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Second Progress Report

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Introduction

The purpose of this phase of the research has been to investigate the flexural behavior of C-shaped members with web openings. Three common industry standard C-sections were tested as outlined in the first progress report. The web openings were located at 24 inches on center as illustrated in Fig. 1. Each test specimen was subjected to two point loads until the ultimate flexural strength of the member was obtained. This report summarizes the test procedure and results of the research to date.

Test Setup

In each test, two C-shaped beams were connected together using 3/4 x 3/4 x 1/8 inch angles and self tapping screws to fabricate one test specimen. See Fig. 2. Each specimen was tested as a simply supported beam. Two concentrated loads were applied six feet apart positioning a hole at mid-span as shown in Fig. 1. This loading configuration provided a pure moment region in the center of the beam. The load was applied using a hydraulic jack. An electric load cell placed between the jack and the cross beam measured the applied load. Figure 3 shows the test setup. The span length and the "a" dimension are given in Table 3. The ends of the beam were supported with vertical rollers to prevent lateral movement of the ends as shown by Fig. 4. In order to prevent premature failure of the beam due to lateral-torsional buckling, lateral bracing was provided along the length of the span. A typical bracing scheme is shown in Fig. 5.

Test Specimens

Three sizes of C-shapes were tested: 2.5", 3.625" and 12" web depths. Various thicknesses of C-shapes were also tested. The cross-sectional dimensions and thickness of each test specimen is recorded in Table 1. The material properties of the steel, for each test specimen, were established by standard tensile coupon tests. Table 2 lists the tensile test data on thickness, yield point, ultimate tensile strength and percent elongation in 2-in. gage length.

Test Procedure

The load was applied to the test specimens in predetermined increments using a hydraulic jack. At each load increment the load and strain gage readings were recorded to a data file. In addition, for each load the vertical displacement of the beam was measured using a dial gage. The load was increased in increments until the beam reached failure and could no longer sustain the additional load.

Test Results

The applied failure load, P, for each test specimen is recorded in Table 3. The value of P is the total load applied by the hydraulic jack at mid-span. The dead load due to the cross beam and the test specimen have been accounted for in the moment calculations. Table 4 lists the tested moment capacity for each specimen as well as the predicted moment capacity calculated according to the 1986 AISI Specification.

The moment ratio Mu test/Mu comp is a measure of how well the AISI Specification estimates the bending strength of a C-shaped member with web openings. Table 4 lists the values of Mu test/Mu comp. The 12" deep sections have an average moment ratio of 0.74. This low average moment ratio is not attributed to the presence of punchouts, but is believed to be caused by the flange web interaction. The very narrow flange, nominally 1.625-in., did not appear to provide adequate edge restraint for the 12-in. deep web. The average ratios for the 3.625" and 2.5" sections are 0.89 and 0.96 respectively. The lower ratio for the 3.625-in. sections are attributed to the presence of a punchout. For each test specimen, the failure occurred at the location of a punchout (Fig. 6).

Future Work

The next phase of this study will be to conduct a series of tests using C-sections having a nominal yield strength of 50 ksi. The specimens will be tested and evaluated as described in this report. Also, analytical work will begin to evaluate the moment capacity using the net cross-section to compute the section modulus.

TABLE 1
DIMENSIONS OF TEST SPECIMENS

Beam Specimen No.	Cross-Section Dimenisions (inches)											Hole Geom. (in)	
	Thick.	D1	D2	B1	B2	B3	B4	d1	d2	d3	d4	x	y
12,14,1&2	0.098	12.076	12.071	1.642	1.634	1.694	1.625	0.689	0.605	0.604	0.617	4	1.5
12,14,3&4	0.098	12.050	12.000	1.638	1.600	1.670	1.710	0.645	0.635	0.645	0.644	4	1.5
12,16,1&2	0.055	11.961	11.970	1.569	1.570	1.566	1.559	0.499	0.609	0.520	0.435	4	1.5
12,16,3&4	0.055	12.071	11.959	1.558	1.572	1.570	1.579	0.422	0.528	0.584	0.525	4	1.5
3,14,1&2	0.077	3.683	3.682	1.645	1.640	1.630	1.631	0.566	0.545	0.560	0.522	4	1.5
3,14,3&4	0.077	3.685	3.685	1.625	1.620	1.640	1.630	0.531	0.530	0.620	0.552	4	1.5
3,18,1&2	0.044	3.745	3.655	1.562	1.561	1.575	1.585	0.585	0.560	0.585	0.535	4	1.5
3,18,3&4	0.044	3.646	3.639	1.564	1.582	1.560	1.574	0.564	0.575	0.535	0.535	4	1.5
3,20,1&2	0.044	3.645	3.705	1.560	1.637	1.550	1.589	0.520	0.556	0.550	0.561	4	1.5
3,20,3&4	0.044	3.665	3.690	1.565	1.590	1.553	1.609	0.598	0.556	0.520	0.594	4	1.5
2,16,1&2	0.062	2.511	2.507	1.61	1.612	1.634	1.607	0.4	0.448	0.425	0.435	2	0.75
2,16,3&4	0.062	2.514	2.531	1.617	1.635	1.633	1.615	0.429	0.45	0.409	0.404	2	0.75
2,20,1&2	0.039	2.502	2.485	1.598	1.603	1.603	1.602	0.417	0.415	0.416	0.41	2	0.75
2,20,3&4	0.039	2.512	2.517	1.593	1.619	1.583	1.604	0.364	0.416	0.465	0.403	2	0.75

Note: See Fig. 2 for the symbols used for dimensions.
See Fig. 1 for the symbols used for the hole geometry.

TABLE 2
MATERIAL PROPERTIES

Specimen No.	Thick. (in)	Fy (ksi)	Fu (ksi)	%Elong.
12,14,1	0.098	35.93	47.27	36
12,14,2	0.098	35.93	47.59	35
12,16,1	0.055	48.38	56.15	30
12,16,2	0.055	49.84	58.84	34
3,14,1	0.078	62.43	77.09	24
3,14,2	0.076	65.01	79.74	23
3,18,1	0.044	45.25	59.34	32
3,18,2	0.044	48.59	61.30	30
3,20,1	0.044	46.47	59.97	27
3,20,2	0.044	47.16	60.64	34
2,16,1	0.062	37.37	47.90	39
2,16,2	0.062	37.09	49.81	38
2,20,1	0.039	33.78	48.98	46
2,20,2	0.039	33.61	47.05	42

TABLE 3
TEST RESULTS

Beam Specimen No.	Span Length (ft)	a (in)	P (kips)
12,12,1&2	14	48	13.40
12,12,3&4	14	48	16.90
12,14,1&2	16	60	7.16
12,14,3&4	16	60	7.50
12,16,1&2	16	60	4.38
12,16,3&4	16	60	4.79
3,14,1&2	12.5	39	3.70
3,14,3&4	12.5	39	3.54
3,18,1&2	12.5	39	1.35
3,18,3&4	12.5	39	1.37
3,20,1&2	12.5	39	1.35
3,20,3&4	12.5	39	1.43
2,16,1&2	12.5	39	1.04
2,16,3&4	12.5	39	0.90
2,20,1&2	12.5	39	0.46
2,20,3&4	12.5	39	0.46

TABLE 4
COMPARSION OF TEST RESULTS

Beam Specimen No.	h/t	y/h	Mu test (k-in.)	Mu comp (k-in.)	(Mu test)/(Mu comp)
12,14,1&2	118	0.13	219.52	323.42	0.68
12,14,3&4	118	0.13	229.87	326.30	0.70
12,16,1&2	210	0.13	135.97	181.89	0.75
12,16,3&4	211	0.13	148.27	182.18	0.81
				MEAN	0.74
3,14,1&2	42	0.47	75.17	80.25	0.94
3,14,3&4	42	0.47	72.01	82.29	0.88
3,18,1&2	75	0.45	29.32	32.63	0.90
3,18,3&4	74	0.46	29.70	35.09	0.85
3,20,1&2	74	0.46	29.31	33.48	0.88
3,20,3&4	74	0.46	30.78	33.61	0.92
				MEAN	0.89
2,16,1&2	33	0.36	23.37	22.95	1.02
2,16,3&4	34	0.36	20.54	23.18	0.89
2,20,1&2	54	0.36	11.85	12.51	0.95
2,20,3&4	54	0.35	11.95	12.04	0.99
				MEAN	0.96

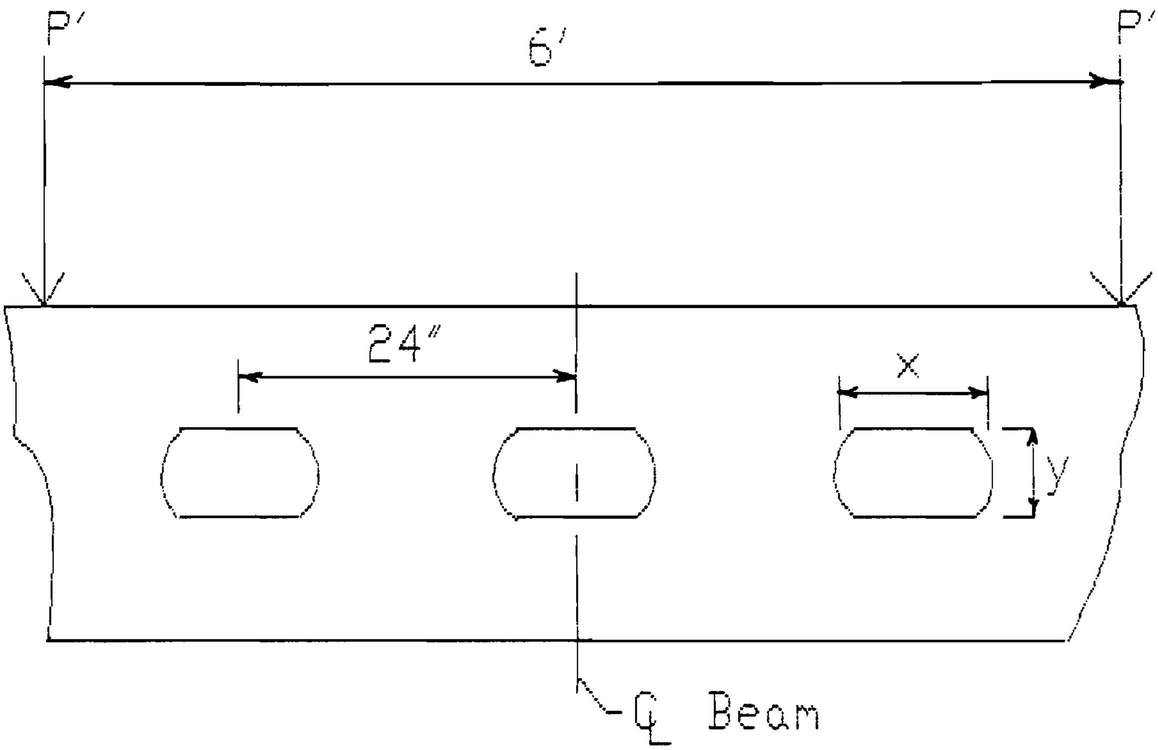

Figure 1. Opening Configuration

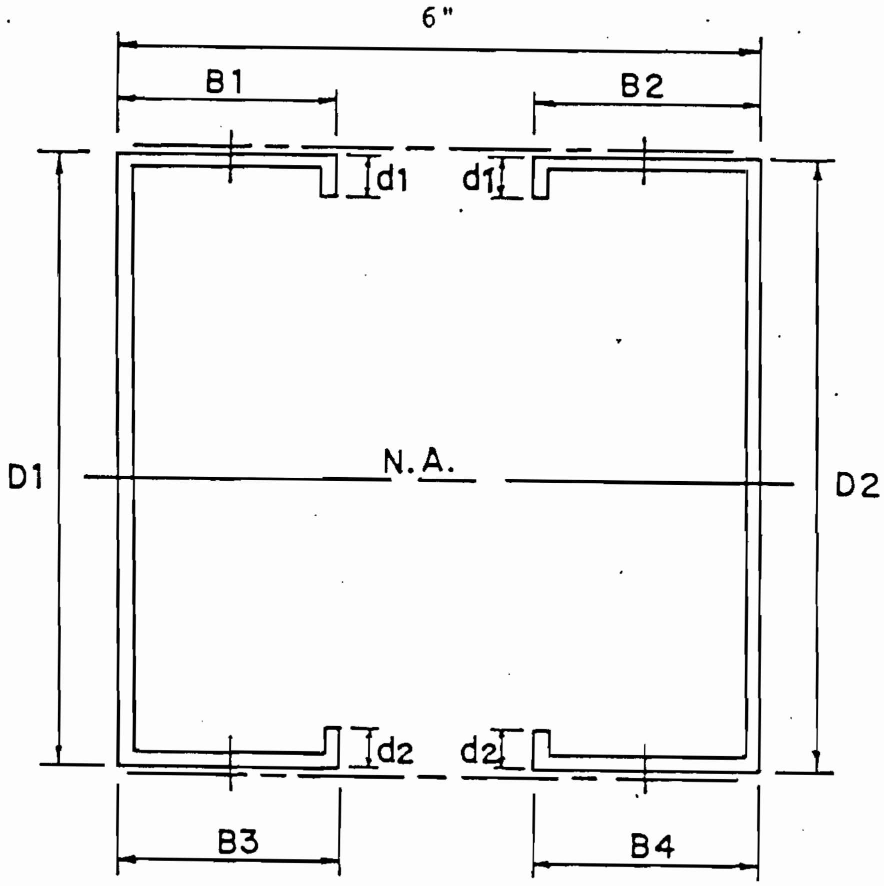

Figure 2. Beam Cross-Section

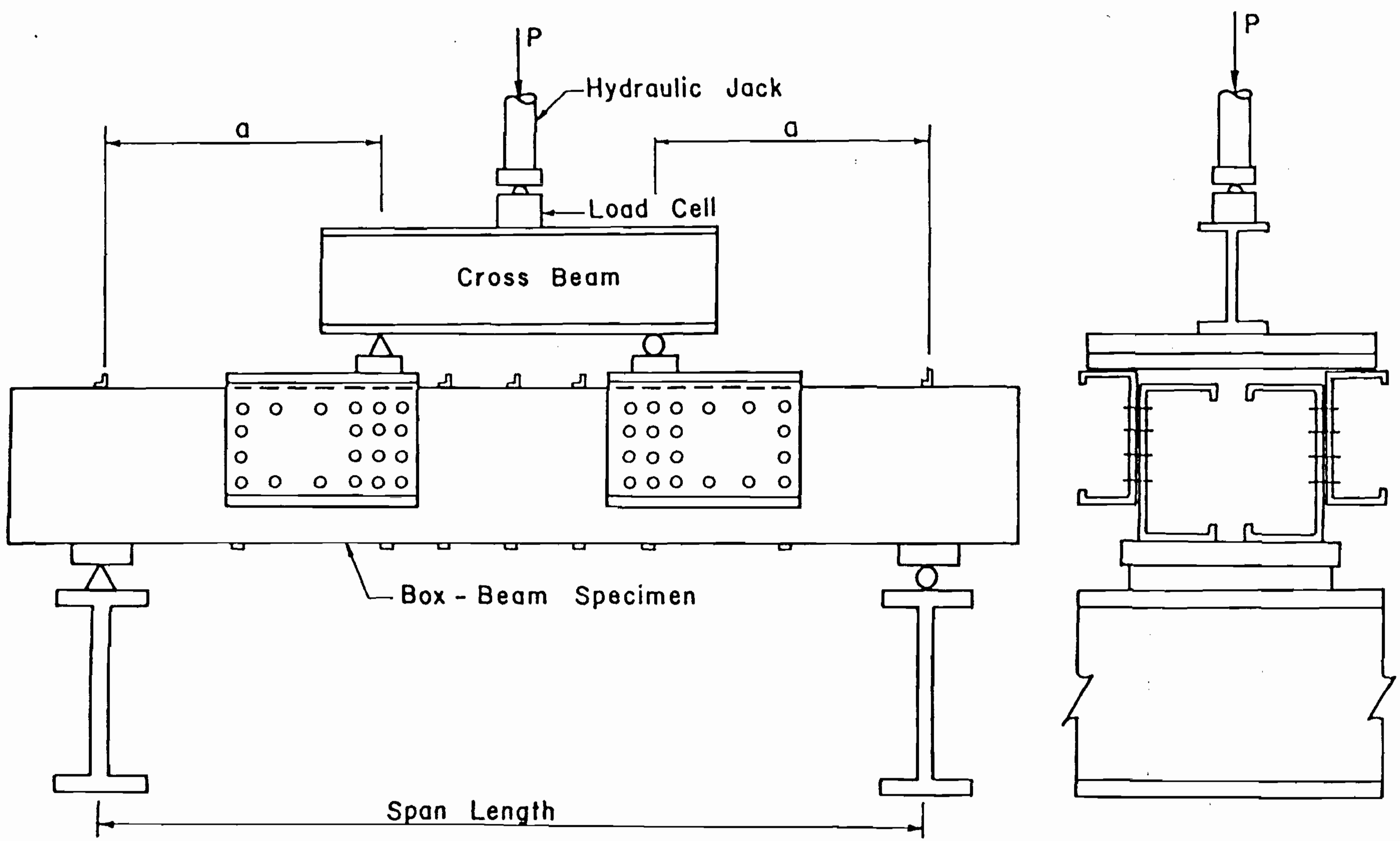

Figure 3. Test Setup

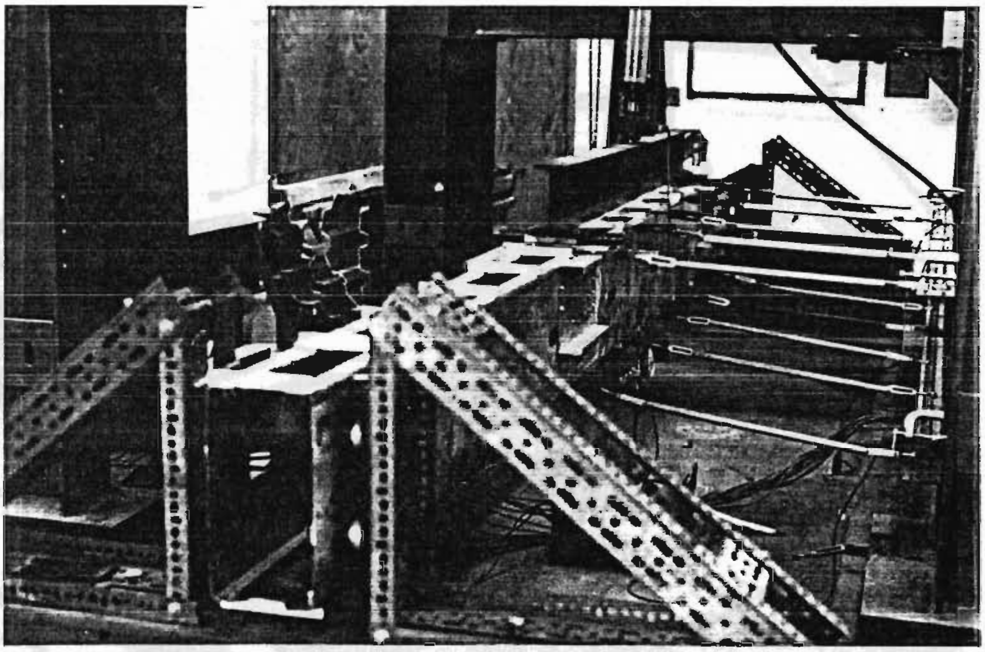

Figure 4. Support at End of Beam

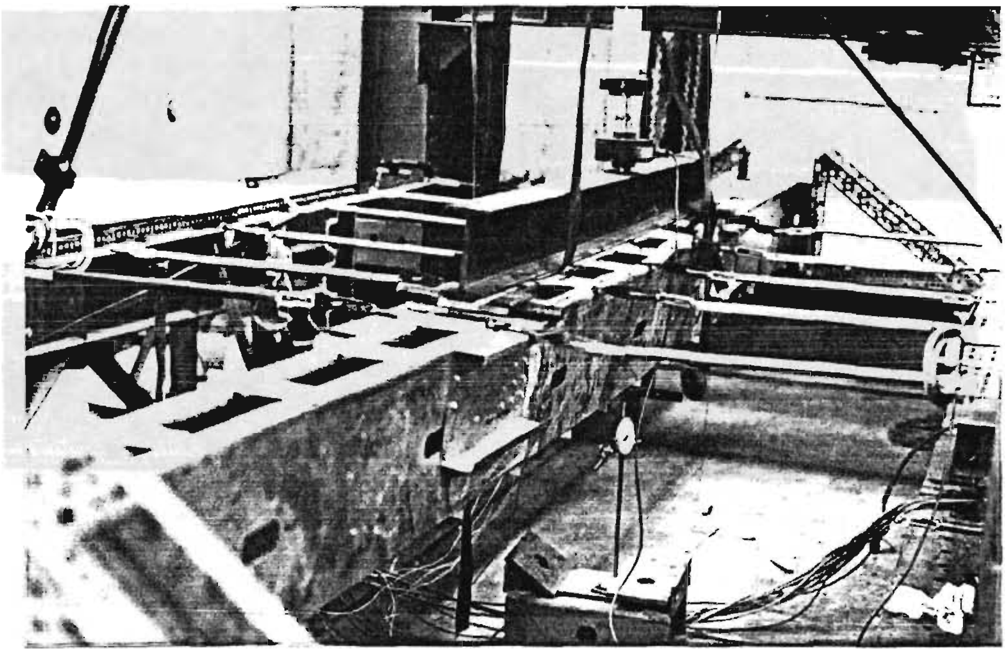

Figure 5. Typical Bracing System

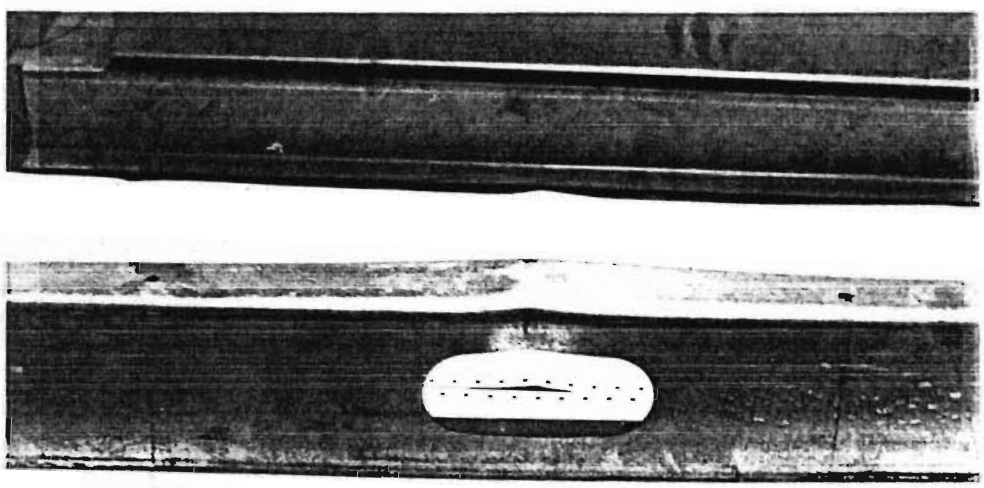

Figure 6. Typical Failure Mode