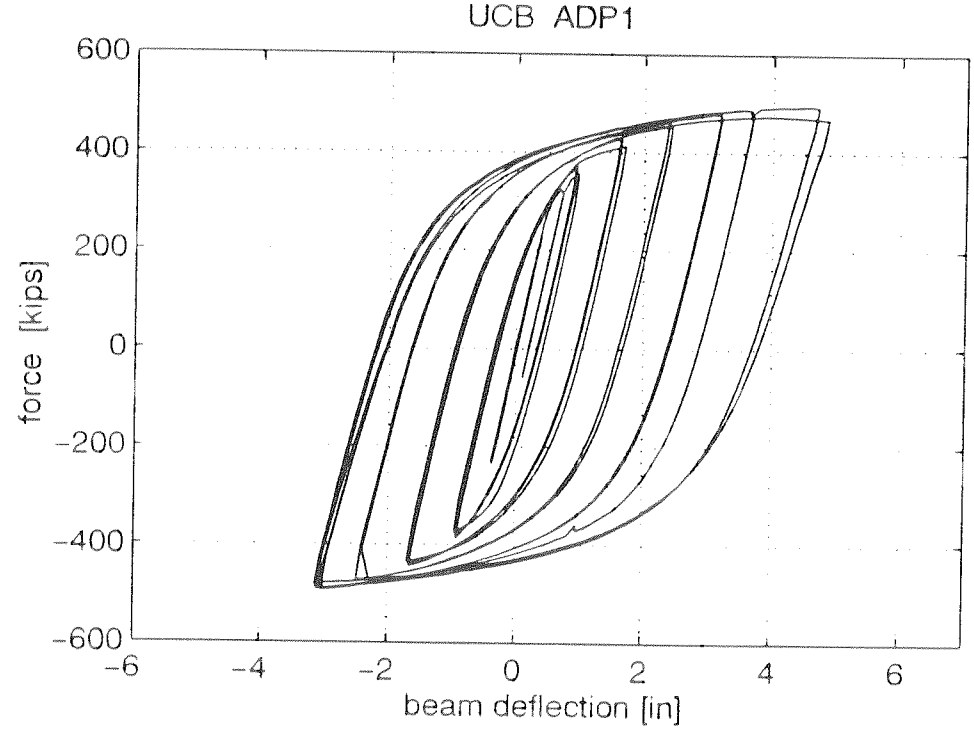


FIGURE 13: LOCAL RESPONSE -- TOP BEAM FLANGE (EDGE)

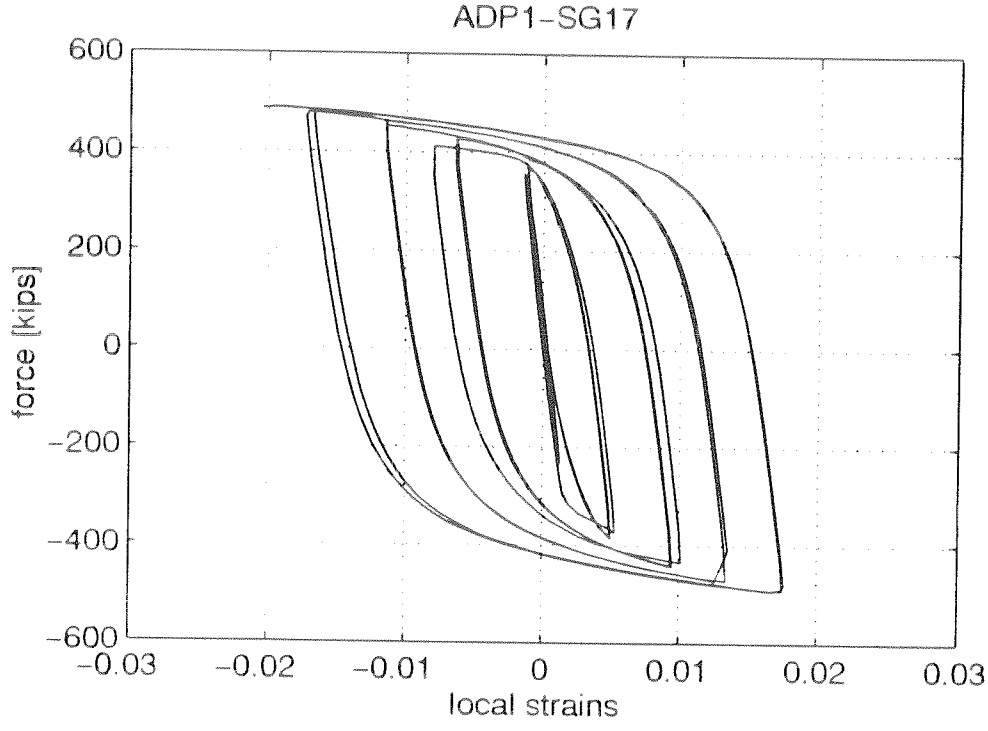


FIGURE 14: LOCAL RESPONSE -- TOP BEAM FLANGE (AXIS)

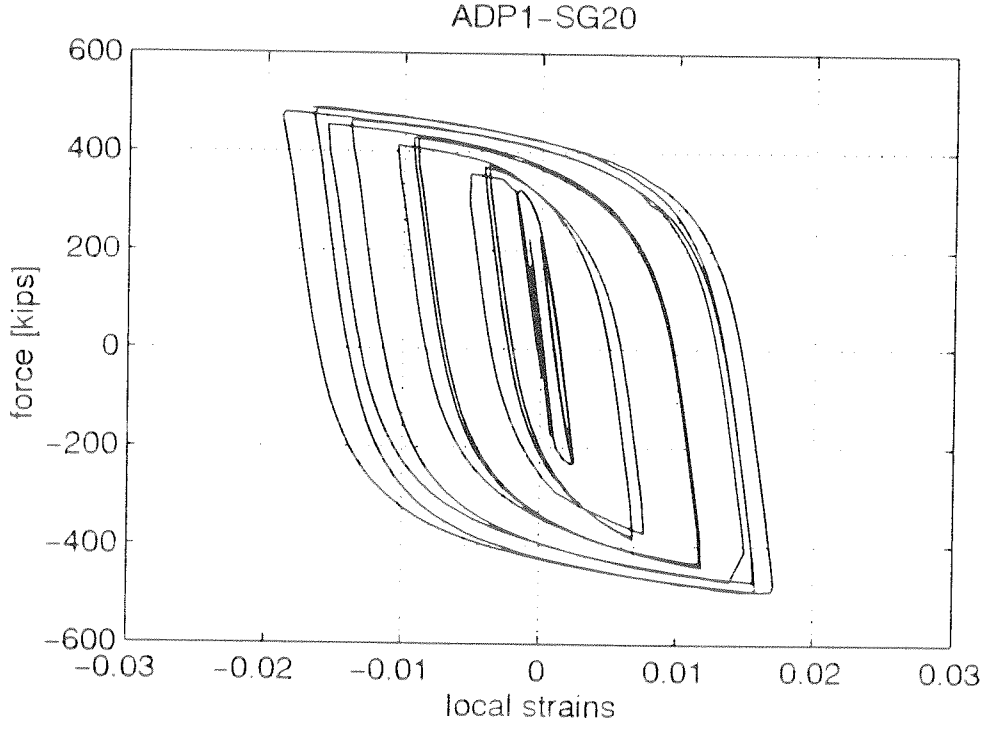


FIGURE 15: LOCAL RESPONSE -- BOTTOM BEAM FLANGE (EDGE)

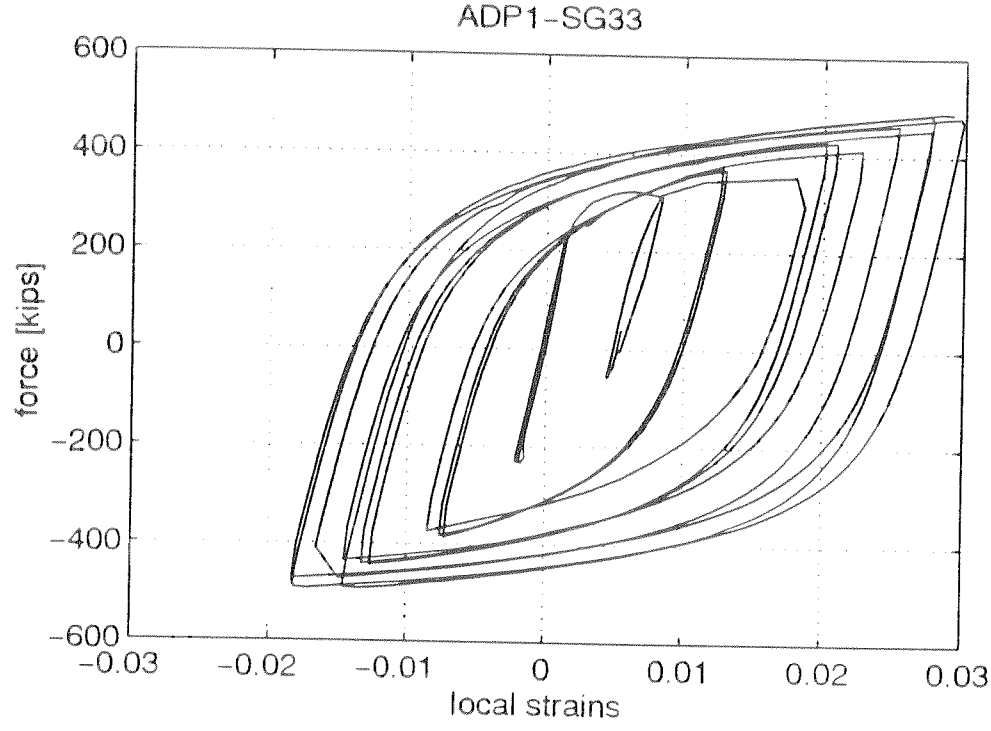


FIGURE 16: LOCAL RESPONSE -- BOTTOM BEAM FLANGE (AXIS)

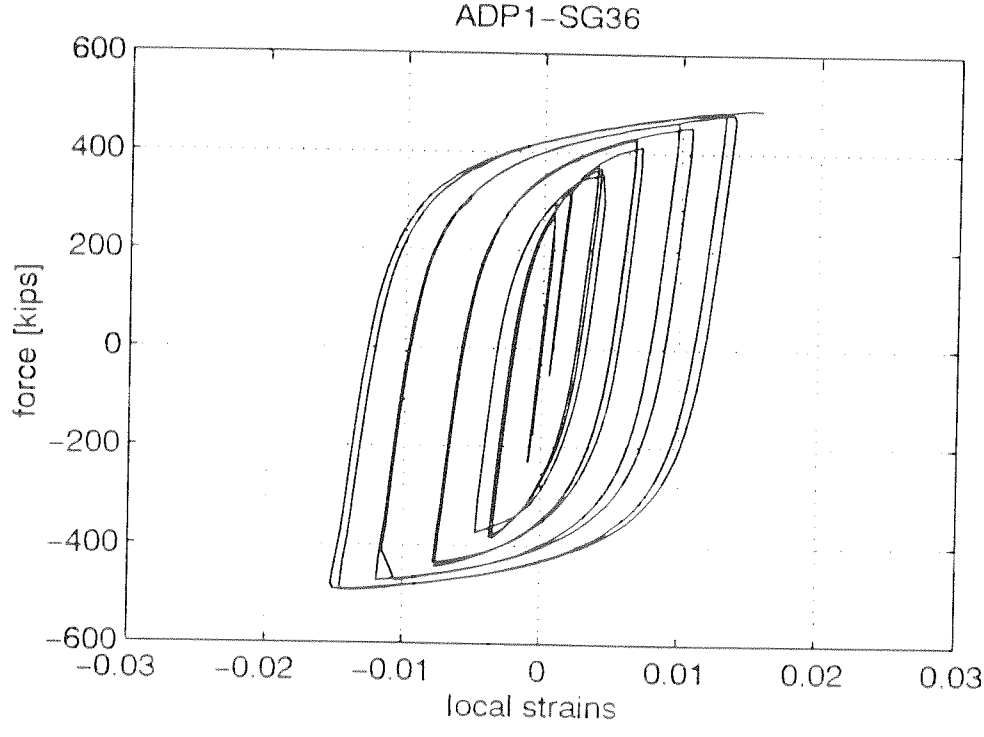


FIGURE 17: LOCAL RESPONSE -- TOP COVER PLATE (EDGE)

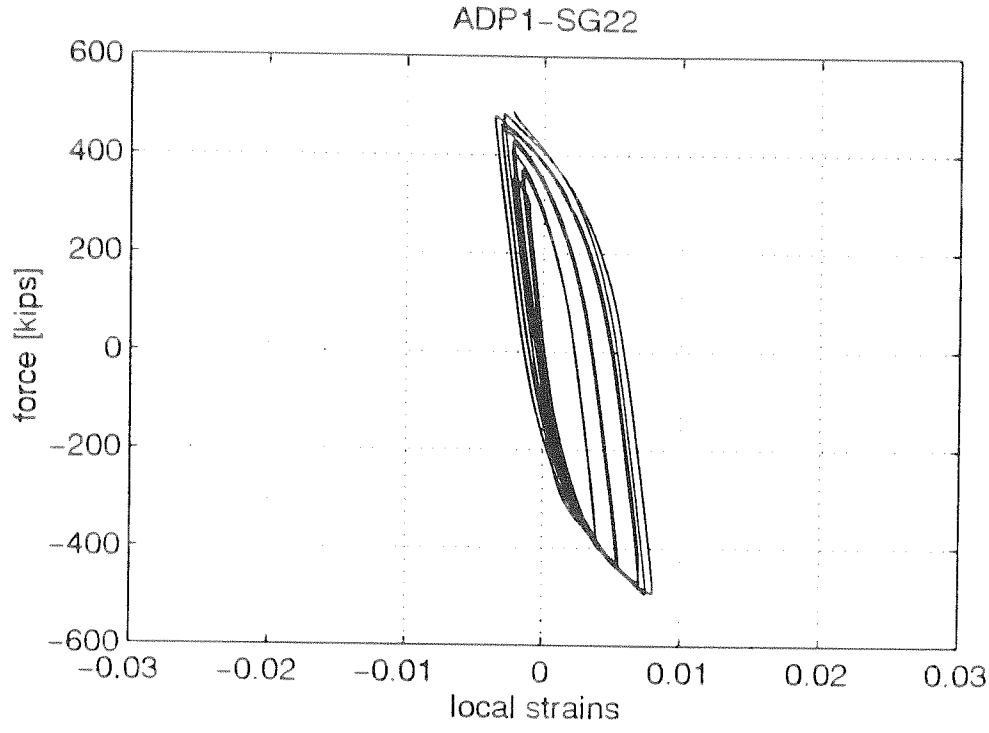


FIGURE 18: LOCAL RESPONSE -- TOP COVER PLATE (AXIS)

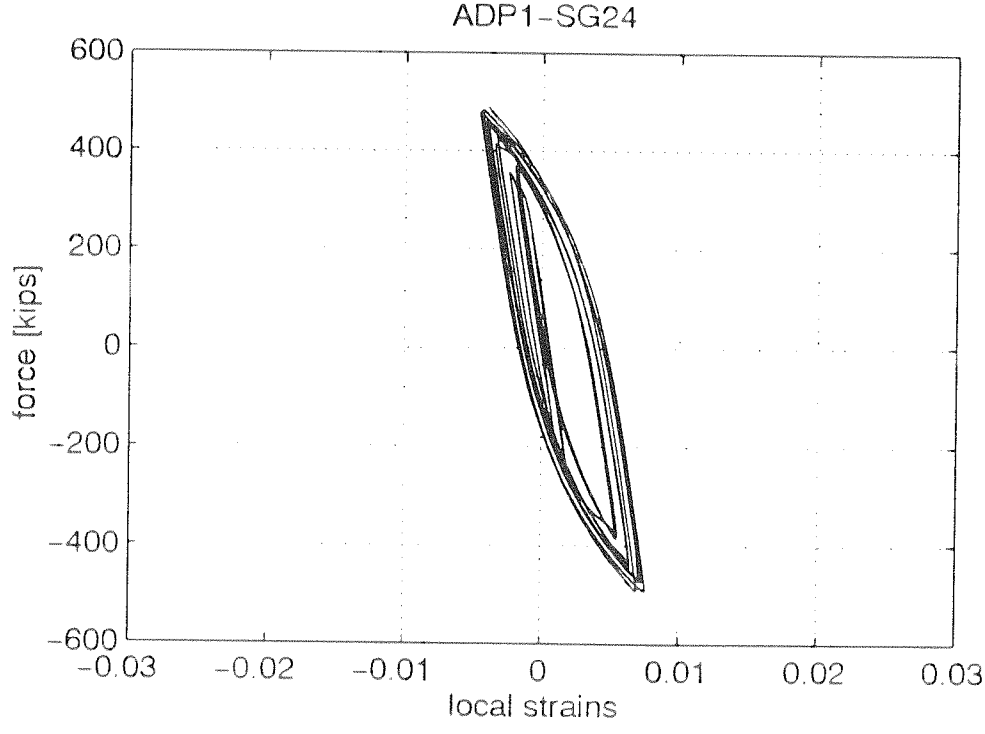


FIGURE 19: LOCAL RESPONSE -- BOTTOM COVER PLATE (EDGE)

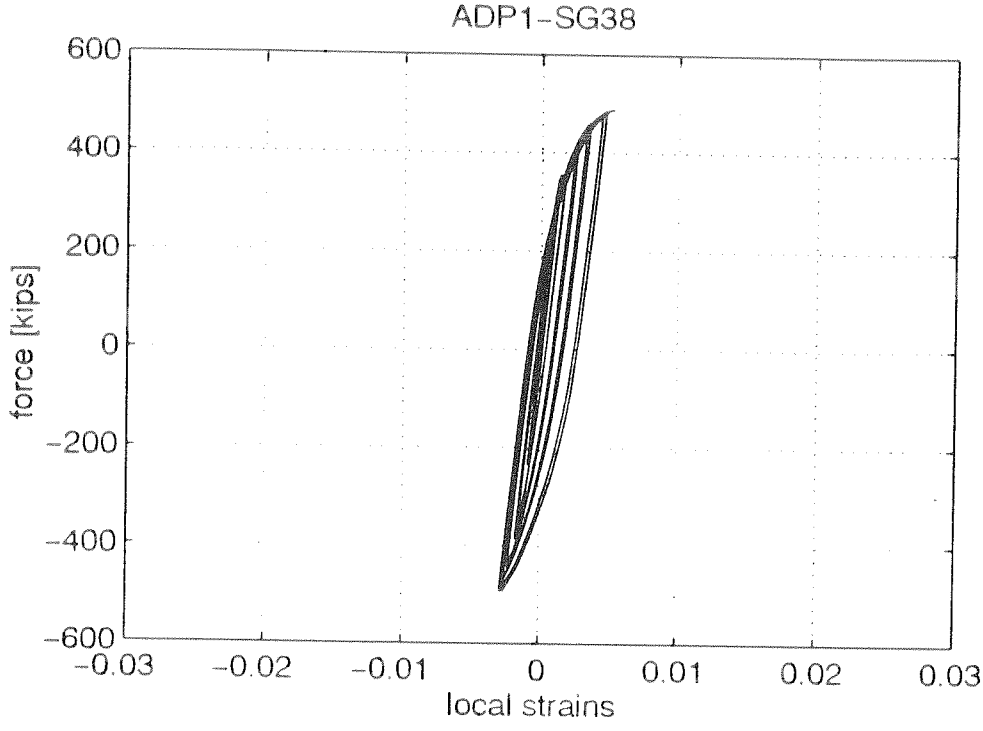


FIGURE 20: LOCAL RESPONSE -- BOTTOM COVER PLATE (AXIS)

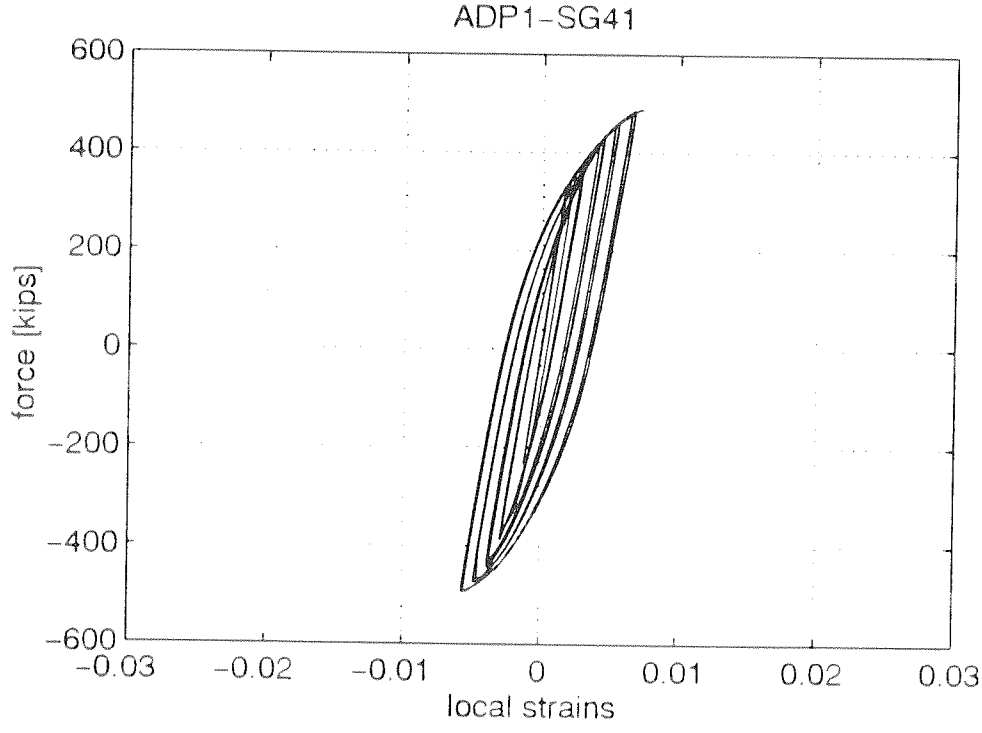


FIGURE 21: LOCAL RESPONSE -- BEAM WEB (TOP@SHEAR TAB)

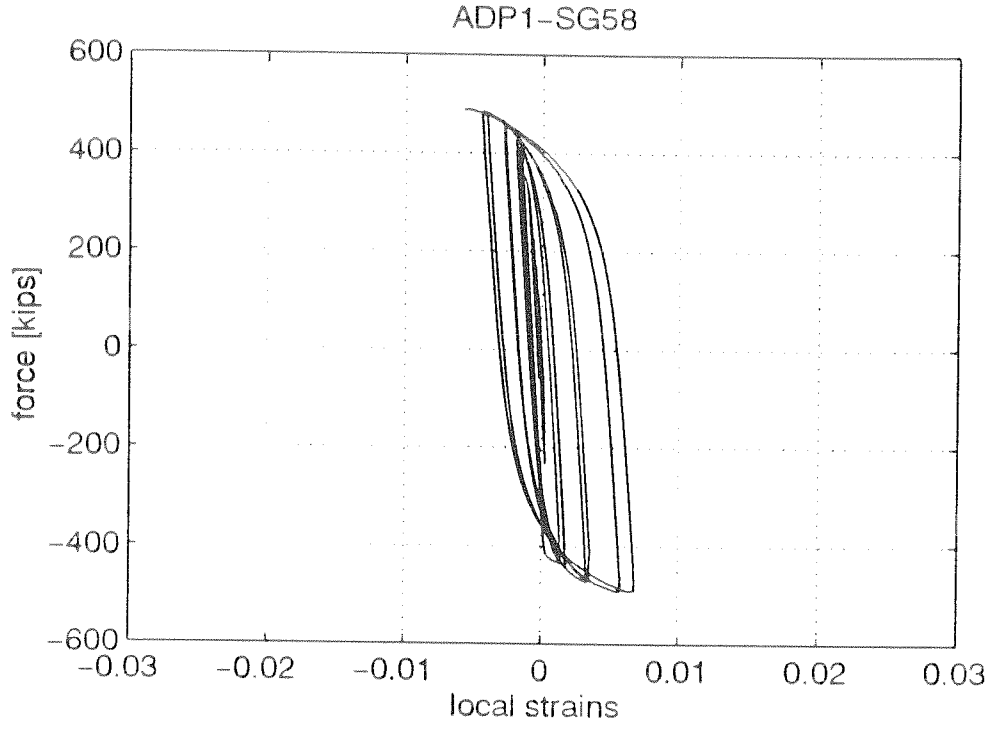


FIGURE 22: LOCAL RESPONSE --BEAM WEB (BOTTOM@SHEAR TAB)

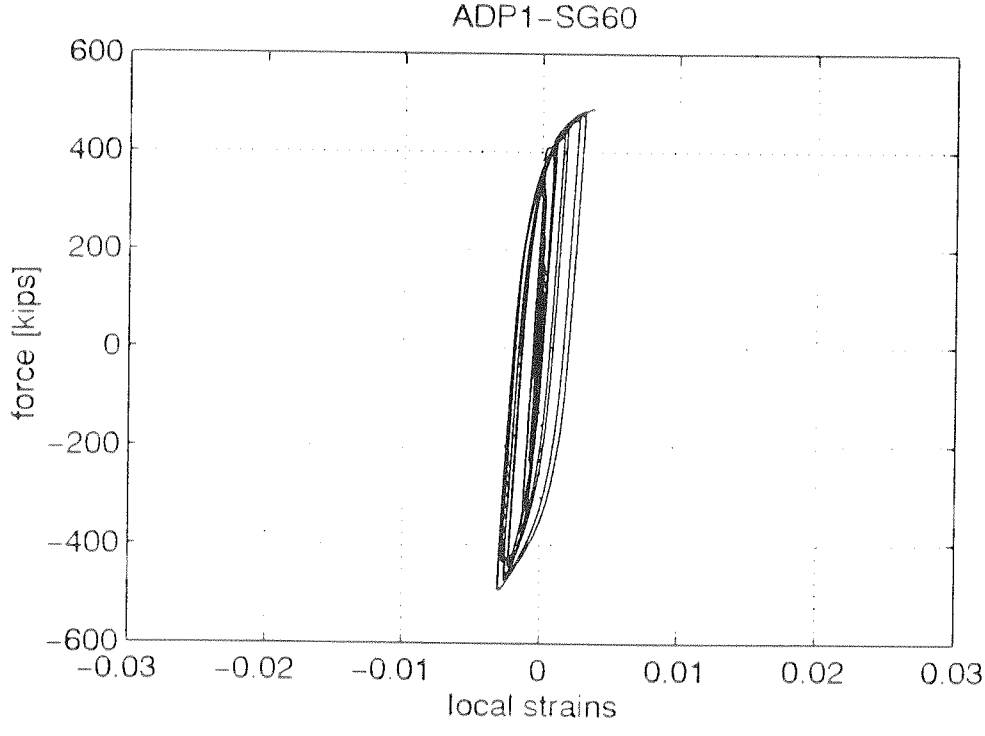


FIGURE 23: LOCAL RESPONSE -- BEAM WEB (TOP@COVER PLATE)

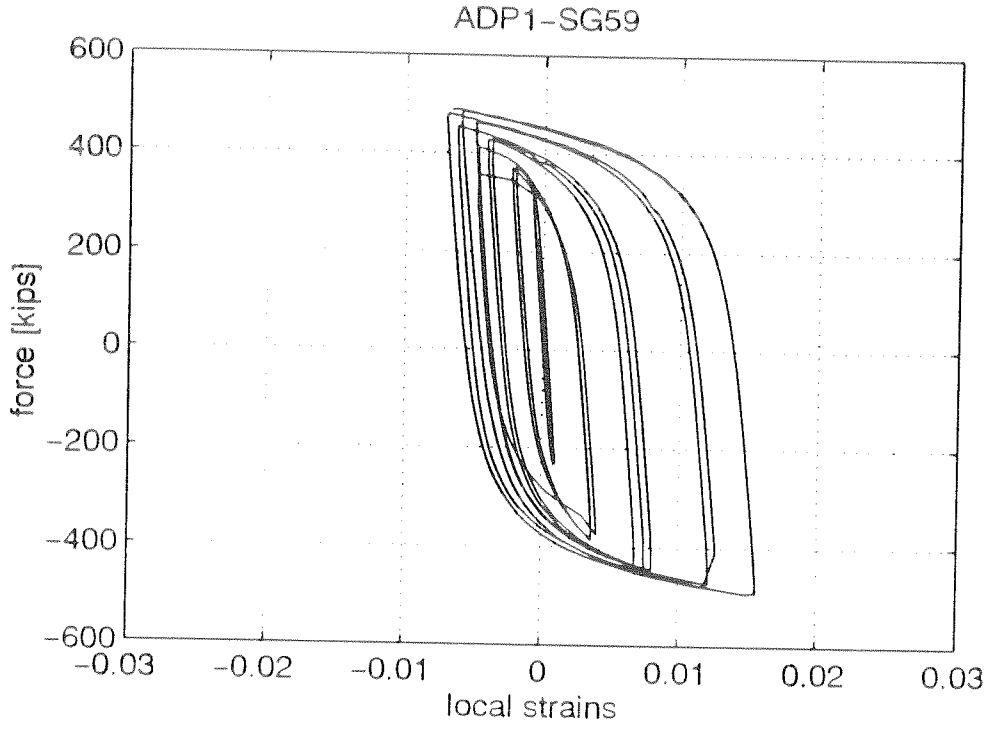


FIGURE 24: LOCAL RESPONSE --BEAM WEB (BOTTOM@COVER PLATE)

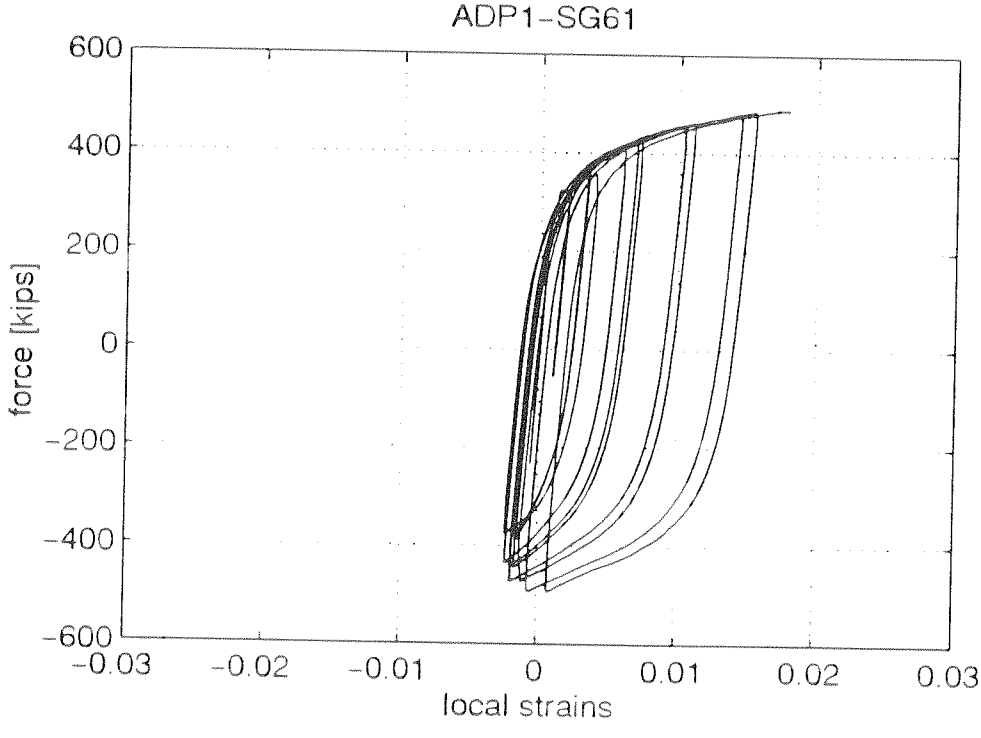


FIGURE 25: LOCAL RESPONSE -- COLUMN FLANGE (@TOP BEAM FLANGE)

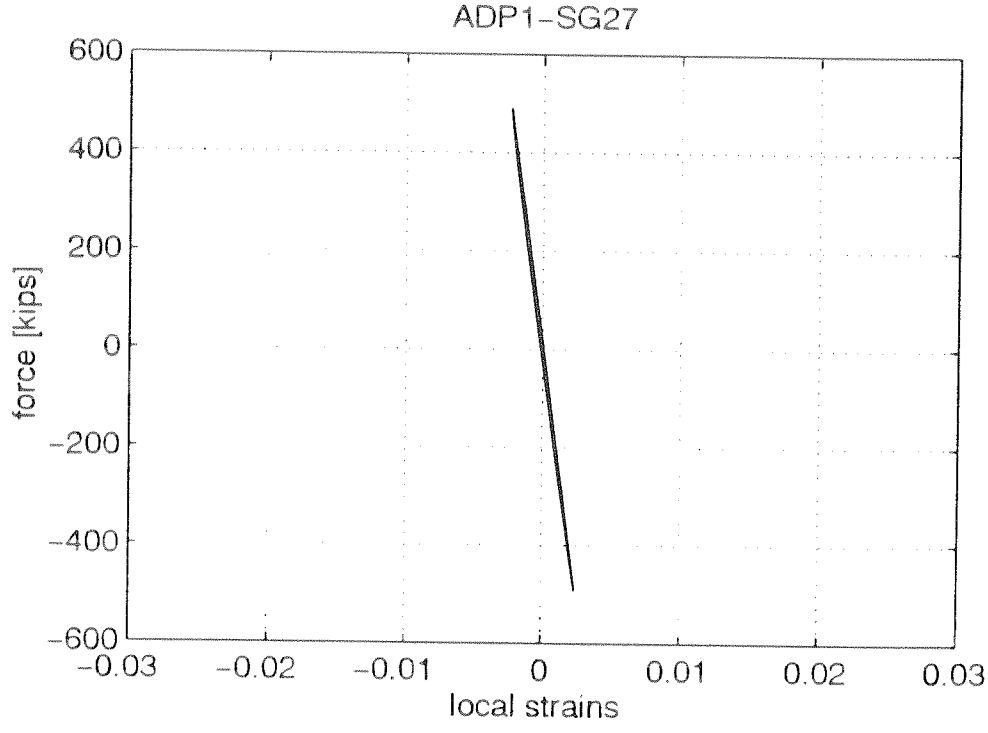


FIGURE 26: LOCAL RESPONSE --COLUMN FLANGE(@BOTTOM BEAM FLANGE)

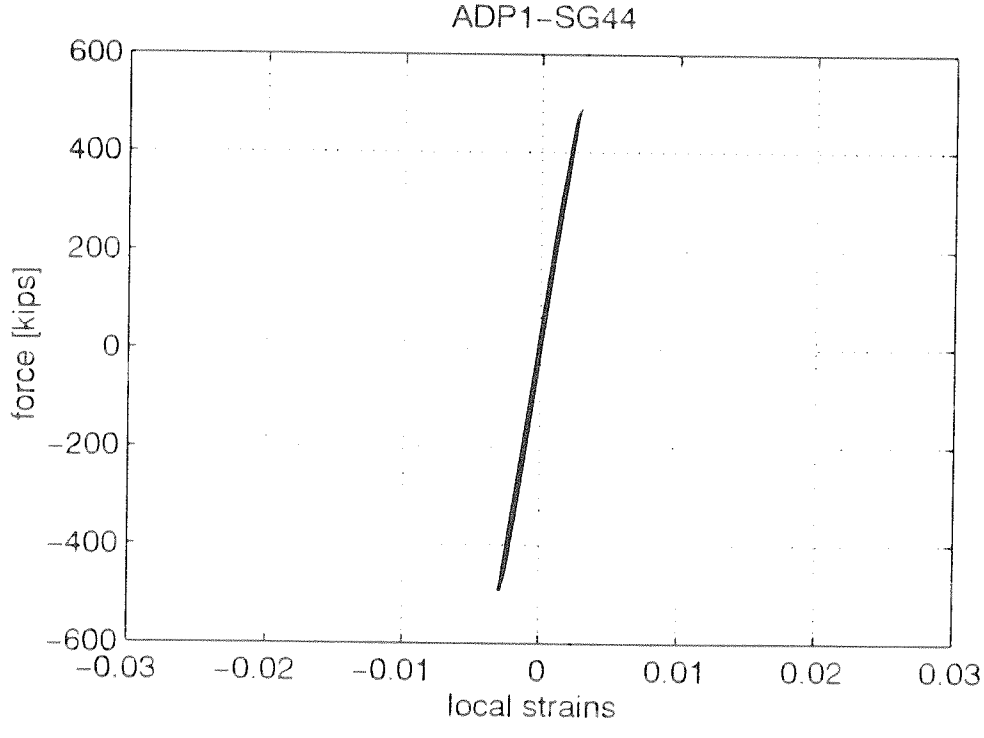


FIGURE 27: CRACK IN TOP COVER PLATE-BEAM FLANGE WELD AFTER 5" CYCLES

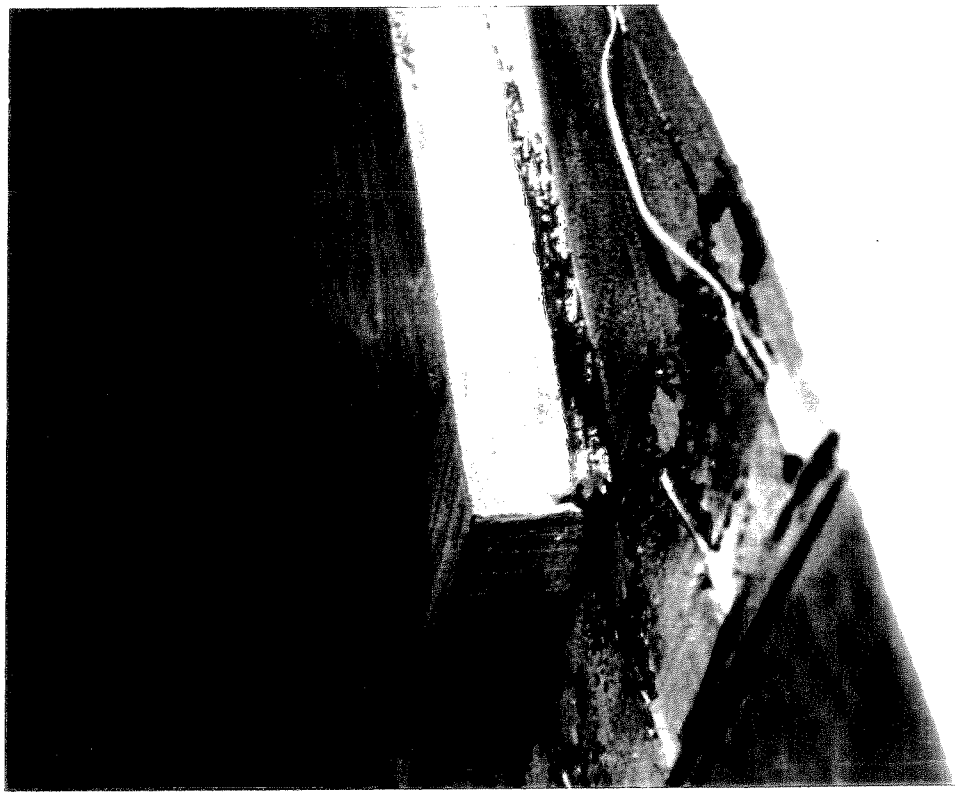


FIGURE 28: CRACK OPENING AFTER 6" CYCLES

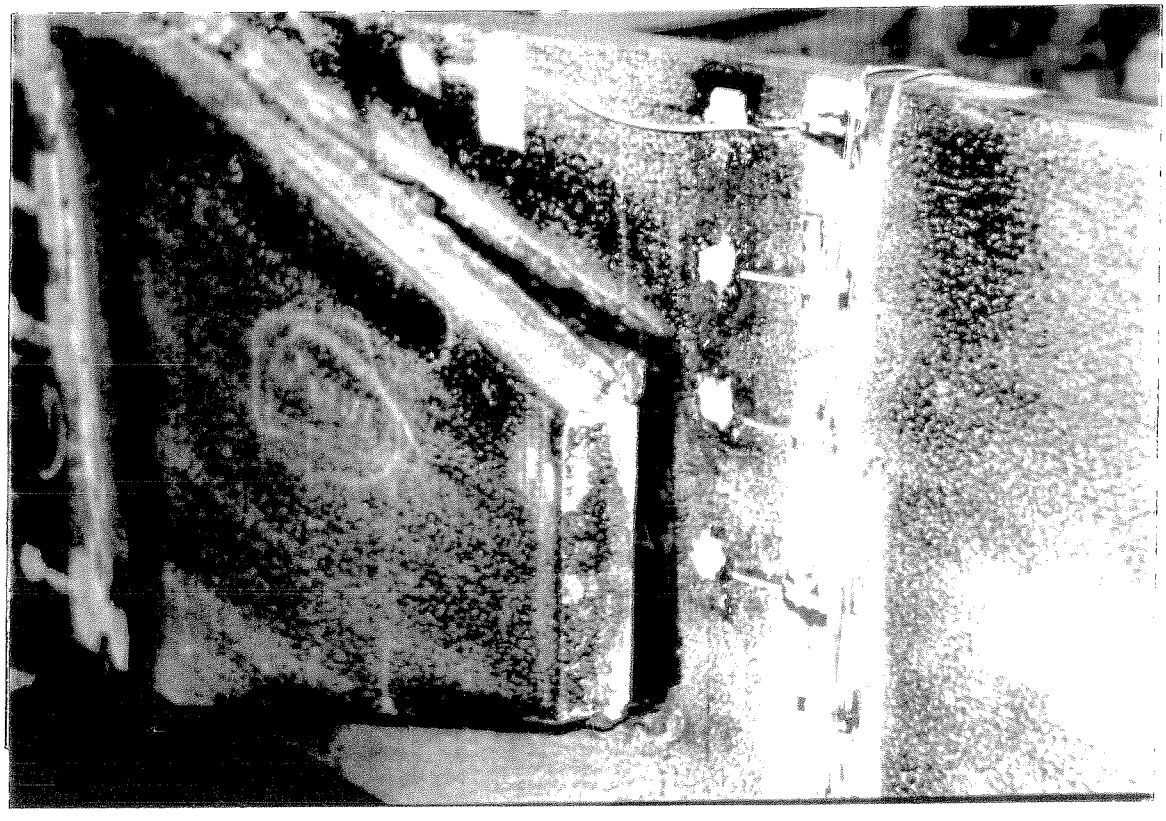


FIGURE 29: BENDING OF BEAM BOTTOM FLANGE (@ 6" DISPLACEMENT)

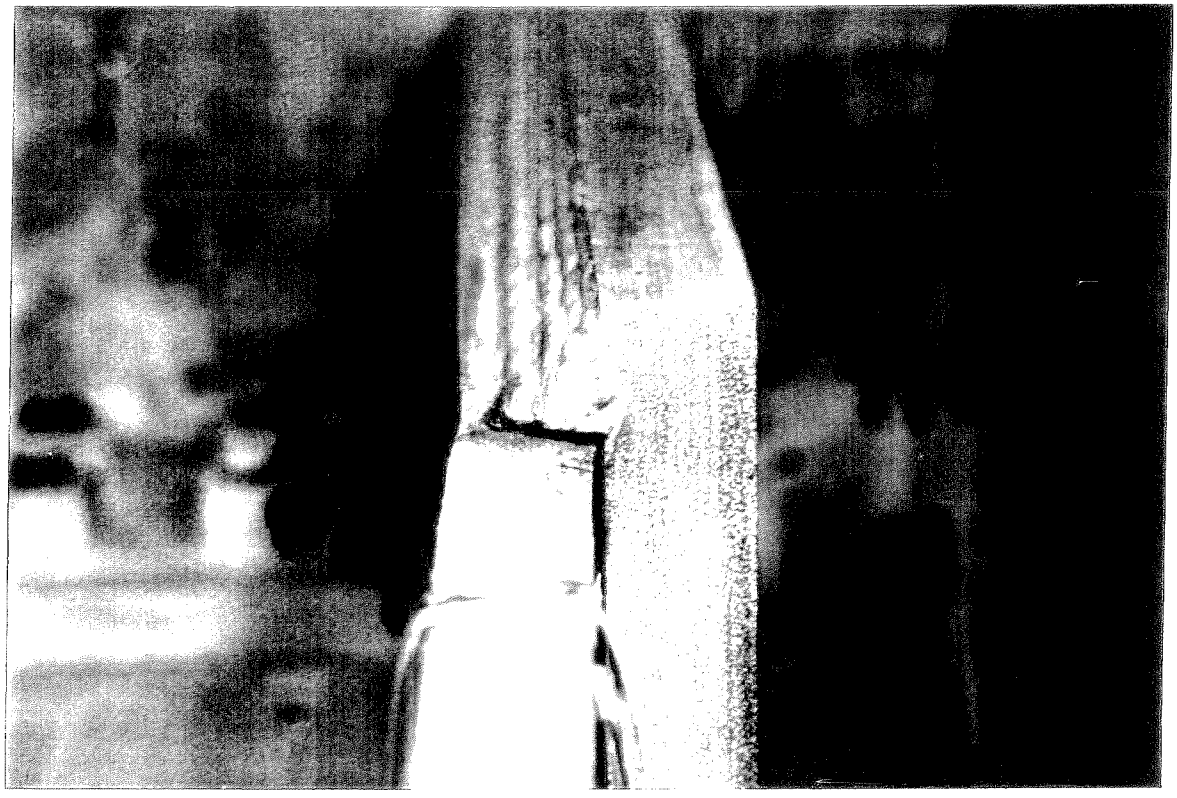


FIGURE 30: BUCKLING OF BEAM TOP FLANGE (@ 6" DISPLACEMENT)

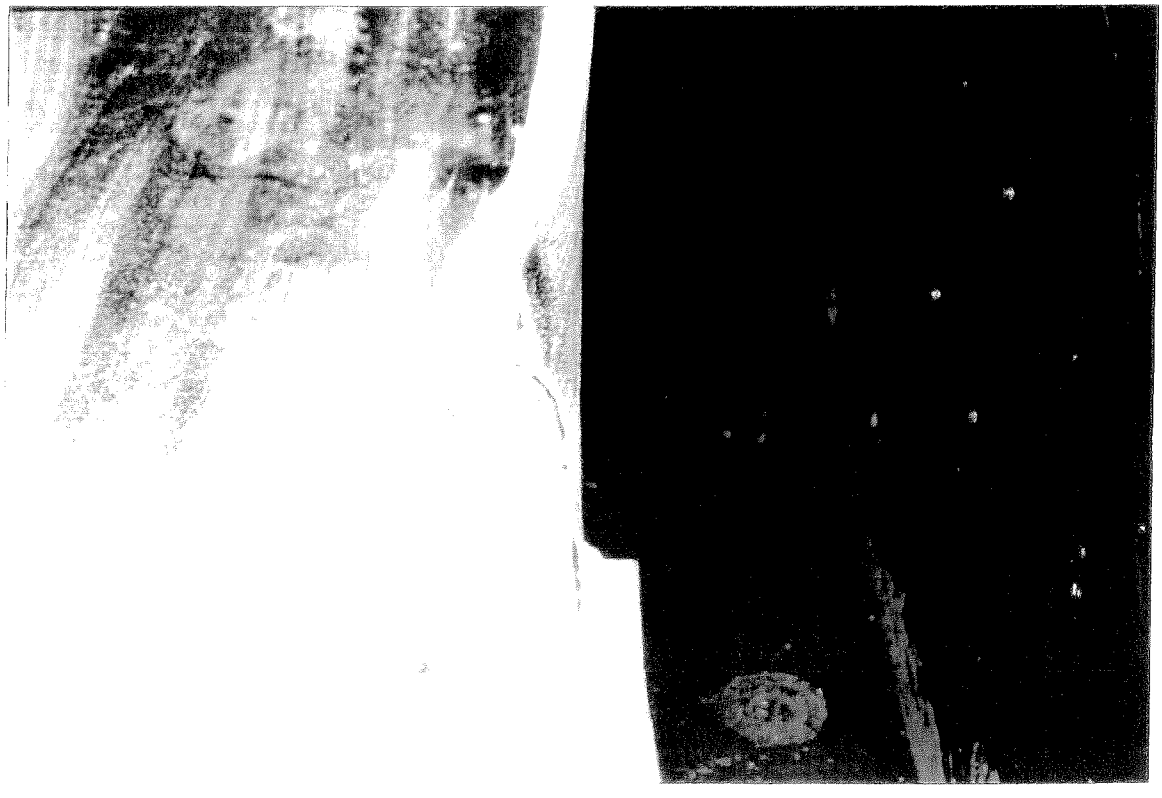


FIGURE 31: TEARING IN TOP COVER PLATE WELD (AFTER 6" CYCLES)

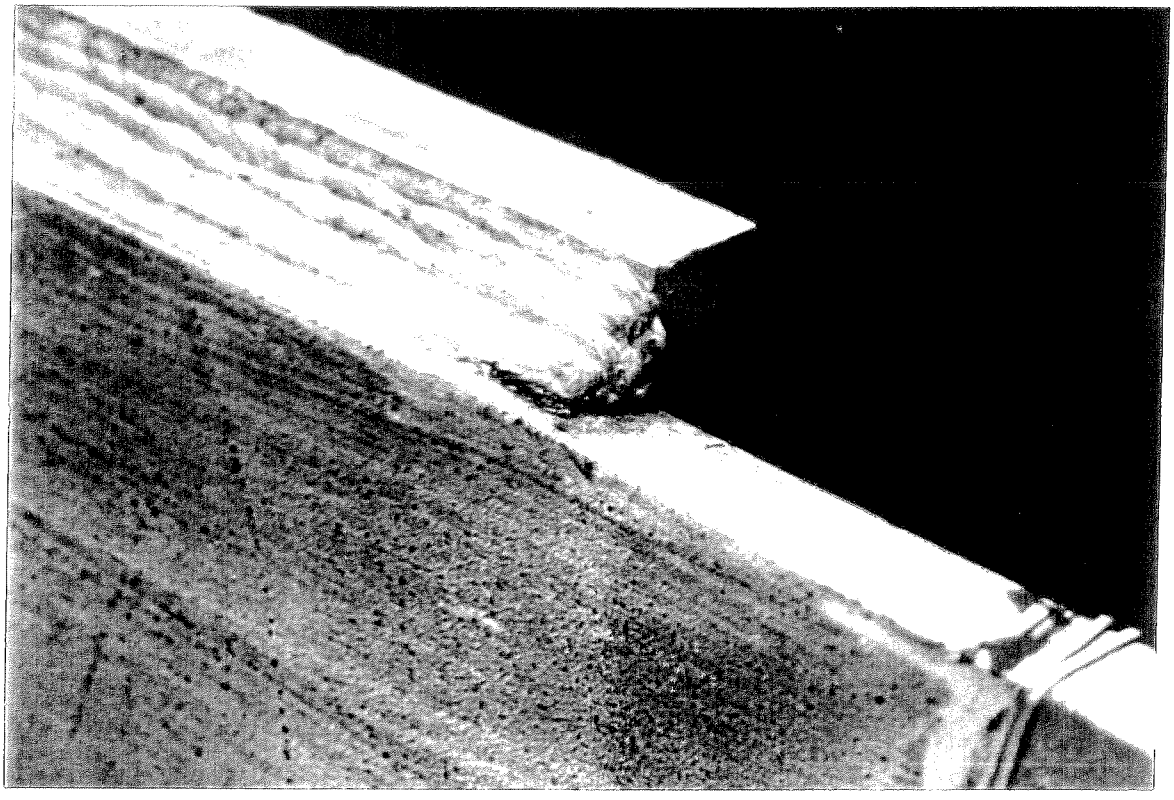


FIGURE 32: TEARING IN TOP COVER PLATE WELD (AFTER 6" CYCLES)

FIGURE 33: IMPOSED LOADING HISTORY -- ACTUATOR DISPLACEMENT

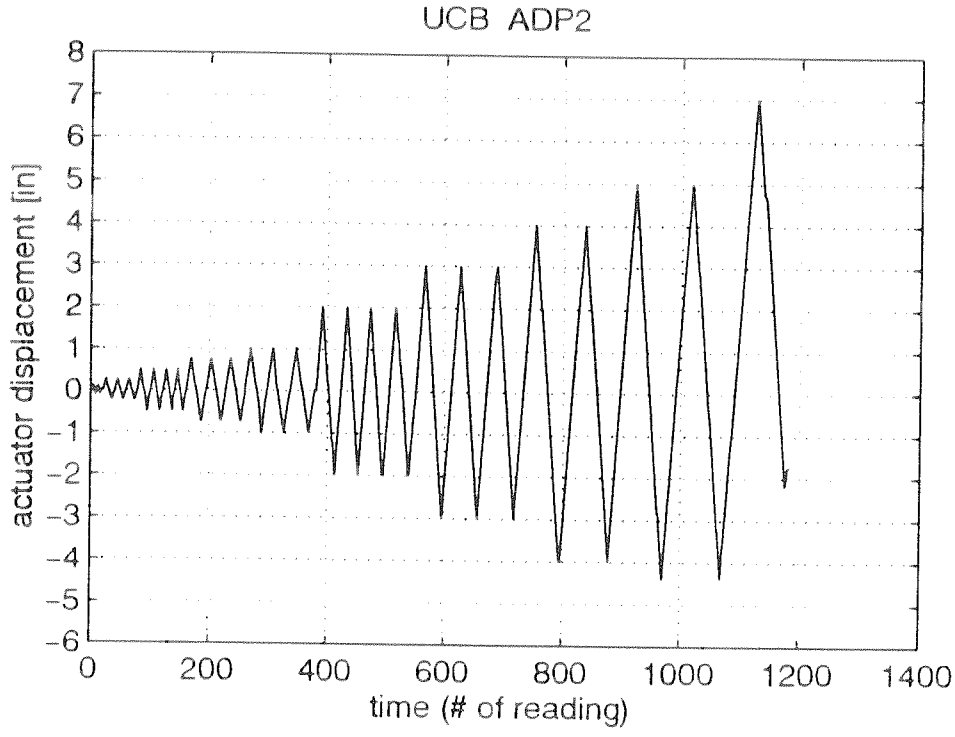


FIGURE 34: APPLIED LOAD / BEAM END DISPLACEMENT RESPONSE

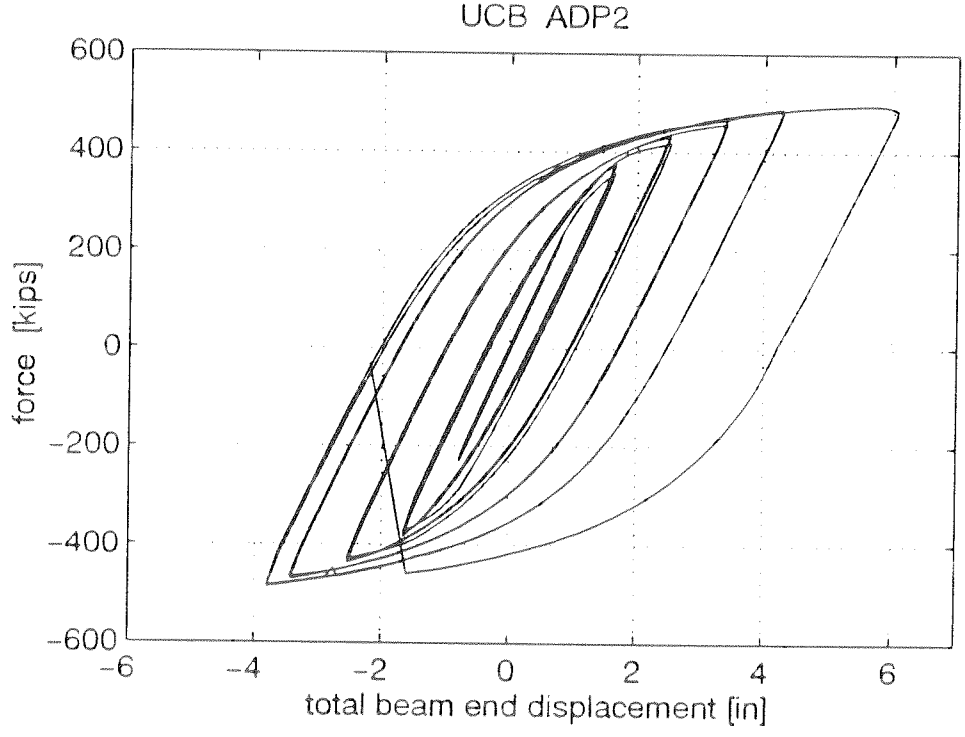


FIGURE 35: PLASTIC ROTATION VERSUS MOMENT @ COVER PLATE EDGE

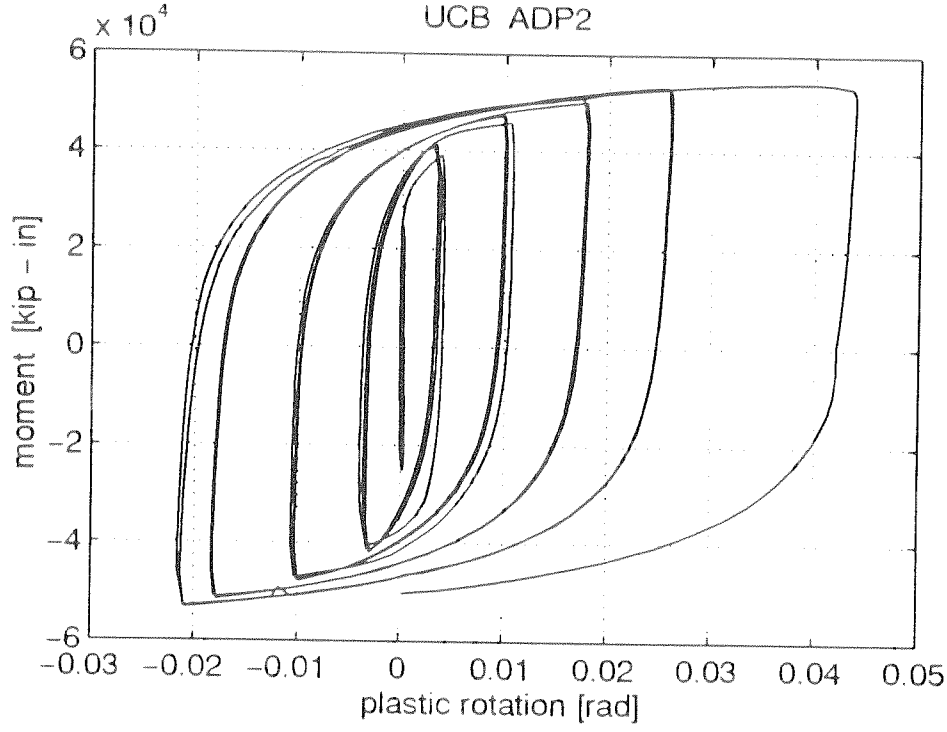


FIGURE 36: DISSIPATED ENERGY

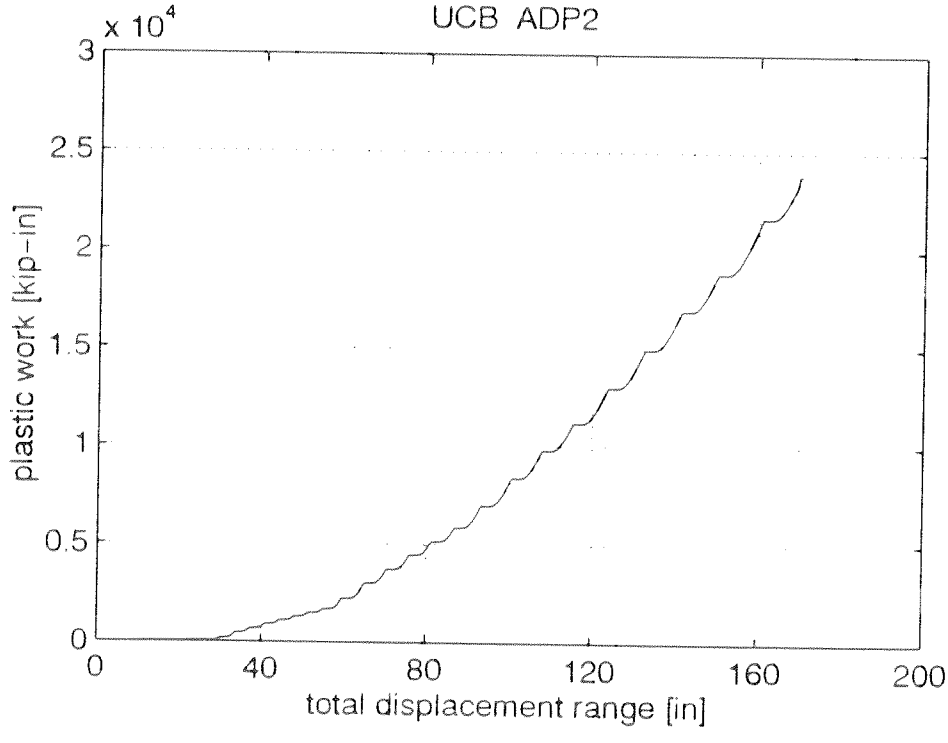


FIGURE 37: PANEL ZONE SHEAR DEFORMATION

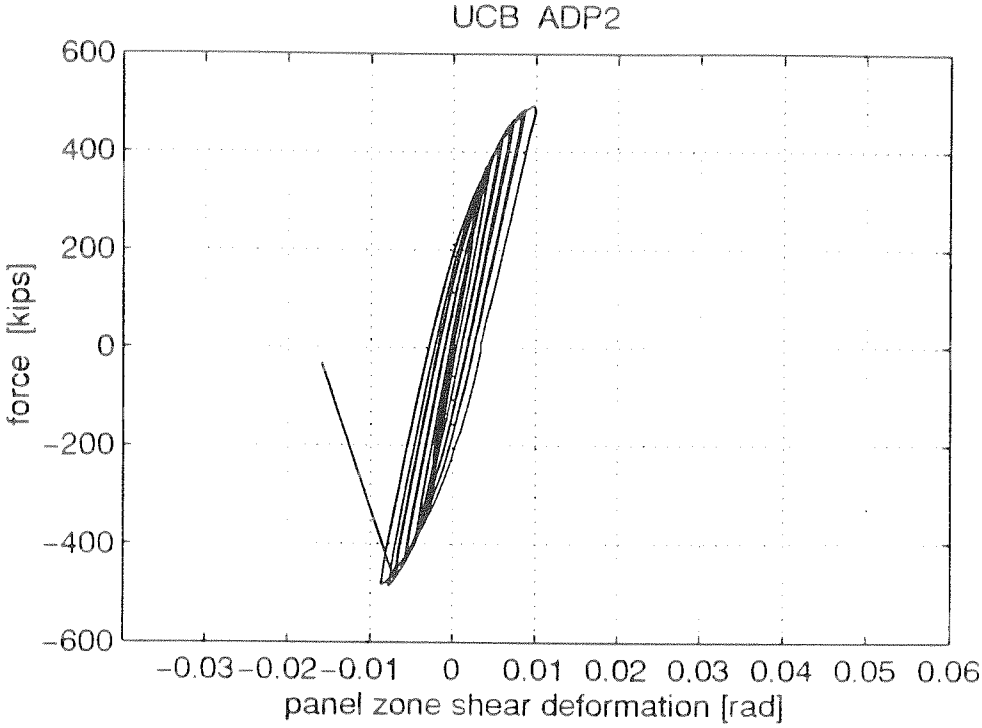


FIGURE 38: BEAM CONTRIBUTION IN TOTAL DISPLACEMENT

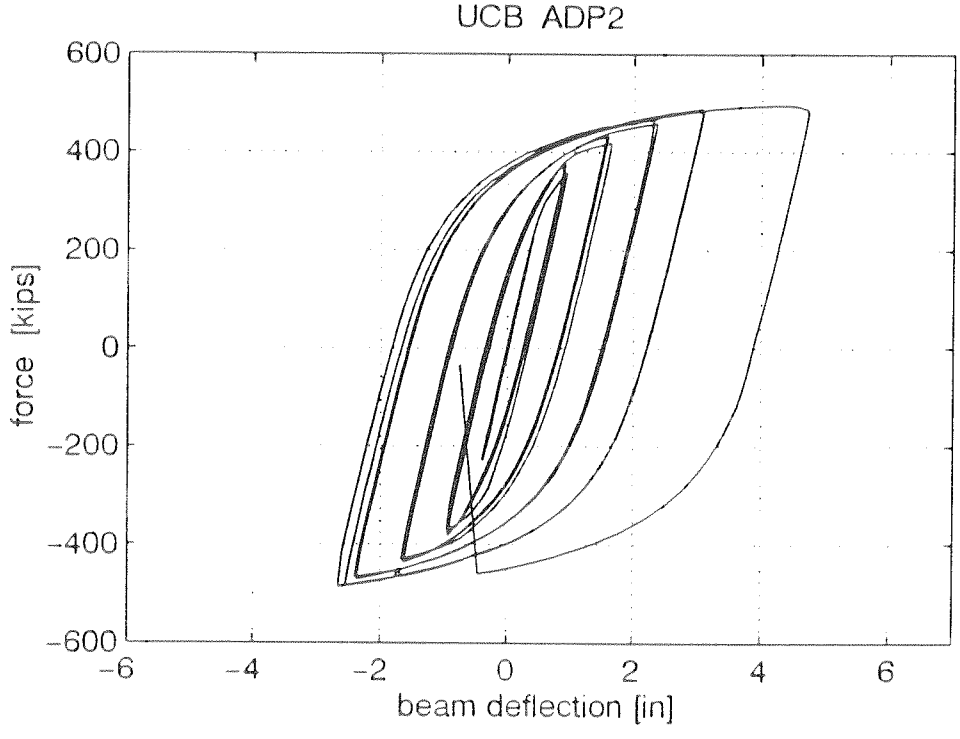


FIGURE 39: LOCAL RESPONSE -- TOP BEAM FLANGE (EDGE)

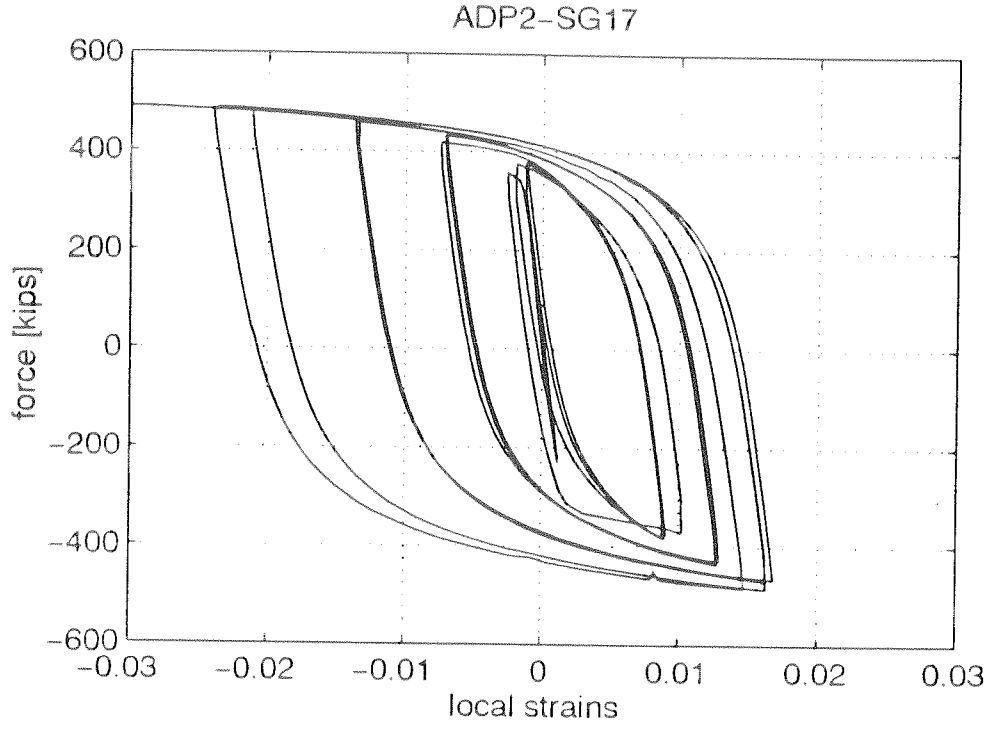


FIGURE 40: LOCAL RESPONSE -- TOP BEAM FLANGE (AXIS)

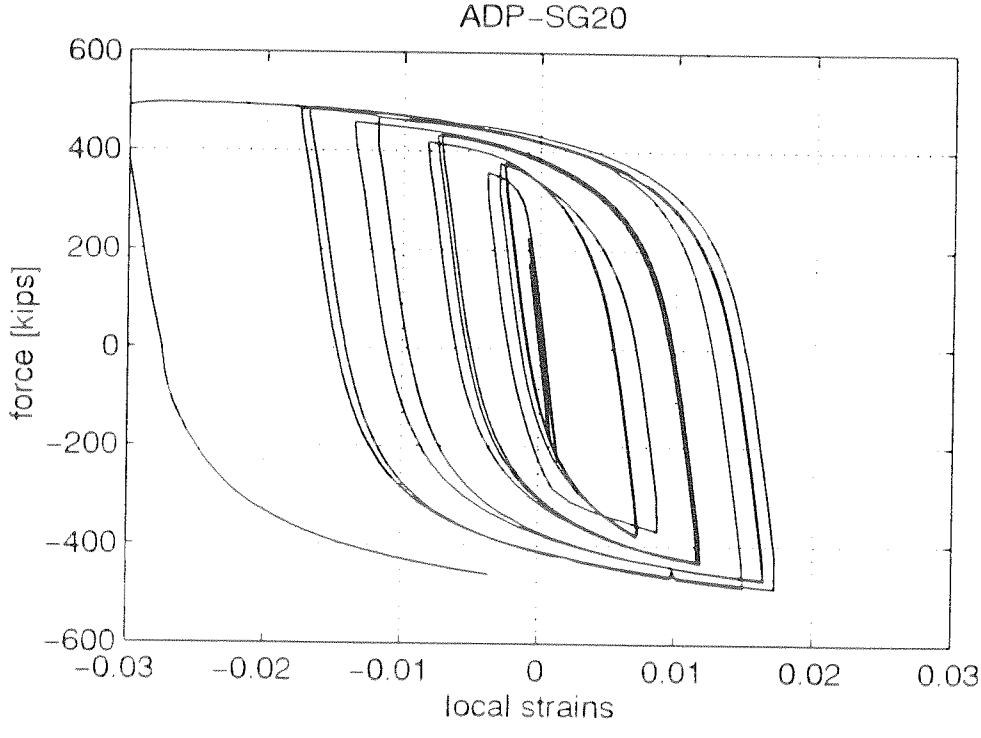


FIGURE 41: LOCAL RESPONSE -- BOTTOM BEAM FLANGE (EDGE)

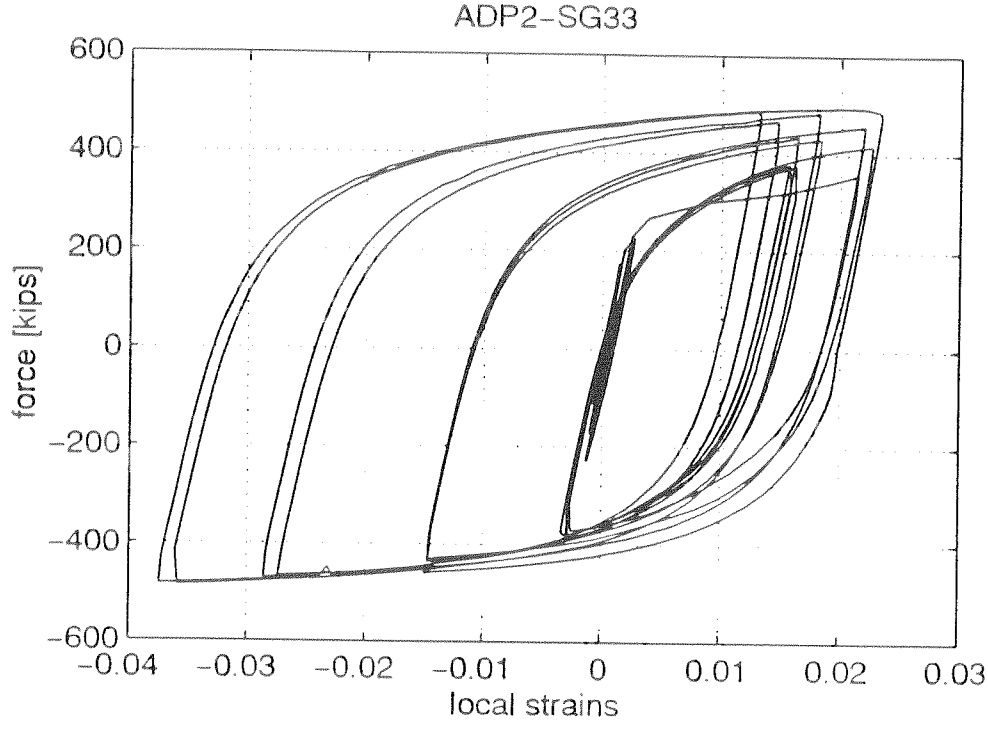


FIGURE 42: LOCAL RESPONSE -- BOTTOM BEAM FLANGE (AXIS)

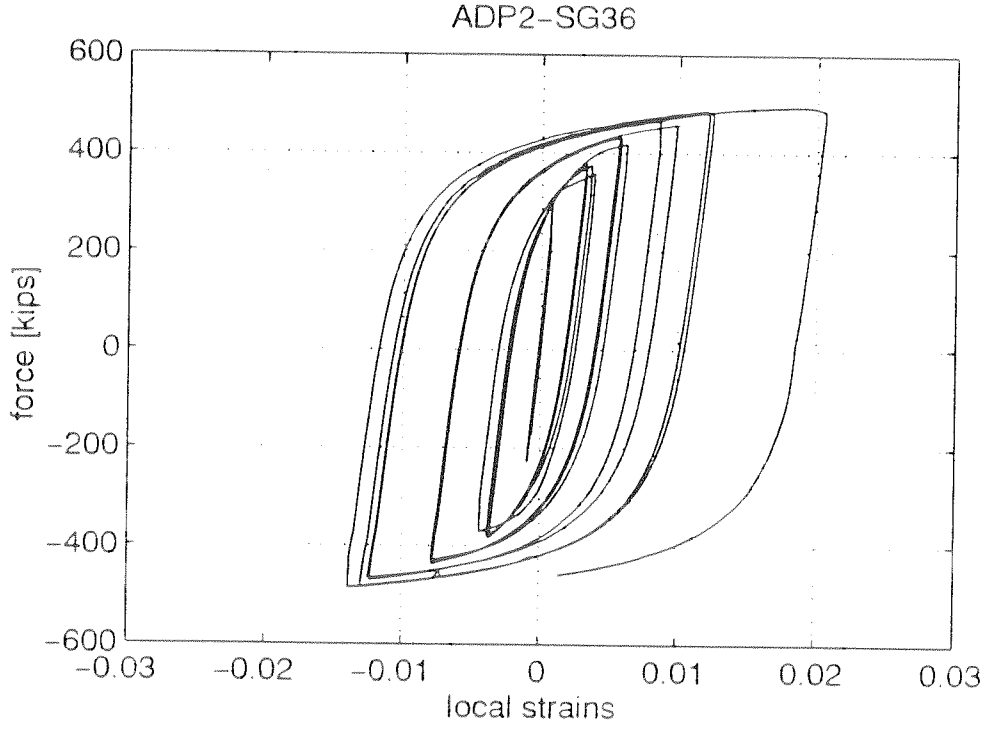


FIGURE 43: LOCAL RESPONSE -- TOP COVER PLATE (EDGE)

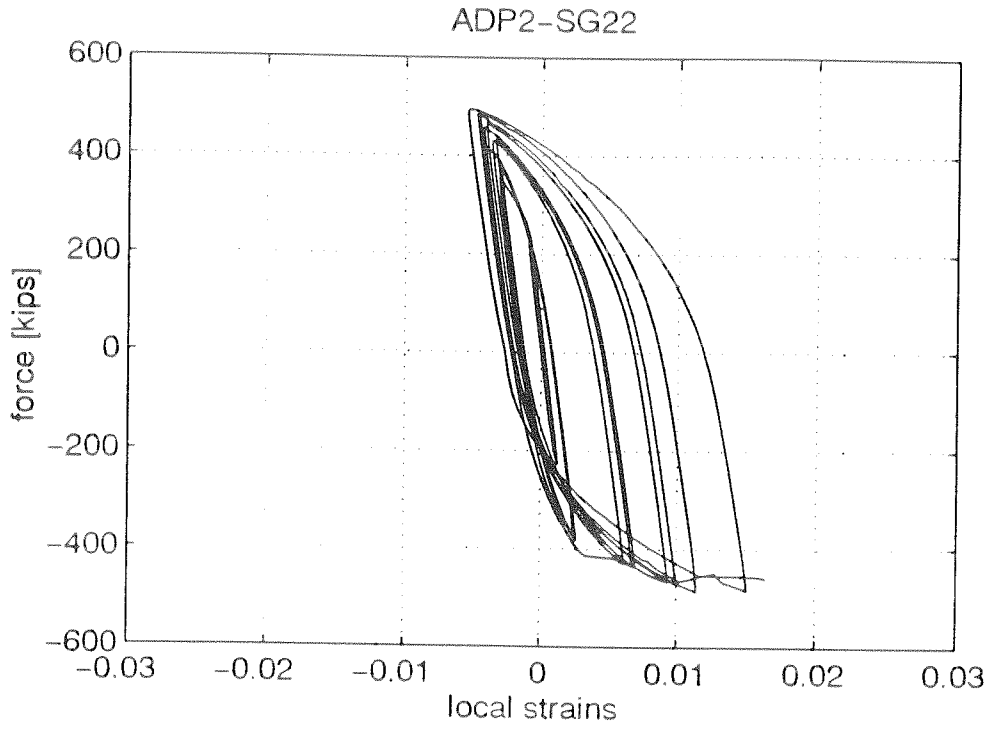


FIGURE 44: LOCAL RESPONSE -- TOP COVER PLATE (AXIS)

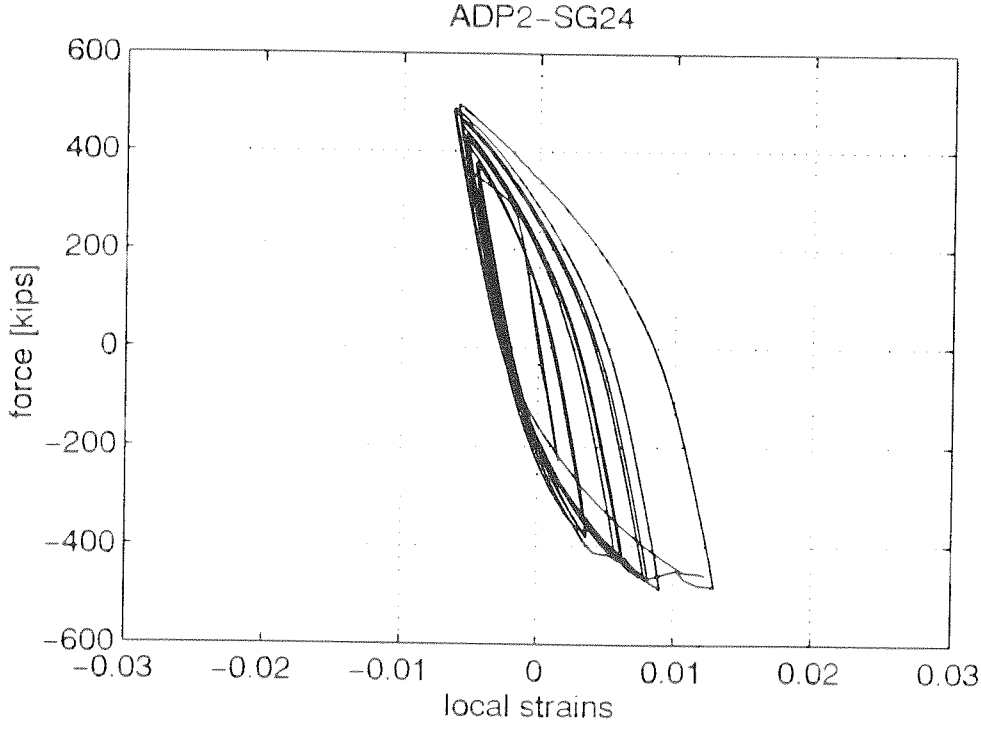


FIGURE 45: LOCAL RESPONSE -- BOTTOM COVER PLATE (EDGE)

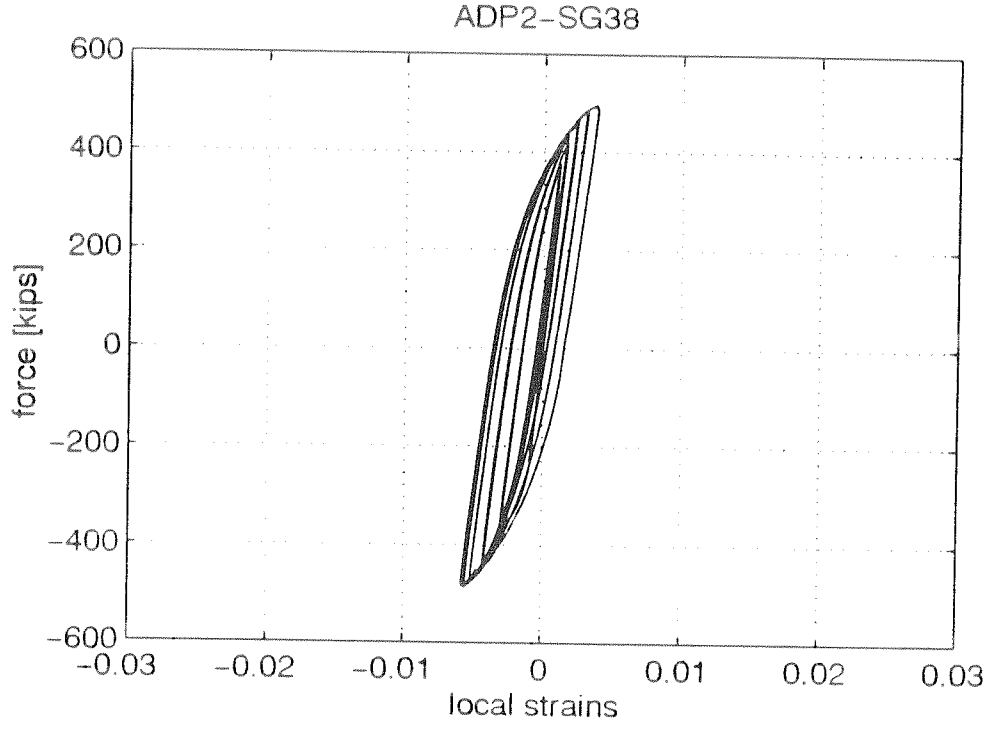


FIGURE 46: LOCAL RESPONSE -- BOTTOM COVER PLATE (AXIS)

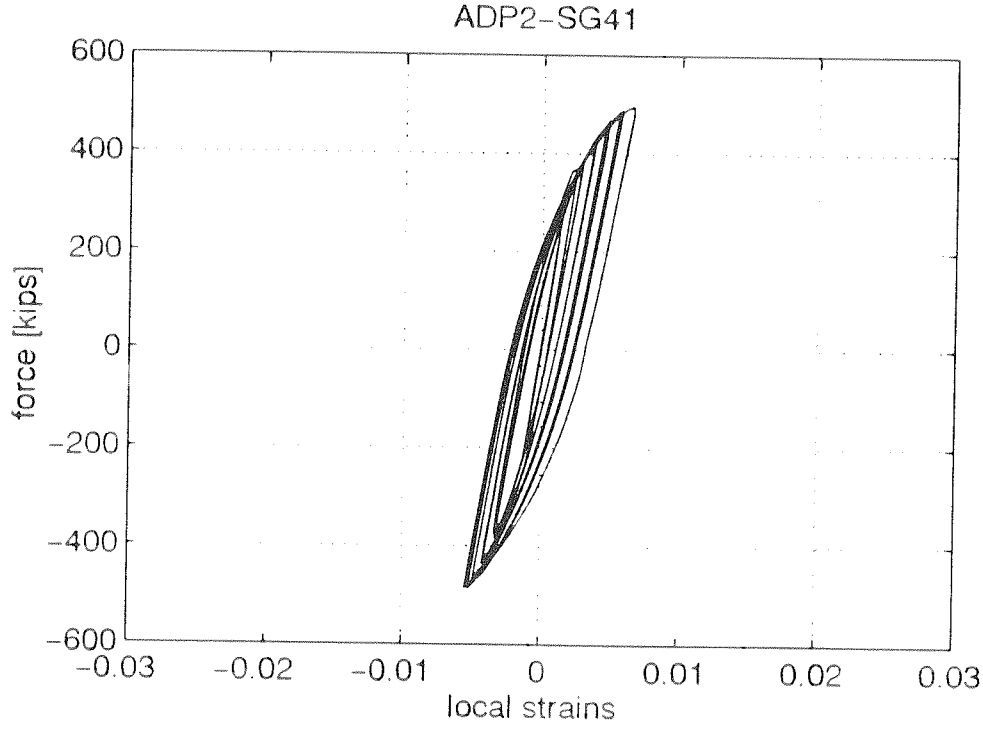


FIGURE 47: LOCAL RESPONSE -- BEAM WEB (TOP@SHEAR TAB)

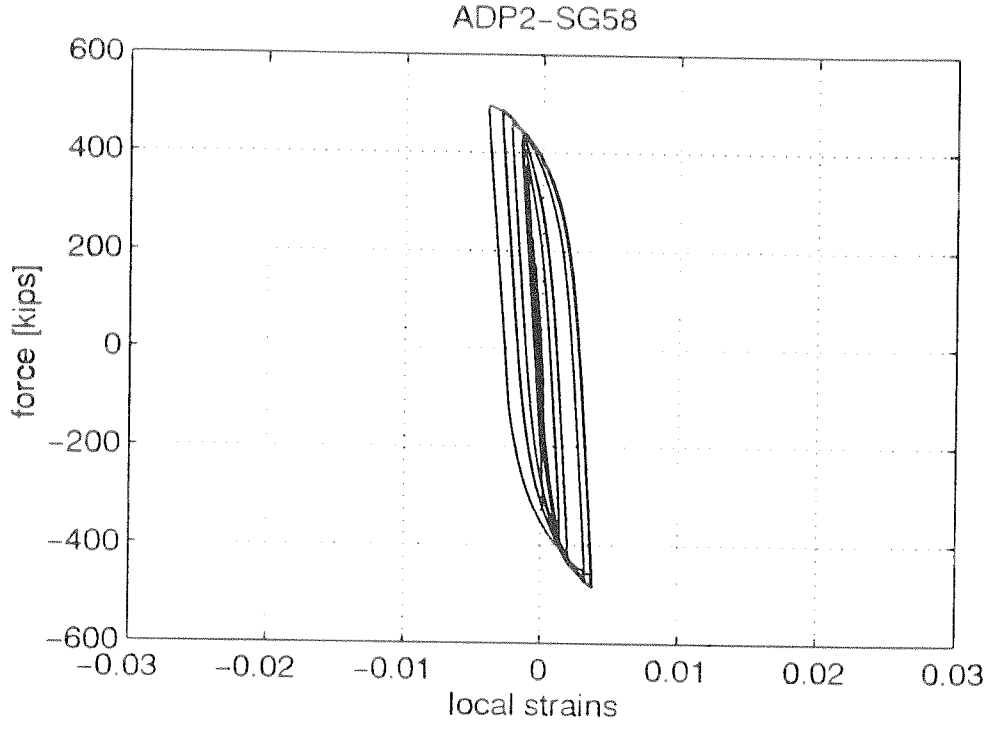


FIGURE 48: LOCAL RESPONSE --BEAM WEB (BOTTOM@SHEAR TAB)

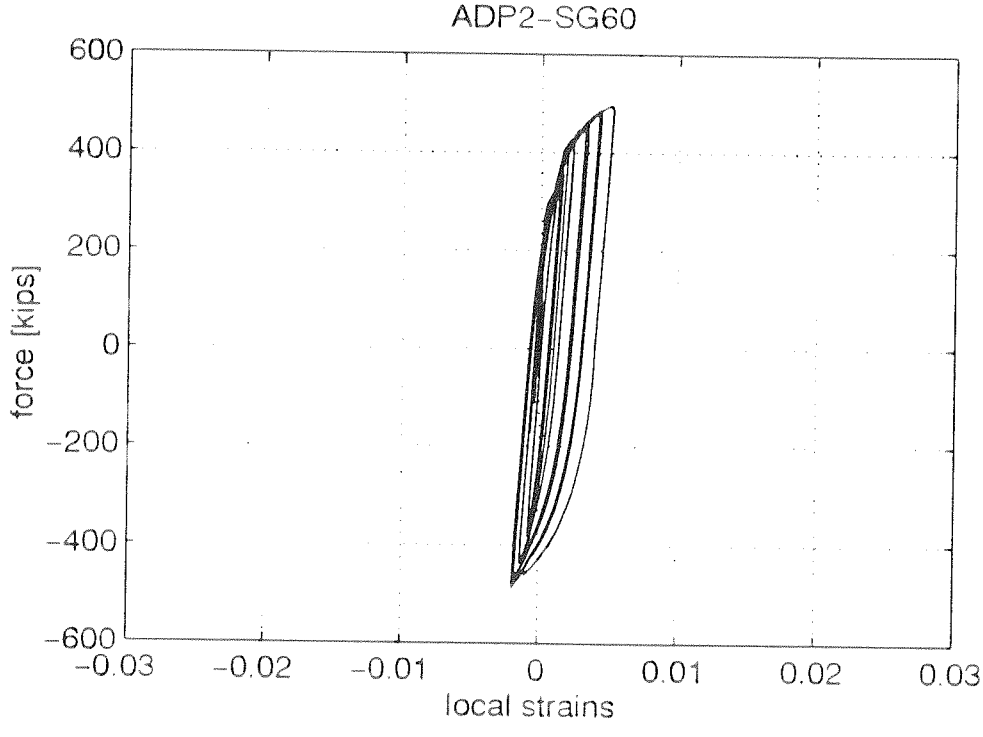


FIGURE 49: LOCAL RESPONSE -- BEAM WEB (TOP@COVER PLATE)

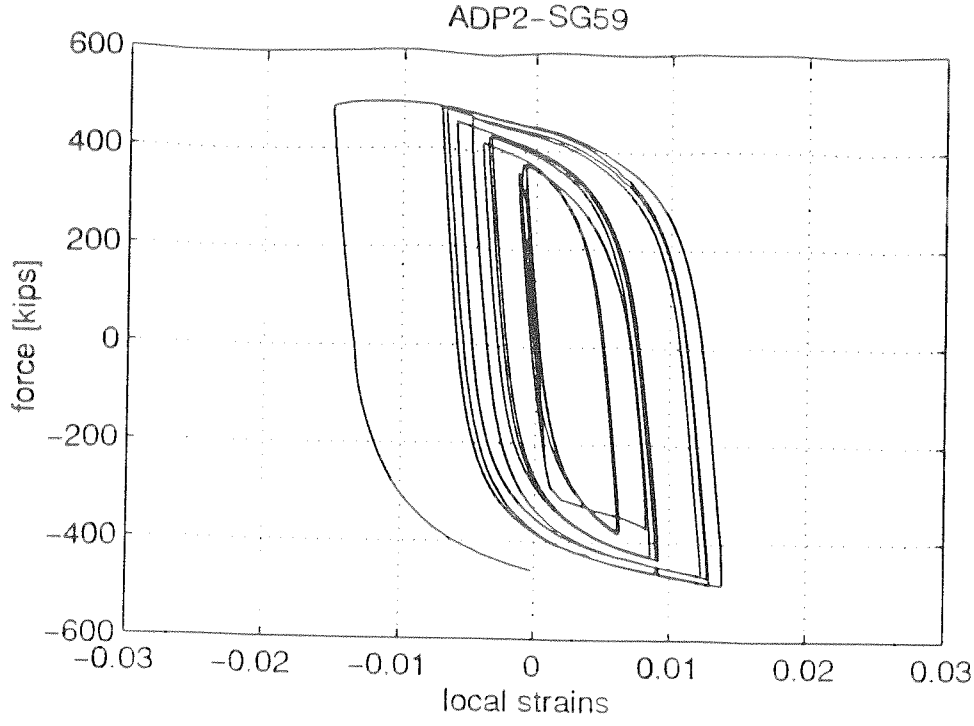


FIGURE 50: LOCAL RESPONSE --BEAM WEB (BOTTOM@COVER PLATE)

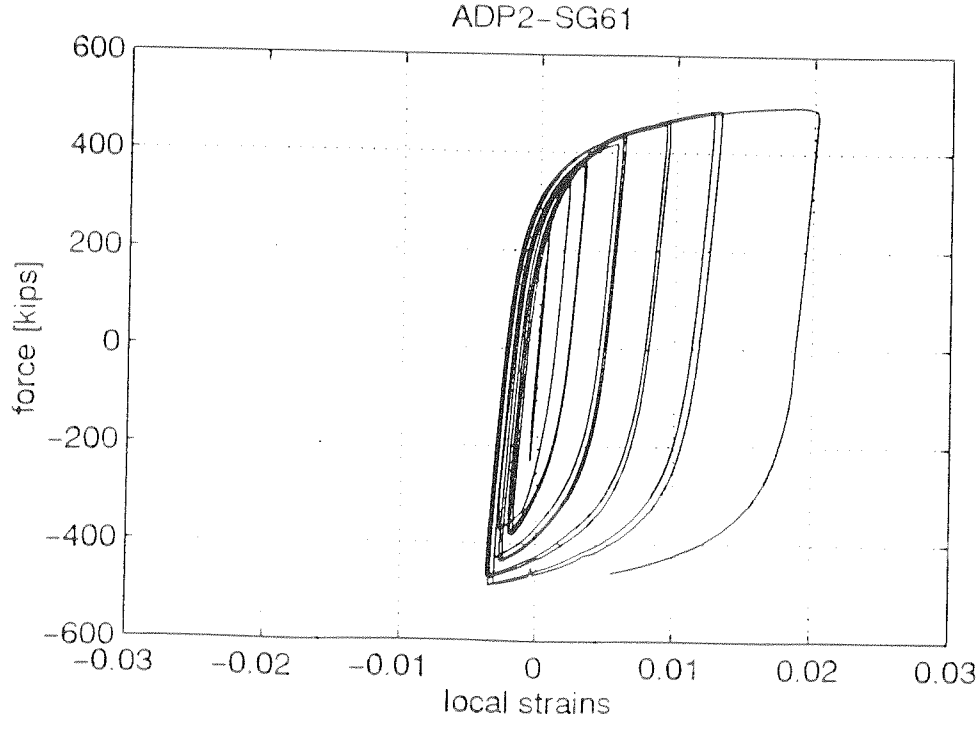


FIGURE 51: LOCAL RESPONSE -- COLUMN FLANGE (ABOVE TOP COVER PLATE)

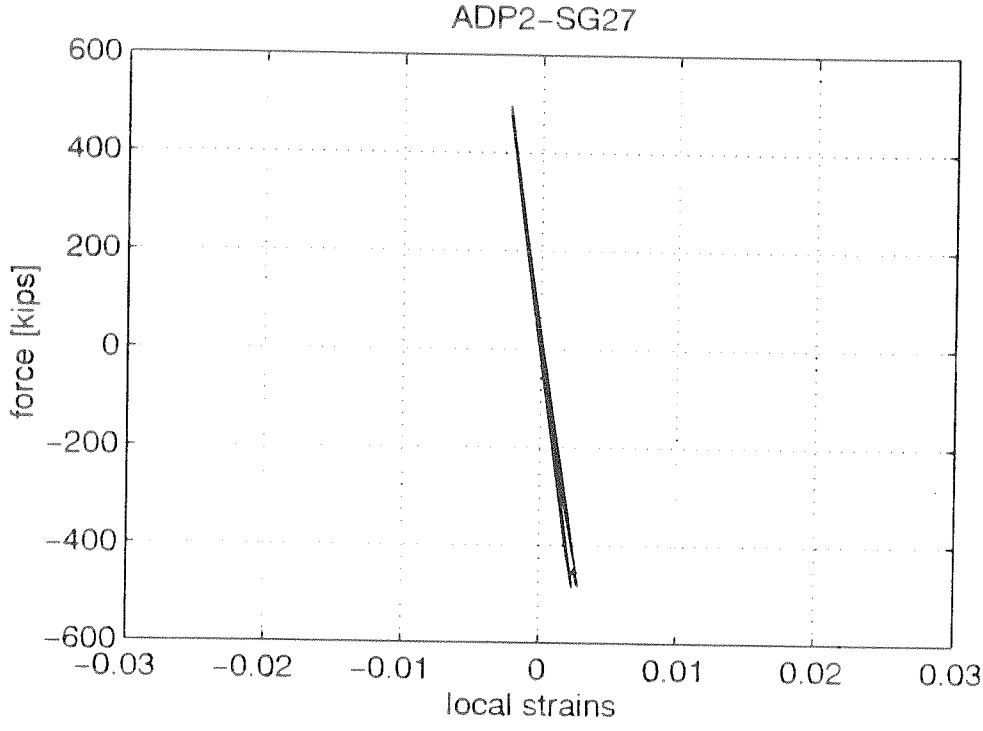


FIGURE 52: LOCAL RESPONSE --COLUMN FLANGE (UNDER TOP BEAM FLANGE)

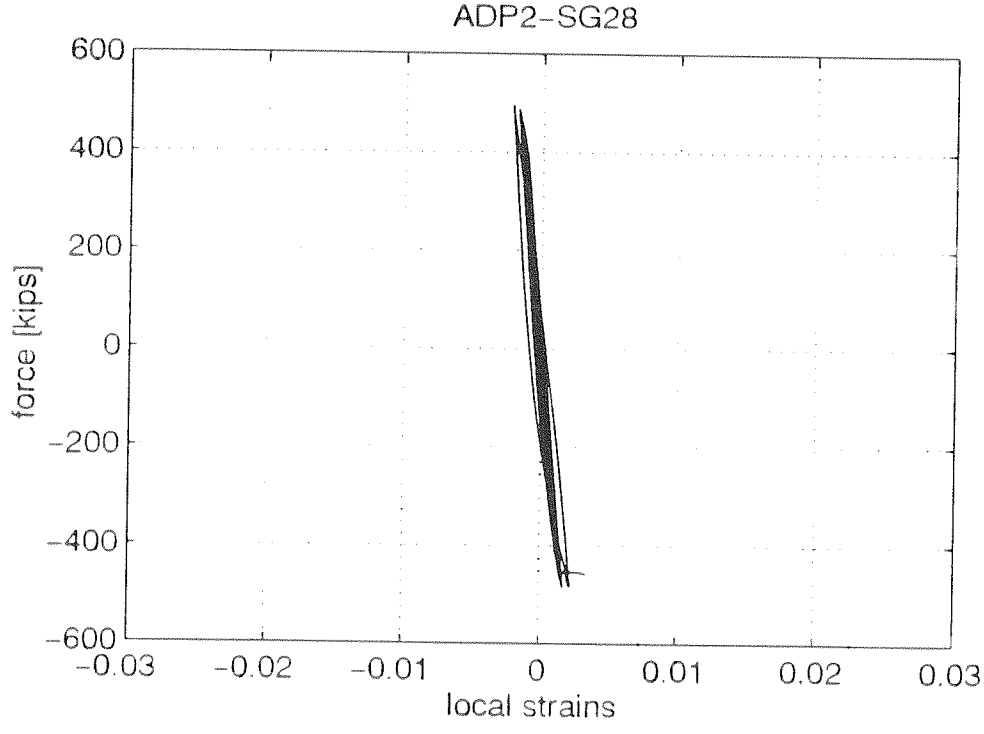


FIGURE 57: PHOTOGRAPH SHOWING FRACTURE OF SPECIMEN ADP2

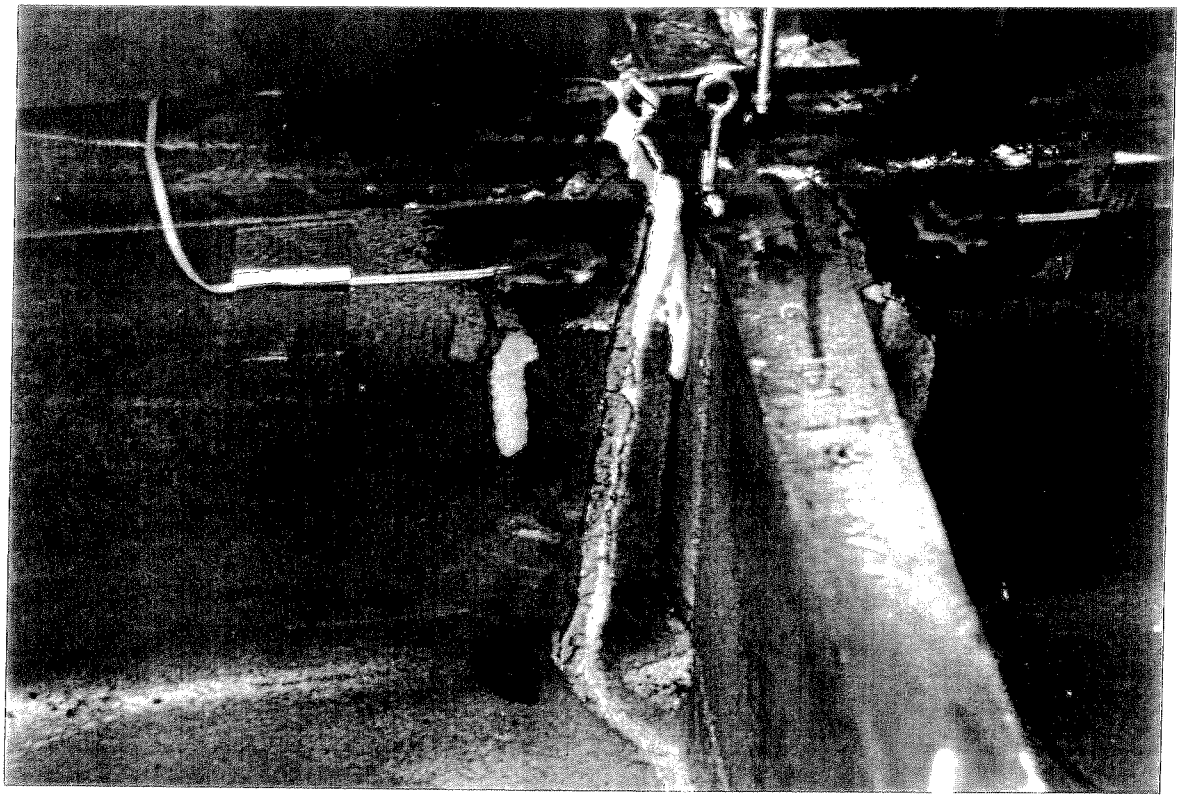


FIGURE 58: PHOTOGRAPH SHOWING FRACTURE OF SPECIMEN ADP2

FIGURE 53: PHOTOGRAPH SHOWING FRACTURE OF SPECIMEN ADP2

FIGURE 54: PHOTOGRAPH SHOWING FRACTURE OF SPECIMEN ADP2

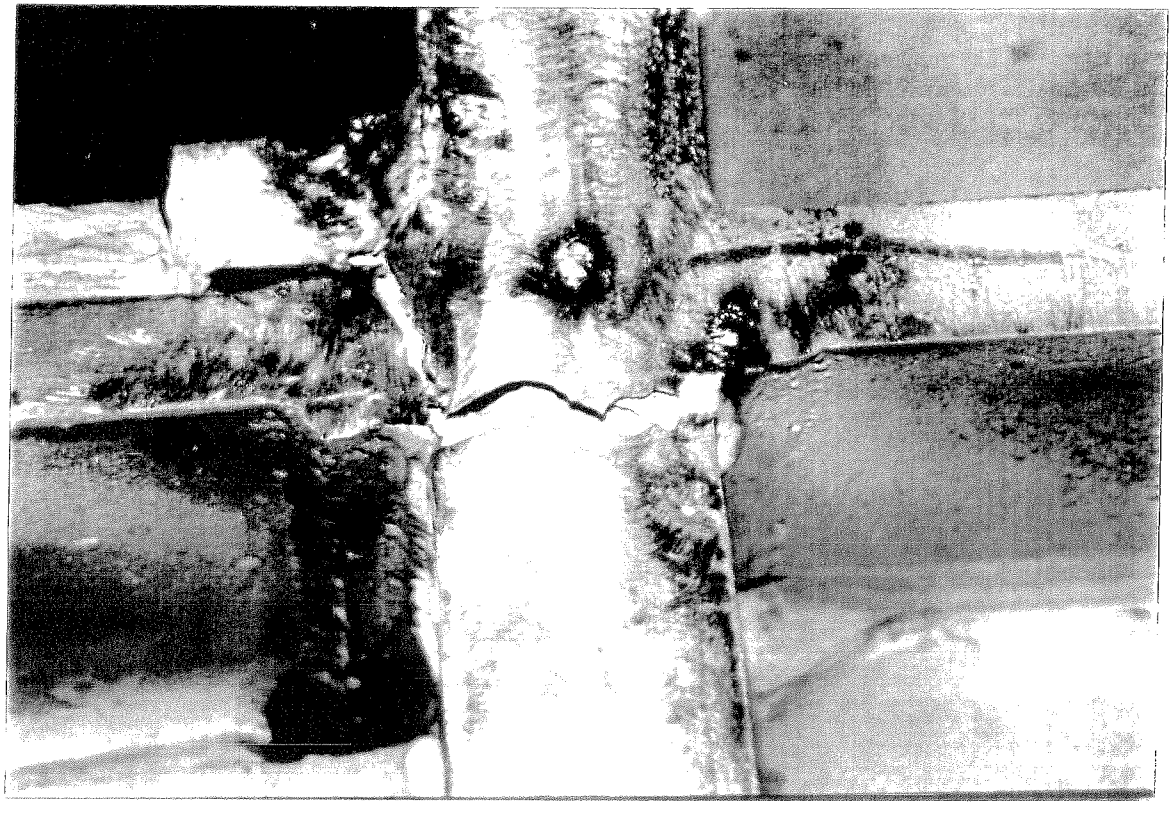


FIGURE 55: PHOTOGRAPH SHOWING FRACTURE OF SPECIMEN ADP2

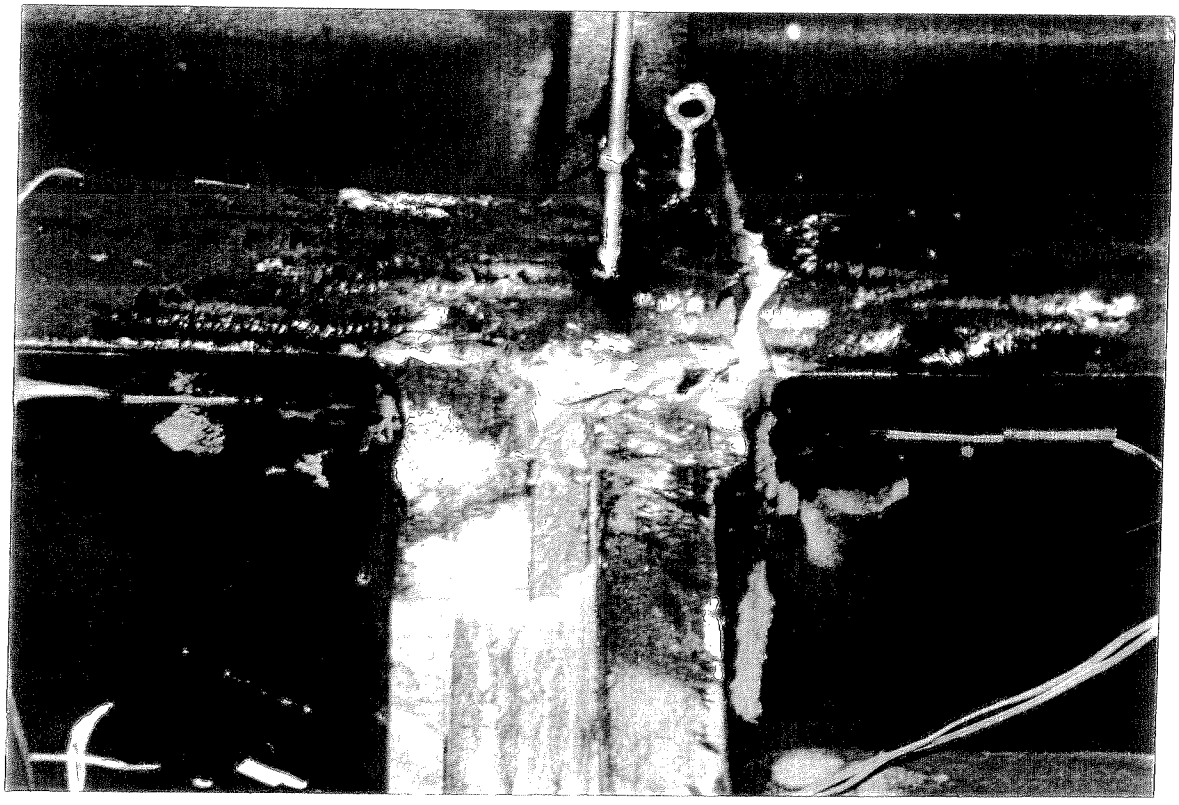


FIGURE 56: PHOTOGRAPH SHOWING FRACTURE OF SPECIMEN ADP2

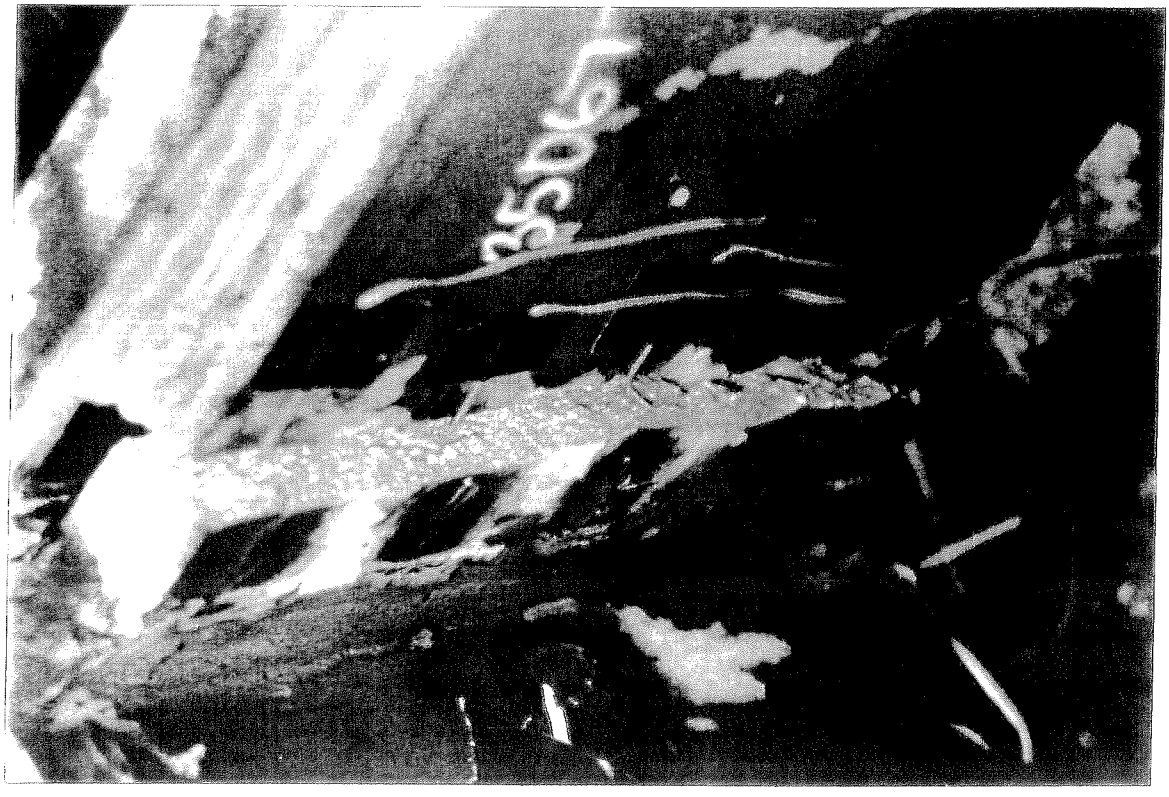


FIGURE 59: IMPOSED LOADING HISTORY -- ACTUATOR DISPLACEMENT

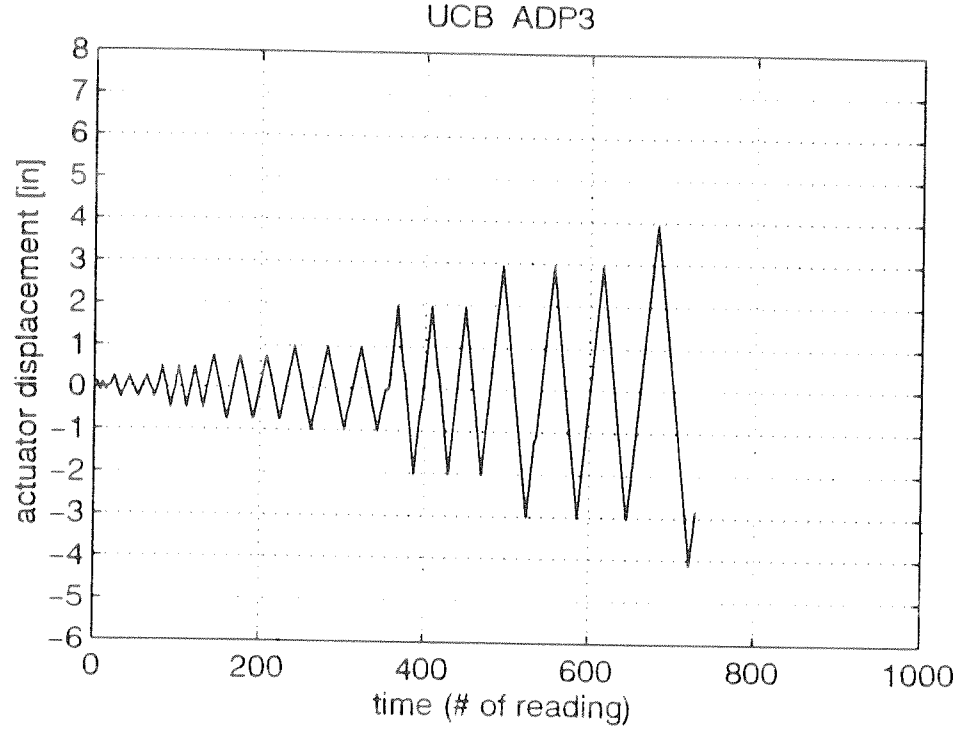


FIGURE 60: APPLIED LOAD / BEAM END DISPLACEMENT RESPONSE

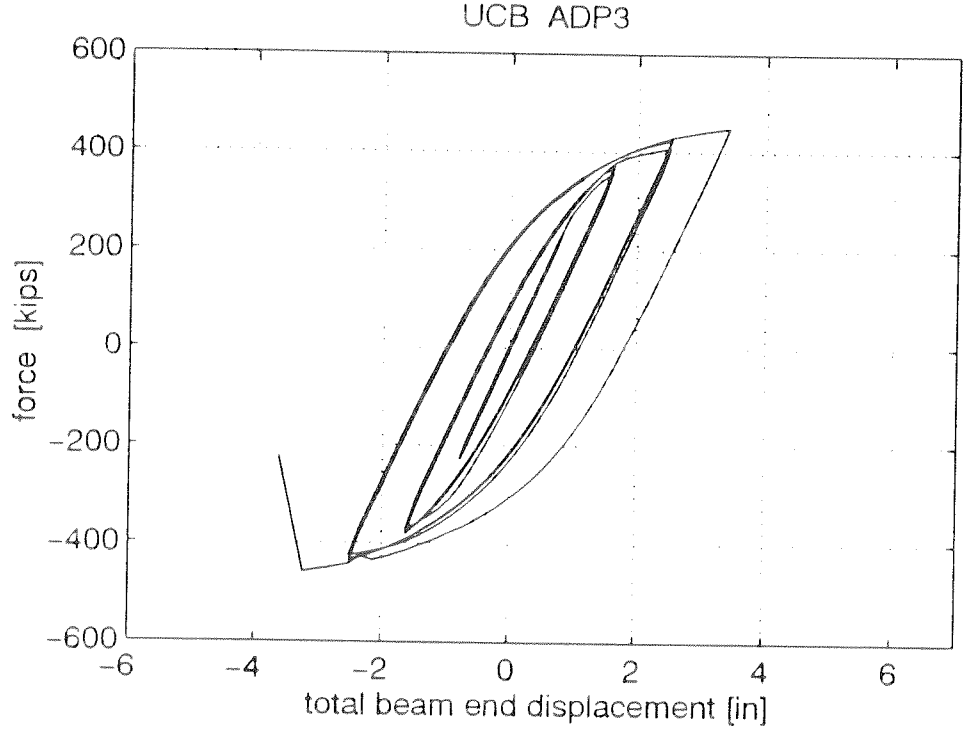


FIGURE 61: PLASTIC ROTATION VERSUS MOMENT @ COVER PLATE EDGE

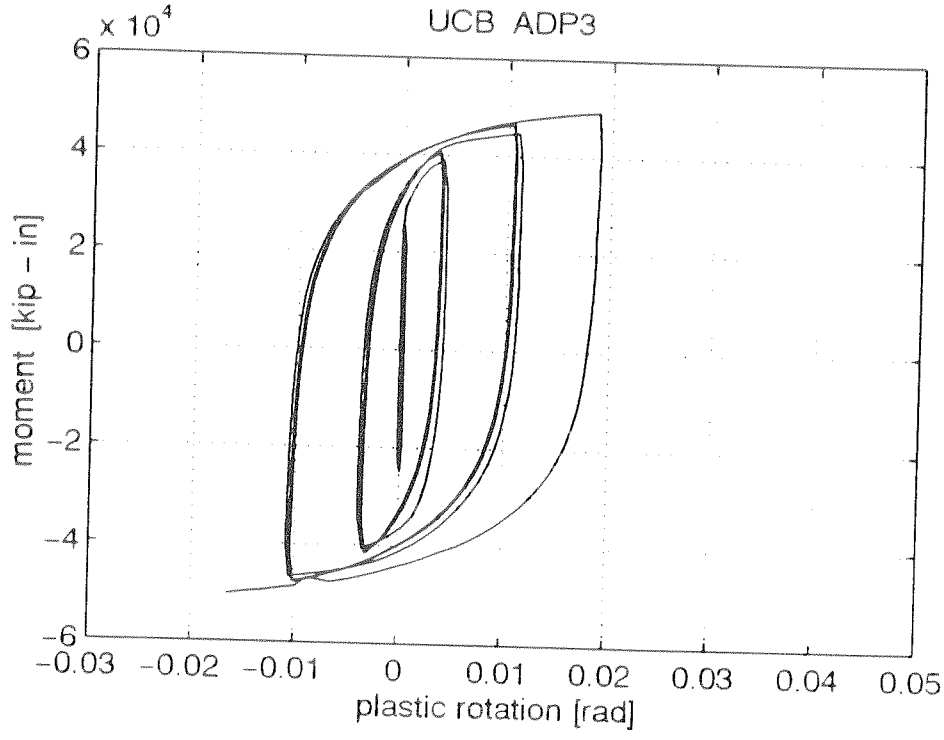


FIGURE 62: DISSIPATED ENERGY

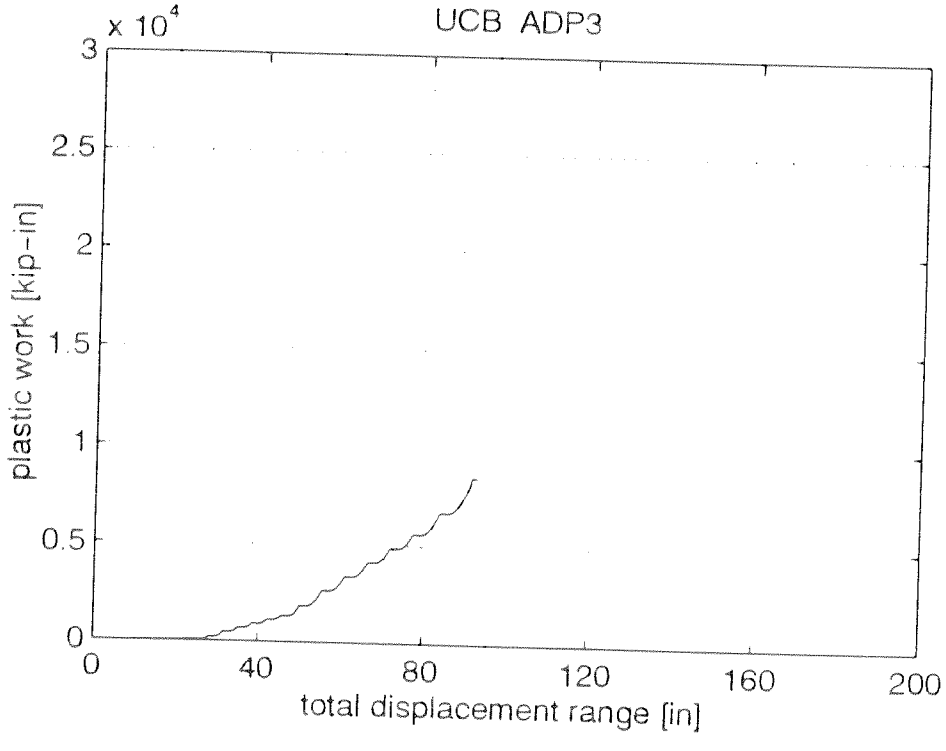


FIGURE 63: PANEL ZONE SHEAR DEFORMATION

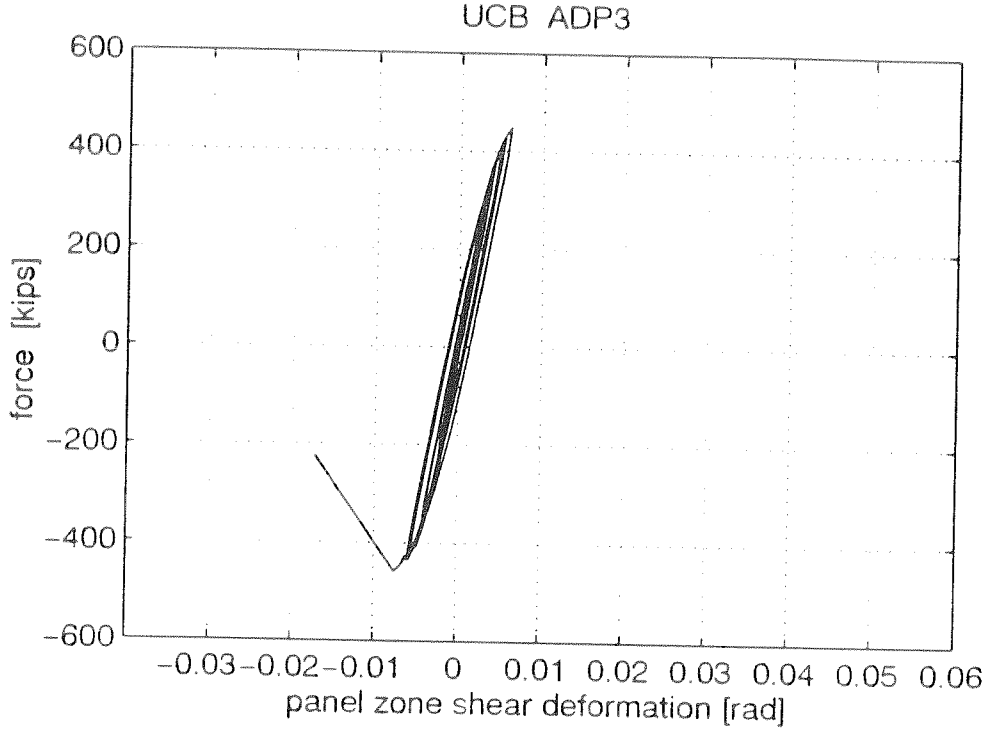


FIGURE 64: BEAM CONTRIBUTION IN TOTAL DISPLACEMENT

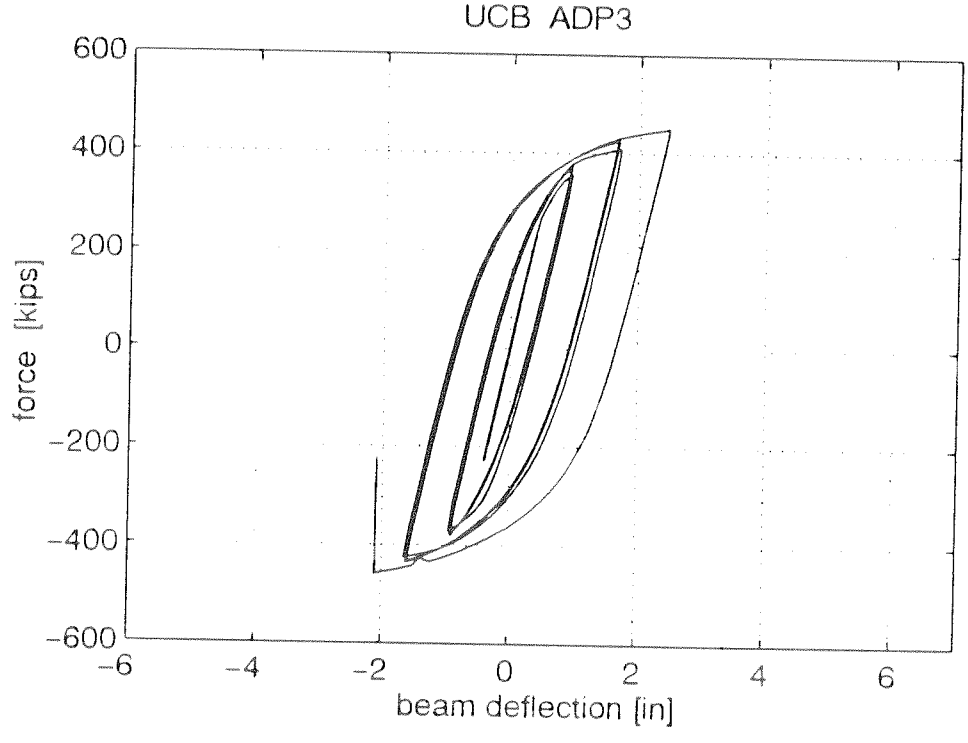


FIGURE 65: LOCAL RESPONSE -- TOP BEAM FLANGE (EDGE)

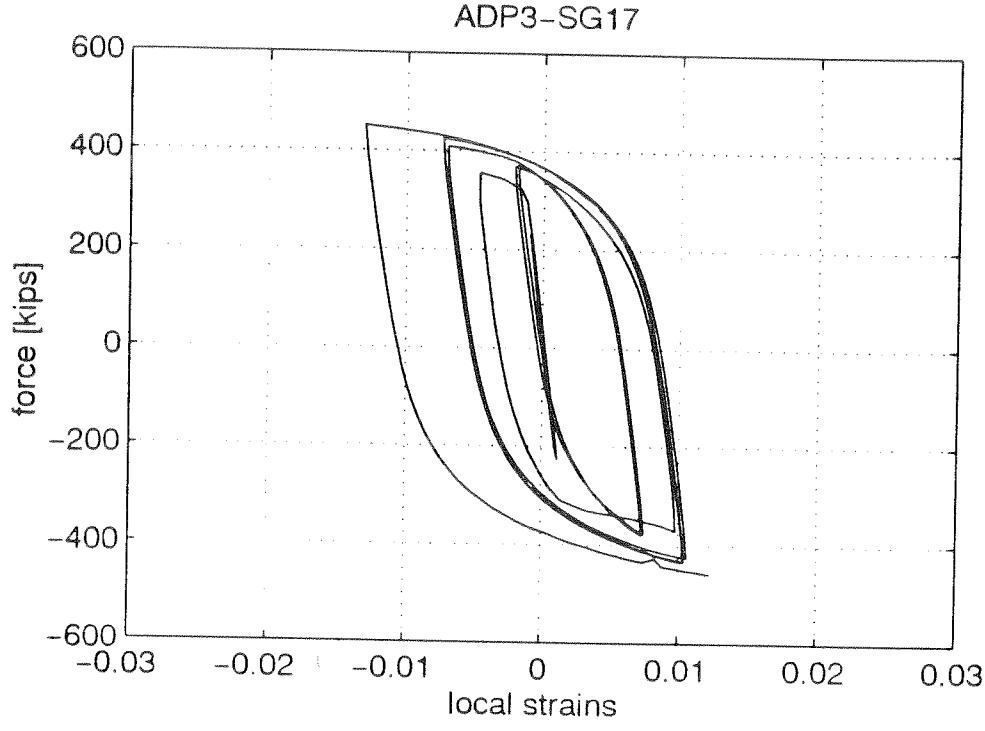


FIGURE 66: LOCAL RESPONSE -- TOP BEAM FLANGE (AXIS)

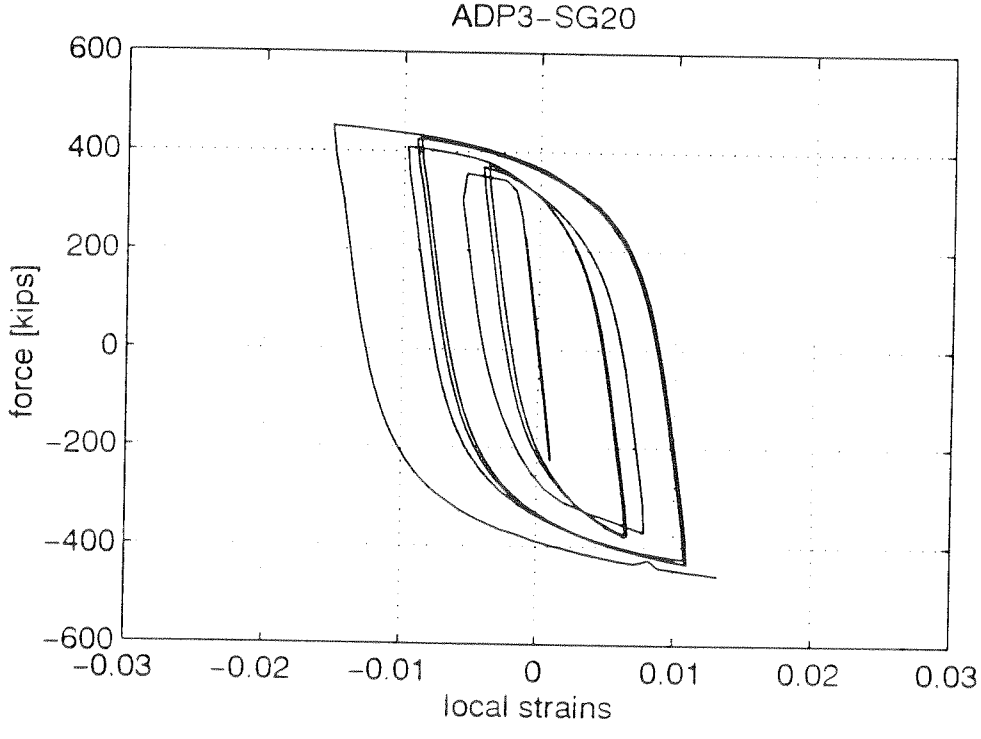


FIGURE 67: LOCAL RESPONSE -- BOTTOM BEAM FLANGE (EDGE)

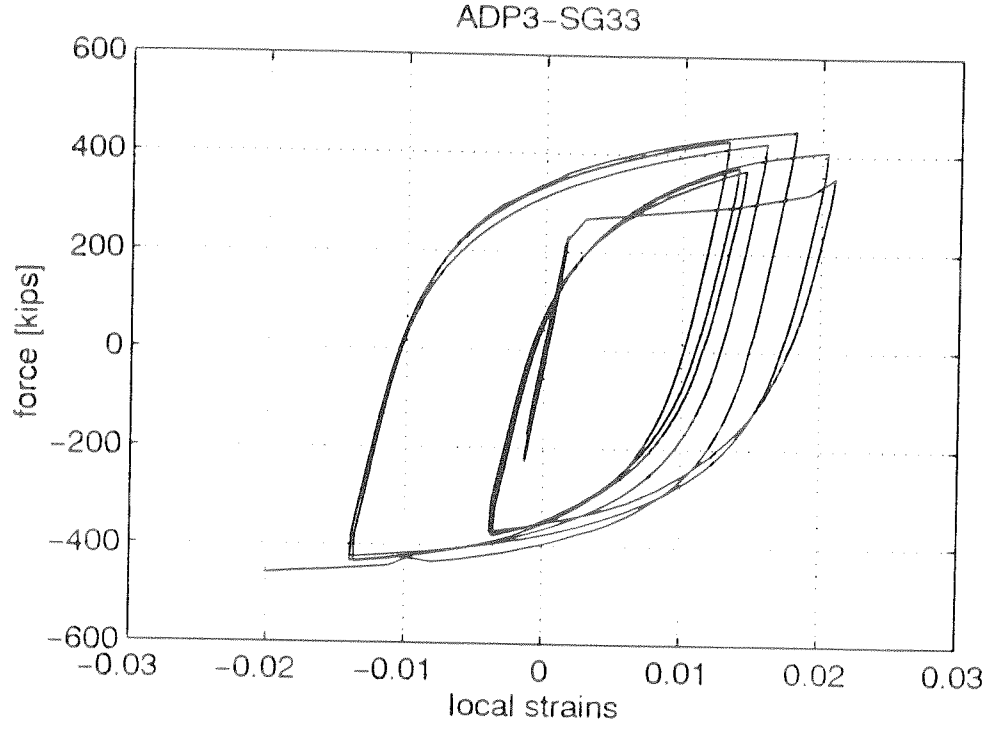


FIGURE 68: LOCAL RESPONSE -- BOTTOM BEAM FLANGE (AXIS)

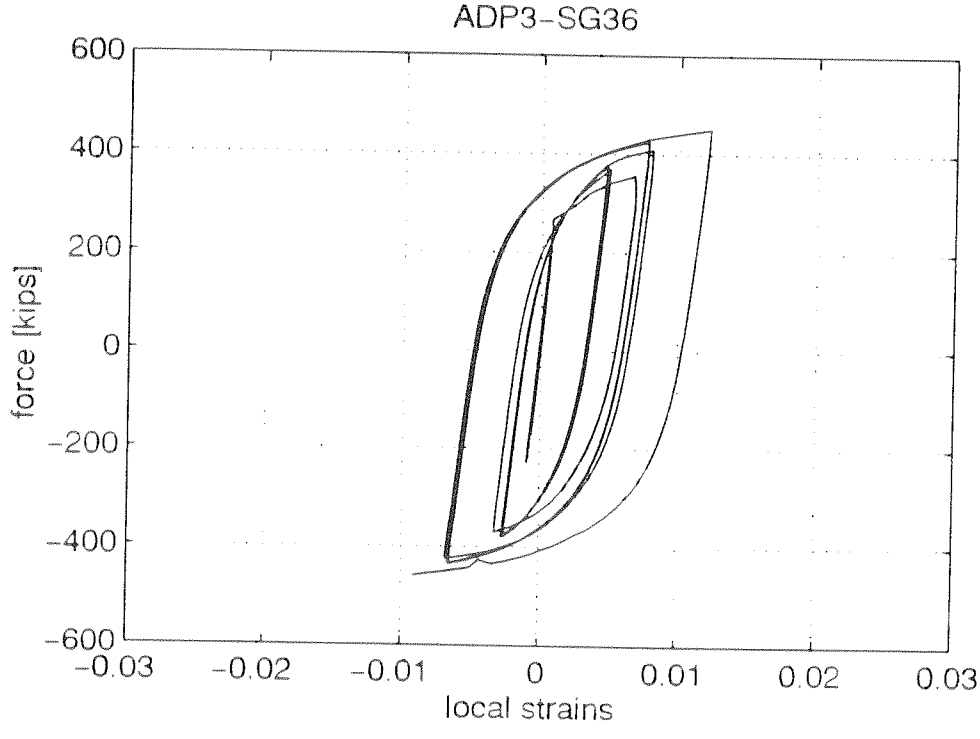


FIGURE 69: LOCAL RESPONSE -- TOP COVER PLATE (EDGE)

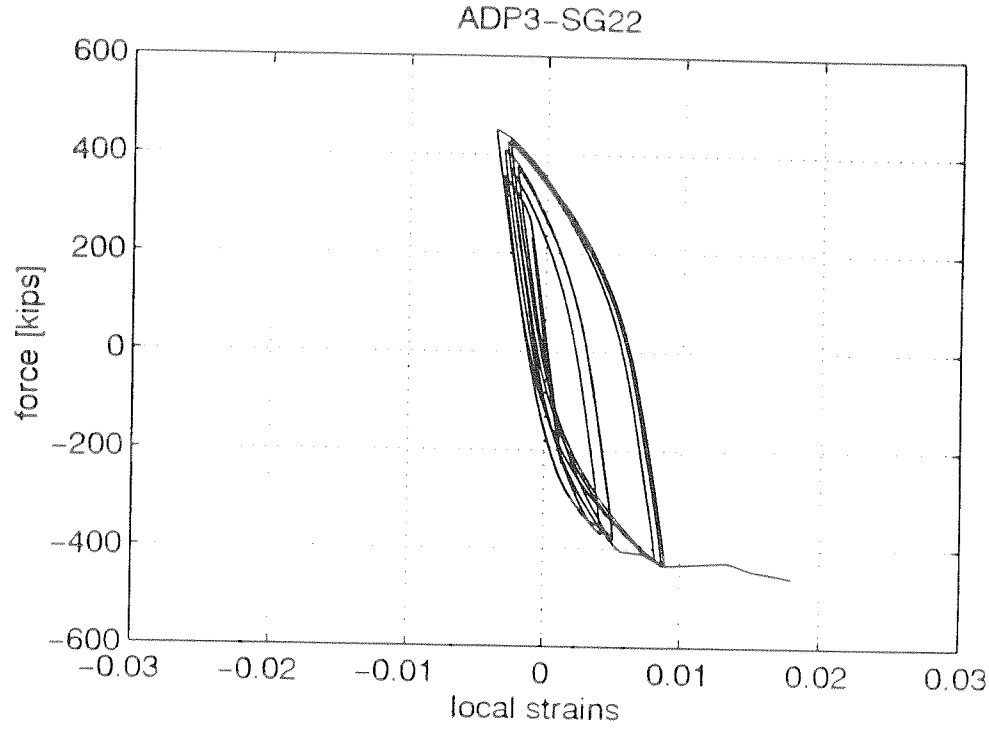


FIGURE 70: LOCAL RESPONSE -- TOP COVER PLATE (AXIS)

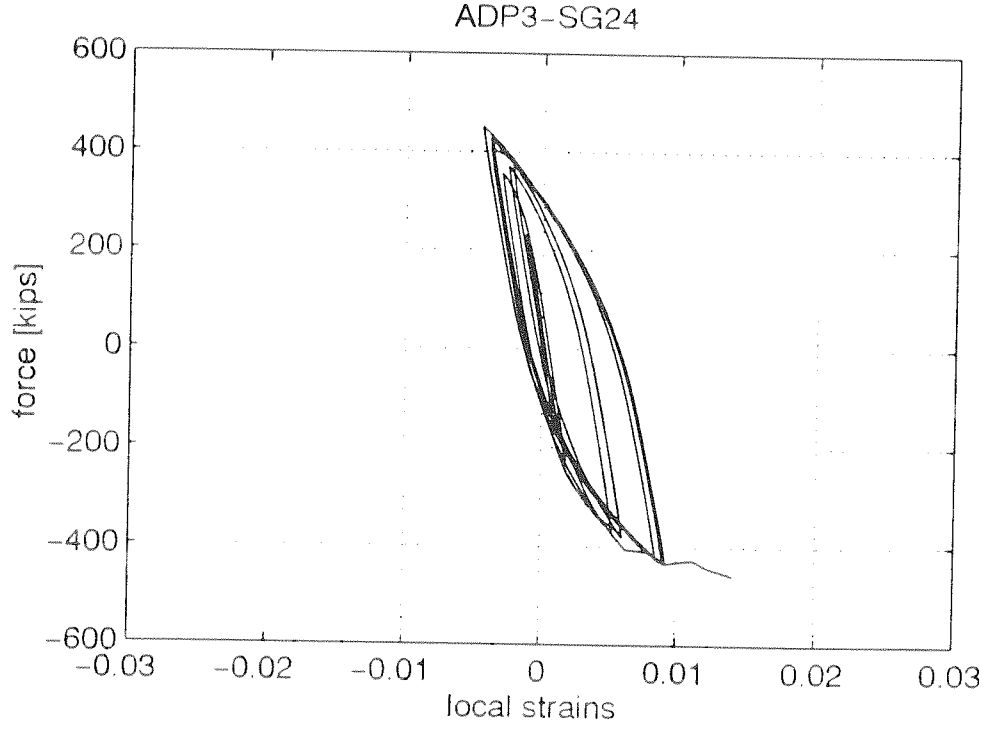


FIGURE 71: LOCAL RESPONSE -- BOTTOM COVER PLATE (EDGE)

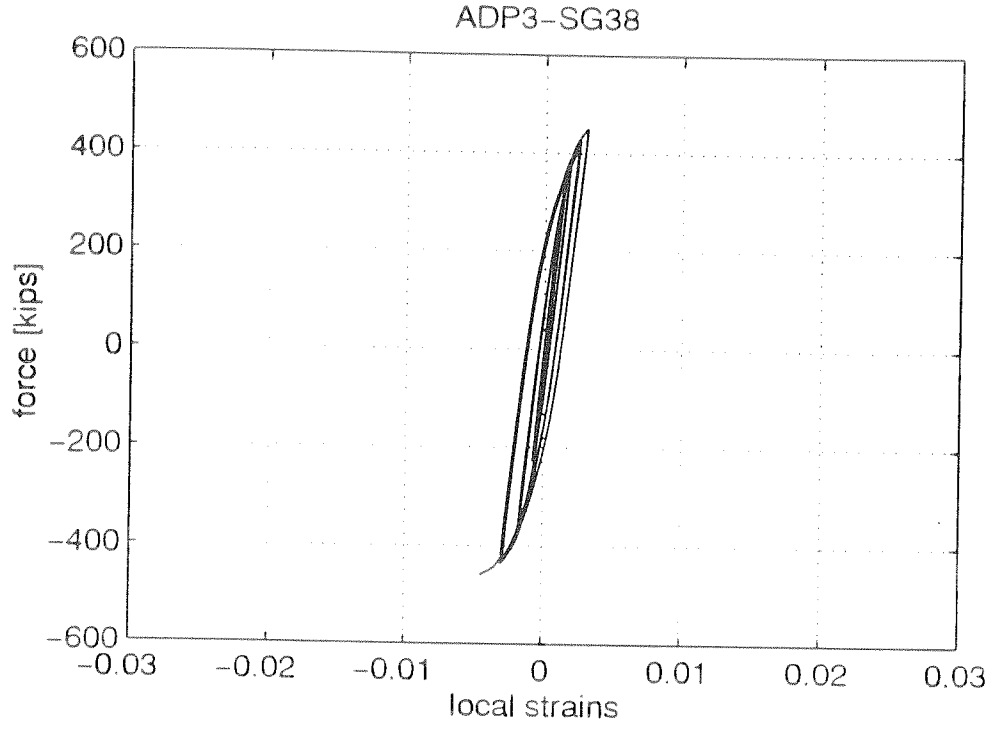


FIGURE 72: LOCAL RESPONSE -- BOTTOM COVER PLATE (AXIS)

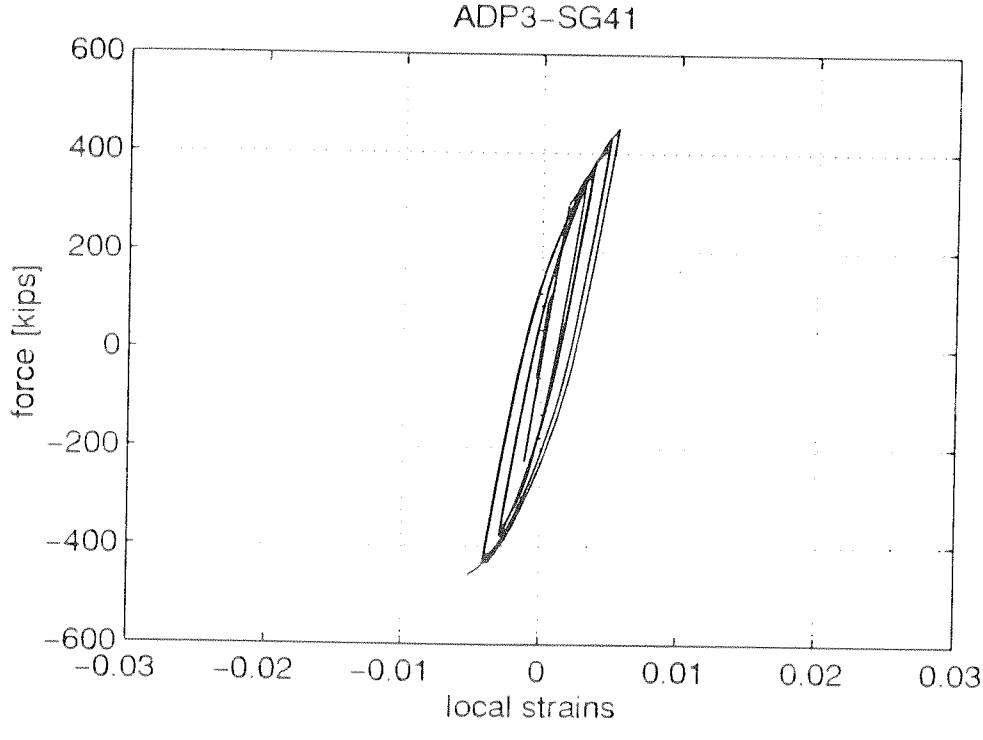


FIGURE 73: LOCAL RESPONSE -- BEAM WEB (TOP@SHEAR TAB)

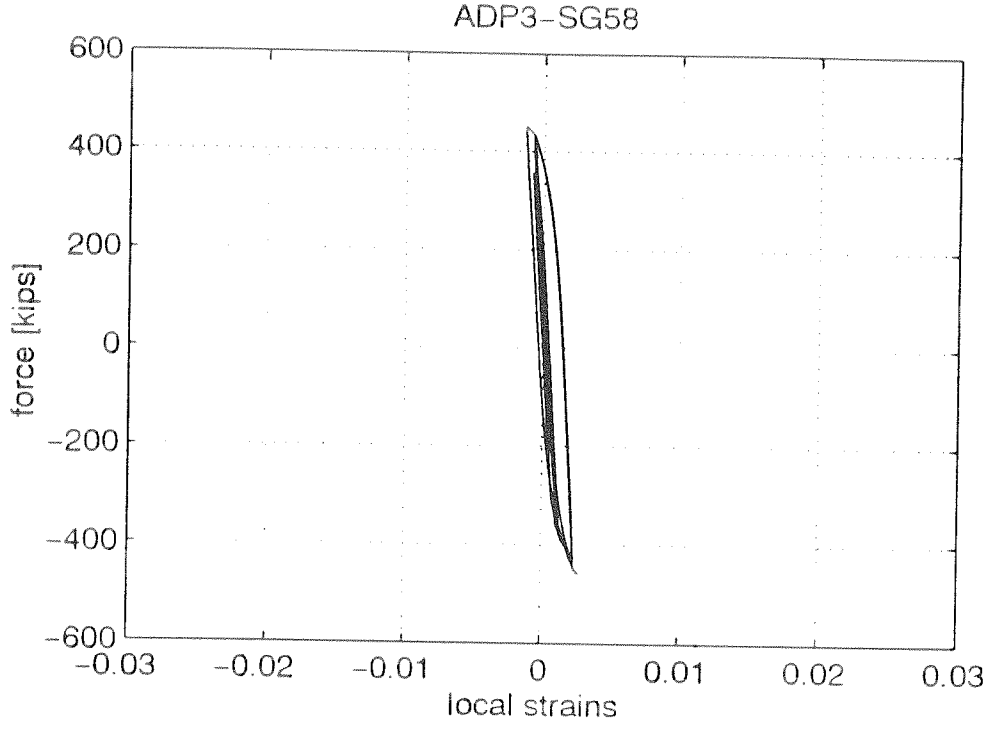


FIGURE 74: LOCAL RESPONSE --BEAM WEB (BOTTOM@SHEAR TAB)

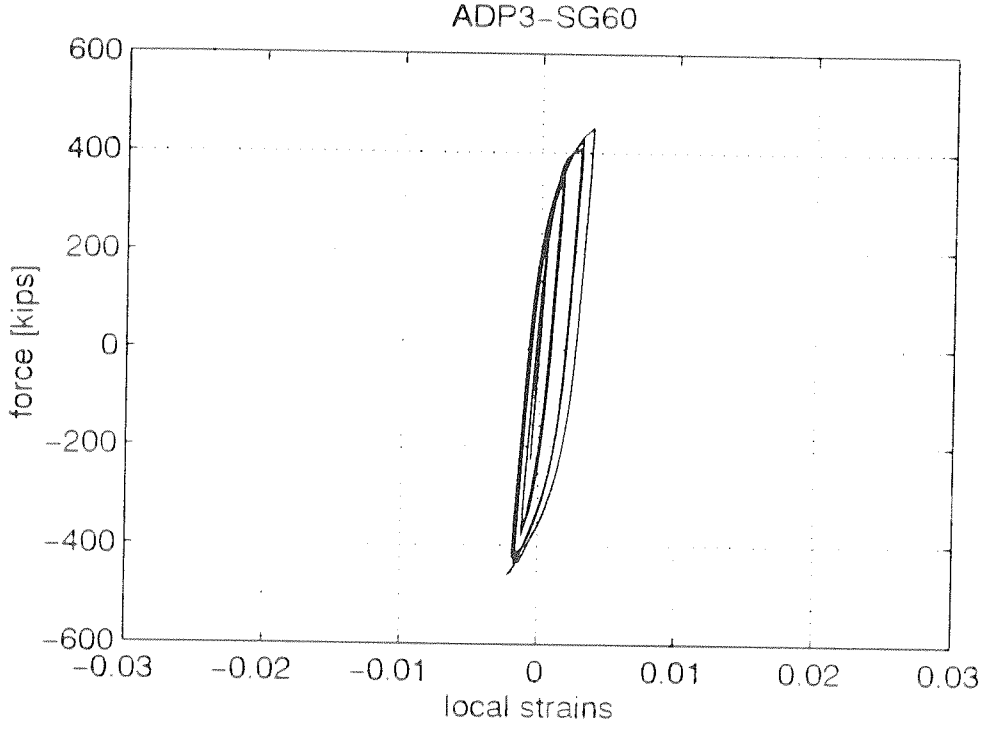


FIGURE 75: LOCAL RESPONSE -- BEAM WEB (TOP@COVER PLATE)

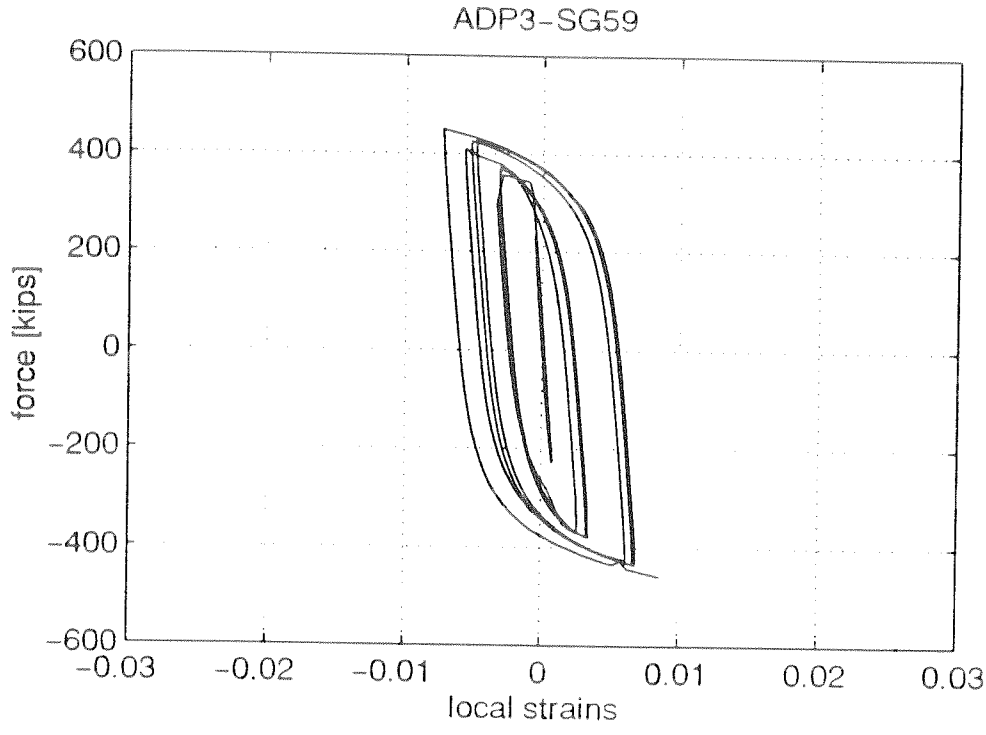


FIGURE 76: LOCAL RESPONSE --BEAM WEB (BOTTOM@COVER PLATE)

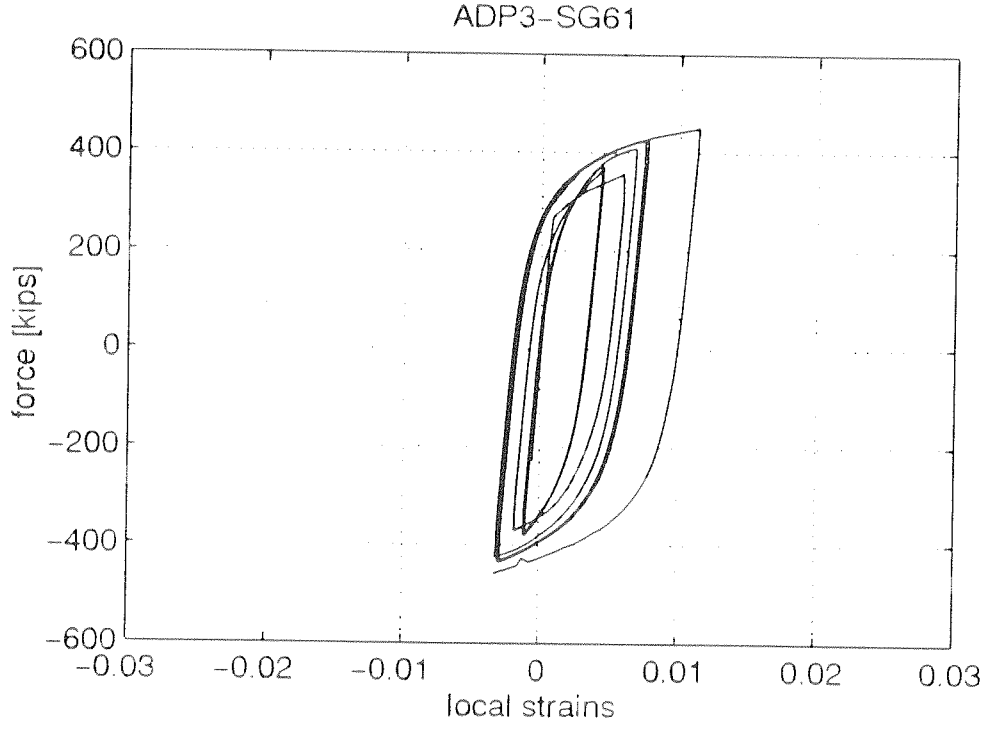


FIGURE 77: LOCAL RESPONSE -- COLUMN FLANGE (ABOVE TOP COVER PLATE)

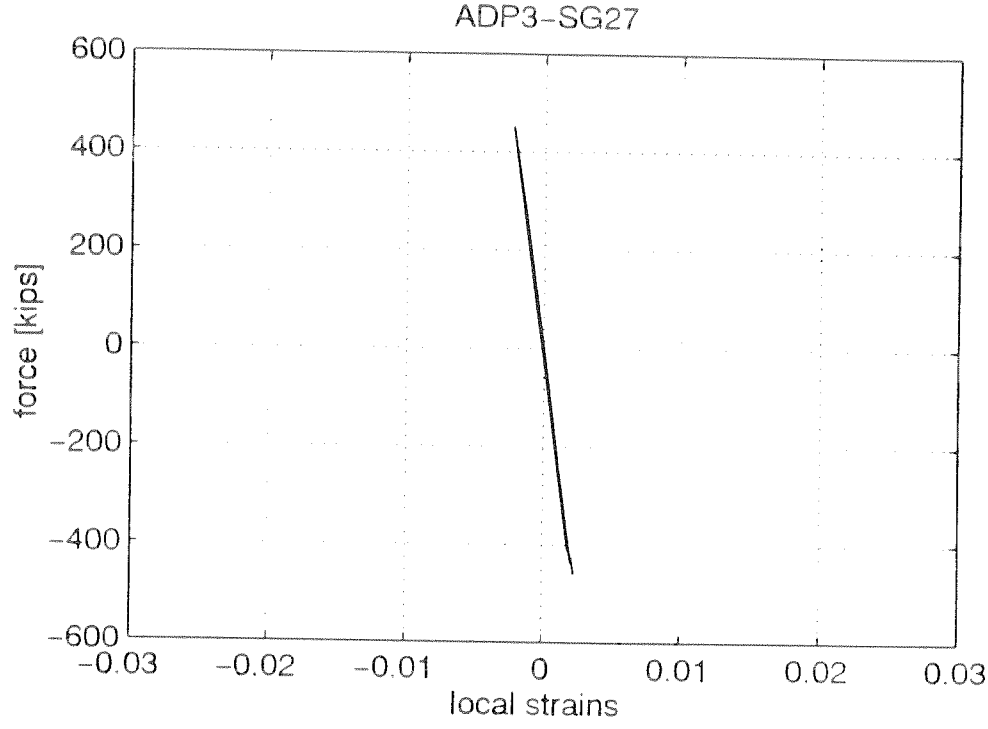


FIGURE 78: LOCAL RESPONSE -- TOP BEAM FLANGE (EDGE @ COLUMN)

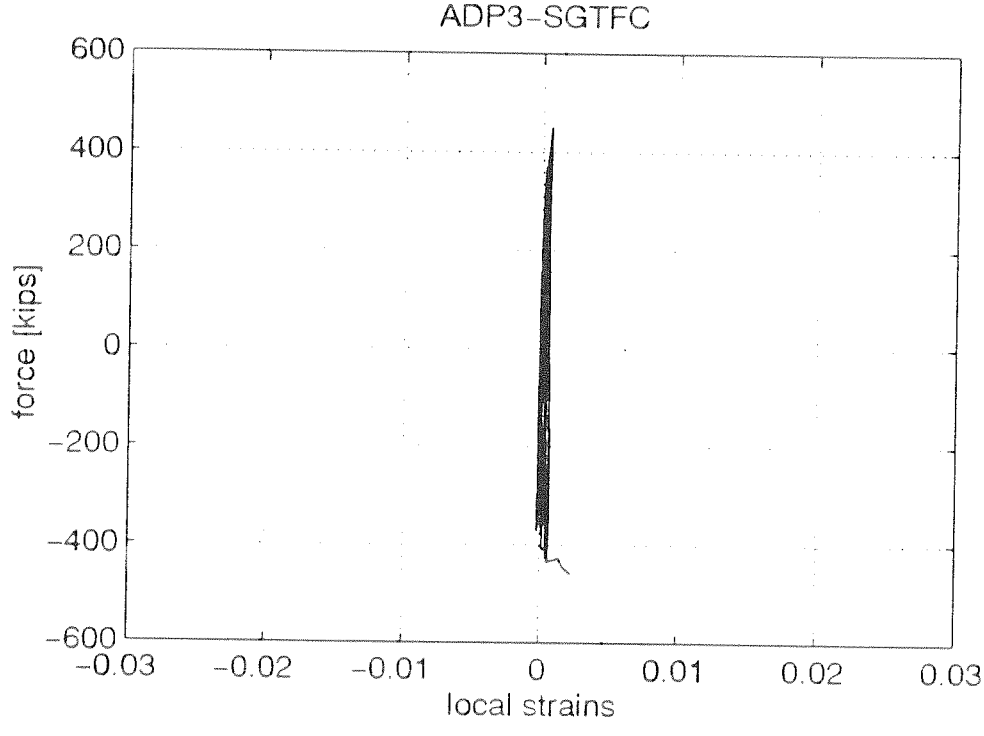


FIGURE 79: PHOTOGRAPH SHOWING FRACTURE OF SPECIMEN ADP3

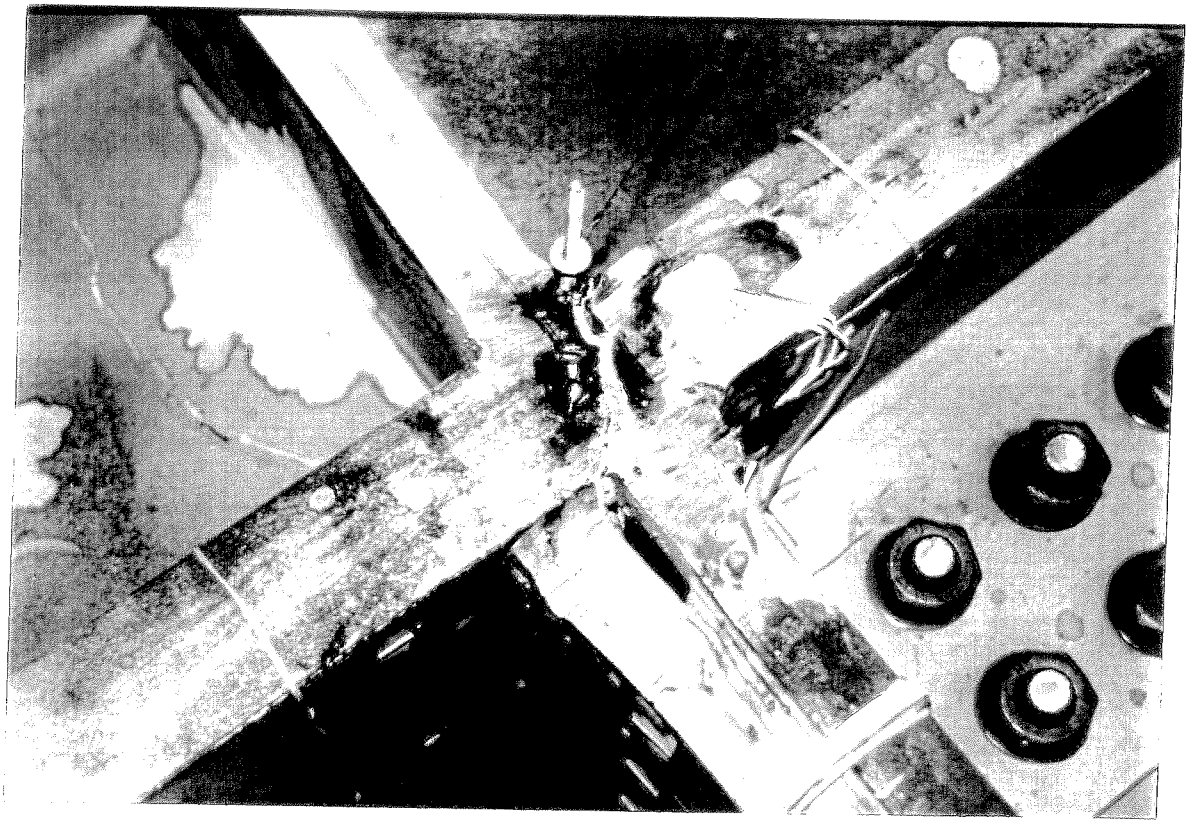


FIGURE 80: PHOTOGRAPH SHOWING FRACTURE OF SPECIMEN ADP3

FIGURE 81: PHOTOGRAPH SHOWING FRACTURE OF SPECIMEN ADP3

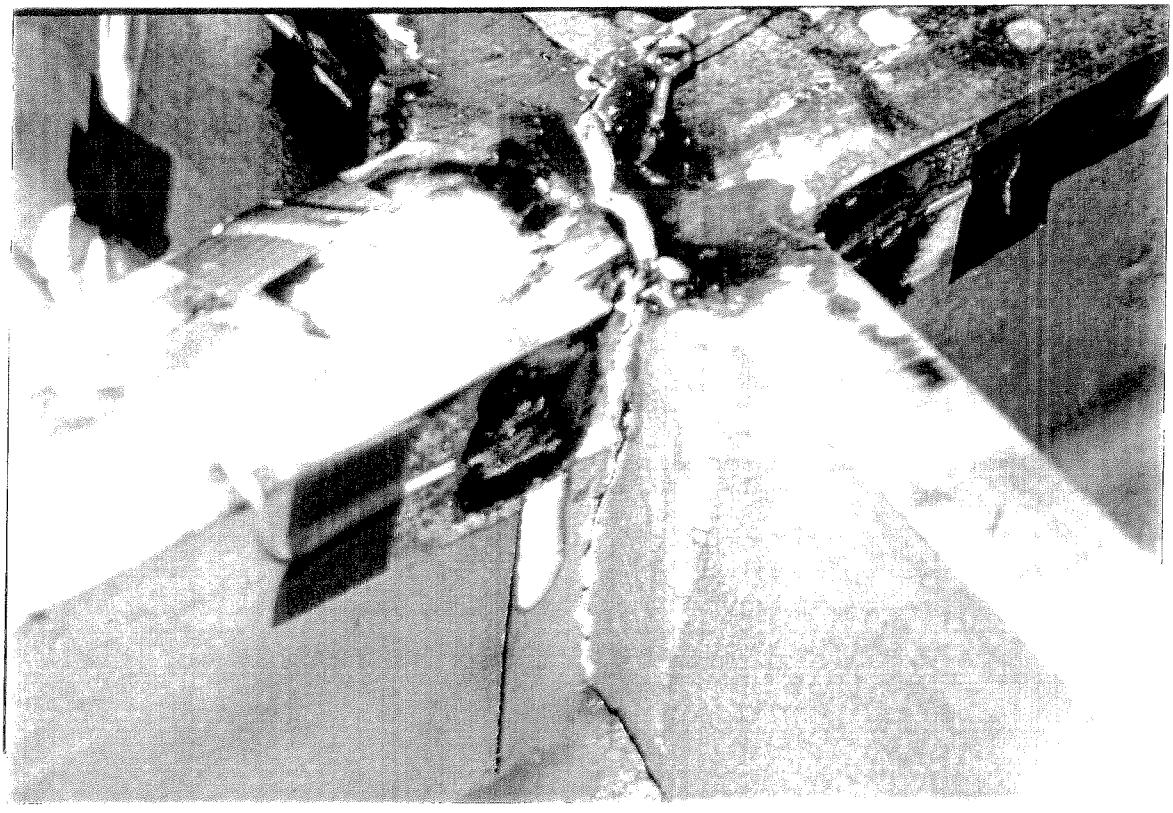


FIGURE 82: PHOTOGRAPH SHOWING FRACTURE OF SPECIMEN ADP3
(COLUMN WEB OUTSIDE PANEL ZONE)