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**Acceptance Criteria For Welds
In ASTM A106 Grade B Steel Pipe And Plate**

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C. Michael Hudson, Davis B. Wright, Jr. and
Brian N. Leis

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Langley Research Center
Hampton, Virginia 23665

ACCEPTANCE CRITERIA FOR WELDS IN ASTM A106 GRADE B STEEL PIPE AND PLATE

C. MICHAEL HUDSON,* DAVIS B. WRIGHT, JR.* AND
BRIAN N. LEIS**

SUMMARY

Several National Consensus Codes contain acceptance criteria for indications in welds. Welds containing indications which fail to meet these criteria are unacceptable and must be repaired. The technical literature indicates that these criteria are based upon workmanship standards rather than upon the welds' structural integrity. The findings from NASA-Langley's RECERT Program support this indication. This Program has identified thousands of unacceptable welds. Some of these welds have been in service for fifty years without exhibiting evidence of structural degradation. Thus the current acceptance criteria appear to be very conservative from the standpoint of structural integrity.

Based on the RECERT Program findings, NASA-Langley funded a fatigue study of code-unacceptable welds. This study was conducted to develop usage curves which were based on the structural integrity of the welds. The details of this study are presented in NASA CR-178114. The information presented herein is a condensation and reinterpretation of the information in NASA CR-178114. This condensation and reinterpretation generated usage curves for welds having (a) indications 0.20-inch deep by 0.40-inch long and (b) indications 0.195-inch deep by 8.4-inches long. These curves were developed using the procedures used in formulating the design curves in Section VIII, Division 2 of the American Society of Mechanical Engineers Boiler and Pressure Vessel Code.

* NASA-Langley Research Center

** Battelle's Columbus Laboratories

INTRODUCTION

Reference 1 contains typical acceptance criteria for indications in welds. Welds containing indications which fail to meet these criteria are unacceptable and must be repaired. Reference 2 indicates that these criteria are based upon workmanship standards rather than upon the welds' structural integrity. The findings from NASA-Langley's RECERT Program support this indication. (Reference 3 describes the details of the RECERT Program.) This program has identified thousands of unacceptable welds. Some of the most severely unacceptable welds were probably on the verge of failing. Their identification and repair may have precluded serious accidents at NASA-Langley. The remainder of the unacceptable welds exhibited no evidence of structural degradation. Some of these welds had been in service for fifty years. Thus the current acceptance criteria appear to be very conservative from the standpoint of structural integrity. Reference 2 refers to this conservatism in its discussion of these acceptance criteria.

Based on the RECERT Program findings, NASA-Langley funded a fatigue study of code-unacceptable welds. This study was conducted to develop usage curves which were based on the structural integrity of the welds. Battelle, Columbus Division conducted this study, and presented their findings in reference 4. The information presented herein is a condensation and reinterpretation of the information in reference 4.

TESTS

Specimens

The study used four specimen configurations for the fatigue life tests; flat plate, pipe-wall-segment, pipe segment and service pipe. The following paragraphs describe these configurations.

Flat plate specimens. Figure 1 shows the configuration of the flat plate specimens. (Note: Inspection of Figure 1 will clarify the following discussion). To fabricate these specimens, sections of 8-inch diameter pipe were first cut to the desired length. These sections were then cut lengthwise to form two, equal-sized curved shells. These shells were flattened and normalized to relieve flattening stresses. (The normalization process involved heating the flattened shells (plates) to 1600°F for 30 minutes and air cooling.) The normalized plates were saw cut at two locations and the edges at both locations were beveled for welding. The plate pieces were then welded together to reform the flat plates. The welds were radiographed and found to be code-acceptable. The plates were then normalized again and the specimens were machined from these plates.

Fifteen pertinent specimens were tested. For twelve specimens, planar notches were electrodischarge machined into the welds. These notches simulated linear indications in the welds, e.g. lack-of-fusion and lack-of-penetration. For three specimens, volumetric notches were electrodischarge machined into the welds. These notches simulated three-dimensional indications in the welds, e.g. porosity and slag. Table 1 describes the depths and widths of these semi-elliptical notches. Figure 2 describes the radii at the base of the notches. Figure 3 shows how notch depths are measured from the inside surface of the plate.

Test conditions dictated that the backing rings be intact in some instances and cut in others. Similarly, they dictated that the weld reinforcement be left unground in some instances and ground in others. Table I also describes the condition of the backing ring and weld reinforcement for each specimen. The impact of the backing rings and weld reinforcement are reviewed in the "RESULTS" section of this paper.

Pipe-wall-segment specimens. Figure 4 shows the configuration of the pipe-wall-segment specimens. (Note: Inspection of Figure 4 will clarify the following discussion). To fabricate these specimens, sections of 8-inch diameter pipe were cut to the desired length. These sections were then cut lengthwise to form two, equal-sized curved shells. These shells were saw cut at midlength to form two curved half-shells. The saw-cut edges of these half-shells were beveled and the two half-shells were welded together to reform the shells. The shells were then normalized. After normalizing, each shell was cut lengthwise into six specimen blanks. These blanks were machined to the final configuration.

Ten pertinent specimens were tested. For five specimens, planar notches were electrodischarge machined into the welds. For the five other specimens, natural weld indications were introduced during the welding process. Table II presents the dimensions of the semi-elliptical notches and of the indications in the welds. Table II also describes the nature of the natural weld indications, the condition of the backing rings, and the status of the weld reinforcement.

Pipe segment specimens. Figure 5 shows the configuration for the pipe segment specimens. To fabricate these specimens, sections of 8-inch diameter pipe were saw cut to a length of 12 inches. The saw-cut edges were beveled, and two sections were welded together to form a 24-inch long pipe segment. End caps were welded to the ends of each segment. The segments were normalized and one end cap was fitted with a pipe nipple for pressurizing the specimen.

Twelve specimens were tested. For four specimens, internal planar notches were electrodischarge machined into the center girth welds. For four other specimens, internal volumetric notches were electrodischarge machined into the center girth welds. For the remaining four specimens, natural indications were introduced during the welding process. Table III presents the dimensions of the notches and of the indications in the welds. Table III also describes the condition of the backing rings, and the status of the weld reinforcement.

Service pipe specimens. Figure 6 shows the configurations of the service pipe specimens. To fabricate these specimens, two sections of 3-inch diameter piping were removed from service at NASA-Langley Research Center. End caps were welded to the open ends of these sections. One end cap on both specimens was fitted with a pipe nipple for pressurizing the specimen.

Specimen 1, Figure 6a, contained a pipe tee, a pipe elbow, two lengths of pipe, three end caps, a pipe nipple, three code-acceptable welds, and three code-unacceptable welds. The code-unacceptable welds contained lack-of-fusion, porosity, slag, and melt-through indications. The dimensions of these indications were not available from reference 4.

Specimen 2, Figure 6b, contained a pipe tee, two elbows, two miter joints, two lengths of pipe, three end caps, a pipe nipple, three code-acceptable welds, and six code-unacceptable girth welds. The code-unacceptable welds contained lack-of-penetration, lack-of-fusion, porosity, slag, undercut, burn-through and melt-through. The dimensions of these indications were not available from reference 4.

The backing rings were intact and the weld reinforcement was unground on these two specimens.

General. All specimens were made of ASTM A106 Grade B Steel. The steel for the flat plate, pipe-wall-segment and pipe segment specimens came from the same mill heat. Table IV presents the average chemical composition of this steel. This composition satisfies the chemical requirements for A106 Grade B steel. Table V presents the average tensile properties of this steel in both the "as-received" and normalized conditions. These properties satisfy the tensile requirements for A106 Grade B steel for both conditions. The steel for the flat plate, pipe-wall-segment and pipe segment specimens was approximately 0.322-inch thick.

Available records for the service pipe specimens indicate the steel was A106 Grade B. However, no chemical composition or tensile property data could be located for this steel. The steel for the service pipe specimens was approximately 0.216-inch thick.

Welding Procedures and Details of Indications

Welds were made using E7018 electrodes and backing rings. Four basic types of weld indications were evaluated in this program: artificial planar, artificial volumetric, natural planar, and natural volumetric. The artificial indications were introduced into code-acceptable welds using electrodischarge machining techniques.

Different approaches were used to introduce natural indications into the welds. Lack-of-penetration (LOP) was produced by fitting the pipe sections together tightly while leaving the root face slightly larger than normal. Lack-of-fusion (LOF) was produced by allowing the weld deposit to build up on one side of the weld joint. Painting a coat of zinc-oxide mold-release compound on one side of the joint assisted this production.

Slag pockets were produced by not cleaning the welds between weld passes. Porosity was introduced by upsetting the welding parameters during the gas-metal-arc (GMA) welding process.

Equipment

Flat plate and pipe-wall-segment tests. Load-control tests were conducted in 25 kip and 50 kip servo-hydraulic testing machines. The load cells on these machines were calibrated using standards which were traceable to the National Bureau of Standards. The alignment of these machines was verified using a strain-gaged alignment specimen.

The pipe-wall-segment specimens were gripped by using conventional flat plate grips with curved inserts. A reference test was conducted to determine whether bending stresses were introduced by this gripping arrangement. The results of this test are discussed in the "Reference Test" portion of this report.

Pipe segment and service pipe tests. Pressure-control tests were conducted in the test facility which Figure 7 describes. The pressure transducer in this facility was calibrated using standards which were traceable to the National Bureau of Standards.

The test specimens were mounted inside a containment vessel and were pressurized using hydraulic oil. In the pipe segment tests, two systems were used to detect specimen failure. The first system had a switch positioned over the centerline of the welds. If a crack broke through the weld, the resulting jet of oil activated the switch. The second system included a float switch which was activated as the oil level in the containment vessel rose. Activation of either switch terminated the test. In the service pipe tests, only the float switch system was used.

Reference Test

A reference test was conducted to measure bending stresses in the pipe-wall-segment specimens. Analysis showed that bending stresses were highly dependent upon the resistance of the grips to rotation. For this reason, a strain-gaged specimen was tested to quantify the bending stresses. Bending stresses were negative on the convex side of the specimen, and positive on the concave side. The ratio of bending stress to axial stress at midwidth on the concave side was 1-to-10 or less. However at the midwidth on the convex side, the ratio varied from 3-to-10 to 2-to-5. The maximum ratio for any point on the cross section was about 2-to-5. These data were used to correct nominal stresses in the tests.

Fatigue Tests

Constant-amplitude fatigue life tests were conducted on all pertinent specimens. For the flat plate specimens, the maximum stresses ranged from 13.0 ksi to 33.0 ksi, and the stress ratio, R , was 0.01. (The stress ratio is defined herein as the ratio of the minimum stress to the maximum stress.) For the pipe-wall-segment specimens, the maximum stresses ranged from 8.75 ksi to 33.0 ksi and the stress ratio was 0.01. For the pipe segment specimens, the maximum longitudinal stresses ranged from 7.7 ksi to 16.0 ksi and the stress ratio was 0.10. For the service pipe specimens, the maximum longitudinal stress was 12.5 ksi and the stress ratio was 0.10.

For the flat plate and pipe-wall-segment specimens, the loading frequency ranged from 60 cpm to 1200 cpm. For the pipe segment and service pipe specimens, the loading frequency was 60 cpm.

RESULTS

Flat Plate Specimens.

Table VI summarizes the test results for the flat plate specimens. Consider first the specimens having planar notches, Table VI a. For specimens having an initial notch depth of 0.1-inch, the backing rings appear to inhibit crack growth from the notch. In two specimens (Nos. FPA-S-3 and 4), fatigue cracks initiated at the code-acceptable toes of the welds and not at the notches. In a third specimen (No. FPA-S-2), the crack initiated at the notch, however a very large number of cycles (2.4×10^6) was required to propagate this crack to failure. Because of this inhibition, the backing rings on the remaining flat plate specimens and the pipe-wall-segment specimens were cut. Similarly, the weld reinforcement was ground to reduce stress concentrations at the weld toe. Figure 8 shows a plot of maximum stress against cycles to failure for the flat plate specimens having a 0.1-inch notch depth. An S-N curve is faired through these data in Figure 8 to show the general trend of the data.

For specimens having an initial notch depth of 0.2-inch, all cracks initiated at the notch. Figure 9 shows a plot of maximum stress against cycles to failure for these specimens. An S-N curve (solid line) is faired through these data. Figure 9 includes the S-N curve (dashed line) for specimens having a 0.1-inch deep notch. Comparison of these curves indicates the following. At high stress levels, specimens containing 0.1-inch notches had fatigue lives approximately five time longer than the specimens containing 0.2-inch notches. At low stress levels, the fatigue lives of the specimens with both sizes of notch were approximately the same.

Consider next specimens having volumetric notches, Table VI b. In two specimens (Nos. FPA-ES-1 and FPA-ES-4), cracks initiated at the code-acceptable backing ring-pipe interface, not at the notch. In the third specimen (No. FPA-ES-2), no crack initiated. Since the cracks did not initiate at the notches in these specimens, it is not meaningful to compare their fatigue lives with the fatigue lives of the planar notch specimens.

Pipe-Wall-Segment Specimens.

Table VII summarizes the test results for the pipe-wall-segment specimens. Consider first the planar notch specimens. Cracks initiated at the notch in four of these specimens. No crack initiated in the fifth specimen. (See Table VII a.) Figure 10 shows a plot of maximum stress against cycles to failure for these specimens. An S-N curve is faired through these data to show the general trend of the data. Figure 11 compares the S-N curves for the flat plate and pipe-wall-segment specimens having 0.2-inch deep notches. Essentially no difference exists between these curves indicating that the flattening of the pipe had little impact on fatigue behavior.

Consider next the specimens with natural indications. Cracks initiated at the indications in four of these specimens. No crack initiated in the fifth specimen. (See Table VII b.) Figure 12 shows a plot of maximum stress against cycles to failure for these specimens. Figure 12 includes the S-N curve for pipe-wall-segment specimens containing planar notches. The fatigue lives of all specimens containing natural indications exceeded the S-N curve for the specimens containing planar notches. Thus the natural indications were not as deleterious to fatigue life as the planar notches were.

Pipe Segment Specimens.

Table VIII summarizes the test results for the pipe segment specimens. Consider first the specimens having planar notches, Table VIII a. Fatigue cracks initiated at the notches in all of these specimens. Figure 13 shows a plot of maximum stress against cycles to failure for these specimens. An S-N curve is faired through the data in Figure 13 to show the general trend of the data.

Consider next the specimens having volumetric notches, Table VIII b. Fatigue cracks initiated at the code-acceptable end cap welds in two specimens (Nos. 43Q5 and 43Q8). Crack initiation appeared to be associated with the nearby pipe nipple welds. These pipe nipple welds were not normalized during specimen fabrication. Such normalization is not required by the codes for branch connections on A106 Grade B piping.

Fatigue cracks initiated at the notches in the two other specimens (Nos. 43Q6 and 43Q7). The pipe nipple welds were normalized on these two specimens prior to testing. Figure 14 shows a plot of maximum stress against cycles to failure for Specimen Nos. 43Q6 and 43Q7. The S-N curve for the pipe segment specimens containing planar notches is included on this figure. The fatigue lives of the volumetric notch specimens were four to eight times longer than the fatigue lives of the planar notch specimens.

Consider finally the specimens having natural, planar indications, Table VIII c. Three of these specimens (Nos. 54P1, 54P2 and 54P3) failed in the code-acceptable end cap welds. The pipe nipple welds were not normalized during the fabrication of these three specimens. A fourth specimen (No. 54P4) also failed in the code-acceptable end cap weld. However, the pipe nipple on this specimen was normalized during specimen fabrication.

Table III shows that the indication areas for Specimen Nos. 54P1 through 54P4 were only 20% to 50% of the desired areas. The undersizing of the indications probably contributed to shifting the failure location from the center weld to the end cap welds.

Service Pipe Specimens.

Table IX summarizes the test results for the service pipe specimens. In spite of numerous weld indications, both service pipe specimens failed due to fatigue cracking of the base metal in the piping tee. Apparently, the stress concentrations in the tee were more deleterious than the numerous, code-unacceptable weld indications were.

DISCUSSION

The results of this study indicate that some code-unacceptable weld indications are not as deleterious as various code-acceptable stress concentrations, e.g. weld toes, backing ring-pipe interfaces, branch connections and piping tees. They also explain why thousands of code-unacceptable welds have survived long periods of service without failing. Finally, they confirm the conservatism of the current code acceptance criteria.

The tests on the flat plate specimens indicated an important aspect of using backing rings in making weld joints. Apparently, backing rings reduced the stresses acting on the notches at the weld root. This stress reduction shifted the fatigue critical area to the weld toe. (Similar results have been found by other investigators, reference 5.) This shift implies that lack-of-penetration indications at backing rings are not particularly fatigue-sensitive. Additional research is needed to verify this implication.

The tests on pipe-wall-segment specimens showed the efficiency of using electrodischarge machined notches to simulate natural weld indications. The size, shape and locations of these notches can be more easily controlled than the size, shape and locations of natural weld indications. Further, the fatigue lives of the specimens containing notches were consistently shorter than the fatigue lives of specimens containing both planar and volumetric natural indications. These fatigue lives were shorter even though the notches were considerably smaller than the natural indications. Thus, specimens with notches can be readily prepared, and will provide more conservative estimates of fatigue behavior.

USAGE CURVES

The S-N curves for the pipe-wall-segment specimens, Figure 10, and for the pipe segment specimens, Figure 13, were used to develop usage curves for code-unacceptable welds. The procedures outlined in reference 6 were used to complete this development. These procedures are described in the following paragraphs.

First, the S-N curves in Figure 10 and 13 were adjusted to equivalent S-N curves for R = - 1 loading. The following relationship from reference 6 was used to make these adjustments.

$$S_{eq} = \frac{S_{alt}}{1 - \frac{S_{mean}}{S_u}} \quad (1)$$

where

S_{eq} is the alternating stress which produces the same fatigue damage for an R = - 1 loading as the combined alternating and mean stress, S_{alt} and S_{mean} , produce at any other R value.

S_{alt} is the actual alternating stress

S_{mean} is the actual mean stress

S_U is the ultimate tensile strength of the material

Next the adjusted S-N curves were modified to eliminate the effects of mean stress. The following relationship from reference 6 was used to make this modification.

$$S_{eq'} = S_{eq} \frac{S_U - S_y}{S_U - S_{eq}} \quad \text{for } S_{eq} \leq S_y \quad (2A)$$

and

$$S_{eq'} = S_{eq} \quad \text{for } S_{eq} > S_y \quad (2B)$$

where

$S_{eq'}$ is the adjusted alternating stress for which mean stress effects can be ignored.

S_y is the yield strength of the material

S_{eq} and S_U have been previously defined.

Finally, a safety factor of two on stress or twenty on cycles, whichever was greater, was applied to the adjusted and modified curves. The resulting usage curves are shown in Figure 15 and 16. The reader should note that the procedures used herein to develop the usage curves differ somewhat from the procedures used in reference 4.

The curves shown in Figures 15 and 16 were generated using a limited amount of data. These curves provide a starting point for the rational development of usage curves for existing code-unacceptable welds. Additional data should be generated to verify these usage curves.

The usage curves were developed for girth welds in A106 Grade B steel piping. They may be applicable to other weld configurations and to other materials. However, this applicability should be verified before these curves are used.

Further, the usage curves were developed for specific pipe thicknesses. The curves should be applicable to this thickness and to thicker pipe sections. However, the applicability of these curves to thinner pipe sections should be experimentally verified.

The usage curve in Figure 15 was developed using the S-N curve for specimens containing 0.20-inch-deep planar notches. The lives of specimens containing volumetric and planar natural indications exceeded this S-N curve. Thus the usage curve should be applicable to both volumetric and planar indications, other than cracks.

The usage curve in Figure 16 should only be used for 8-inch diameter pipe and larger. The large flaw size for this curve (0.195-inch deep by 8.4-inches long) will significantly reduce the remaining cross-section area of smaller pipe sizes. This reduction will make the resulting net section stresses much higher.

CONCLUSIONS

A series of fatigue tests were conducted on specimens made of A106 Grade B steel. Four specimen configurations were tested; flat plate, pipe-wall-segment, pipe segment and service pipe. Based on the test results, the following conclusions were reached:

1. Usage curves were developed for welds having indications both 0.20-inch deep by 0.40-inch long and 0.195-inch deep by 8.4-inches long. These curves were developed using the procedures used in formulating the design curves in Section VIII, Division 2 of the American Society of Mechanical Engineers Boiler and Pressure Vessel Code.
2. Some code-unacceptable weld indications are not as deleterious as various code-acceptable stress concentrations; e.g. weld toes, backing ring-pipe interfaces, branch connections and piping tees.
3. Backing rings appear to reduce the stresses acting across indications at weld roots. This reduction can shift the fatigue critical area from the weld indication to the weld toe.
4. The fatigue lives of specimens containing electrodischarge machined notches were consistently shorter than the fatigue lives of specimens containing both planar and volumetric natural indications, excluding cracks. These fatigue lives were shorter even though the notches were considerably smaller than the natural indications. The impact of weld toes, backing rings and other discontinuities must, of course, be considered when evaluating fatigue resistance.

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TABLE I. Configuration Details for Flat Plate Specimens

a. Specimens With Planar Notches

Specimen Number	Notch Depth, In.	Notch Width, In.	Backing Ring Condition	Weld Reinforcement
FPA-S-2	0.1	0.3	Intact	Ground
FPA-S-3	0.1	0.3	Intact	Unground
FPA-S-4	0.1	0.3	Intact	Ground
FPA-S-5	0.1	0.3	Cut	Ground
FPA-S-6	0.1	0.3	Cut	Ground
FPA-S-7	0.2	0.6	Cut	Ground
FPA-S-8	0.2	0.6	Cut	Ground
FPA-S-9	0.2	0.6	Cut	Ground
FPA-S-10	0.1	0.3	Cut	Ground
FPA-S-11	0.1	0.3	Cut	Ground
FPA-S-14	0.2	0.6	Cut	Ground
FPA-S-17	0.2	0.6	Cut	Ground

b. Specimens With Volumetric Notches

FPA-ES-1	0.1	0.3	Cut	Ground
FPA-ES-2	0.1	0.3	Cut	Ground
FPA-ES-4	0.2	0.6	Cut	Ground

Table II. Configuration Details for Pipe-Wall-Segment Specimens

a. Specimen With Planar Notches

Specimen Number	Notch Depth, In.	Notch Width, In.	Backing Ring Condition	Weld Reinforcement
CPA-S-3	0.2	0.6	Cut	Ground
CPA-S-4	0.2	0.6	Cut	Ground
CPA-S-5	0.2	0.6	Cut	Ground
CPA-S-8	0.2	0.6	Cut	Ground
CPA-S-9	0.2	0.6	Cut	Ground

b. Specimens With Natural Indications

Specimen Number	Approximate Indication Depth, In.	Approximate Indication Width, In.	Backing Ring Condition	Weld Reinforcement	Type of Indication
CPN-1	0.13	1.2	Cut	Ground	Planar
CPN-3	0.13	1.2	Cut	Ground	Planar
CPN-5	0.13	1.2	Cut	Ground	Volumetric
CPN-6	0.13	1.2	Cut	Ground	Planar
CPN-8	0.13	1.2	Cut	Ground	Planar

TABLE III. Configuration Details for the Pipe Segment Specimens

a. Specimens With Planar Notches

Specimen Number	Notch Depth, In.	Notch Width, In.	Backing Ring Condition	Weld Reinforcement
43Q1	0.195	8.4	Cut	Unground
43Q2	0.195	8.4	Cut	Unground
43Q3	0.195	8.4	Cut	Unground
43Q4	0.195	8.4	Cut	Unground

b. Specimens With Volumetric Notches

43G5	0.195	8.4	Cut	Unground
43G6	0.195	8.4	Cut	Unground
43G7	0.195	8.4	Cut	Unground
43G8	0.195	8.4	Cut	Unground

c. Specimens With Natural, Planar Indications

Specimen Number	Target Indication Depth, In.	Target Indication Width, In.	Backing Ring Condition	Weld Reinforcement
54P1*	0.195	8.4	Cut	Unground
54P2*	0.195	8.4	Cut	Unground
54P3*	0.195	8.4	Cut	Unground
54P4*	0.195	8.4	Cut	Unground

* - Actual indication areas (i.e. depth times width) were only 20% to 50% of the desired areas.

TABLE IV Average Pertinent Chemical Composition of the ASTM A106 Gr. B Steel Tested

Element	C	Mn	P	S	Si	Fe
Percent	0.23	0.79	0.009	0.017	0.31	Balance

Table V. Average Tensile Properties of the ASTM A106 Gr. B Steel Tested. (Longitudinal Grain Direction)

Condition	Ultimate Tensile Strength, ksi	Yield Strength (0.2% Offset), ksi	Elongation (1-Inch Gage length), percent
"As Received"	84.0	53.1	32.1
Normalized	78.9	50.3	35.0

TABLE VI. Fatigue Test Results for the Flat Plate Specimens. R=0.01

Specimen Number	Maximum Stress in Test, ksi	Number of Cycles to Failure, Kilocycles	Comments
a. Specimens With Planar Notches			
i. Notch Depth 0.1-Inch			
FPA-S-6	33.0	234.8	Crack initiated at notch
FPA-S-5	27.5	326.3	Crack initiated at notch
FPA-S-4	27.5	541.7	Crack initiated at code-acceptable toe of weld, not at notch
FPA-S-3	27.5	659.6	Crack initiated at code-acceptable toe of weld, not at notch
FPA-S-10	20.0	973.8	Crack initiated at notch
FPA-S-2	20.0	2414.7	Crack initiated at notch
FPA-S-11	13.0	10365.0	Runout, crack never initiated
ii. Notch Depth 0.2-Inch			
FPA-S-14	33.0	53.2	Crack initiated at notch
FPA-S-7	27.5	114.9	Crack initiated at notch
FPA-S-9	20.0	287.8	Crack initiated at notch
FPA-S-8	20.0	2704.3	Crack initiated at notch
FPA-S-17	14.0	1980.3	Crack initiated at notch

TABLE VI. (Concluded) Fatigue Test Results for the Flat Plate Specimens. R=0.01

Specimen Number	Maximum Stress in Test, ksi	Number of Cycles to Failure, Kilocycles	Comments
b. Specimens With Volumetric Notches			
i. Notch Depth 0.1-Inch			
FPA-ES-1	33.0	313.9	Crack initiated at Code-acceptable backing ring-pipe interface, not at notch
FPA-ES-2	20.0	10400.0	Runout, crack never initiated
ii. Notch Depth 0.2-Inch			
FPA-ES-4	27.5	145.3	Crack initiated at Code-acceptable backing ring-pipe interface, not at notch

TABLE VII. Fatigue Test Results for the Pipe-Wall-Segment Specimens. R=0.01

Specimen Number	Maximum Stress in Test, ksi	Number of Cycles to Failure, Kilocycles	Comments
a. Specimens With Planar Notches			
CPA-S-3	33.0	29.3	Crack initiated at notch
CPA-S-4	20.0	257.1	Crack initiated at notch
CPA-S-5	13.0	1814.8	Crack initiated at notch
CPA-S-8	10.0	2439.5	Crack initiated at notch
CPA-S-9	8.75	20500.0	Runout
b. Specimens With Natural Indications			
CPN-6	33.0	54.1	Crack initiated at indication
CPN-1	27.5	100.4	Crack initiated at indication
CPN-5	27.5	334.1	Crack initiated at indication
CPN-3	20.0	845.1	Crack initiated at indication
CPN-8	13.0	7228.0	Runout

TABLE VIII. Fatigue Test Results for the Pipe Segment Specimens. R = 0.10

Specimen Number	Maximum Longitudinal Stress in Test, ksi	Number of Cycles to Failure, Kilocycles	Comments
a. Specimens With Planar Notches			
43Q1	12.9	48.8	Crack initiated at notch
43Q2	10.3	222.6	Crack initiated at notch
43Q3	9.0	207.0	Crack initiated at notch
43Q4	7.7	377.4	Crack initiated at notch
b. Specimens With Volumetric Notches			
43Q7	14.5	96.7	Crack initiated at notch ^a
43Q5	12.9	48.0	Crack initiated at Code-acceptable end cap weld ^b
43Q8	12.9	59.1	Crack initiated at Code-acceptable end cap weld ^b
43Q6	11.6	388.0	Crack initiated at notch ^a

TABLE VIII (Concluded). Fatigue Test Results for the Pipe Segment Specimens. R = 0.10

Specimen Number	Maximum Longitudinal Stress in Test, ksi	Number of Cycles to Failure, Kilocycles	Comments
54P3	16.0	122.5	Crack initiated at Code- ^b acceptable end cap weld
54P2	14.5	226.6	Crack initiated at Code- ^b acceptable end cap weld
54P1	12.9	148.0	Crack initiated at Code- ^b acceptable end cap weld
54P4	11.6	1,337.9	Crack initiated at Code- ^a acceptable end cap weld

c. Specimens With Natural, Planar Indications

- a. Pipe nipple weld normalized
- b. Pipe nipple weld not normalized

TABLE IX. Fatigue Test Results for the Service Pipe Specimens. $R = 0.10$

Specimen Number	Number of Maximum Longitudinal Stress in Test, ksi	Cycles to Failure, Kilocycles	Comments
1	12.5	37.0 of piping tee	Crack initiated in base metal
2	12.5	189.3 of piping tee	Crack initiated in base metal

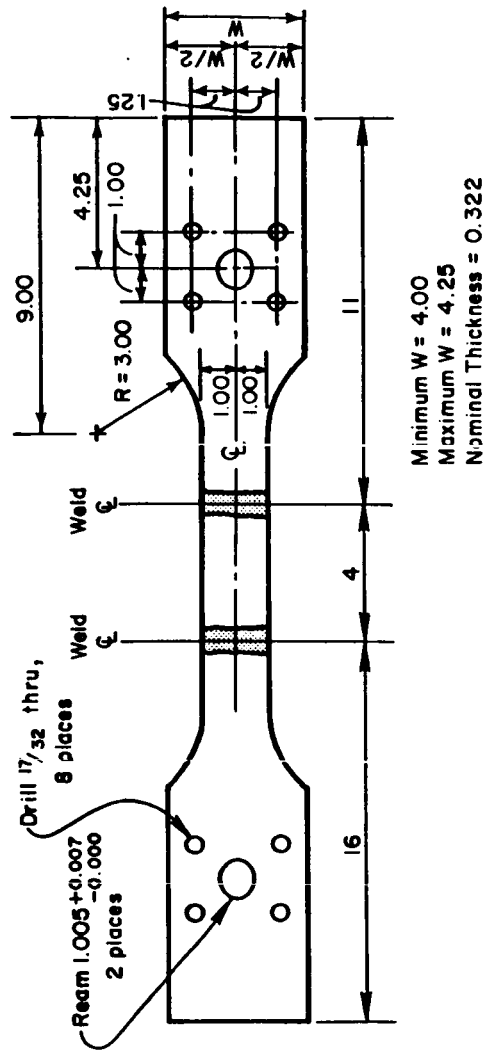
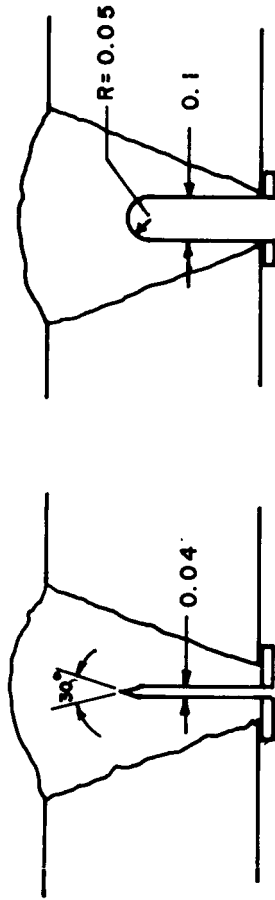


FIGURE 1. FLAT PLATE SPECIMEN CONFIGURATION. ALL DIMENSIONS IN INCHES.
FROM REFERENCE 4.



a, Planar Notch

b, Volumetric Notch

FIGURE 2. DETAILS OF NOTCH RADII. ALL DIMENSIONS IN INCHES.

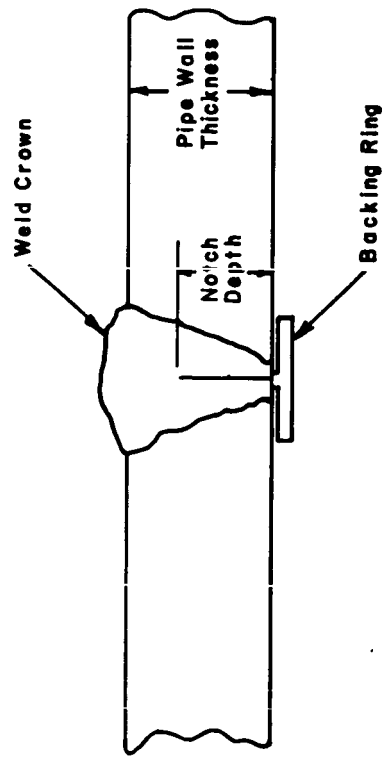


FIGURE 3. NOTCH DEPTH DEFINITION

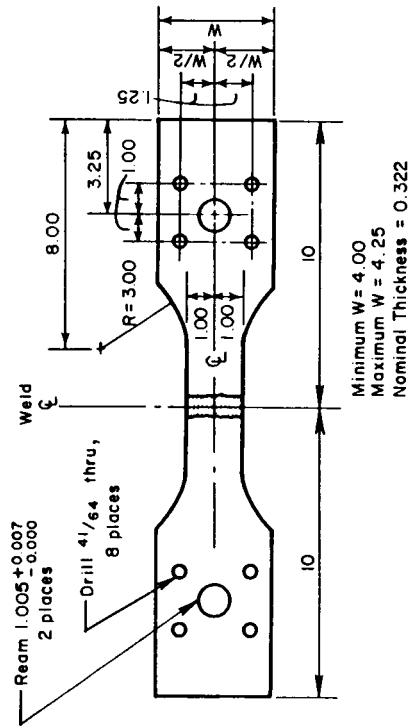


FIGURE 4. PIPE-WALL-SEGMENT SPECIMEN CONFIGURATION. ALL DIMENSIONS IN INCHES, FROM REFERENCE 4.

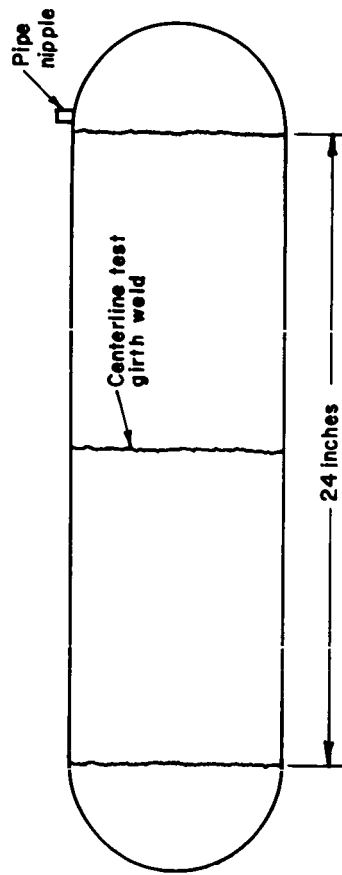


FIGURE 5. PIPE SEGMENT SPECIMEN CONFIGURATION

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7506-6

a. Specimen No. 1



7506-3

b. Specimen No. 2

FIGURE 6. SERVICE PIPE SPECIMEN CONFIGURATION. FROM REFERENCE 4.

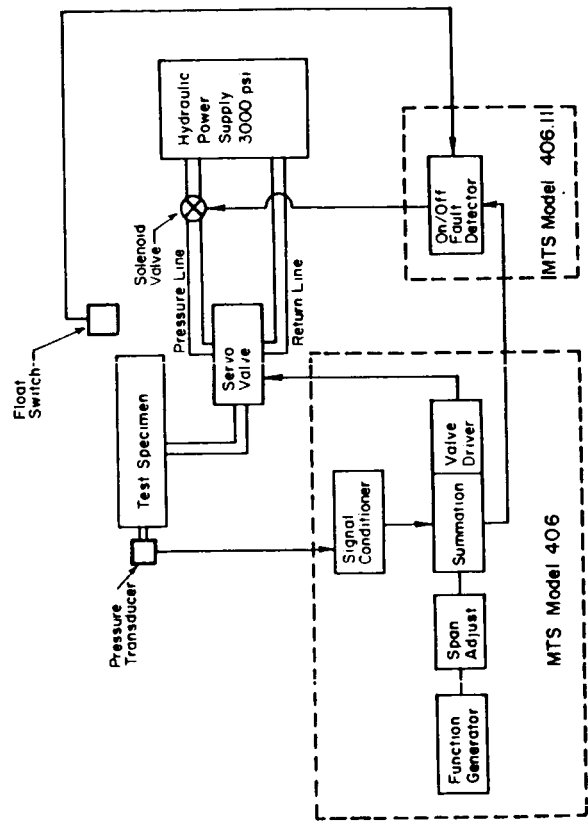


FIGURE 7. SCHEMATIC OF THE VESSEL AND PIPE TEST LOOP. FROM REFERENCE 4.

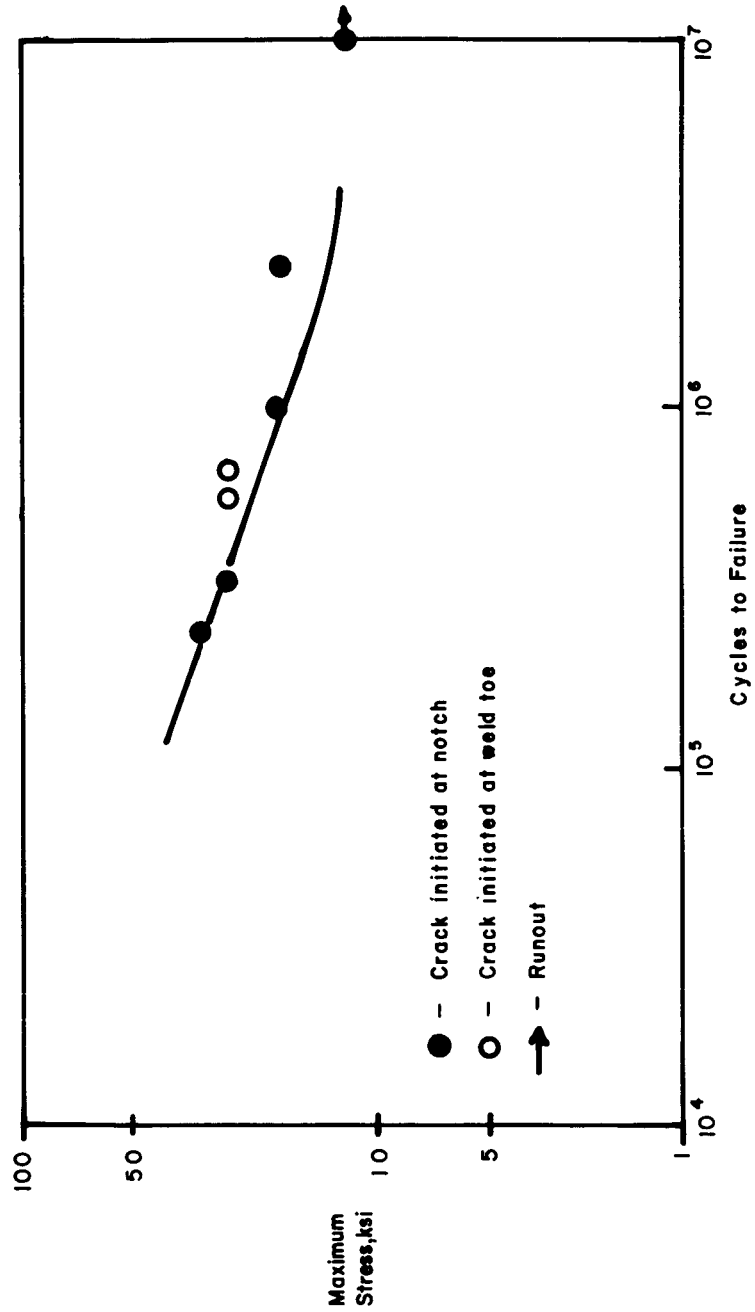


FIGURE 8. FATIGUE LIFE DATA FOR FLAT PLATE SPECIMENS. INITIAL NOTCH DEPTH IS 0.1-INCH. R = 0.01.

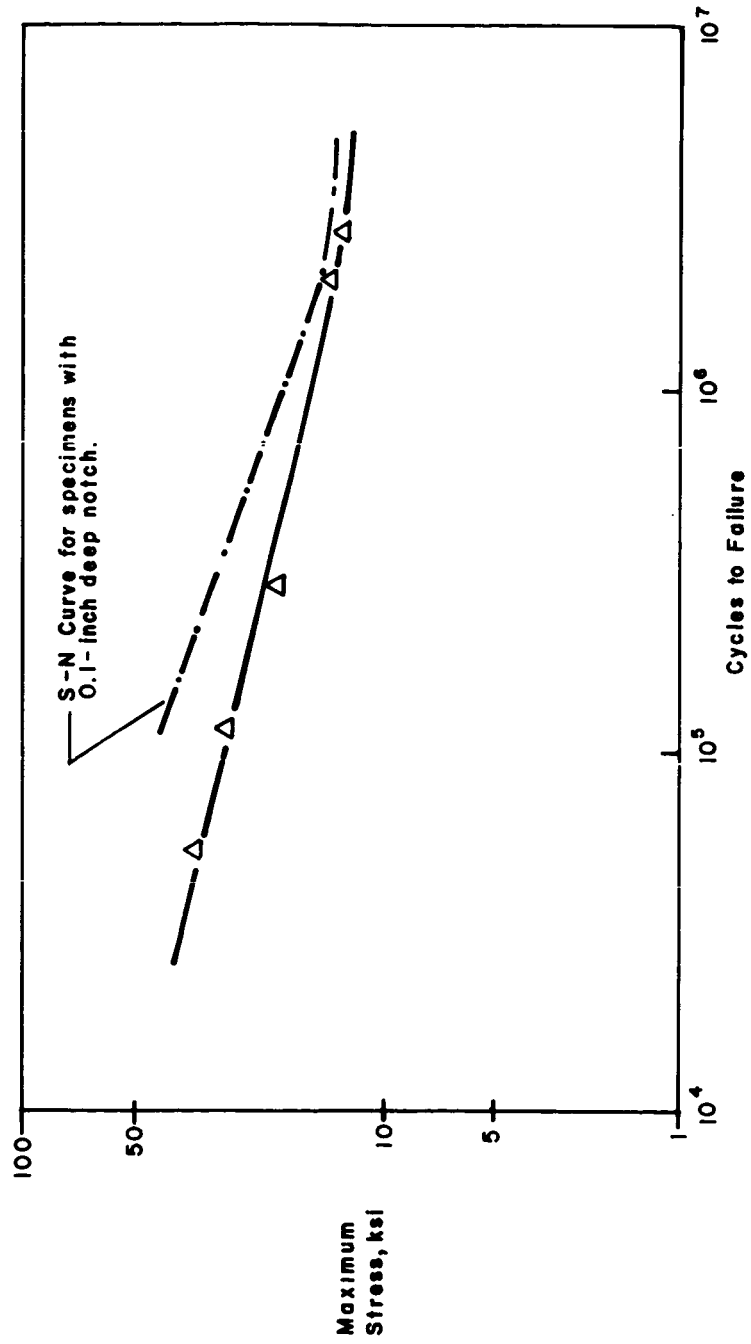


FIGURE 9. FATIGUE LIFE DATA FOR FLAT PLATE SPECIMENS. INITIAL NOTCH DEPTH IS 0.2-INCH.
R = 0.01.

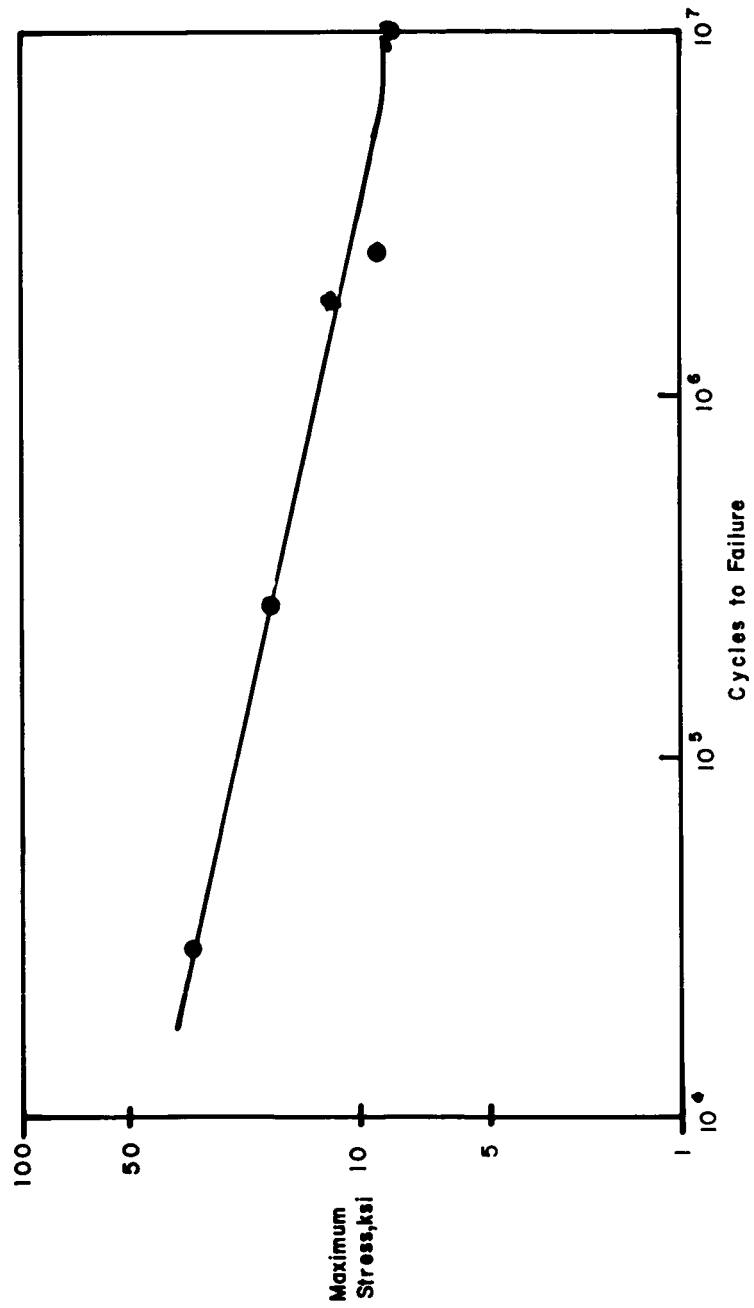


FIGURE 10. FATIGUE LIFE DATA FOR PIPE-WALL-SEGMENT SPECIMENS CONTAINING NOTCHES. $R = 0.01$.

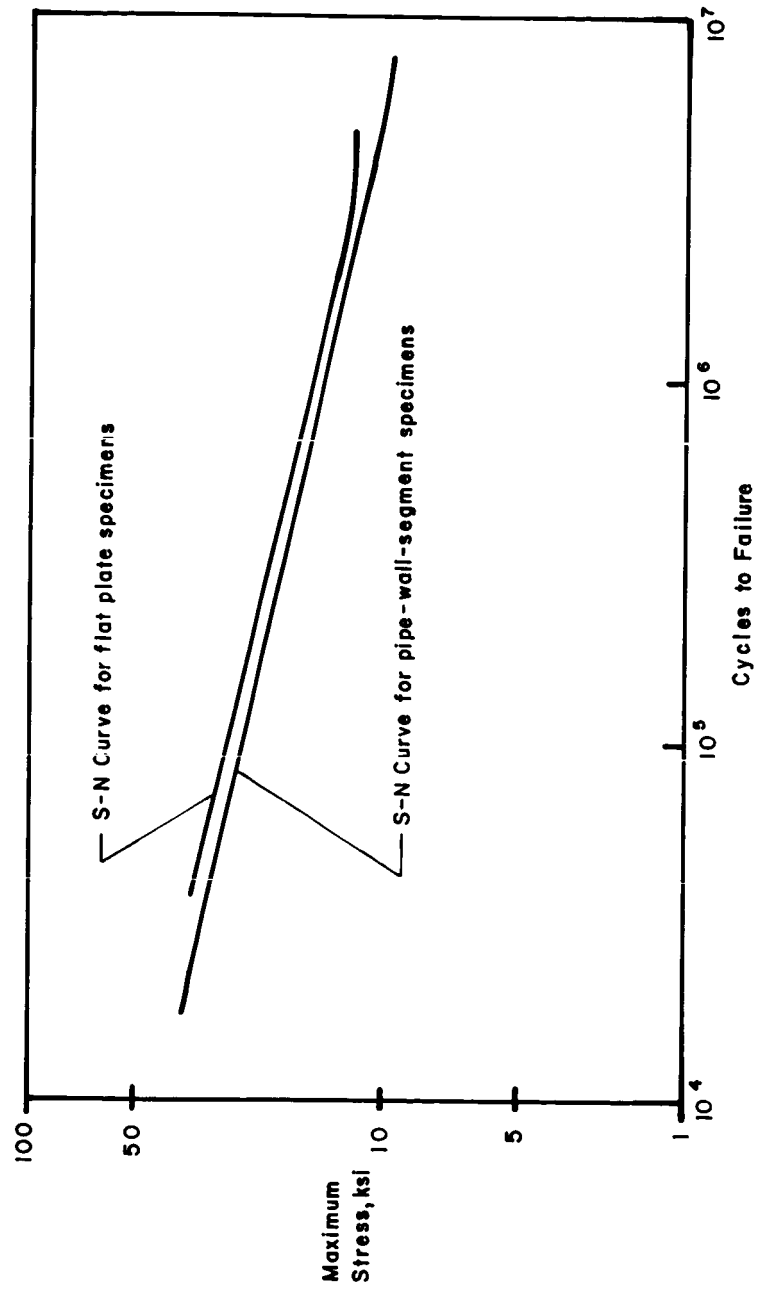


FIGURE 11. COMPARISON OF S-N CURVES FOR FLAT PLATE AND PIPE-WALL-SEGMENT SPECIMENS. NOTCH DEPTH IS 0.2-INCH. $R = 0.01$.

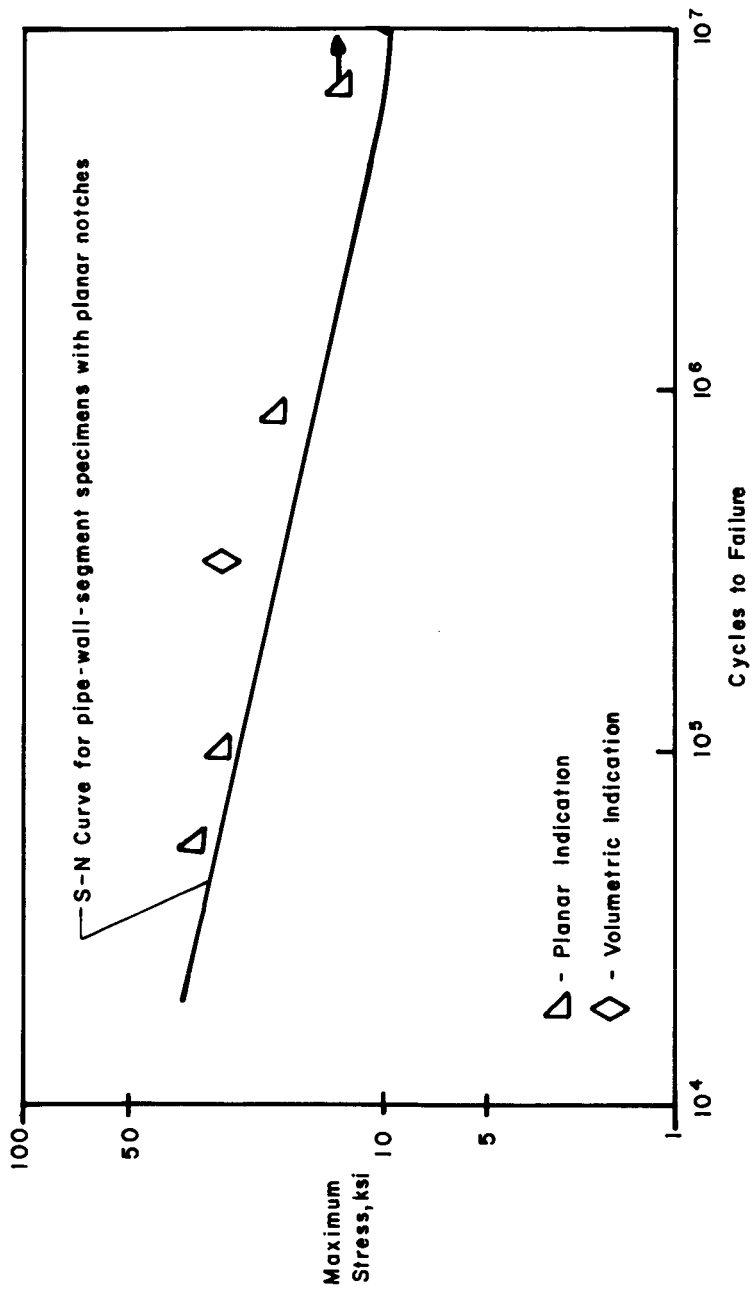


FIGURE 12. FATIGUE LIFE DATA FOR PIPE-WALL-SEGMENT SPECIMENS CONTAINING NATURAL INDICATIONS.
 $R = 0.01$.

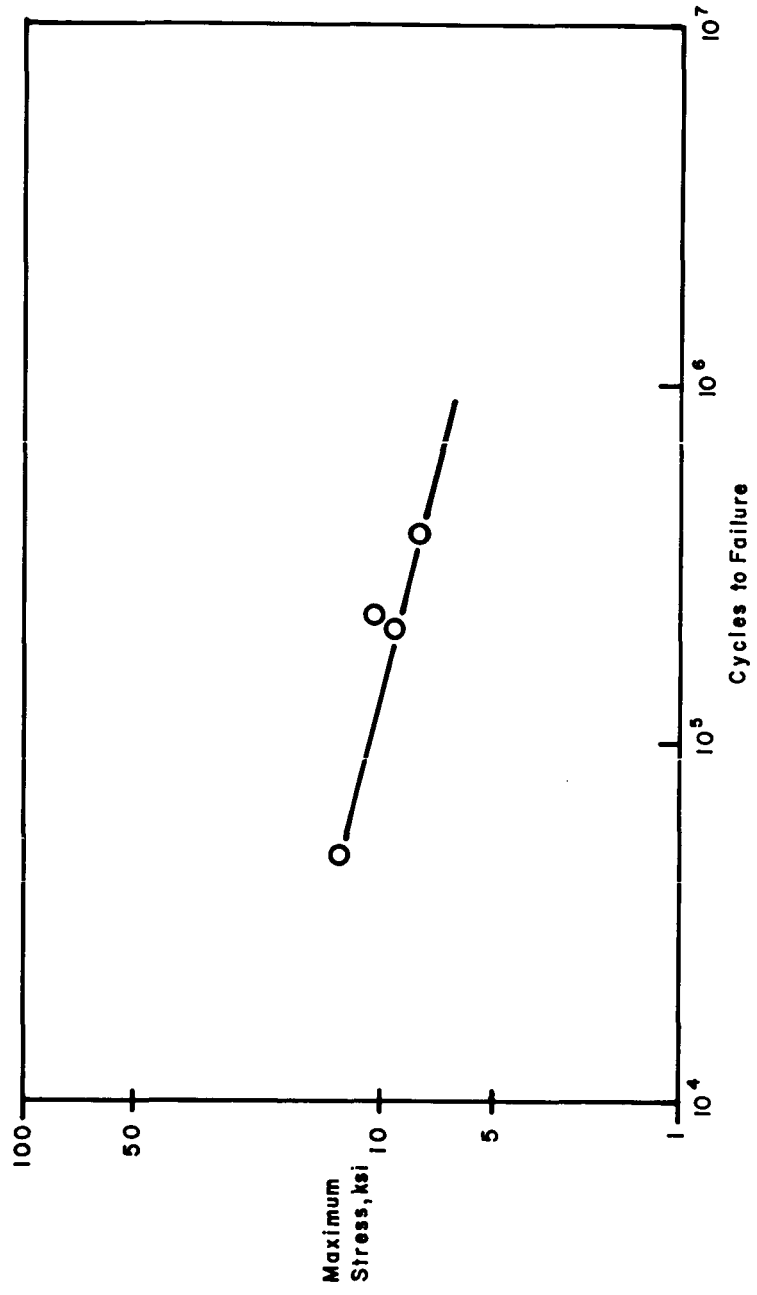


FIGURE 13. FATIGUE LIFE DATA FOR PIPE SEGMENT SPECIMENS CONTAINING PLANAR NOTCHES. R = 0.10.

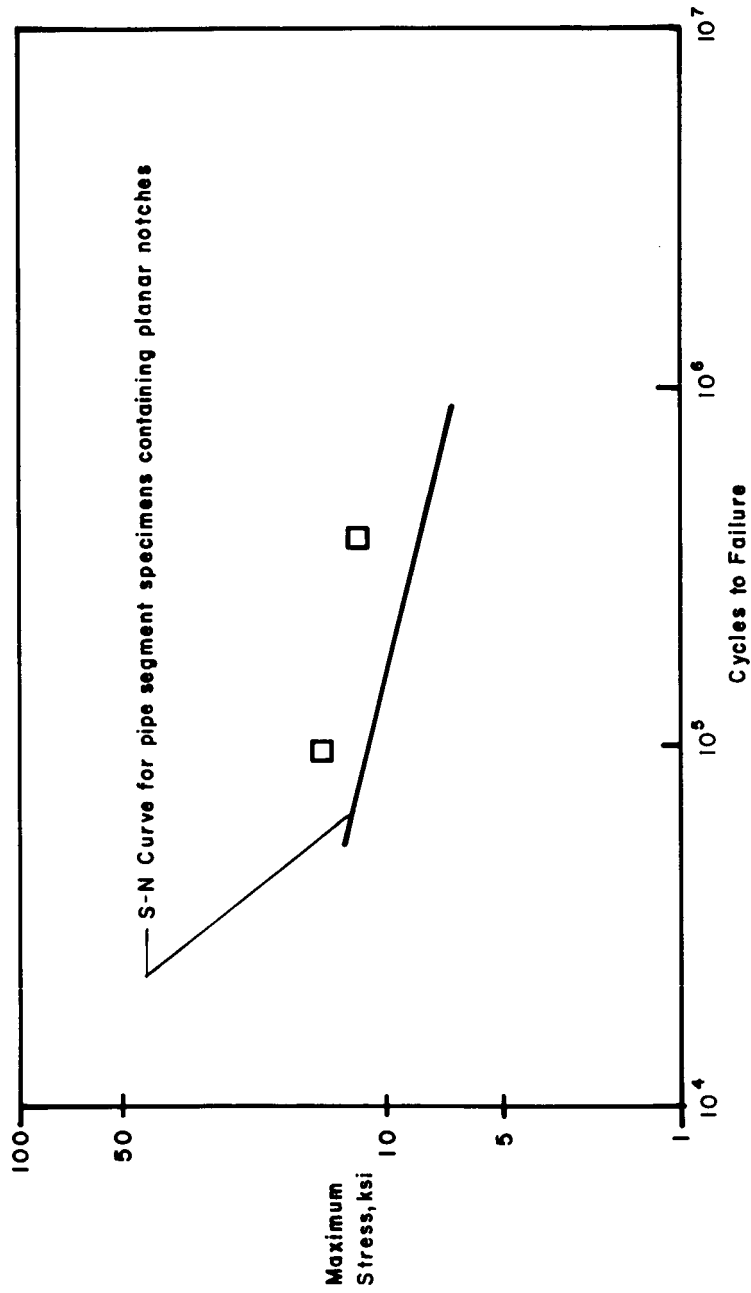


FIGURE 14. FATIGUE LIFE DATA FOR PIPE SEGMENT SPECIMENS CONTAINING VOLUMETRIC NOTCHES WHICH INITIATED FAILURE. $R = 0.10$.

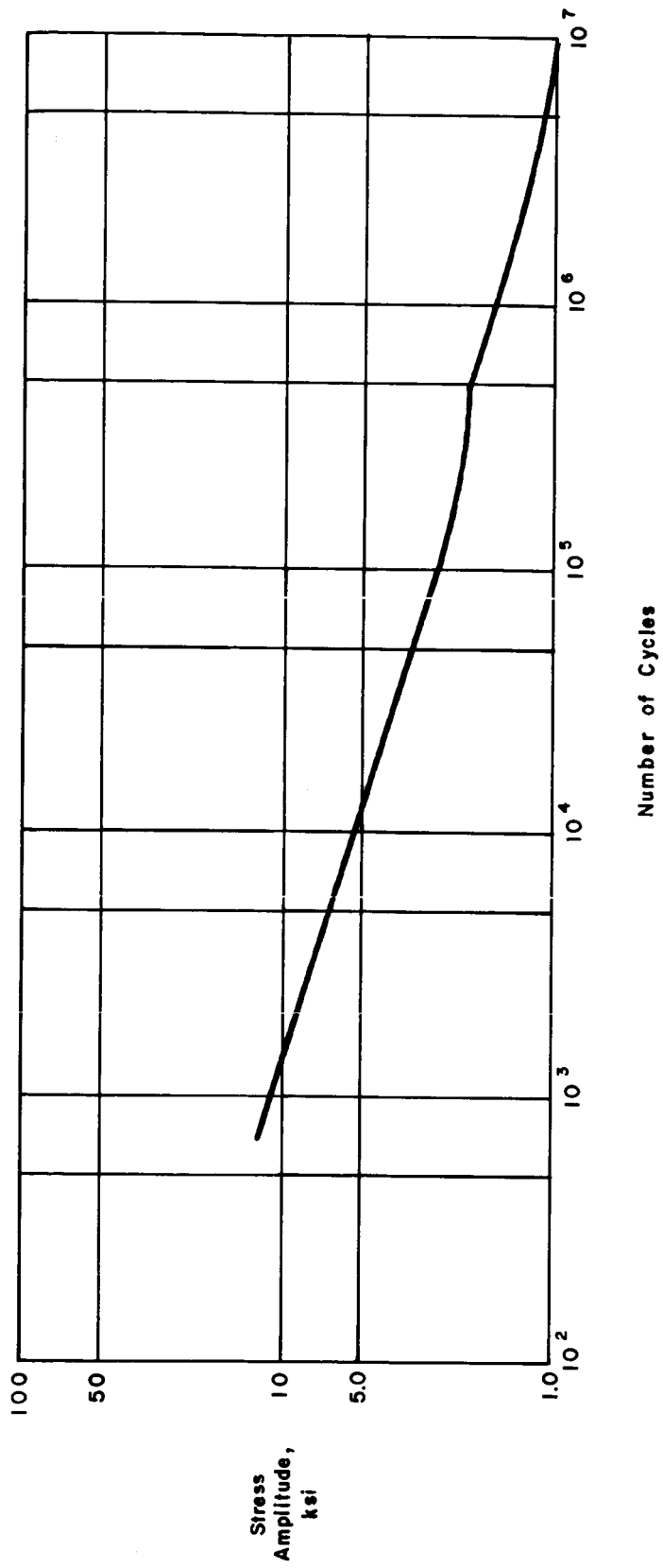


FIGURE 15. USAGE CURVE FOR INDICATIONS HAVING A DEPTH OF 0.20-INCH AND A LENGTH OF 0.4-INCH.

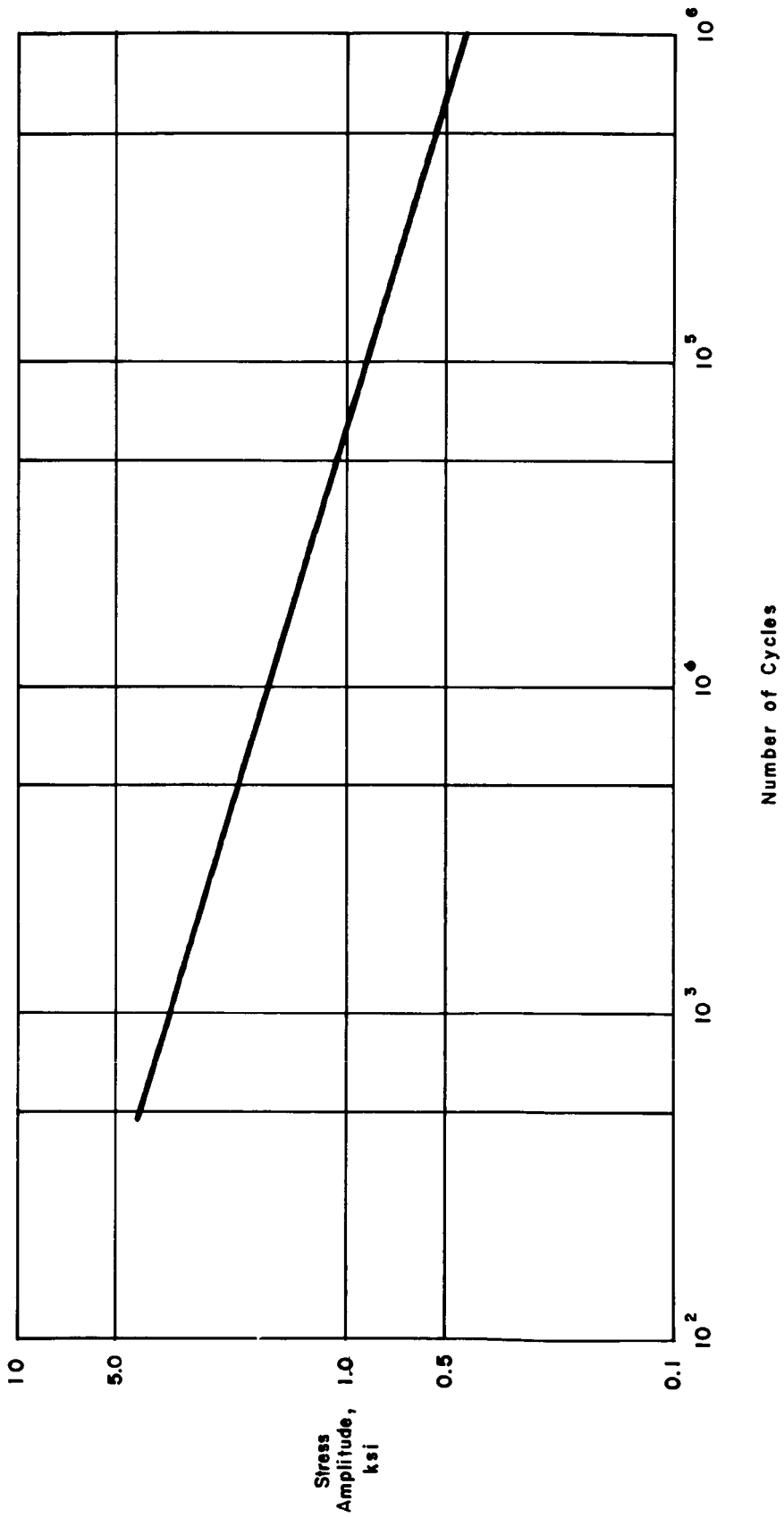


FIGURE 16. USAGE CURVE FOR INDICATIONS HAVING A DEPTH OF 0.195-INCH AND A LENGTH OF 8.4 INCHES.

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16. Abstract Based on the RECERT Program findings, NASA-Langley funded a fatigue study of code-unacceptable welds. This study was conducted to developed usage curves which were based on the structural integrity of the welds. The details of this study are presented in NASA CR-178114. The information presented herein is a condensation and reinterpretation of the information in NASA CR-178114. This condensation and reinterpretation generated usage curves for welds having (a) indications 0.20-inch deep by 0.40-inch long and (b) indications 0.195-inch deep by 8.4-inches long. These curves were developed using the procedures used in formulating the design curves in Section VIII, Division 2 of the American Society of Mechanical Engineers Boiler and Pressure Vessel Code.					
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