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ABSTRACT

This paper presents the results from a series of fragility tests to assess the capacity of integral welded pipe attachments of various configurations. Both limit load and fatigue tests were performed on rectangular lugs and crosses (cruciforms) on straight pipe. The results of the limit load tests are presented as a limit moment. The results of the fatigue tests are cycles-to-failure. Markl's equation is then used 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 to determine the level of conservatism in the Code Case.

NOMENCLATURE

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

B	= B_L or B_N of Case N-318; B=(2/3)C
C	= C_L or C_N of Case N-318
L	= longitudinal moment
N	= circumferential moment
i	= stress intensification factor
i_t	= test-determined stress intensification factor
M	= moment applied in fatigue test
M_{CL}	= limit moment (long or circ) per Case N-318
M_t	= test-determined limit moment
N_f	= cycles-to-failure in fatigue tests
S	= nominal stress amplitude = M/Z for lugs
S_y	= pipe material yield stress
Z	= Z_{IL} or Z_{IN} of Case N-318
δ	= displacement applied in fatigue test

INTRODUCTION

The issue of welded attachments on pipes and vessels has been under investigation for many years. Wichman, Hopper, and Mershon performed some of the earliest work on welded attachments. Their work was presented in the Welding Research Council Bulletin 107.[1] In the early 1980s two nonmandatory Code Cases N-122[2] and N-318[3] were released as part of the ASME Boiler and Pressure Vessel Code, Section III, Division 1, "Nuclear Power Plant Components", hereafter called the Code. These two Code Cases are for rectangular lugs on piping, and have been extensively used in the evaluation of lugs on nuclear plant piping systems. Code Case N-122 is used for lugs on Class 1 piping, while N-318 is used for Class 2 and 3 piping. This paper will use Code Case N-318 as the basis for its comparisons to the test data.

In the past two years much work has been done on welded attachments in an attempt to quantify the conservatism in these Code Cases. Recent tests compiled by Foster, et al.[4] show that the Code Cases have much conservatism. This paper will present additional tests used to determine the capacity of several integral welded pipe attachments of various configurations.

The tests are of interest for two reasons. First, more data are obtained from the tests than from the Code Case calculation; therefore, a better understanding of the failure mode is obtained. Second, some of the attachments are of a complex cruciform shape and do not meet the requirements of the Code Case, which addresses rectangular shapes. These tests will be followed by a second series of tests of the same lug configurations on elbows.

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 pipe. In each case the lug had a fillet weld around all sides of the attachment. The configurations tested are as follows:

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

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

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

For each case both a limit load and a fatigue test were performed. The piping material was ASTM A53 GR B with a yield strength of 49 KSI. The lug material was ASTM A588 GR B with a yield strength of 60.2 KSI.

In both the limit load and the fatigue tests the specimens were tested to failure. The failure criterion for the limit load test was Article II-1000,"Experimental Stress Analysis", Section II-1430, of the ASME Code. The failure criterion for the fatigue tests was the formation of a through-wall crack in the pipe wall, determined by the appearance of moisture on the outside surface of the pipe.

LIMIT LOAD TESTS

The concept of limit analysis is the basic design philosophy behind the code equations for primary stress intensity. The code equations, for primary stress intensity, are a method of design to limit gross plastic deformation of piping. Section III of the ASME Code uses the B_2-indices to relate moment loading in piping components to gross plastic deformation. Equations (8) and (9) of the Code then give a stress limit to avoid gross plastic deformation.

Code Case N-318 provides a modified version of code Equations (8) and (9) which include the effect of the welded attachment by adding the S_{ml} term to code Equations (8) and (9). S_{ml} is calculated in Equation (1) of 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 tests 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 test configuration.

Therefore Equation (1) of N-318 reduces to

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

Using S_y as the allowable stress and solving for the limit moment yields

$$M_{CL} = \frac{S_y Z}{B} \tag{2}$$

This equation can then be applied to determine the calculated limit moment based on the Code Case. 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 can then be defined by the ratio M_t/M_{CL}. The calculated limit moments from the four limit load tests (Tests 1-4) are compared with the test data in Table 1.

The evaluation of the cruciform shape for the limit load test was done by determining the moment capacity of each section of the cross individually using the methodology of N-318. The two moments were then summed to compare with the limit moment determined from the test.

The ratios of M_t/M_{CL} presented in Table 1 show that the Code Case is conservative by a factor ranging from 3.9 to 5.7.

FATIGUE TESTS

The fatigue tests on the welded attachments are based on bending fatigue tests that follow Markl's work.[5] Markl developed the following equation for Grade B Carbon Steel.

$$iS = 245{,}000\ N^{-0.2} \tag{3}$$

The above equation is used to determine stress intensification factors (SIF) after the cycles-to-failure value is determined from the test. The SIF determined from the test data is defined i_t.

Code Case N-318 is based on the C-indices for the evaluation of fatigue loadings. The C-indices indicate 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 SIF and C_2-indices can be related by the code equation from Section NC-3673.2, ASME 1989 Boiler and Pressure Vessel Code.[6]

$$i = \frac{C_2 K_2}{2} \qquad (4)$$

To evaluate the fatigue data using the methodology of the Code Case N-318, Equation (11) is modified to include the effect of the welded attachment. When reduced to evaluate the fatigue test data the equation becomes:

$$\frac{S_{pl}}{2} \leq (S_h + S_a) \qquad (5)$$

Where:

$$S_{pl} = K_l (S_{nl}) = K_l \frac{CM}{Z} \qquad (6)$$

or

$$iS = K_l \frac{CM}{2Z} \qquad (7)$$

The K_l-index accounts for the peak stress due to the welded attachment. For the case of a fillet weld on four sides of a lug N-318 specifies a value of $K_l = 2.0$. Since $S = M/Z$ (stress amplitude) the above equation can be related to the Markl fatigue equation by use of the relationship from NC-3673.2 shown above.

Therefore:

$$i = \frac{K_l C}{2} \qquad (8)$$

The conservatism in the Code Case can then be defined by the ratio $(K_l C/2)/i_t$.

The test data from the four fatigue tests are given in Table 2 (Tests 5-8). The elastic slope values (F/δ) given in Table 2 were determined by static load tests. These static load tests were used to determine the loads to be applied during the fatigue tests. The loads applied during the fatigue tests were taken at a point where the pipe material would cycle slightly into the plastic range.

For the evaluation of the cruciform shape for the fatigue tests, only the leg in the plane of loading is considered in the N-318 calculation. In each case the cracks formed and failure occurred at the ends of the leg in the plane of loading.

Table 3 presents the evaluation of the test data compared to Code Case N-318. The ratios of $(K_1C/2)/i_t$ show that the Code Case is conservative by a factor ranging from 3.4 to 5.1.

CONCLUSION

The data from the four limit load and four fatigue tests show that Code Case N-318 is conservative by at least a factor of 3 against failure. The factors of conservatism determined in these tests compare closely with other tests compiled by Foster, et al.[4] The factor of conservatism determined in the evaluation of the cruciforms also shows close agreement with rectangular shapes when compared to Code Case N-318 as described in this paper.

ACKNOWLEDGEMENTS

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REFERENCES

1. WRC Bulletin 107, August 1965, "Local Stresses in Spherical and Cylindrical Shells due to External Loadings."

2. ASME Code Case N-122, "Procedure for Evaluation of the Design of Rectangular Cross Section Attachments on Class I Piping," Section III, Division 1, Rev 1.

3. ASME Code Case N-318, "Procedure for Evaluation of the Design of Rectangular Cross-Section Attachments on Class 2 or 3 Piping," Section III, Division 1, Rev. 3.

4. Foster, Rodabaugh, Wais, and Steck, "Interpretation, With Respect to ASME Code Case N-318, of Limit Moment and Fatigue Tests of Lugs Welded to Pipe".

5. Markl, A.R.C., 1952, "Fatigue Tests of Piping Components:, Transactions ASME, Vol 74, pp 287-303.

6. ASME 1989 Boiler and Pressure Vessel Code, Section III, Division I, Subsection NC, "Nuclear Power Plant Components", Class 2 Components.

Table 1

Limit Load Tests

TEST	Lug Shape	Load Plane (a)	M_t in-kips	t (in.)	r/t	C (b)	M_{CL} in-kips (c)	M_t/M_{CL}
1	Rec.	Circ	39.4	.2653	23.56	8.017	9.17	4.3
2	Rec.	Long	99.2	.2603	24.01	4.188	17.55	5.65
3	Cross	Circ	120	.2594	24.05	35.9 8.337	12.28 8.86 Σ21.10	5.69
4	Cross	Long	189	.2598	24.06	14.48 4.204	30.46 17.48 Σ47.94	3.94

(a) See Code Case N-318; M_L = Long, M_N = Circ.
(b) See Code Case N-318; C_L = Long, C_N = Circ.
(c) $M_{CL} = S_y Z / [(2/3\ C)]$

Table 2

Fatigue Test Data

TEST	Lug Shape	Load Plane (a)	t (in.)	r/t	$\pm\delta$ (in.) (b)	F/δ kips/in	M_t in-kips (c)	N_f (d)
5	Rec.	Circ	.2628	23.78	.85	0.82	22.3	2009
6	Rec.	Long	.2600	24.04	1.396	1.50	67.0	328
7	Cross	Circ	.2578	24.24	.5	4.17	66.7	274
8	Cross	Long	.2615	23.90	.31	10.00	99.2	682

(a) See Code Case N-318; M_L = Long, M_N = Circ.
(b) Displacement applied in fatigue test
(c) $M = (F/\delta) \times \delta \times 32$
(d) N_f = Best estimate of cycles to failure

Table 3

Evaluation of Fatigue Test Data

TEST	Z	B_1	B_2	i_t (a)	C (b)	K_1 (c)	$C K_1/2$ (d)	$(C K_1/2)/i_t$
5	1.00	.08	.48	2.42	8.16	2.0	8.16	3.39
6	1.00	.48	.08	1.15	4.198	2.0	4.20	3.65
7	6.00	.48	.08	7.17	36.41	2.0	36.4	5.08
8	6.00	.08	.48	4.02	14.31	2.0	14.3	3.56

(a) $i_t = 245{,}000 / [(M/Z)\, N_f^{0.2})]$

(b) See Code Case N-318; M_L = Long, M_N = Circ ; for crosses only leg in loaded direction is used

(c) $K_1 = 2.0$ for 4-sided weld, per Case N-318

(d) $C K_1/2$ = Case N-318 equivalent of i

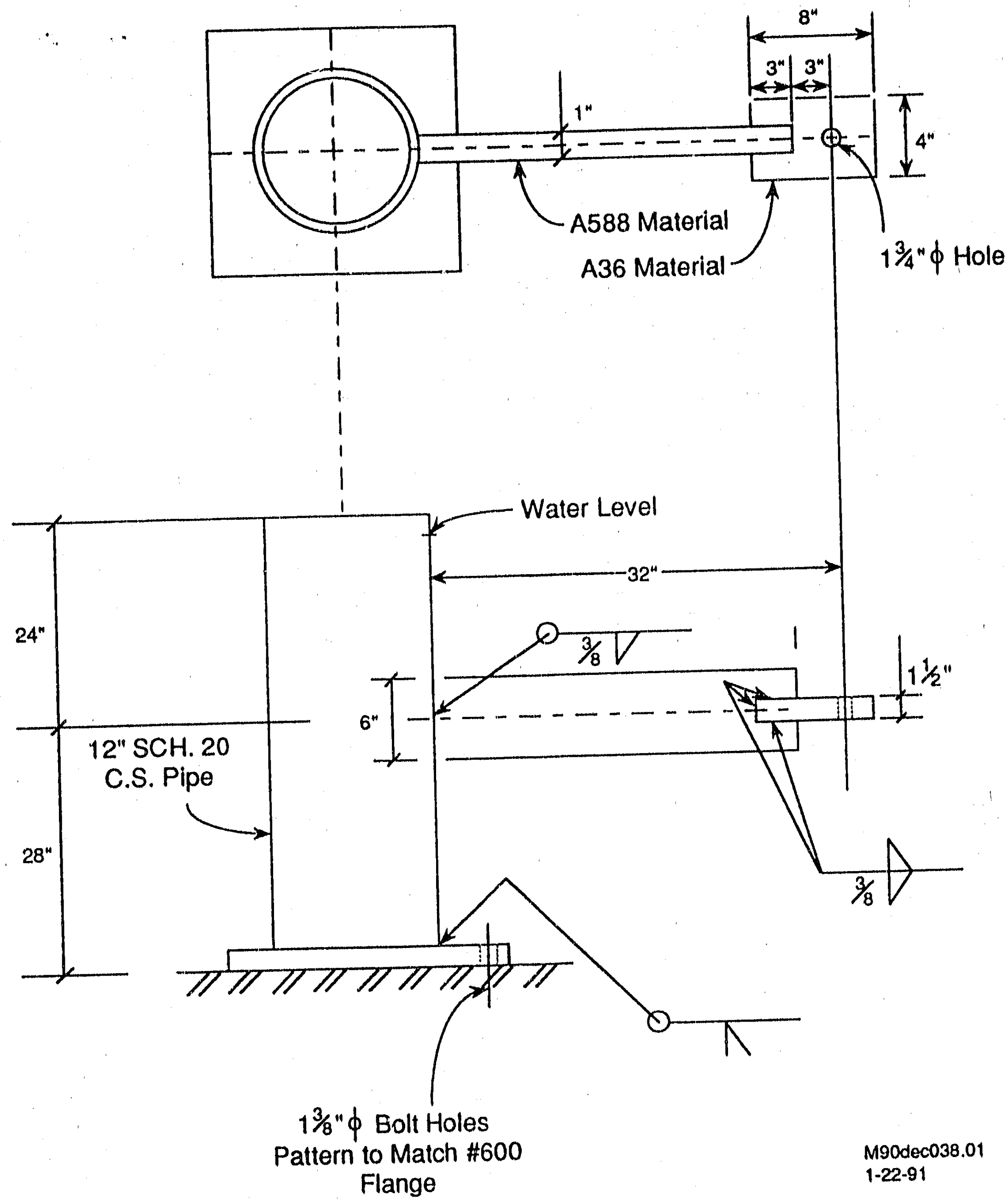

Figure 1. Typical Specimen for Tests 1 and 5

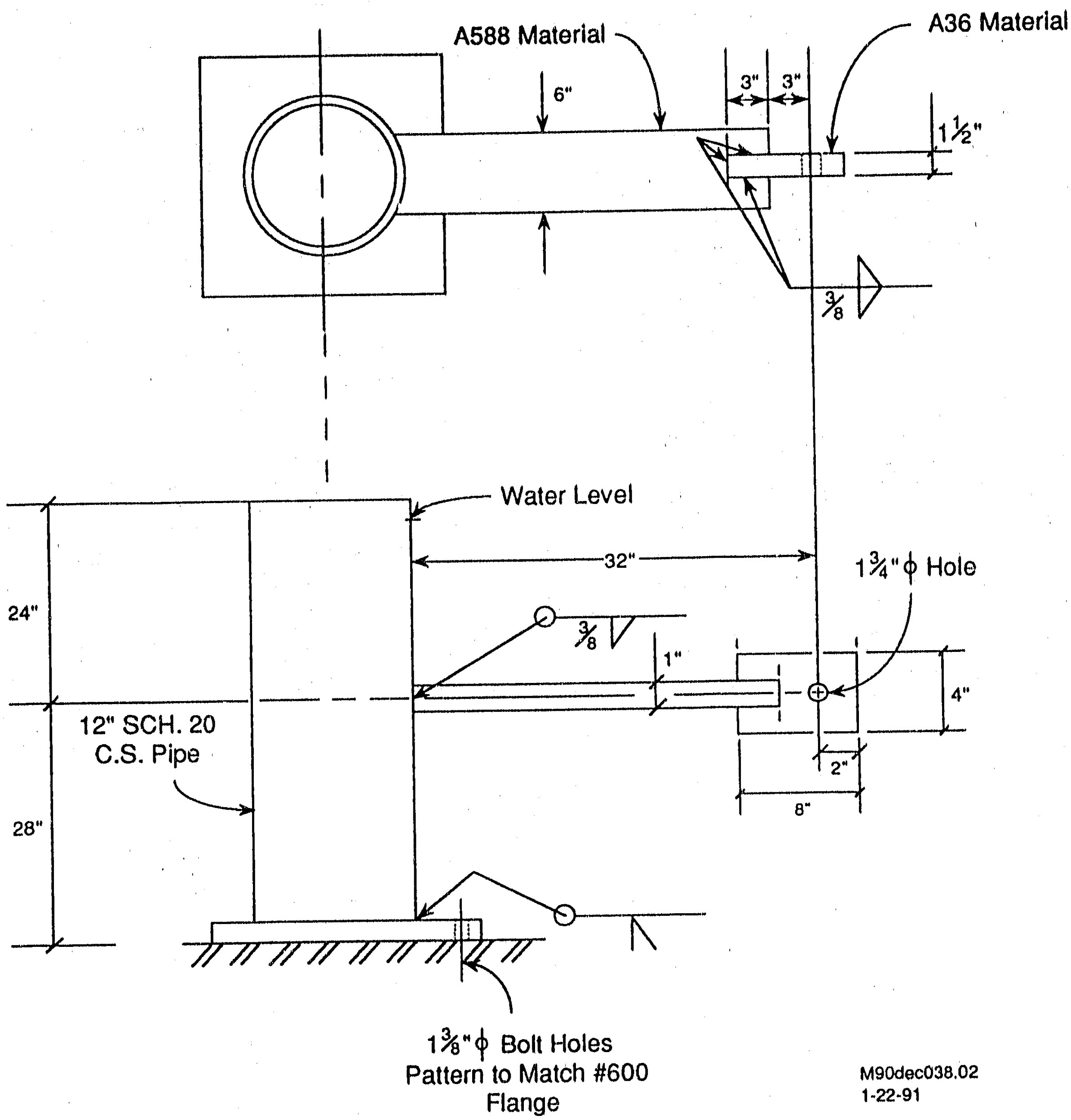

Figure 2. Typical Specimen for Tests 2 and 6

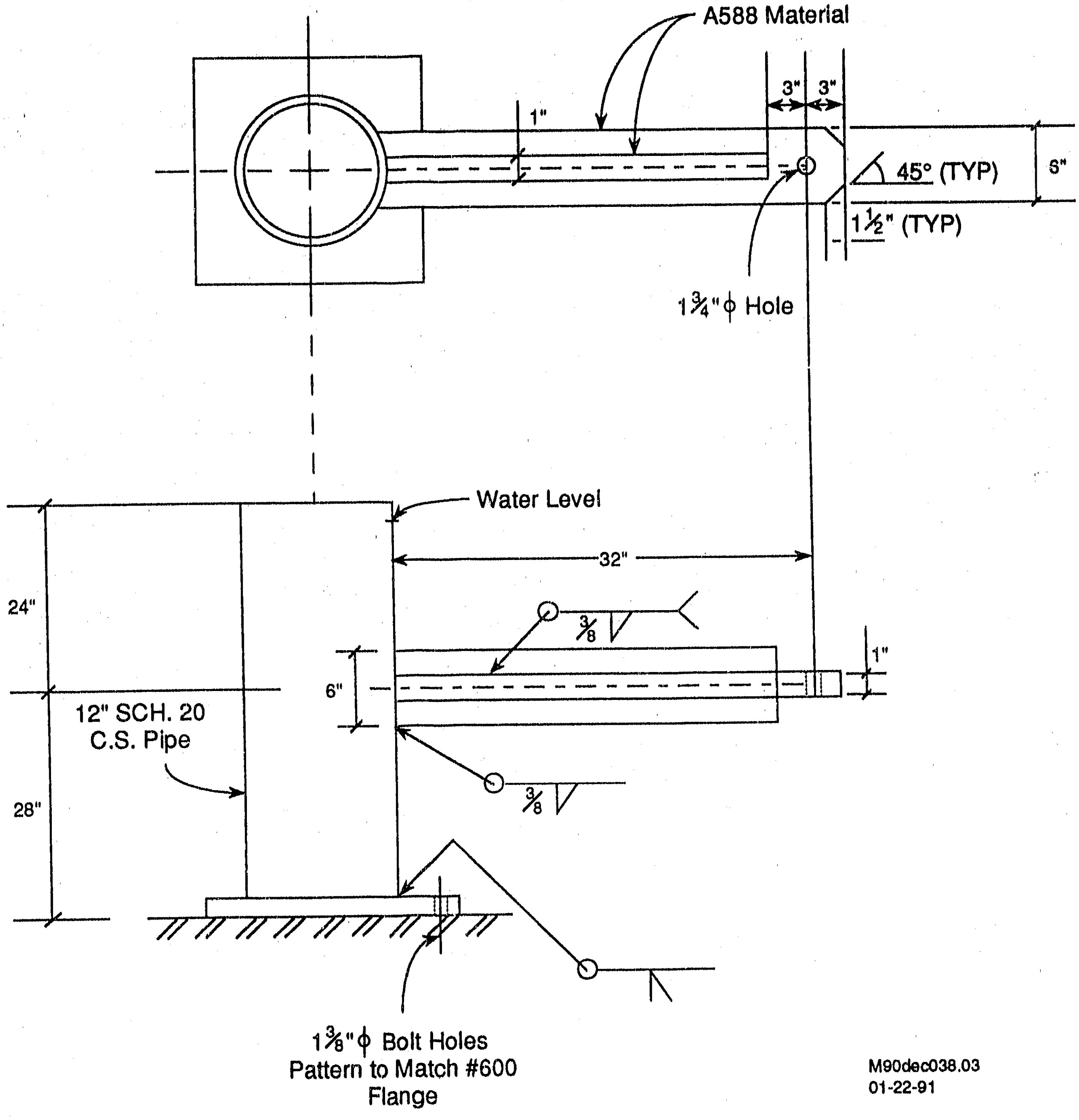

Figure 3. Typical Specimen for Tests 3, 4, 7, and 8

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