CONF-920631--13

WSRC-MS--91-420

DE92 009408

EVALUATION OF THE CAPACITY OF WELDED ATTACHMENTS TO ELBOWS AS COMPARED TO THE METHODOLOGY OF ASME CODE CASE N-318 (U)

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A paper for presentation at the
ASME Pressure Vessel and Piping Conference
New Orleans, Louisiana
June 21-25, 1992

and publication in the proceedings

The work described in this paper was prepared in connection with work done under Contract No. DE-AC09-89SR18035 with the U.S. Department of Energy. By acceptance of this paper, the publisher and/or recipient acknowledges the U.S. Government's right to retain a nonexclusive, royalty-free license in and to any copyright covering this paper, along with the right to reproduce and to authorize others to reproduce all or part of the copyrighted paper.

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EVALUATION OF THE CAPACITY OF WELDED ATTACHMENTS TO ELBOWS AS COMPARED TO THE METHODOLOGY OF ASME CODE CASE N-318

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ABSTRACT

This paper presents the results of a series of tests conducted to assess the capacity of various configurations of integral welded attachments. These tests are unique in that the attachments are welded to the outer radius of pipe elbows. The lug configurations tested include both rectangular and cross(cruciform) shapes.Both limit load and fatigue tests are performed on the lug-elbow configurations. The results of the limit load tests are presented as limit moments. The results of the fatigue tests are cycles-to-failure. Markl's equation is then used, with the fatigue results, to determine stress intensification factors. The limit moments and stress intensification factors are then compared to those developed using the methodology of ASME Code Case N-318. The level of conservatism in the Code Case methodology is then compared to the test results.

NOMENCLATURE

The nomenclature used in this paper is the same as that used in Code Case N-318. Additional symbols are defined as follows:

B	=	B_L of B_N of Code Case N-318
C	=	C_L of C_N of Code Case N-318
C_{2e}	=	C_2 value for an elbow
C'_L	=	C value for lug accounting for stress in elbow
i	=	stress intensification factor
i_t	=	test-determined stress intensification
K_e	=	K value for elbow with lug attachment $K_e = K_l = 2$
M	=	moment applied in fatigue test
M_{CL}	=	limit moment (long or circ)_ per N-318
M_t	=	test-determined limit moment
N_f	=	cycles-to-failure in fatigue test
S	=	nominal stress amplitude = M/Z_l for lug
S_y	=	Material yield stress
Z_l	=	Z_{lL} or Z_{lN} of Code Case N-318
δ	=	displacement applied in fatigue test

INTRODUCTION

This paper presents the results of a series of tests on integral welded attachments to elbows. Previous work on welded attachments to elbows is limited. Emera and Rossow used the Finite Element Method to address the effect of a thrust load on a piping elbow, in their paper "Stresses in Elbows Created by Supporting Lug Loads".[1]

The data presented in this paper are from tests of both standard rectangular and cross (cruciform) configurations on elbows. The results from the tests are compared to an evaluation of the lug-elbow configurations using the methodology of ASME Code Case N-318.[2] Code Case N-318 was released as part of the ASME Boiler and Pressure Vessel Code, Section III, Division I, 'Nuclear Power Plant Components" hereafter called the Code.[3] Code Case N-318 is used for the evaluation of rectangular lugs on Class 2 and Class 3 piping, and has been used extensively in the evaluation of lugs on nuclear plant piping systems. The results of the Code Case evaluation are then compared with the test results to determine the level of conservatism in applying the Code Case methodology to the nonstandard lug-elbow configurations.

These tests are the second in a series of tests on welded attachments. In the first series of tests, welded attachment of the same geometric and loading configurations described in this paper are used on straight piping sections. The results of the straight pipe tests are presented in Reference 4.

TEST SPECIMENS AND METHOD

Eight tests were conducted with three different lug configurations. All of the tests were on 12-inch diameter schedule 20 carbon steel elbows. In each case the lug had a fillet weld around all 4 sides of the attachment. Prior to testing all welds were inspected. The fillet weld size averaged 1/2-inch. Additionally all specimens were ultrasonically tested for wall thickness at locations near the welded attachments. The average wall thickness is determined and used in the Code Case calculations. The configurations tested were as follows:

1. Long narrow lug with long direction parallel to the vertical axis of the pipe, loaded out-of-plane (Figure 1).

2. Long narrow lug with long direction circumferential to the vertical axis of the pipe, loaded in-plane (Figure 2).

3. Symmetric cruciform, loaded in-plane and out-of-plane (Figure 3).

Both a limit load and a fatigue test were performed for each of the lug configurations and loading directions. The fatigue testing method follows the requirements of Reference 5 "Standardized Methods for Developing Stress Intensification Factors for Piping Components". Figures 4 and 5 show the test setup of the limit load and fatigue test.

The elbow was fabricated to ANSI B16.9 "Factory-Make Wrought Steel Butt Welding Fittings", and had a yield strength of 46.2 KSI. The lug material was ASTM A588 Grade B with a yield strength of 60.2 KSI. Thin wall pipe was used with high strength lug material because the interest was in pipe wall failure, not failure of the lug or the weld.

FAILURE CRITERION

In bothe the limit load and fatigue tests the specimens were tested to failure. The failure criterion for the limit load tests was Article II-1000, "Experimen tal Stress Analysis", Section II-1430, of the ASME Code. The test limit moment (M_t) is then determined by multiplying the limit load by the moment arm.

The failure criterion for the fatigue tests was the formation of a through-wall crack in the elbow wall. Crack initiation was determined by observation of the specimen. The cracks formed along the toe of the weld at the elbow wall. Prior to beginning the fatigue test the speciments were filled with water, The determination of when the crack propagated through the wall was determined by the appearance of moisture on the outside surface oif the elbow.

LIMIT LOAD TESTS

The concept of limit analysis is the basic design philosophy behind the ASME Code equations for primary stress intensity. The Code equations, for primary stress intensity are intended to limit gross plastic deformation of piping. The limit on gross plastic deformation is the criterion used to provide integrity of the pressure boundary for primary loads. Equations (8) and (9) of the Code provide stress limits to avoid gross plastic deformation.

In Code Case N-318 Code Equations (8) and (9) are modified to include the effect of welded attachments. The modification is the addition of the S_{ml} term to the Code Equations. S_{ml} is calculated in Equation (1) of Code Case N-318. The B-indices used in Equation (1) of N-318 are analogous to the B-indices used in code Equations (8) and (9). For the limit moment test described in this paper all the terms in Equation (1) of N-318 can be neglected except for the in-plane or out-of-plane moment term depending on the loading direction.

Therefore Equation (1) of N-318 reduces to :

$$S_{ml} = B\left(\frac{M_{CL}}{Z_l}\right) \quad (1)$$

Using S_Y as the allowable stress and solving for the limit moment yields:

$$S_{ml} = \frac{S_Y Z_l}{B} = \frac{S_Y Z_l}{\frac{2}{3}C} \quad (2)$$

Equation (2) above can then be applied to determine the calculated limit moment based on the Code Case methodology. The calculated limit moment M_{CL} can then be compared with the limit moment determined from the test (M_t). The conservatism in the Code Case methodology can then be defined by the ratio M_t/M_{CL}. The calculated limit moment for the four limit load tests (Tests 9-12) are compared with the test data in Table 1.

TABLE 1

LIMIT LOAD TEST

TEST	LUG SHAPE	LOAD PLANE (a)	M_t (in.KIPS)	t (in.)	r/t	C (b)	M_{CL} (in.KIPS)	M_t/M_{CL}
9	Rec	Circ	76.8	.2775	22.472	6.593	13.9	5.53
10	Rec	Long	107.8	.2708	23.043	14.240	24.0	4.49
11	Cross	Long	383.0	.2725	22.895	14.240 6.521 Σ20.760	65.3 20.4 Σ85.7	4.47
12	Cross	Circ	242.1	.2858	21.805	43.458 7.154 Σ50.640	15.4 12.4 Σ27.8	8.72

M_N = Circ
(b) See Code Case N-318; C_L = Long, C_N = Circ
(c) per Equation 2

The evaluation of the cruciform shape for the limit load test is analyzed by determining the moment capacity of each section of the cruciform individually using the methodology of N-318. The two moment capacities are then summed to compare with the limit moment determined by the test. The summation of the two moment capacities based on the Code Case Methodology is a reasonable approach, because the limit moment represents gross yielding of the entire section. Since the tests are performed on elbows the section modulus is based on the actual footprint size of the lug and accounts for the curvature of the elbow.

The ratios of M_t/M_{CL} presented in Table 1 show that the Code Case methodology is conservative by a factor ranging from 4.4 to 8.7.

FATIGUE TEST

The fatigue tests on the welded attachments are based on bending fatigue tests that follow the work of Markl.[6] Markl developed the following equation for Grade B Carbon Steel:

$$iS = 245{,}000N^{-0.2} \qquad (3)$$

Code Case N-318 is based on C-indices for the evaluation of fatigue loadings. The C-indices indicated the magnitude of primary-plus-secondary stress due to various loads. The C_2-indices for moment loading are very closely tied to the stress intensification factors from the Markl work. The stress intensification factor and C_2-indices can be related by the Code equation from Section NC-3672.2 of the Code.[3]

$$i = \frac{C_2K_2}{2} \qquad (4)$$

Equation (3) above could be used to determine the stress intensification (SIF) after the cycles-to-failure value (N_f) is determined from the test. However, since the component being tested is an elbow, a term shall be included to account for the additional stress in the elbow due to the applied moment. For welded attachment to straight pipes as described in Reference 4, the stress, due to the applied moment, does not significantly affect the calculation of i_t.

The methodology used to determine the SIF from the test data on the lug-elbow configurations is as follows:

In Equation (10) of Code Case N-318 the stress due to the lug, the S_{pl} term, is added to the stress due to the moment loading on the component.

Equation (10) from Code Case n-318:

$$S_E = \frac{iM_C}{Z} + \frac{S_{pl}}{2} \qquad (5)$$

where:

$$S_{pl} = K_l(S_{nl}) = K_lC_L'\frac{M}{Z_l} \qquad (6)$$

therefore:

$$S = i\frac{M}{Z} + K_lC_L'\frac{M}{Z} \qquad (7)$$

substituting Equation (4) into (7) with $K_e = K_L = 2$ yields:

$$S_E = \frac{C_{2e}M}{Z_e} + \frac{C_L'M}{Z_l} \qquad (8)$$

The (S_E) term above is equivalent to the (is) term in Equation (3). Therefore, Equation (8) can be solved for C'_L:

$$C'_L = \left(245{,}000 N_f^{-0.2} - C_{2e}\frac{M}{Z_e}\right)\frac{Z_1}{M} \qquad (9)$$

The cycles-to-failure value (N_f) is determined from the fatigue test. C_{2e} is calculated from the Code. Therefore, C'_L-indicies is a fatigue test based value which can be compared to the C-indices calculated from Code Case N-318 methodology.

When Equation (4) is applied to both the c-indice calculated from the Code Case methodology and the C'_L value calculated from Equation (9) it can be shown that:

$$C = i \qquad (10)$$

and

$$C'_L = i_t \qquad (11)$$

The conservatism in the Code Case methodology can then be defined by the ratio C/C'_L or i/i_t.

The test data from the four fatigue tests are given in Table 2 (Tests 13-16). The elastic slope values (F/δ) given in Table 2 are determined by static load tests. The static load tests are used to determine the loads to be applied during the fatigue tests. The loads applied during the fatigue tests are at a magnitude where the pipe material will cycle slightly into the plastic range.

TABLE 2

FATIGUE TEST DATA

TEST	LUG SHAPE	LOAD PLANE (a)	t (in.)	r/t	±δ (in.) (b)	f/δ KIPS/in	Moment Arm (in.) (c)	M_t in-KIPS (d)	N_f (e)
13	Rect	Circ	.2725	22.90	1.1	1.29	26.93	38.11	81.4
14	Rect	Long	.2883	21.61	1.2	1.35	39.94	64.54	1506
15	Cross	Long	.2860	21.79	.2	15.04	39.94	120.14	1883
16	Cross	Circ	.2795	22.61	.4	12.63	26.93	136.00	394

(a) See Code Case N-318; M_L = Long, M_N = Circ
(b) Displacement applied in fatigue test
(c) Distance (perpendicular to pipe surface) from point of load application, through lug center line, to intersection of outer pipe wall
(d) M = (f/δ) x δ x MOMENT ARM
(e) N_f = Best estimate of cycles-to-failure

In each case the cracks formed and failure occurred at the root of the weld-elbow interface in the plane of loading. Therefore, for the cruciform shape, only the leg in the plane of loading is considered in the N-318 capacity calculation.

Table 3 presents the evaluation of the test data compared to Code Case N-318. The ratios of (i/i_t) show that the Code Case methodology is conservative by a factor ranging from 3.5 to 14.8.

TABLE 3

EVALUATION OF FATIGUE TEST DATA

TEST	Z_L (a)	Z_e (b)	K_1 (c)	C_{2e} (d)	C (e)	i_t (f)	i	i/i_t
13	1.525	33.32	2	7.76	7.85	2.210	7.85	3.55
14	2.282	35.17	2	7.46	5.90	1.521	5.90	3.88
15	13.416	34.89	2	7.50	13.03	3.171	13.03	4.11
16	9.637	33.72	2	7.42	46.46	3.133	46.46	14.83

(a) Lug footprint section modulus, (in^3)
(b) Elbow section modulus, (in^3)
(c) $K_1 = 2.0$ for 4-sided weld, per Code Case N-318
(d) Per ASME, Section III
(e) See Code Case N-318
(f) Per Equation (9)

CONCLUSION

This paper presents an application of Code Case N-318 methodology to both an elbow and a nonstandard lug configuration, a cruciform. Both the cruciform configuration and the use of a component, an elbow, instead of a straight pipe are beyond the "Limitations to Applicability", Section 1, of Code Case N-318. The test data from the four limit load and four fatigue tests show that the Code Case methodology can be applied to these conditions and still maintain a conservative margin of safety. The methodology described in this paper is a reasonable, but conservative approach to be applied to both rectangular and cruciform shaped welded attachments on elbows. This is confirmed by the data presented in this paper and in Reference 4. In both straight pipe tests and elbow tests for lugs of the same configuration and loading condition the minimum factor of conservatism found was 3.0.

ACKNOWLEDGEMENTS

The authors would like to thank WFI international of Houston, Texas for performing these tests.

The work described in this paper was prepared in connection with work done under Contract No. DE-AC09-89SR18035 with the U.S. Department of Energy.

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4. Rawls, Wais, and Rodabaugh, "Fagility Tests of Welded Attachments as Compared to ASME Code Case N-318", ASME 1991, PVP-Vol. 214, pp 107-110.

5. Rodabaugh, E.C., "Standardized Method for Developing Stress Intensification Factors for Piping Components", Draft Welding Research Council Bulletin, April 1990.

6. Markl, A.R.C., 1952, "Fatigue Tests of Piping Components", Transactions ASME, Vol, 74, pp287-303

Figure 4. Limit Load Test Setup

Figure 5. Fatigue Test Setup

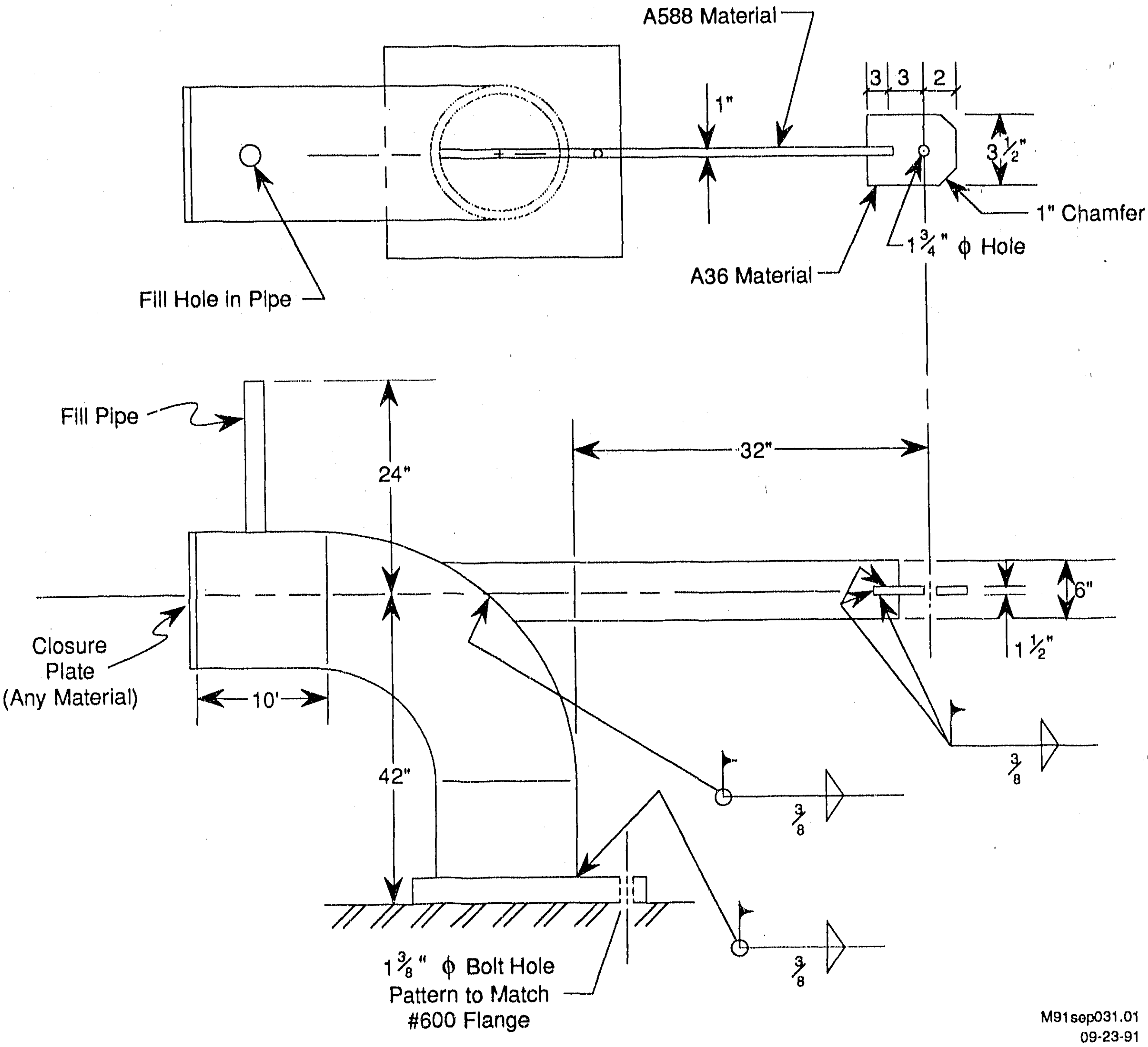

Figure 1. Typical Specimen for Tests 9 and 13

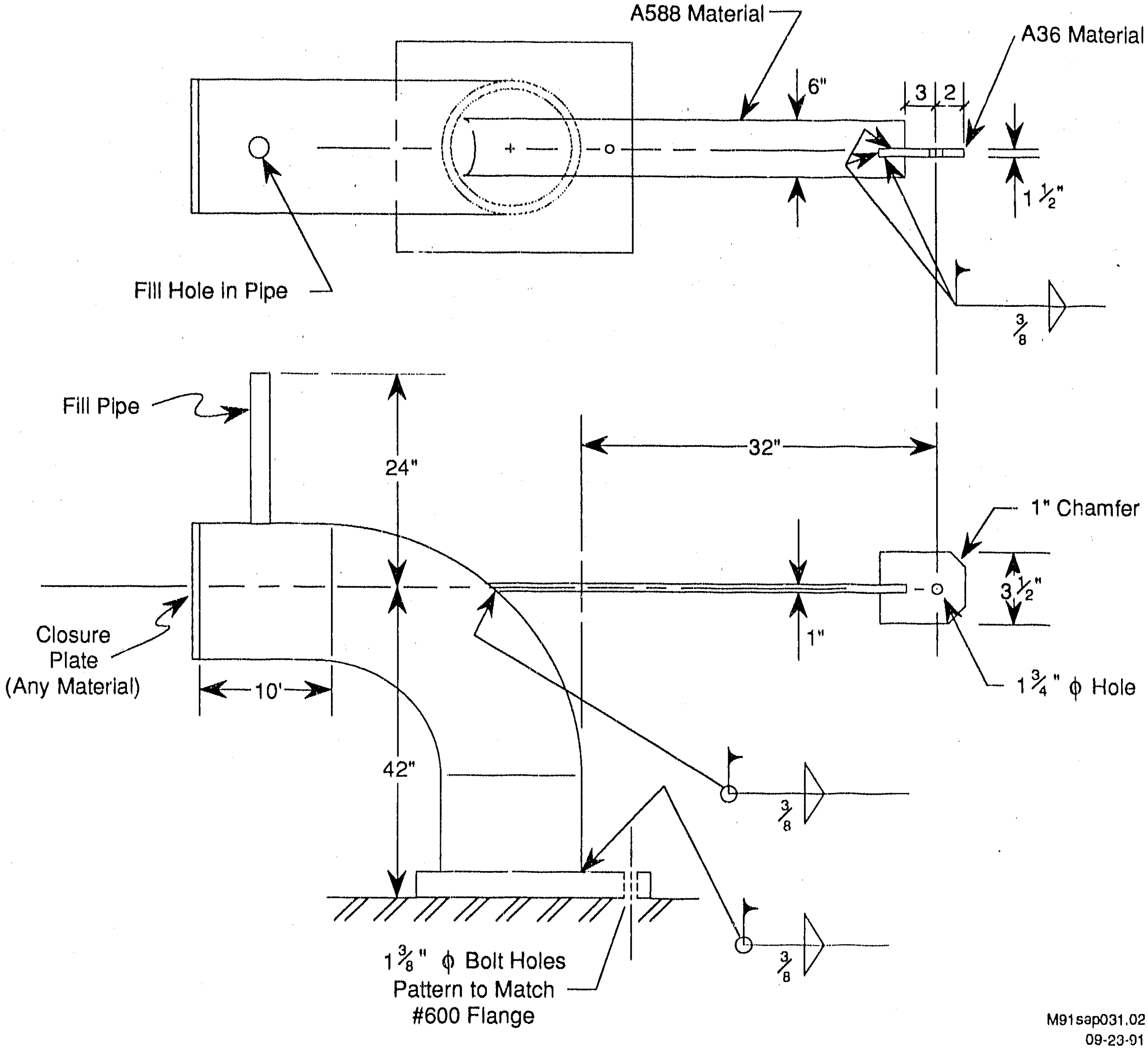

Figure 2. Typical Specimen for Tests 10 and 14

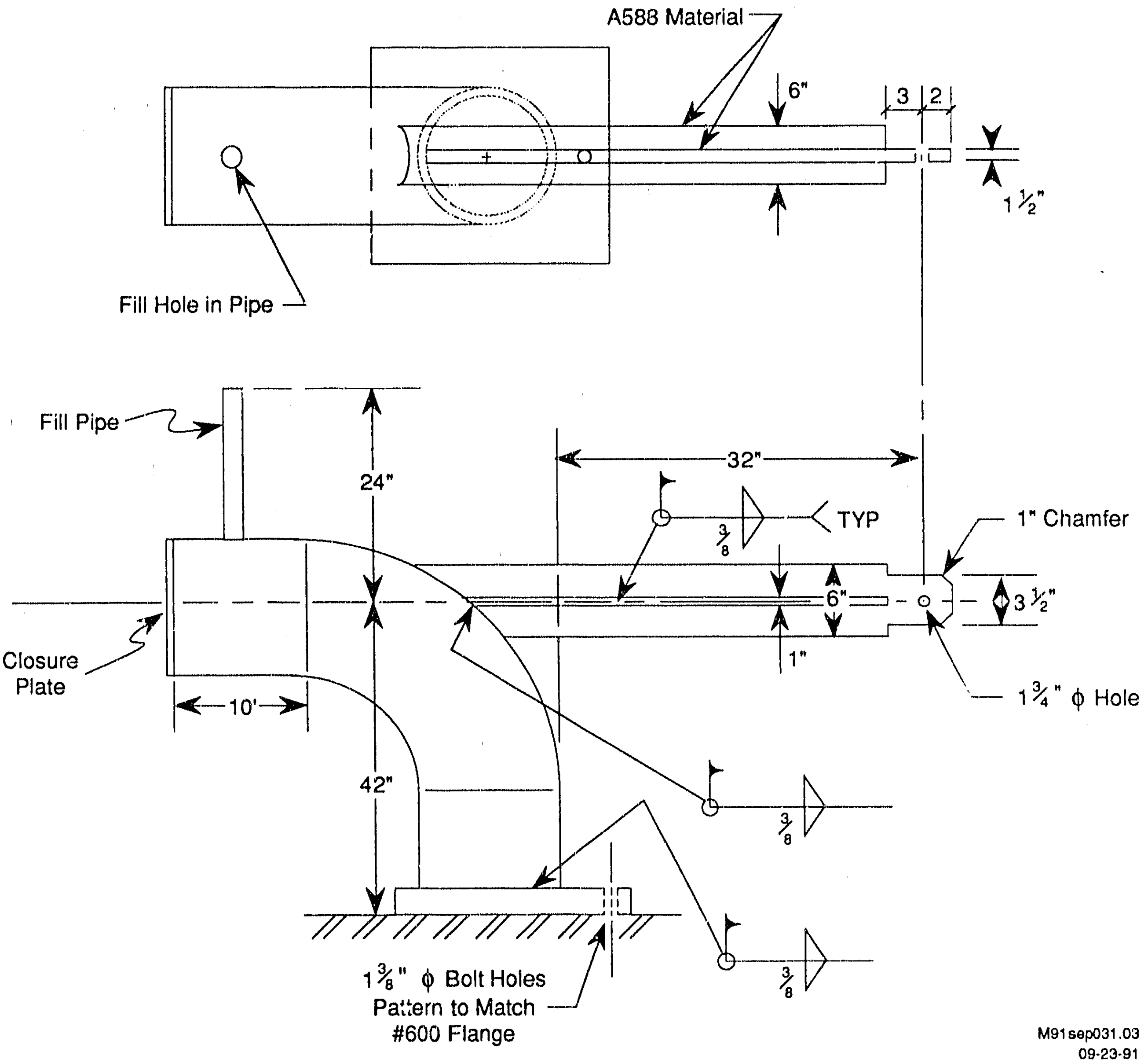

Figure 3. Typical Specimen for Tests 11, 12, 15, and 16

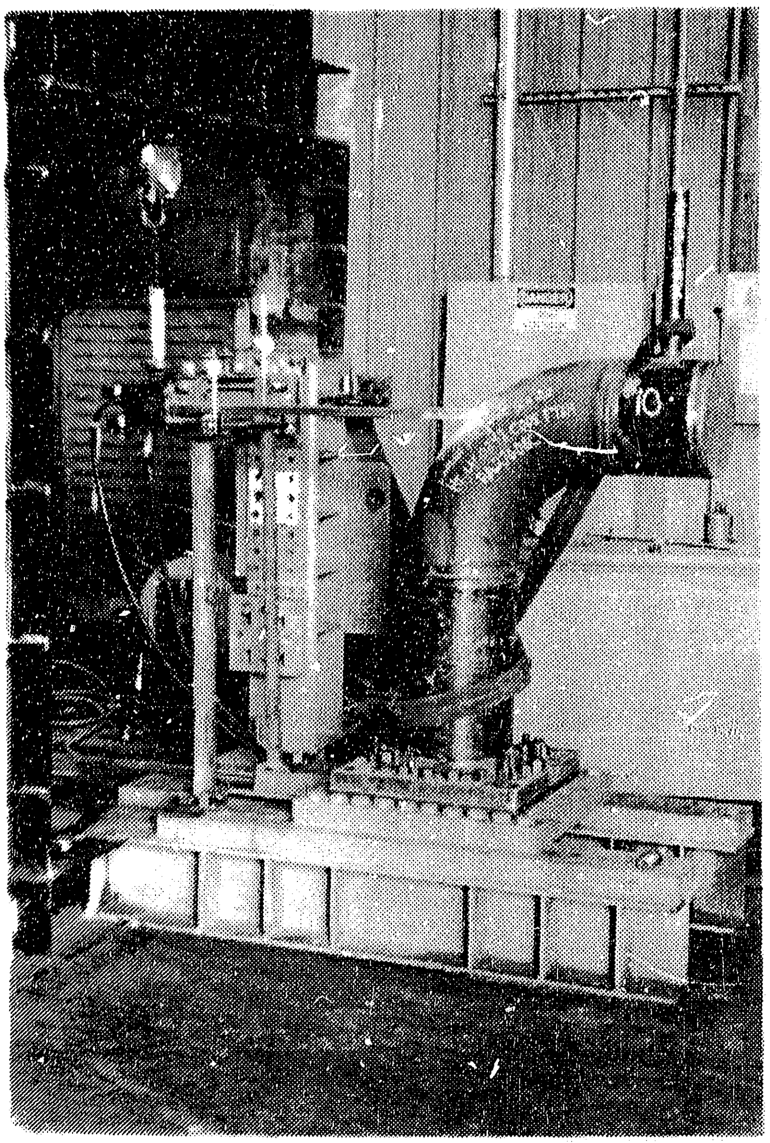

Figure 4. Limit Load Test Setup

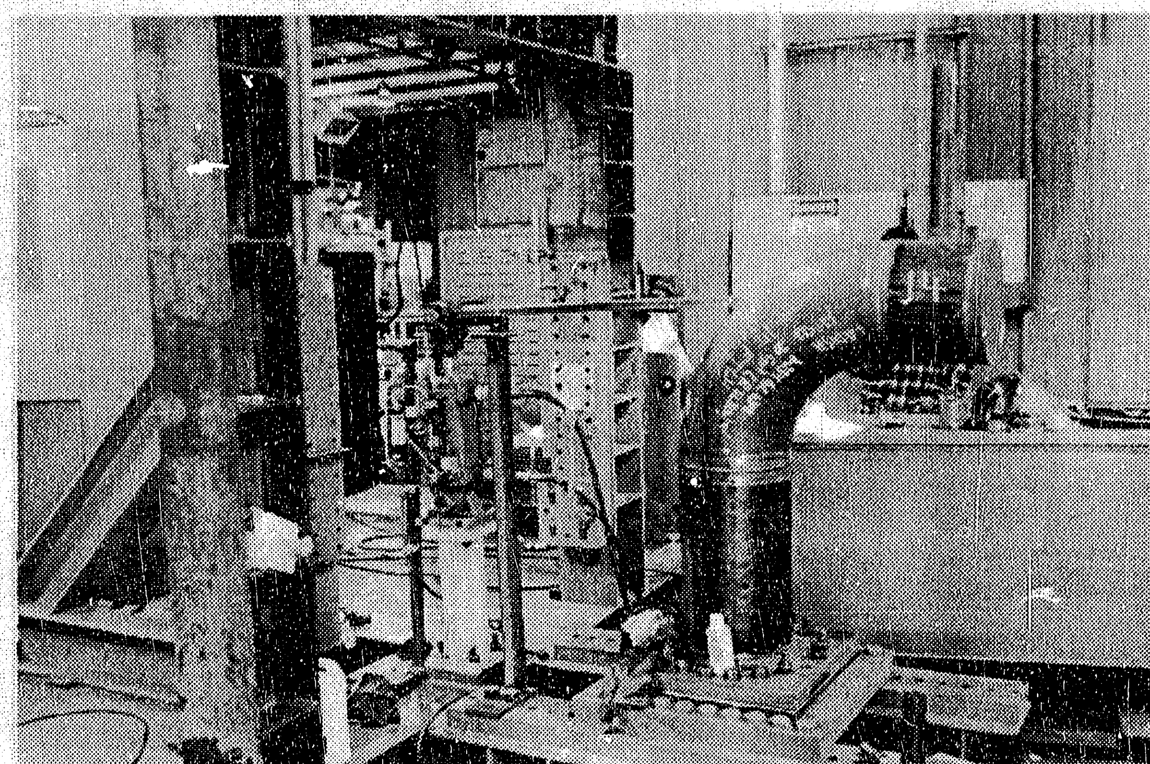

Figure 5. Fatigue Test Setup

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