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Investigation of Torsional Stress Intensification Factors and Stress Indices for Girth Butt Welds in Straight Pipe

This report describes research sponsored by EPRI and the U.S. Department of Energy under the Nuclear Energy Plant Optimization (NEPO) Program.

Technical Report

Investigation of Torsional Stress Intensification Factors and Stress Indices for Girth Butt Welds in Straight Pipe

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EPRI Project Manager
R.G. Carter

EPRI • 3412 Hillview Avenue, Palo Alto, California 94304 • PO Box 10412, Palo Alto, California 94303 • USA
800.313.3774 • 650.855.2121 • askepri@epri.com • www.epri.com

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This report was prepared by

Wais and Associates, Inc.
2475 Spalding Drive
Atlanta, Georgia 30350

Principal Investigators
E. A. Wais
E. C. Rodabaugh

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REPORT SUMMARY

Design and engineering for fatigue are major concerns in piping systems. Stress indices and stress intensification factors (SIFs) are used in the design of piping systems that must meet the requirements of ASME Section III and ANSI B31.1. This report reviews the effects of torsional loading on SIFs and stress indices for girth butt welds in straight pipe.

Background

SIFs are fatigue correlation factors that compare the fatigue life of piping components (for example, tees and branch connections) to that of girth butt welds in straight pipe subjected to bending moments. Stress indices such as C_2 and K_2 are used to account for fatigue effects produced by reversing loads.

The SIF of 1.0 for butt welds is based on extensive bending tests on carbon steel straight pipe. However, no testing has been performed to date to assess the effect of torsion on SIFs and stress indices for butt welds in carbon steel straight pipe.

Objective

- To develop SIFs and stress indices for girth butt welds subjected to torsion and bending

Approach

Existing data used to derive the SIF for girth butt welds were reviewed. Several new fatigue tests were performed to establish SIFs and stress indices for torsion and bending conditions. Fatigue evaluations were performed for each test, based on the ASME Section III approach to determine the value of C_2 that yielded a cumulative usage factor of 1.0.

Results

An SIF of 1.0 for girth butt welds in piping subjected to bending, as suggested by Markl and adopted by ASME Section III and other piping codes, was verified by new fatigue tests. The value of the SIF and C_2 for girth butt welds for torsional moments can be taken as 0.50. Recommendations are also made to modify the ASME Section III equations that use the SIF for the calculation of stress to account for torsion and bending.

EPRI Perspective

Design for fatigue is a significant concern for any power or process facility. Accurate methods of engineering for fatigue are important to ensure cost-effective design, determine root cause failures, and evaluate remaining fatigue life of plant designs. This work continues to establish the technical justification to allow reductions in current ASME Code stress indices. These and associated reductions in design stresses can provide a basis for reducing the scope of ongoing pressure boundary component testing and inspection programs for operating nuclear power

plants. Examples include reductions in both the inspection scope of postulated high- and moderate-energy line break locations and snubber testing.

Keywords
ASME Code
Fatigue
Piping design and analysis
Stress intensity factors
Stress indices

ABSTRACT

Stress intensification factors (SIFs) are fatigue correlation factors that compare the fatigue life of piping components to that for circumferential butt welds in straight pipe subjected to bending loads, such as thermal expansion. The basis of ASME Section III, Class 2 and Class 3 and ANSI B31.1 piping is the fatigue life of girth butt welds in carbon steel pipe. The fatigue life of a component should be at least equal to that of butt welds. This report compares the fatigue life of butt welds in piping subjected to torsional loadings to the fatigue life when subjected to bending moment loadings. As part of this study, tests were performed to establish SIFs and stress indices for torsion and bending loading conditions. This effort will serve as the basis for Code change suggestions.

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1
INTRODUCTION

1.1 Background

SIFs (stress intensification factors) are fatigue correlation factors that compare the fatigue life of piping components (for example, tees and branch connections) to that of girth butt welds in straight pipe subjected to bending moments. The SIF for girth butt welds is defined to be 1.0.

There are advantages to using welds rather than polished bars or plain unwelded pipe as the baseline. Markl [1] discussed the advantages and disadvantages of polished bars, plain unwelded pipe, and pipe with girth butt welds and concluded that the butt welded joints in straight pipe should be used as the basis for evaluating components such as elbows and branch connections.

A significant benefit of this approach is that, because the SIF is 1.0, butt welds can be located anywhere in the piping system. This differs from ASME Section III, Class 1 [2] piping where the butt welds must be specifically qualified and installed according to design drawings. They cannot be located at other points in the piping system without calculations that justify that location.

Markl [1] also provides background information on SIFs. They are based on deflection controlled, fully reversed, cyclic bending fatigue tests. Markl used the following equation for the SIF, i:

$$i = C\,N^{-0.2}/S \qquad \textbf{Eq. 1-1}$$

where:

i = stress intensification factor

C = 245,000 for carbon steel materials

N = cycles to failure

S = nominal stress amplitude

Failure was defined as the formation of through-wall cracks and leakage of water through the cracks. As noted, the basis of the definition for SIFs was bending tests. This study investigates SIFs based on torsional fatigue tests and compares the results to those for bending.

1.2 Nomenclature

Figure 1-1 indicates the basic configuration and loading used in the evaluation of butt weld pipe connections. The nomenclature includes the terminology used in the body of this report and in the appendices.

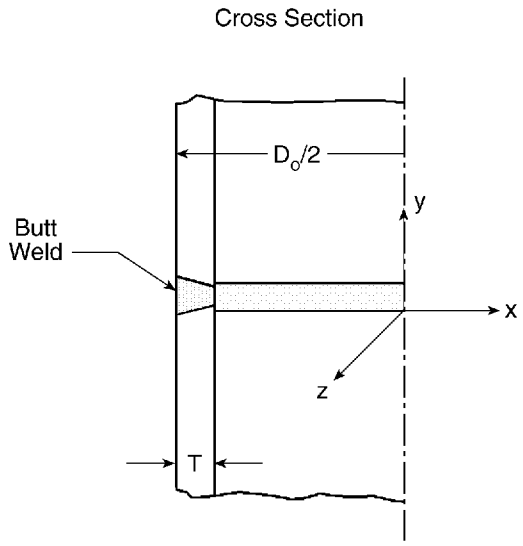

Figure 1-1
Girth Butt Weld in Pipe

C = constant in Markl's equation (see Equation 1-1); 245,000 for carbon steel

C_2 = primary plus secondary stress index

C_{2b} = primary plus secondary stress index for bending

C_{2t} = primary plus secondary stress index for torsion

D_o = outside diameter of the pipe, in. (mm)

F = force applied in tests, lbs. (kg)

i = stress intensification factor

i_b = stress intensification factor corresponding to bending moments

i_t = stress intensification factor corresponding to torsion moments

K_2 = peak stress index

L = distance from load point to failure point in tests, in. (mm)

M_x = bending moment about x-axis, in-lb. (J)

M_y = torsional moment about y-axis, in-lb. (J)

M_z = bending moment about z-axis, in-lb. (J)

N = number of cycles to failure

$N_{allowable}$ = number of allowable cycles used in fatigue evaluation (see Equation 2-2)

r = mean radius of pipe, in. (mm)

S = nominal stress range, ksi (Pa)

S_{alt} = alternating stress intensity, ksi (Pa)

S_b = nominal bending stress, ksi (Pa)

S_t = nominal stress given by M_y/Z, where M_y is the torsion moment

t = wall thickness of the run pipe, in. (mm)

Z = section modulus of the pipe, in^3 (mm^3)

2
EXPERIMENTAL DATA

2.1 Introduction

This investigation is focused on test data that include both previous and new data. This section describes the previously available data and the new test data that were developed as part of this study.

2.2 Existing Experimental Data

The existing test data are applicable to butt welded joints and are described in Sections 2.2.1 through 2.2.3.

2.2.1 Markl Test Data on Butt Welded Joints

Markl [1] summarizes the test data for butt welded joints in straight pipe that were used as the basis for developing SIFs. All tests were performed on 4-inch (101-mm) standard carbon steel pipe. Tests were performed on approximately 53 specimens (as noted from a graph in *Fatigue Tests of Piping Components* [1]). Because various procedures were used in the manufacture of the welds, variance exists in the SIFs obtained from the test data. However, when the results of the various methods were compared, "more variation was observed between the strength of welds produced by different qualified welders using supposedly identical procedures" [1].

Fatigue Tests of Piping Components [1] presents test data in the form of a plot of the stress (S) versus the number of cycles to failure (N). The plot was copied and enlarged so that the values of S and N could be read and evaluated. Because of the small size of the original plot, it is not possible to obtain exact values for S and N. However, for the purpose of this evaluation, the results are believed to be sufficiently accurate.

These data consist of three configurations: welds without backing rings, welds with various backing rings and welds with recessed backing rings of 10-degree taper. These data points were analyzed, and the results are provided in Table 2-1.

Although some variation was present in the results (as would be expected), the average value of the SIF was i = 1.04. The standard deviation of the results is 0.127. This clearly justifies the use of an SIF of 1.00 for butt welded joints.

Table 2-1
Markl Test Data Analysis [1]

Weld Type	Number of Specimens	Average SIF	Standard Deviation	Maximum SIF	Minimum SIF
Backing ring	31	1.00	0.110	1.21	0.791
No backing ring	17	1.05	0.095	1.31	0.927
Recessed taper backing ring	5	1.26	0.106	1.40	1.15
All tests	53	1.04	0.127	1.40	0.791

2.2.2 Markl Test Data on Girth Butt Welded Joints Using Welding Flanges

Markl [3] also contains additional data that are appropriate in evaluating butt welds. The specific tests of interest were of welding neck flanges. Because of the welding neck configuration, these tests are effectively tests of the girth butt weld. Five tests had normal sized welds, which yielded an average SIF of 0.98. In addition, six tests of "minimum welds" had an average SIF of 1.09. For these welds, the welders had been instructed to deposit the minimum of weldment that still satisfied the appropriate Code requirements. There were six tests run where the pipe had a wall thickness of 0.080 inch (2.032 mm) versus 0.237 inch (6.020 mm) for NPS schedule 40 pipe. The average SIF for these six tests was 1.06. The average of all 17 tests was 1.05. This also supports the use of an SIF of 1.00 for butt weld joints.

2.2.3 Woods Test Data on Girth Butt Welded Joints Using Welding Flanges

Woods et al. [4] contains data using 4-inch (101-mm) NPS schedule 40 welding neck flanges of 6061-T6 (aluminum) material welded to type 304 (stainless steel) pipe. Because of the configuration of the specimens, the test is equivalent to testing butt welds in straight pipe. Four bending and three torsion tests were performed. Because these specimens were not made of carbon steel, the use of Markl's equation (Equation 1-1) to evaluate the SIFs is not directly applicable. The value of "C," which is 245,000 for carbon steel, is not appropriate. *Piping Burst and Cyclic Moment Testing and Standardized Flexibility Factor Method* [4] suggests a value of 83,000 for 6061-T6, based on the results of four bending tests, and assumes that the modified Markl equation is valid.

Woods et al. [4] also contains data for the four bending and three torsion tests (see Table 2-2). For each test, Table 2-2 lists the equivalent number of cycles to failure and the nominal stress. Section 2.3.3 provides additional information on the definition of the equivalent number of cycles and nominal stress.

Table 2-2
Woods Test Data on Joints Between 6061-T6 and 304 Pipe [4]

Bending Tests				
	Test Number	**N (Equivalent Cycles to Failure)**	**S (ksi)**	**$N^{-0.2}/S$**
	4	121	29.0	0.0132
	5	604	23.1	0.0120
	6	2123	22.3	0.0097
	7	2275	16.1	0.0132
				Average = 0.0120
Torsion Tests				
	8	566	42.9	0.0066
	9	744	40.9	0.0065
	10	2356	37.4	0.0053
				Average = 0.0061

1 ksi = 6.855 MPa

The ratio of the average SIF for torsion to the average SIF for bending is given by:

$$\text{Average } i_{Torsion}/i_{Bending} = (CN^{-0.2}/S)(\text{Torsion})/(CN^{-0.2}/S)(\text{Bending})$$

$$= (N^{-0.2}/S)(\text{Torsion})/(N^{-0.2}/S)(\text{Bending})$$

$$= 0.509$$

Woods et al. [4] states that because of the design of the test fixture, for the torsion tests, the specimen was also was also subjected to some bending stress. When this additional bending stress was added directly to the torsion stress, the value of the Average $i_{Torsion}/i_{Bending}$ changes from 0.509 to 0.503.

2.3 Project Test Program

As part of this project, eight fatigue tests (four torsion and four bending tests) were performed on specimens made of carbon steel. These tests are described in the following sections.

2.3.1 Test Specimens

Figure 2-1 shows the basic test specimen design configuration.

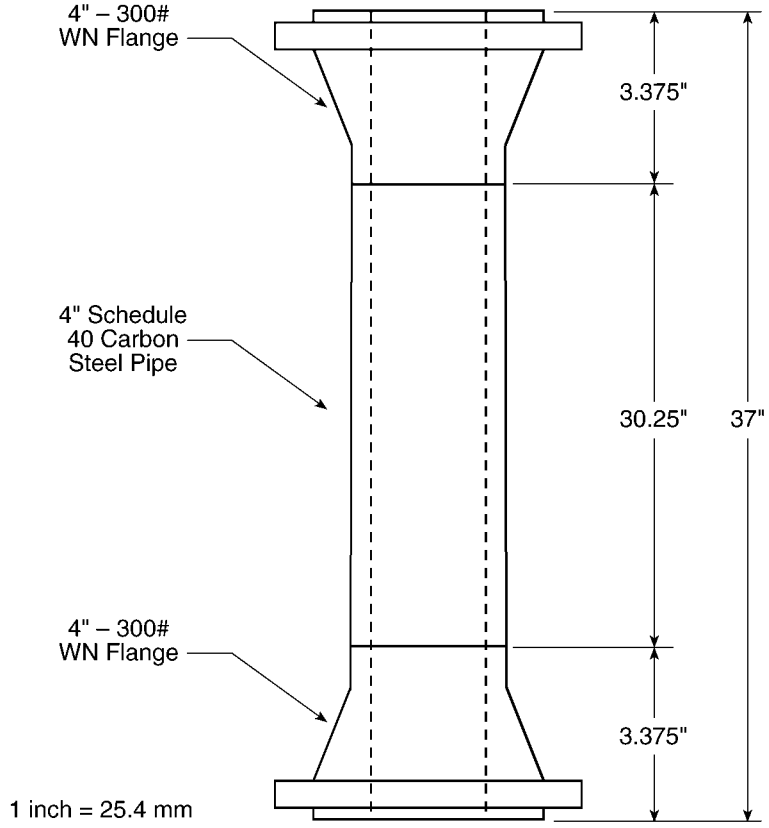

Figure 2-1
Test Specimen

The specimens were manufactured by Wilson Welding Services, Incorporated, of Georgia. The manufacturer was directed to make the welds between the pipe and the flange "industry standard." It was requested that all of the specimens have, as much as possible, the same weld configuration. The material used for the specimens was A106, Gr. B. The material certification is included in this report as Appendix A. Finally, the welds at the interface of the flange and pipe were normal full penetration, in an as-welded condition. The test specimens were labeled 1 through 4 for the torsion tests and 5 through 8 for the bending tests.

2.3.2 Test Performance

The testing was performed at North Carolina State University. The tests were performed on an MTS Systems Corporation Series 3222.31-55 kip Load Frame. A computerized control panel provides local, precise operations of the crosshead, hydraulic grips, and actuator. The maximum actuator displacement is ±3 inches (76 mm). Programmable servo valves control the loading pattern applied to the specimen.

Built-in loading programs include sinusoidal and triangular waves with the user being able to select, within machine limits, the desired amplitude and frequency. The displacement of the actuator is measured by a linear variable differential transformer (LVDT). During a test, the number of cycles of applied load or displacement is recorded by a digital counter and displayed on the MTS console.

In these tests, the load was sinusoidal with frequencies ranging from 0.3 to 0.5 Hz. Actuator displacement was designated as the test control variable. The selection of displacement as the control parameter meant that the actuator movement was used by the MTS system for feedback in the closed loop controls. This resulted in virtually identical cycles of actuator displacement being recorded throughout the duration of each test. The load was measured by a load cell, Interface Model 1020AF-25K. The output of the load cell was monitored continuously throughout the duration of each test.

2.3.3 Test Results

The test data, results, and other information are provided in Appendix B. The tests were displacement controlled moment tests and followed the standard approach, corresponding to Markl type tests [1] as defined in WRC Bulletin 392 [5]. Each specimen was first tested to determine its load deflection curve. The load deflection curve was used to determine the stiffness of each specimen and the load applied to the specimen by a given amount of displacement. The load deflection curves were determined for loading in both positive and negative directions (up and down). Each specimen was then fatigue tested by cycling the deflection in both directions of loading by a controlled amount. The cycles to failure were counted in order to determine the fatigue life. Failure was defined as the formation of through-wall cracks and leakage of water through the cracks. Tables 2-3 provides a summary of the test data.

Table 2-3
Summary of Fatigue Test Results – Girth Butt Welds

Test	Loading Type	Total Cycles to Failure	Equivalent Cycles to Failure	S (ksi)	SIF (i)	C_2
1	Torsion	15,864	3,314	95.1	0.509	0.500
2	Torsion	7,388	5,183	83.2	0.532	0.516
3	Torsion	3,499	1,660	109.2	0.509	0.485
4	Torsion	2,242	2,242	111.9	0.481	0.454
5	Bending	2,321	2,321	54.3	0.958	0.906
6	Bending	1,943	1,943	52.8	1.020	0.962
7	Bending	2,790	2,790	52.7	0.952	0.903
8	Bending	2,139	2,139	51.7	1.022	0.965

1 ksi = 6.855 MPa

As indicated in Appendix B, the value of i is calculated from $i = 245{,}000\ N^{-0.2}/S$, where N = equivalent cycles to failure, and S = M/Z. Z is based on nominal dimensions of the pipe ($Z = 3.215\ in^3$). After completion of the tests, the specimens were cut up and the diameter and thickness measured. This verified the use of the nominal value of Z. When the test has more than one loading condition, the value of S is taken as the stress that corresponds to the maximum loading condition. The equivalent number of cycles is calculated from

$$N_{eq} = \Sigma\ (\delta_i/\delta_{max})^5 * N_i \qquad \textbf{Eq. 2-1}$$

where δ_{max} is the largest deflection and δ_i is the deflection corresponding to the i^{th} condition. These calculations are detailed in the appendices.

The average SIF for the torsion tests is 0.508. The average SIF for the bending tests is 0.988. The ratio of the average torsion SIF to the average bending SIF is 0.514.

The C_2 indices are discussed in the next section.

2.3.4 ASME Section III Component Fatigue Evaluation

Appendix B includes a fatigue evaluation for each test specimen based on the ASME Section III approach. This evaluation determines the value of C_2 that yields a cumulative usage factor (CUF) of 1.00, assuming a value of $K_2 = 1.80$ (according to ASME Section III [2]). This evaluation is based on an allowable number of cycles from the expression derived from *Criteria of the ASME Boiler and Pressure Vessel Code for Design by Analysis in Sections III and VIII, Division 2* [6]:

$$N_{allowable} = (8{,}664/(S_{alt}-21.645))^2 \qquad \textbf{Eq. 2-2}$$

This expression does not include a factor of safety of 2 on stress and 20 on cycles that are part of the Section III, Class I, Appendix I, S-N design curves [6].

Table 2-3 includes the value of C_2 that yields a CUF of 1.0, assuming a value of K_2 of 1.80. The average value of C_2 is 0.489 for the torsion tests and 0.934 for the bending tests. The average ratio of C_2 (torsion)/C_2 (bending) = 0.523.

3
CONCLUSIONS

3.1 Results of Investigation

The following results were derived from this investigation:

1. The value of the SIF of 1.0 for girth butt welds in piping, as suggested by Markl [1] and adopted by ASME Section III [2] and other piping codes, was verified by the new tests described in this report.

2. The value of the SIF for girth butt welds for torsional moments can be taken as 0.50. This is confirmed by Woods et al. [4] for other materials, for example, aluminum welded to stainless steel.

3. The value of C_2 for girth butt welds for torsional moments can be taken as 0.50.

3.2 Conclusions of Investigation

Typically, in the calculations for Class 1 or 2, ASME Section III uses the same general methodology for determining the resultant moment:

$$M = (M_x^2+M_y^2+M_z^2)^{1/2} \qquad \textbf{Eq. 3-1}$$

The nominal stress is calculated by:

$$S = M/Z \qquad \textbf{Eq. 3-2}$$

Assuming that M_y corresponds to the torsion (see Figure 1-1) and the shear stress is given by $\tau = M_y/(2Z)$, then:

$$S = (M_x^2+M_y^2+M_z^2)^{1/2}/Z = [S_b^2+(2\tau)^2]^{1/2} \qquad \textbf{Eq. 3-3}$$

where S_b is the bending stress, calculated by:

$$S_b = (M_x^2+M_z^2)^{1/2}/Z \qquad \textbf{Eq. 3-4}$$

The maximum shear stress or Tresca theory is inherent in this approach.

Based on this study, the use of Equation 3-3 to calculate the nominal stress, S (which is then multiplied by SIFs [for Class 2] or stress indices [for Class 1]) does not work for girth butt welds. If it did, the SIFs and C_2 indices would be equal for torsion and bending loadings. However, as shown in Sections 2.3.3 and 2.3.4, the SIFs and C_2 indices for torsion are one-half those for bending loads.

The Code equations that use SIF generally are of the form iM/Z, where M is the resultant moment, depending on the type of loading. It is suggested that for pipe (with or without welds), this be modified to:

$$S = [(i_b S_b)^2+(i_t S_t)^2]^{1/2} \qquad \textbf{Eq. 3-5}$$

where S_b is the nominal bending stress and is calculated by:

$$S_b = (M_x^2+M_z^2)^{1/2}/Z \qquad \textbf{Eq. 3-6}$$

S_t is calculated by:

$$S_t = M_y/Z \qquad \textbf{Eq. 3-7}$$

and where M_y is the torsional moment, and $i_b = 1.0$ and $i_t = 0.5$.

It is also suggested that for Class 1 analysis, the equations that use C_2 be modified in a similar manner so that the term that uses C_2M/Z (similar to iM/Z) be modified so that C_2M/Z is replaced by:

$$S = [(C_{2b} S_b)^2+(C_{2t} S_t)^2]^{1/2} \qquad \textbf{Eq. 3-8}$$

And S_b and S_t are calculated by Equations 3-6 and 3-7. The indices are given by: $C_{2b} = 1.0$ and $C_{2t} = 0.50$.

4
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A
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SPECIFICATION AND GRADE

PIPE CARBON SMLS STD PIPE API 5L-X42ND EDITION DATED 1/00 PSL-1 GRADE B AND GRADE X42 ASTM A53-X99B ASTM A106-X99 GRADE B QUAD STENCIL ASME SA53-X1998 EDITION 2000 ADDENDUM ASME SA106-X1998 EDITION 2000 ADDENDUM GRADE B CARBON EQUIVALENT .43 MAX TO SR18 BLK REG MILL COAT PE BEV 30 DEG MEETING ALL THE APPLICABLE REQUIREMENTS OF NACE STANDARD MR-01-75 X2000

MATERIAL COND: AS-ROLLED O.D.: 4.500(114.300) in (mm) WALL: 0.237 (6.019) in (mm)

PRODUCT IDENTIFICATION	SPEC TYPE/ DIMENSION	TEST COND.	CHARPY VISION	YIELD PSI	EXT % .50	TENSILE PSI	Y/T	ELONG % IN 2"	HARDNESS SCALE HRB	HIC HYDRO PSI	SSC/LOT
			IN	MIN: 42,000 MAX:		MIN: 60,000 MAX:	MAX.	MIN: 26.0	MIN: MAX: 99.5	3320	5
C25205	STRIP/L/B	AR	1.5	51,000	.50	76,500	0.67	42.6	84.3	3320	5
C25207	STRIP/L/B	AR	1.5	48,400	.50	74,500	0.65	43.1	85.7	3320	5
		MIN	END OF DATA THIS SHEET			MIN					

LEGEND: L - LONGITUDINAL, U - UPSET; T - TRANSVERSE, N - NORMALIZED; QT - QUENCHED & TEMPERED, SR - STRESS RELIEVED; AR - AS-ROLLED; B - BODY; W - WELD

PRODUCT IDENTIFICATION	TYPE	C	MN	P	S	SI	CU	NI	CR	MO	AL	N	V	B	TI	CB	CO				CE MAX .43
C25206	HEAT	18	1.03	.012	.008	.21	.02	.01	.02	.01	.027		.00			.002					.36
C25206	PROD	20	1.07	.013	.009	.22	.02	.01	.03	.01	.026		.00			.003					.39
C25206	PROD	19	1.02	.011	.008	.22	.02	.01	.03	.01	.029		.00			.004					.37
C25207	HEAT	18	1.06	.010	.009	.20	.02	.01	.03	.01	.022		.00			.001					.37
C25207	PROD	19	1.08	.011	.010	.21	.02	.01	.04	.01	.023		.00			.003					.38
C25207	PROD	19	1.06	.011	.010	.21	.02	.01	.04	.01	.023		.00			.004					.38
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*C.E. IS BASED ON THE FOLLOWING EQUATION: C.E. = C + MN/6 + (CR+MO+ V)/5 + (CU+NI)/15 (0.43

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B
TEST DATA AND RESULTS

B.1 Overview

The description of the testing is presented in Section 2, and Table 2-3 contains summaries of the results. This appendix contains detailed reports of the test data for each of the tests. Each report contains the following:

1. Load-deflection data sheets for four conditions (positive and negative directions, loading and unloading). The sheets are used to determine the linear slope of the load-deflection curves for the four loading conditions.

2. Data that include loads, deflections, etc. The "Modified" columns are intended for cases in which adjustments (such as resetting a dial gauge or converting from metric measurements) are required for the data collection.

3. A summary plot of the load-deflection curve and the four straight lines from the load displacement data (Item 1 above). This plot indicates the reasonableness of the slope of the load-deflection curves.

4. The fatigue test data analysis, including the displacement amplitude and number of cycles at each displacement. Calculations of the SIFs are included.

5. The fatigue usage factor calculation that determines C_2 indices (assuming $K_2 = 1.8$), corresponding to a CUF of 1.0 using Equation 2-2: $N_{allowable} = (8{,}664/(S_{alt}-21.645))_2$ and the general approach followed by ASME Section III.

For Tests 1 and 2, the test numbers are identified as 1A and 2B: after the initial loading to determine the load-deflection information, the tests were restarted because of concern about possible slippage in the bolted flanges. The initial load-deflection curves were regenerated.

TEST # : **BUTT WELD TORSION TEST - 1A** **TYPE:** **FATIGUE - LOAD DEFLECTION CURVE**

F = Fo + m δ, "m" TO BE BASED ON "N" DATA POINTS, N = 6
THE VALUE OF "m" = 4122
Fo (LBS) = 0
NOMINAL STRESS = M/Z KSI, M=F x L, L(IN) = 27.5

Do (IN) = 4.5
t (IN) = 0.237
$Z(IN^3)$ = 3.215

POSITIVE LOAD - LOADING CONDITION

DATA POINT #	MEASURED DEFLECTION δ (mm)	MEASURED LOAD F (LBS)	MODIFIED DEFLECTION δ (INCHES)	MODIFIED LOAD F (LBS)	SLOPE FOR START TO DATA POINT (LBS/INCH)	F BASED ON "m" (LBS)	NOMINAL STRESS (KSI)
1	0.030	3	0.000	3	N/A	5	0.0
2	3.010	510	0.117	510	4,321	488	4.2
3	5.960	1002	0.233	1002	4,279	967	8.3
4	9.120	1513	0.358	1513	4,220	1480	12.7
5	12.260	2002	0.481	2002	4,154	1989	17.0
6	15.390	2502	0.605	2502	4,122	2497	21.4
7	18.610	2994	0.731	2994	4,083	3020	25.8
8	22.200	3503	0.873	3503	4,020	3602	30.8
9	26.020	4010	1.023	4010	3,938	4222	36.1
10	29.810	4510	1.172	4510	3,860	4837	41.4
11	31.650	4740	1.245	4740	3,805	5136	43.9
12	33.690	4988	1.325	4988	3,756	5467	46.8
13	35.770	5240	1.407	5240	3,713	5804	49.6
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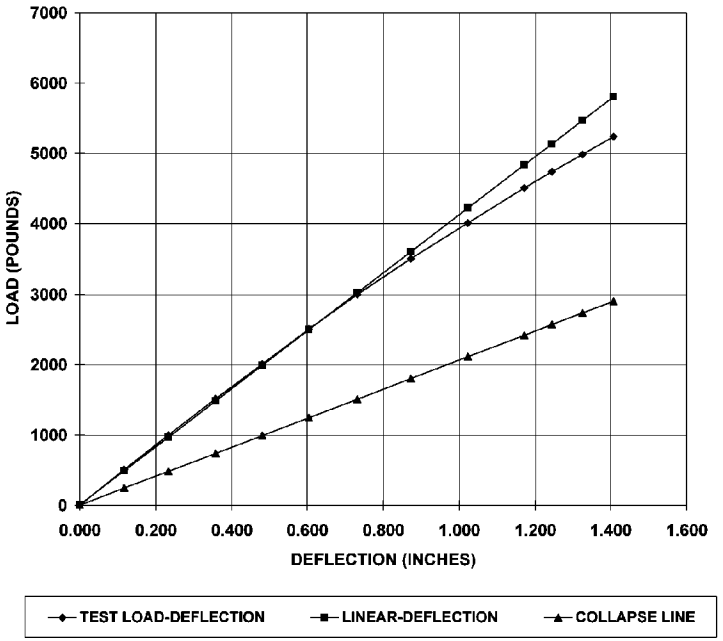

NOTES:
1. Modified data includes deflection and load instrumentation adjustments if required.
2. Loading is in a downward direction. For purposes of the evaluation of the stiffness calculation, the directions of loading (e.g. positive load-loading condition) will remain the same. The sign of the deflection will indicate the load direction.
3. Test number is designated as "1A" because the test was started and in the initial load cycle there was concern regarding slippage between the flange and the supporting structure. It was decided to retighten the bolts and restart the test as 1A.

TEST #: **BUTT WELD TORSION TEST - 1A** **TYPE:** **FATIGUE - LOAD DEFLECTION CURVE**

F = Fo + m δ, "m" TO BE BASED ON "N" DATA POINTS, N = 4
THE VALUE OF "m" = 4346
Fo (LBS) = -1059
NOMINAL STRESS = M/Z KSI, M=F x L, L(IN) = 27.5 Z(IN^3) = 3.215

POSITIVE LOAD - UNLOADING CONDITION

DATA POINT #	MEASURED DEFLECTION δ (mm)	MEASURED LOAD F (LBS)	MODIFIED DEFLECTION δ (INCHES)	MODIFIED LOAD F (LBS)	SLOPE FOR START TO DATA POINT (LBS/INCH)	F BASED ON "m" (LBS)	NOMINAL STRESS (KSI)
1	35.770	5240	1.407	5240	4,480	5056	43.2
2	33.380	4741	1.313	4741	4,427	4647	39.8
3	30.860	4254	1.214	4254	4,385	4216	36.1
4	28.150	3758	1.107	3758	4,346	3752	32.1
5	25.410	3250	0.999	3250	4,301	3283	28.1
6	22.630	2751	0.890	2751	4,260	2808	24.0
7	19.770	2250	0.777	2250	4,219	2318	19.8
8	16.890	1754	0.664	1754	4,172	1826	15.6
9	13.910	1245	0.546	1245	4,110	1316	11.3
10	10.950	751	0.430	751	4,036	809	6.9
11	7.780	245	0.305	245	3,989	267	2.3
12	6.220	0	0.244	0	N/A	0	0.0
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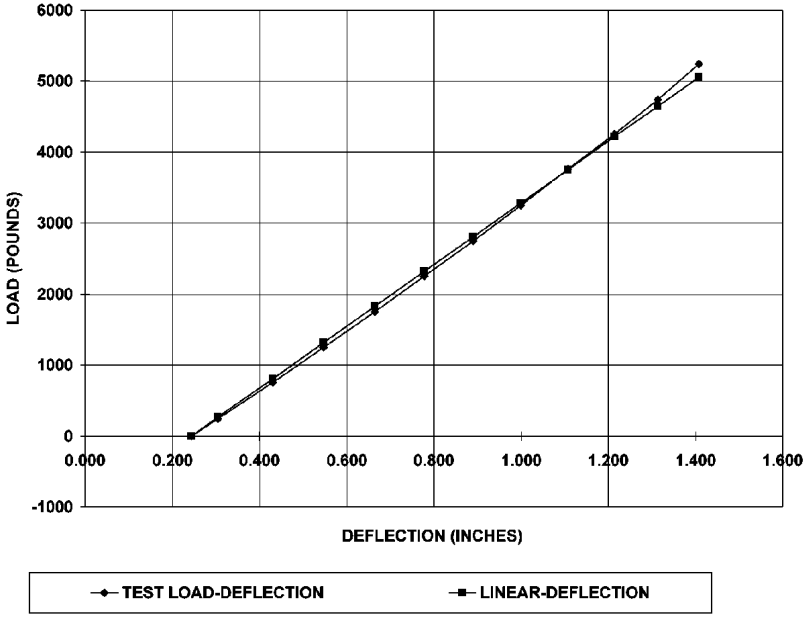

NOTES:
1. Modified data includes deflection and load instrumentation adjustments if required.

TEST #: **BUTT WELD TORSION TEST - 1A** **TYPE:** **FATIGUE - LOAD DEFLECTION CURVE**

F = Fo + m δ, "m" TO BE BASED ON "N" DATA POINTS, N = 5
THE VALUE OF "m" = 3812
Fo (LBS) = 0

NOMINAL STRESS = M/Z KSI, M=F x L, L(IN) = 27.5 $Z(IN^3)$ = 3.215

NEGATIVE LOAD - LOADING CONDITION

DATA POINT #	MEASURED DEFLECTION δ (mm)	MEASURED LOAD F (LBS)	MODIFIED DEFLECTION δ (INCHES)	MODIFIED LOAD F (LBS)	SLOPE FOR START TO DATA POINT (LBS/INCH)	F BASED ON "m" (LBS)	NOMINAL STRESS (KSI)
1	6.220	0	0.244	0	N/A	0	0.0
2	2.630	-505	0.102	-505	3,573	-539	-4.6
3	-0.670	-1002	-0.028	-1002	3,692	-1034	-8.8
4	-3.930	-1505	-0.156	-1505	3,770	-1523	-13.0
5	-7.150	-2000	-0.283	-2000	3,812	-2007	-17.2
6	-10.650	-2490	-0.420	-2490	3,786	-2532	-21.7
7	-14.460	-3000	-0.570	-3000	3,729	-3104	-26.5
8	-18.300	-3502	-0.722	-3502	3,668	-3680	-31.5
9	-22.470	-3990	-0.886	-3990	3,583	-4306	-36.8
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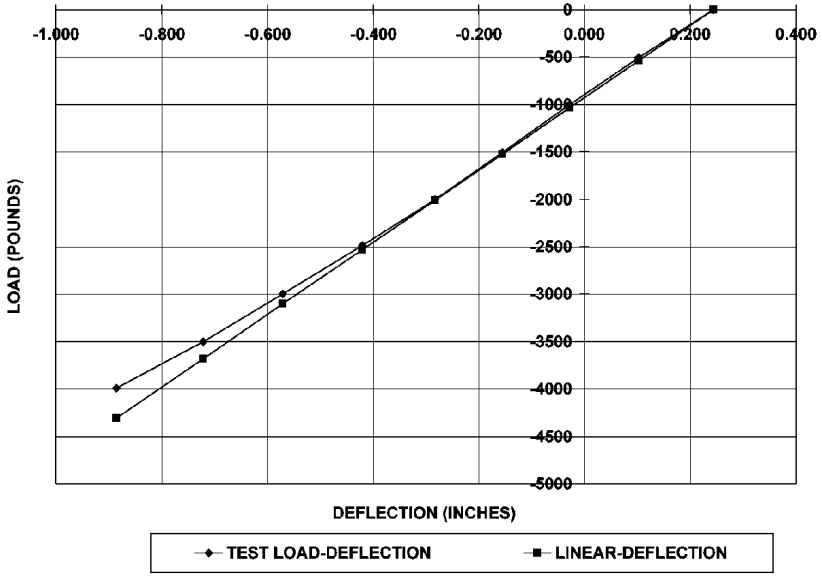

NOTES:
1. Modified data includes deflection and load instrumentation adjustments if required.

TEST #: **BUTT WELD TORSION TEST - 1A** **TYPE:** **FATIGUE - LOAD DEFLECTION CURVE**

F = Fo + m δ, "m" TO BE BASED ON "N" DATA POINTS, N = 4
THE VALUE OF "m" = 4457 Fo (LBS) = 105

NOMINAL STRESS = M/Z KSI, M=F x L, L(IN) = 27.5 $Z(IN^3)$ = 3.215

NEGATIVE LOAD - UNLOADING CONDITION

DATA POINT #	MEASURED DEFLECTION δ (mm)	MEASURED LOAD F (LBS)	MODIFIED DEFLECTION δ (INCHES)	MODIFIED LOAD F (LBS)	SLOPE FOR START TC DATA POINT (LBS/INCH)	F BASED ON "m" (LBS)	NOMINAL STRESS (KSI)
1	-22.470	-3990	-0.886	-3990	4641	-3843	-32.9
2	-20.180	-3502	-0.796	-3502	4570	-3441	-29.4
3	-17.520	-2990	-0.691	-2990	4515	-2975	-25.4
4	-14.940	-2505	-0.589	-2505	4457	-2522	-21.6
5	-12.220	-2000	-0.482	-2000	4384	-2044	-17.5
6	-9.470	-1500	-0.374	-1500	4287	-1562	-13.4
7	-6.710	-1000	-0.265	-1000	4130	-1077	-9.2
8	-3.880	-507	-0.154	-507	3891	-581	-5.0
9	-0.570	0	-0.024	0	N/A	0	0.0
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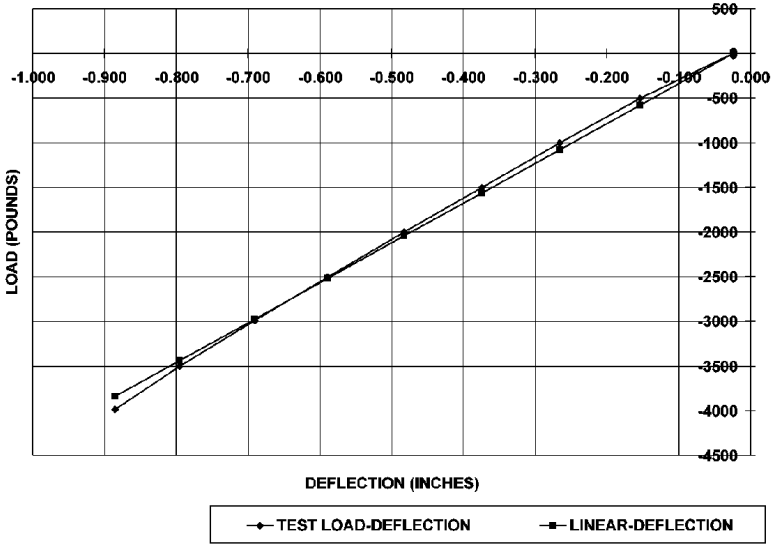
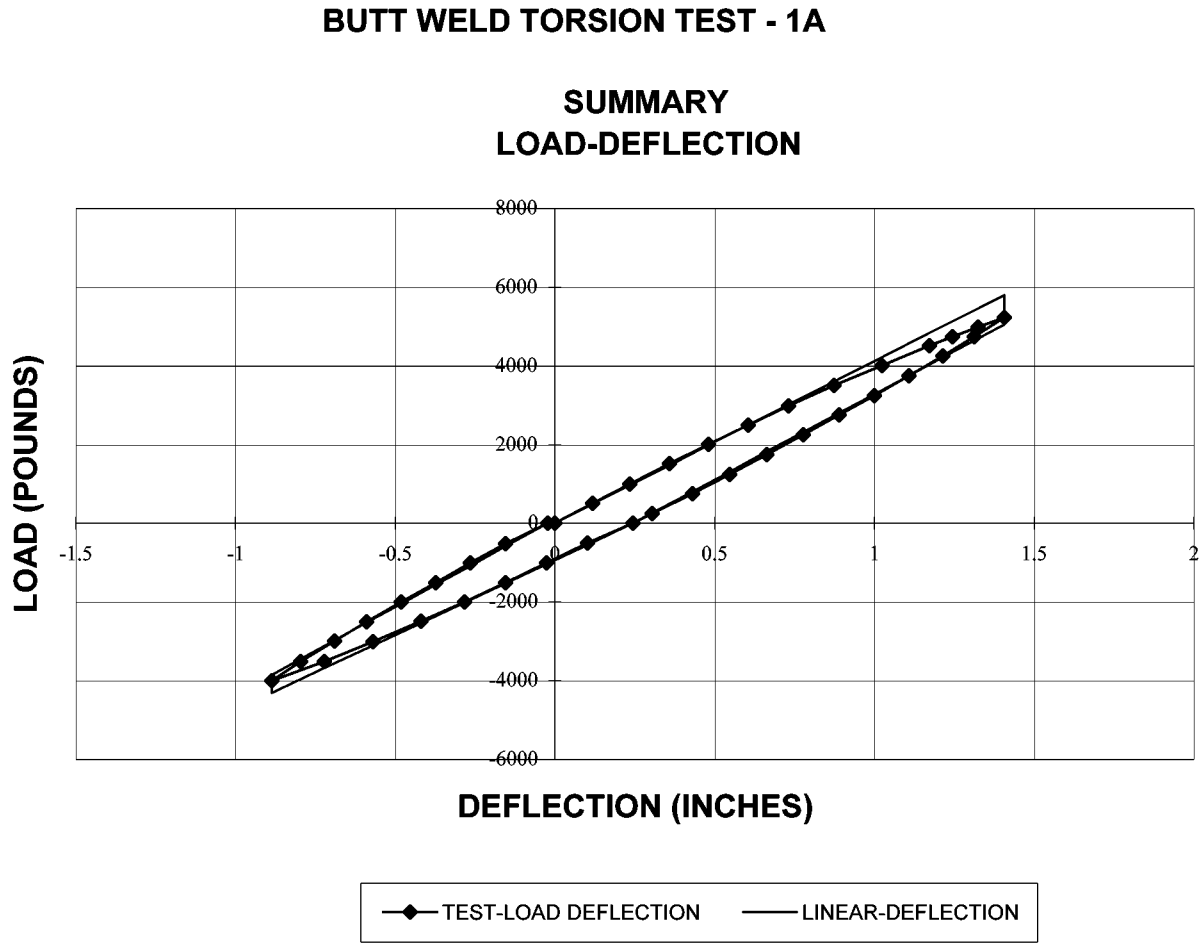


NOTES:


BUTT WELD TORSION TEST - 1A
SUMMARY
LOAD-DEFLECTION
LOAD (POUNDS)
8000
6000
4000
2000
0
-2000
-4000
-6000
-1.5
-1
-0.5
0
0.5
1
1.5
2
DEFLECTION (INCHES)
TEST-LOAD DEFLECTION
LINEAR-DEFLECTION

TEST #: **BUTT WELD TORSION TEST - 1A**

FATIGUE TEST DATA ANALYSIS

Do (IN) = 4.5
t (IN) = 0.237

MOMENT ARM (IN)= L = 27.5
AVERAGE STIFFNESS (LBS/IN) = 4184
AVERAGE STIFFNESS (LBS/IN) (TEST 1)= 3794

TEST DISPLACEMENT/CYCLE DATA:

CONDITION #	DISPLACEMEN AMPLITUDE (+/-) (mm.) δ_i	DISPLACEMENT AMPLITUDE (+/-) (in.) δ_i	EFFECTIVE APPLIED LOAD (LBS)	NOMINAL STRESS (+/-) (PSI) S	NUMBER OF TEST CYCLES N_i
1 (TEST 1)	11.0	0.433	1812	13,358	5
2 (TEST 1)	19.0	0.748	3130	23,073	116
3	19.0	0.748	3130	26,773	2,000
4	30.0	1.181	4942	42,273	1,500
5	38.1	1.500	6277	53,687	4,146
6	42.7	1.682	7040	60,218	4,000
7	52.0	2.047	8566	73,274	2,000
8	67.5	2.657	11120	95,115	2,097
				TOTAL CYCLES:	15,864

FOR THE MAXIMUM DISPLACEMENT, δ_{max} (IN) = 2.657 THE EQUIVALENT NUMBER
OF CYCLES USING $N_{eq} = \Sigma(\delta_i/\delta_{max})^5 * N_i$ IS = 3,314

For $Z(IN^3)$ = 3.215
$i = 245{,}000 * Neq^{(-0.2)}/S$ = **0.509**

COMMENTS:

1. Failure point was at the weld at the fixed end at the pipe side of the weld at about 3 o'clock.
2.. L is distance from load point to center of pipe.
3.. It is assumed that the stresses are calculated by M / Z.
4. Condition 3 was run at a rate of 40 cycles per minute. Changed at 1817 cycles to 80 cycles per minute.
5. For conditon 5 the deflection control appeared to not work. The deflection was measured directly. The rate was about 27 cycles/min.
6. Temperature of pipe went from 25 to 44C for condition 5.
7. Second day restart at condition 6 at 24 cycles/min. Condition 6 at 21 cycles/min. Condition 8 @ 16 cpm (163 F).
8. In condition 8, a fire drill shut the system down at 705 cycles.

TEST #: **BUTT WELD TORSION TEST - 1A**

FATIGUE USAGE FACTOR EVALUATION FOR Z(IN^3)= 3.215

Condition	S_{nom}= +/- M/Z (ksi)	S_n= 2 C_2 M/Z (ksi)	S_p = 2 K_2C_2M/Z (ksi)	K_e	S_{alt}= K_eS_p/2 (ksi)	$N_{allowable}$	N_{test}	USAGE FACTOR	CUMULATIVE USAGE FACTOR
1	13.36	13.4	24.0	1.00	12.0	N/A	5	0.00	0.00
2	23.07	23.1	41.5	1.00	20.77	N/A	116	0.00	0.00
3	26.77	26.8	48.2	1.00	24.10	12,472,087	2,000	0.00	0.00
4	42.27	42.3	76.1	1.00	38.05	278,925	1,500	0.01	0.01
5	53.69	53.7	96.6	1.00	48.32	105,467	4,146	0.04	0.04
6	60.22	60.2	108.4	1.01	54.61	69,085	4,000	0.06	0.10
7	73.27	73.3	131.9	1.44	95.15	13,893	2,000	0.14	0.25
8	95.12	95.1	171.2	2.17	185.85	2,784	2,097	0.75	1.00

INDICES & MATERIAL PROPERTY DATA

C_2 =	**0.500**	S_m (ksi) =	20
K_2 =	**1.80**	m =	3.0
$C_2K_2/2$=	0.45	n =	0.2

TOTAL CUMULATIVE USAGE FACTOR = **1.000**

COMMENTS:

1. The fatigue analysis follows the methodology defined in ASME Section III for Class 1 components (ASME Boiler and Pressure Code, Section III, Nuclear Power Plant Components, ASME, New York, 2001). The definition of the various terms are in accordance with NB-3653 except for the design fatigue which is defined as : $N_{allowable} = (8{,}664/(S_{alt}-21.645))^2$ (from Criteria of the ASME Boiler and Pressure Vessel Code for Design by Analysis in Sections III and VIII, Division 2, The American Society of Mechanical Engineers, 1969). If S_{alt} is less than or equal to 21.645, the expression is not valid and the associated usage factor is taken as 0.0.
2. The usage factor is defined as $N_{test}/N_{allowable}$.
3. The Cumulative Usage Factor is the sum of the usage factors for the particular loading condition and the previous ones.

TEST # : **BUTT WELD TORSION TEST - 2B** **TYPE:** **FATIGUE - LOAD DEFLECTION CURVE**

F = Fo + m δ, "m" TO BE BASED ON "N" DATA POINTS, N = 3
THE VALUE OF "m" = 4292
Fo (LBS) = 0
NOMINAL STRESS = M/Z KSI, M=F x L, L(IN) = 27.5

Do (IN) = 4.5
t (IN) = 0.237
$Z(IN^3)$ = 3.215

POSITIVE LOAD - LOADING CONDITION

DATA POINT #	MEASURED DEFLECTION δ (mm)	MEASURED LOAD F (LBS)	MODIFIED DEFLECTION δ (INCHES)	MODIFIED LOAD F (LBS)	SLOPE FOR START TO DATA POINT (LBS/INCH)	F BASED ON "m" (LBS)	NOMINAL STRESS (KSI)
1	-1.360	5	0.000	5	N/A	5	0.0
2	4.170	1003	0.218	1003	4,584	939	8.0
3	10.430	2000	0.464	2000	4,292	1997	17.1
4	18.710	2995	0.790	2995	3,775	3396	29.0
5	22.000	3340	0.920	3340	3,592	3952	33.8
6	27.000	3845	1.117	3845	3,411	4797	41.0
7	32.000	4300	1.313	4300	3,238	5642	48.3
8	37.000	4650	1.510	4650	3,053	6487	55.5
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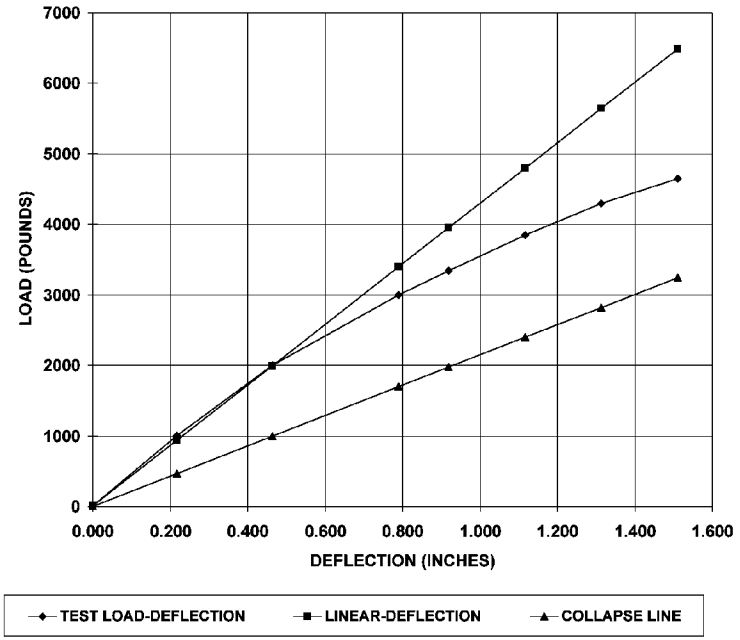

NOTES:
1. Modified data includes deflection and load instrumentation adjustments if required.
2. Loading is in a downward direction. For purposes of the evaluation of the stiffness calculation, the directions of loading (e.g. positive load-loading condition) will remain the same. The sign of the deflection will indicate the load direction.

TEST #: **BUTT WELD TORSION TEST - 2B** **TYPE:** **FATIGUE - LOAD DEFLECTION CURVE**

F = Fo + m δ, "m" TO BE BASED ON "N" DATA POINTS, N = 4
THE VALUE OF "m" = 4142
Fo (LBS) = -1949
NOMINAL STRESS = M/Z KSI, M=F x L, L(IN) = 27.5 Z(IN^3) = 3.215

POSITIVE LOAD - UNLOADING CONDITION

DATA POINT #	MEASURED DEFLECTION δ (mm)	MEASURED LOAD F (LBS)	MODIFIED DEFLECTION δ (INCHES)	MODIFIED LOAD F (LBS)	SLOPE FOR START TO DATA POINT (LBS/INCH)	F BASED ON "m" (LBS)	NOMINAL STRESS (KSI)
1	37.000	4650	1.510	4650	4,426	4307	36.8
2	32.000	3630	1.313	3630	4,295	3491	29.9
3	27.000	2730	1.117	2730	4,219	2676	22.9
4	22.000	1860	0.920	1860	4,142	1861	15.9
5	17.000	1027	0.723	1027	4,077	1045	8.9
6	12.000	220	0.526	220	3,963	230	2.0
7	10.590	0	0.470	0	N/A	0	0.0
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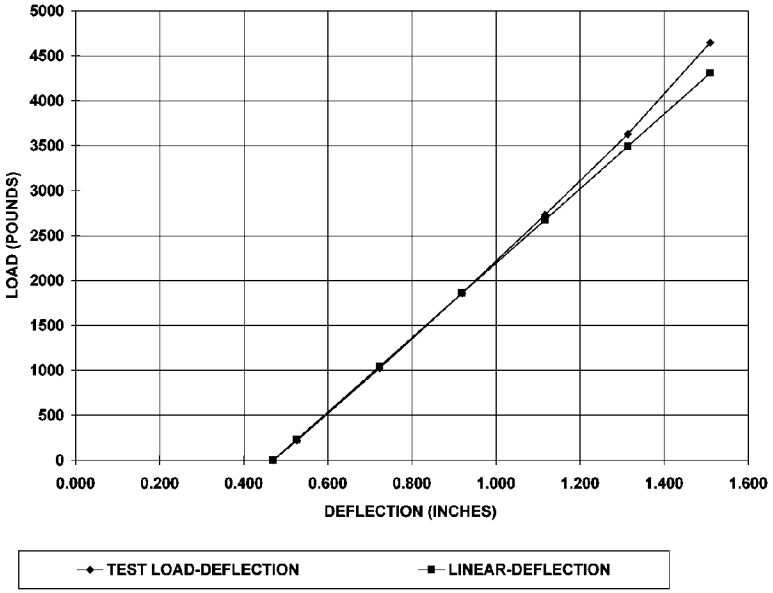

NOTES:
1. Modified data includes deflection and load instrumentation adjustments if required.

TEST #: **BUTT WELD TORSION TEST - 2B** **TYPE:** **FATIGUE - LOAD DEFLECTION CURVE**

F = Fo + m δ, "m" TO BE BASED ON "N" DATA POINTS, N = 3
THE VALUE OF "m" = 3561
Fo (LBS) = 0

NOMINAL STRESS = M/Z KSI, M=F x L, L(IN) = 27.5 Z(IN^3) = 3.215

DATA POINT #	MEASURED DEFLECTION δ (mm)	MEASURED LOAD F (LBS)	MODIFIED DEFLECTION δ (INCHES)	MODIFIED LOAD F (LBS)	SLOPE FOR START TO DATA POINT (LBS/INCH)	F BASED ON "m" (LBS)	NOMINAL STRESS (KSI)
1	10.590	0	0.470	0	N/A	0	0.0
2	5.000	-780	0.250	-780	3,544	-784	-6.7
3	0.000	-1485	0.054	-1485	3,561	-1485	-12.7
4	-5.000	-2135	-0.143	-2135	3,489	-2186	-18.7
5	-10.000	-2715	-0.340	-2715	3,369	-2887	-24.7
6	-15.000	-3210	-0.537	-3210	3,215	-3588	-30.7
7	-20.000	-3715	-0.734	-3715	3,090	-4289	-36.7
8	-25.000	-4090	-0.931	-4090	2,941	-4990	-42.7
9	-30.000	-4415	-1.128	-4415	2,785	-5691	-48.7
10	-35.000	-4700	-1.324	-4700	2,633	-6392	-54.7
11	-40.000	-4930	-1.521	-4930	2,484	-7093	-60.7
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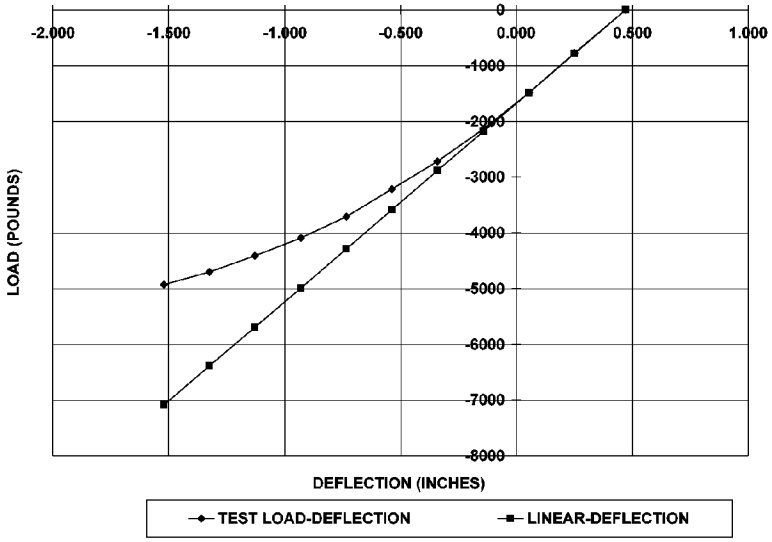
NEGATIVE LOAD - LOADING CONDITION



NOTES:
1. Modified data includes deflection and load instrumentation adjustments if required.

TEST #: **BUTT WELD TORSION TEST - 2E** **TYPE:** **FATIGUE - LOAD DEFLECTION CURVE**

F = Fo + m δ, "m" TO BE BASED ON "N" DATA POINTS, N = 3

THE VALUE OF "m" = 4210 Fo (LBS) = 1687

NEGATIVE LOAD - UNLOADING CONDITIO

NOMINAL STRESS = M/Z KSI, M=F x L, L(IN) = 27.5 $Z(IN^3)$ = 3.215

DATA POINT #	MEASURED DEFLECTION δ (mm)	MEASURED LOAD F (LBS)	MODIFIED DEFLECTION δ (INCHES)	MODIFIED LOAD F (LBS)	SLOPE FOR START TO DATA POINT (LBS/INCH)	F BASED ON "m" (LBS)	NOMINAL STRESS (KSI)
1	-40.000	-4930	-1.521	-4930	4409	-4718	-40.4
2	-35.000	-3945	-1.324	-3945	4302	-3889	-33.3
3	-30.000	-3039	-1.128	-3039	4210	-3060	-26.2
4	-25.000	-2150	-0.931	-2150	4087	-2231	-19.1
5	-20.000	-1280	-0.734	-1280	3899	-1403	-12.0
6	-15.000	-450	-0.537	-450	3581	-574	-4.9
7	-10.000	255	-0.340	255	N/A	255	2.2
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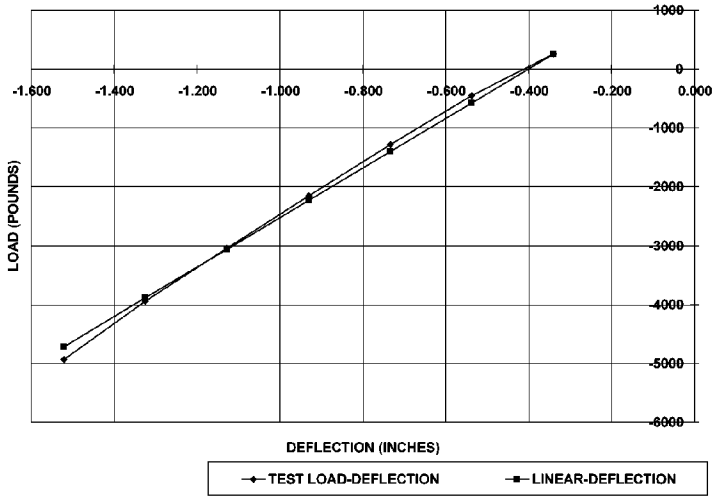
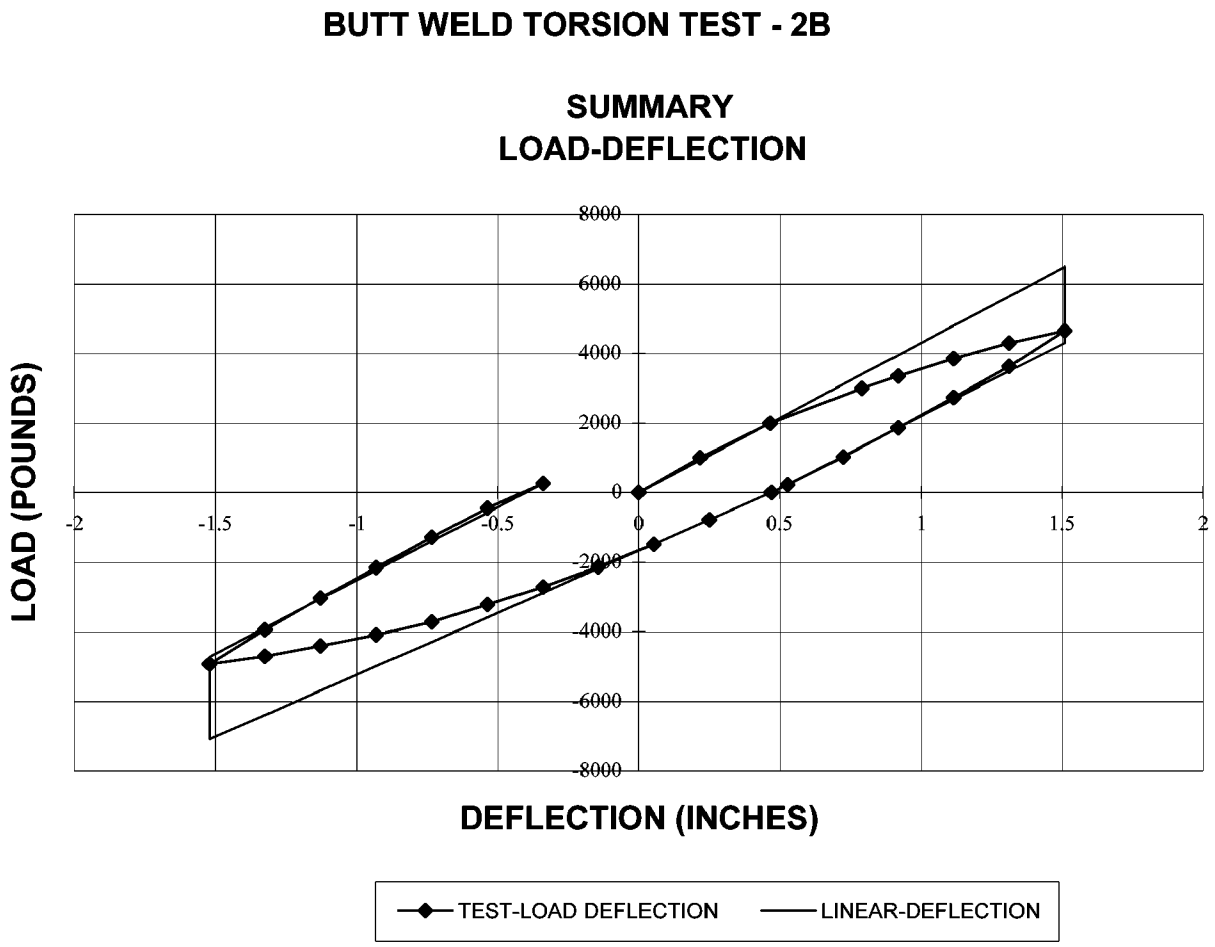


NOTES:


BUTT WELD TORSION TEST - 2B
SUMMARY
LOAD-DEFLECTION
LOAD (POUNDS)
8000
6000
4000
2000
0
-2000
-4000
-6000
-8000
-2
-1.5
-1
-0.5
0
0.5
1
1.5
2
DEFLECTION (INCHES)
TEST-LOAD DEFLECTION
LINEAR-DEFLECTION

TEST #: **BUTT WELD TORSION TEST - 2B**

FATIGUE TEST DATA ANALYSIS

Do (IN) = 4.5 MOMENT ARM (IN)= L = 27.5

t (IN) = 0.237 AVERAGE STIFFNESS (LBS/IN) = 4052

AVERAGE STIFFNESS (LBS/IN) (TEST 1)= 3794

TEST DISPLACEMENT/CYCLE DATA:

CONDITION #	DISPLACEMEN AMPLITUDE (+/-) (mm.) δ_i	DISPLACEMENT AMPLITUDE (+/-) (in.) δ_i	EFFECTIVE APPLIED LOAD (LBS)	NOMINAL STRESS (+/-) (PSI) S	NUMBER OF TEST CYCLES N_i
1	40.0	1.575	6380	54,576	2,329
2	60.0	2.362	9571	81,864	2,000
3	61.0	2.402	9730	83,228	3,059
4		0.000	-	-	0
5		0.000	-	-	0
6		0.000	-	-	0
7		0.000	-	-	0
8		0.000	-	-	0
				TOTAL CYCLES:	7,388

FOR THE MAXIMUM DISPLACEMENT, δ_{max} (IN) = 2.402 THE EQUIVALENT NUMBER OF CYCLES USING $N_{eq} = \Sigma(\delta_i/\delta_{max})^5 * N_i$ IS = 5,183

For $Z(IN^3)$ = 3.215

$i = 245{,}000 * Neq^{(-0.2)}/S$ = **0.532**

COMMENTS:

1. Failure point was at the weld at the end away from the fixed end at the pipe side at about 6:30.
2. L is distance from load point to center of pipe.
3. It is assumed that the stresses are calculated by M / Z.
4. Condition 1 was run at a rate of 28 cycles per minute.
5. Temperature of pipe went from 25 to 40 C for condition 1. 66 C for condition 2.
6. Condition 2 was run at a rate of 18 cycles per minute.
7. Condition 3 was run at a rate of 17 cycles per minute. Temperature was 72 C.

Fatigue

TEST #: **BUTT WELD TORSION TEST - 2B**

FATIGUE USAGE FACTOR EVALUATION ASSUMING Z(IN^3) = 3.215

Condition	S_{nom}= +/- M/Z (ksi)	S_n= 2 C_2 M/Z (ksi)	S_p = 2 K_2C_2M/Z (ksi)	K_e	S_{alt}= K_eS_p/2 (ksi)	$N_{allowable}$	N_{test}	USAGE FACTOR	CUMULATIVE USAGE FACTOR
1	54.58	56.3	101.4	1.00	50.7	88,836	2,329	0.03	0.03
2	81.86	84.5	152.1	1.82	138.25	5,521	2,000	0.36	0.39
3	83.23	85.9	154.7	1.86	144.19	4,999	3,059	0.61	1.00
4	-	-	-	-	-	-	-	0.00	0.00
5	-	-	-	-	-	-	-	0.00	0.00
6	-	-	-	-	-	-	-	0.00	0.00
7	-	-	-	-	-	-	-	0.00	0.00
8	-	-	-	-	-	-	-	0.00	0.00

INDICES & MATERIAL PROPERTY DATA

C_2 =	**0.516**	S_m (ksi) =	20
K_2 =	**1.80**	m =	3.0
$C_2K_2/2$=	0.46	n =	0.2

TOTAL CUMULATIVE USAGE FACTOR = **1.000**

COMMENTS:

1. The fatigue analysis follows the methodology defined in ASME Section III for Class 1 components (ASME Boiler and Pressure Code, Section III, Nuclear Power Plant Components, ASME, New York, 2001). The definition of the various terms are in accordance with NB-3653 except for the design fatigue which is defined as : $N_{allowable} = (8{,}664/(S_{alt}-21.645))^2$ (from Criteria of the ASME Boiler and Pressure Vessel Code for Design by Analysis in Sections III and VIII, Division 2, The American Society of Mechanical Engineers, 1969). If S_{alt} is less than or equal to 21.645, the expression is not valid and the associated usage factor is taken as 0.0.
2. The usage factor is defined as $N_{test}/N_{allowable}$.
3. The Cumulative Usage Factor is the sum of the usage factors for the particular loading condition and the previous ones.

TEST # : **BUTT WELD TORSION TEST - 3** **TYPE:** **FATIGUE - LOAD DEFLECTION CURVE**

F = Fo + m δ, "m" TO BE BASED ON "N" DATA POINTS, N = 3
THE VALUE OF "m" = 4394
Fo (LBS) = 0
NOMINAL STRESS = M/Z KSI, M=F x L, L(IN) = 27.5

Do (IN) = 4.5
t (IN) = 0.237
$Z(IN^3) = \pi r_n^2 t =$ 3.215

POSITIVE LOAD - LOADING CONDITION

DATA POINT #	MEASURED DEFLECTION δ (mm)	MEASURED LOAD F (LBS)	MODIFIED DEFLECTION δ (INCHES)	MODIFIED LOAD F (LBS)	SLOPE FOR START TO DATA POINT (LBS/INCH)	F BASED ON "m" (LBS)	NOMINAL STRESS (KSI)
1	3.530	3	0.000	3	N/A	5	0.0
2	10.000	1091	0.255	1091	4,271	1124	9.6
3	15.000	1990	0.452	1990	4,394	1989	17.0
4	20.000	2848	0.648	2848	4,401	2854	24.4
5	25.000	3680	0.845	3680	4,371	3719	31.8
6	30.000	4470	1.042	4470	4,314	4584	39.2
7	35.000	5025	1.239	5025	4,140	5449	46.6
8	40.000	5280	1.436	5280	3,837	6313	54.0
9	45.000	5470	1.633	5470	3,507	7178	61.4
10	50.000	5620	1.830	5620	3,191	8043	68.8
11	55.000	5750	2.026	5750	2,904	8908	76.2
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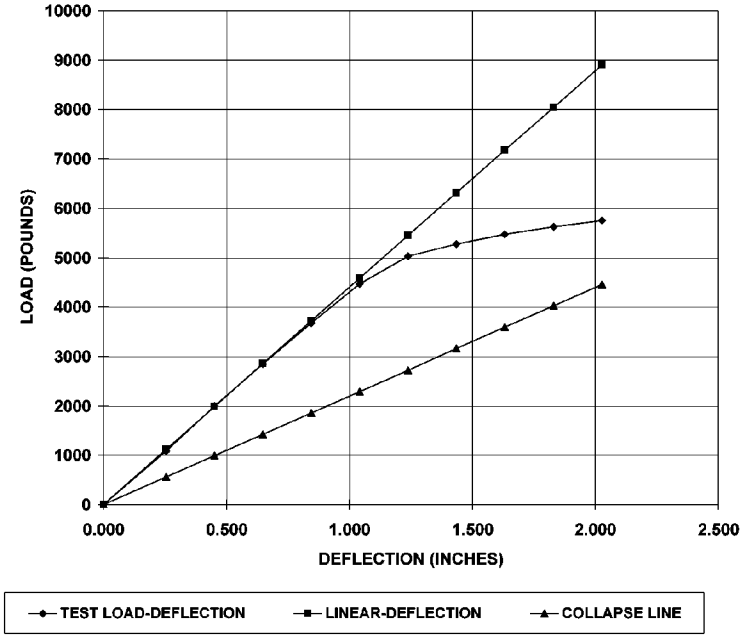

NOTES:
1. Modified data includes deflection and load instrumentation adjustments if required.
2. Loading is in a downward direction. For purposes of the evaluation of the stiffness calculation, the directions of loading (e.g. positive load-loading condition) will remain the same. The sign of the deflection will indicate the load direction.

TEST #: **BUTT WELD TORSION TEST - 3** **TYPE:** **FATIGUE - LOAD DEFLECTION CURVE**

F = Fo + m δ, "m" TO BE BASED ON "N" DATA POINTS, N = 2
THE VALUE OF "m" = 4382
Fo (LBS) = -3250
NOMINAL STRESS = M/Z KSI, M=F x L, L(IN) = 27.5 Z(IN^3) = 3.215

DATA POINT #	MEASURED DEFLECTION δ (mm)	MEASURED LOAD F (LBS)	MODIFIED DEFLECTION δ (INCHES)	MODIFIED LOAD F (LBS)	SLOPE FOR START TO DATA POINT (LBS/INCH)	F BASED ON "m" (LBS)	NOMINAL STRESS (KSI)
1	55.000	5750	2.026	5750	4,474	5629	48.2
2	50.000	4753	1.830	4753	4,382	4767	40.8
3	40.000	2922	1.436	2922	4,237	3041	26.0
4	30.000	1202	1.042	1202	4,023	1316	11.3
5	25.000	382	0.845	382	3,689	454	3.9
6	22.370	0	0.742	0	N/A	0	0.0
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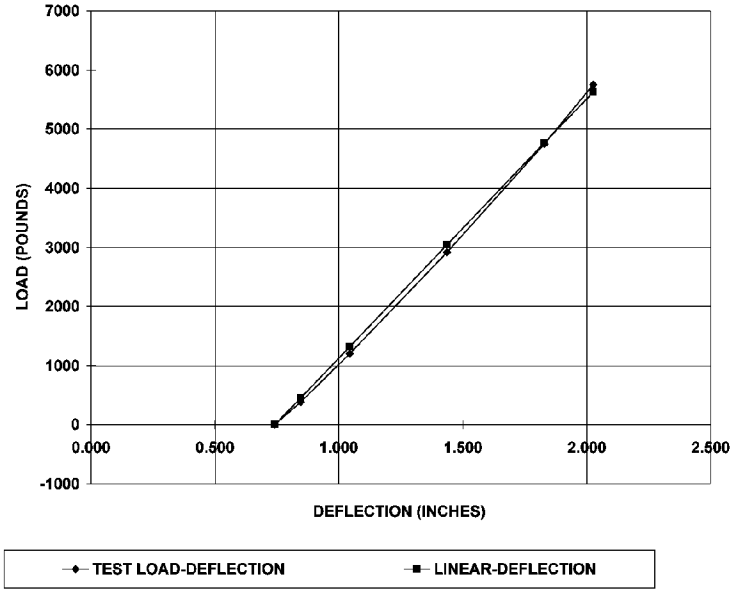
POSITIVE LOAD - UNLOADING CONDITION



NOTES:
1. Modified data includes deflection and load instrumentation adjustments if required.

TEST #: **BUTT WELD TORSION TEST - 3** **TYPE:** **FATIGUE - LOAD DEFLECTION CURVE**

F = Fo + m δ, "m" TO BE BASED ON "N" DATA POINTS, N = 4
THE VALUE OF "m" = 3517
Fo (LBS) = 0

NOMINAL STRESS = M/Z KSI, M=F x L, L(IN) = 27.5 $Z(IN^3)$ = 3.215

DATA POINT #	MEASURED DEFLECTION δ (mm)	MEASURED LOAD F (LBS)	MODIFIED DEFLECTION δ (INCHES)	MODIFIED LOAD F (LBS)	SLOPE FOR START TO DATA POINT (LBS/INCH)	F BASED ON "m" (LBS)	NOMINAL STRESS (KSI)
1	22.370	0	0.742	0	N/A	0	0.0
2	20.000	-338	0.648	-338	3,622	-328	-2.8
3	15.000	-1048	0.452	-1048	3,611	-1021	-8.7
4	10.000	-1710	0.255	-1710	3,517	-1713	-14.7
5	5.000	-2305	0.058	-2305	3,388	-2405	-20.6
6	0.000	-2810	-0.139	-2810	3,225	-3098	-26.5
7	-5.000	-3240	-0.336	-3240	3,050	-3790	-32.4
8	-10.000	-3640	-0.533	-3640	2,891	-4482	-38.3
9	-15.000	-4000	-0.730	-4000	2,744	-5175	-44.3
10	-20.000	-4250	-0.926	-4250	2,588	-5867	-50.2
11	-25.000	-4550	-1.123	-4550	2,454	-6559	-56.1
12	-30.000	-4810	-1.320	-4810	2,333	-7252	-62.0
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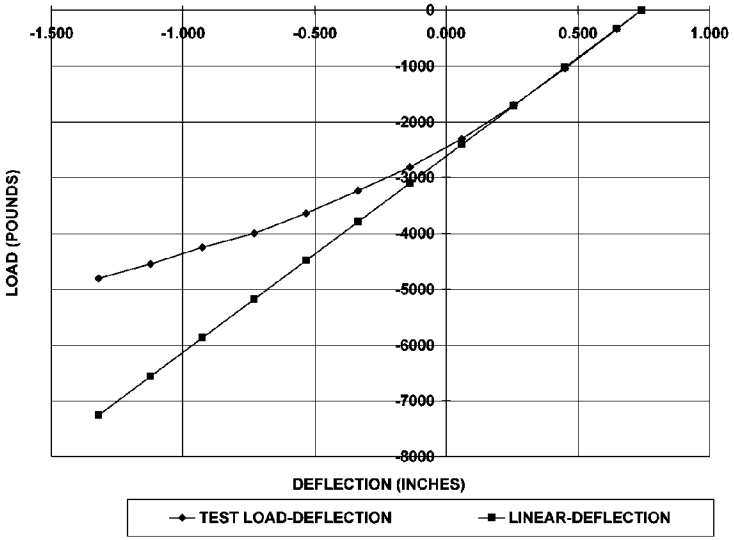
NEGATIVE LOAD - LOADING CONDITION



NOTES:
1. Modified data includes deflection and load instrumentation adjustments if required.

TEST #: **BUTT WELD TORSION TEST - 3** **TYPE:** **FATIGUE - LOAD DEFLECTION CURVE**

F = Fo + m δ, "m" TO BE BASED ON "N" DATA POINTS, N = 3

THE VALUE OF "m" = 4439 Fo (LBS) = 1276

NOMINAL STRESS = M/Z KSI, M=F x L, L(IN) = 27.5 $Z(IN^3)$ = 3.215

NEGATIVE LOAD - UNLOADING CONDITION

DATA POINT #	MEASURED DEFLECTION δ (mm)	MEASURED LOAD F (LBS)	MODIFIED DEFLECTION δ (INCHES)	MODIFIED LOAD F (LBS)	SLOPE FOR START TO DATA POINT (LBS/INCH)	F BASED ON "m" (LBS)	NOMINAL STRESS (KSI)
1	-30.000	-4810	-1.320	-4810	4659	-4584	-39.2
2	-20.000	-2880	-0.926	-2880	4517	-2837	-24.3
3	-15.000	-1950	-0.730	-1950	4439	-1963	-16.8
4	-10.000	-1065	-0.533	-1065	4386	-1089	-9.3
5	-5.000	-180	-0.336	-180	3717	-215	-1.8
6	-3.770	0	-0.287	0	N/A	0	0.0
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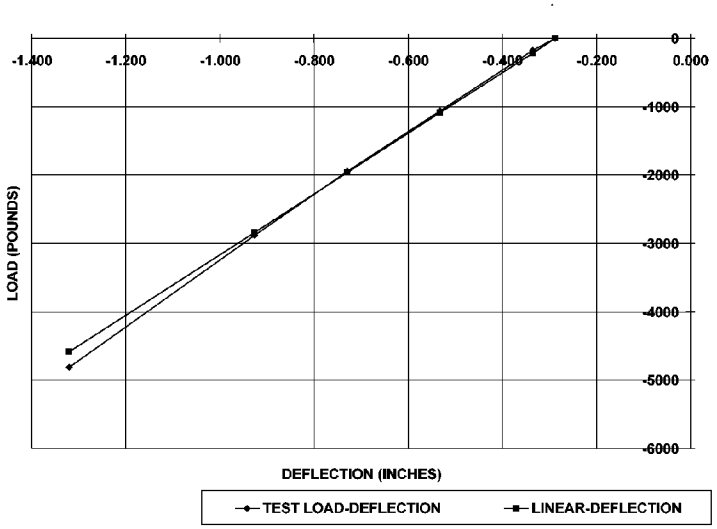
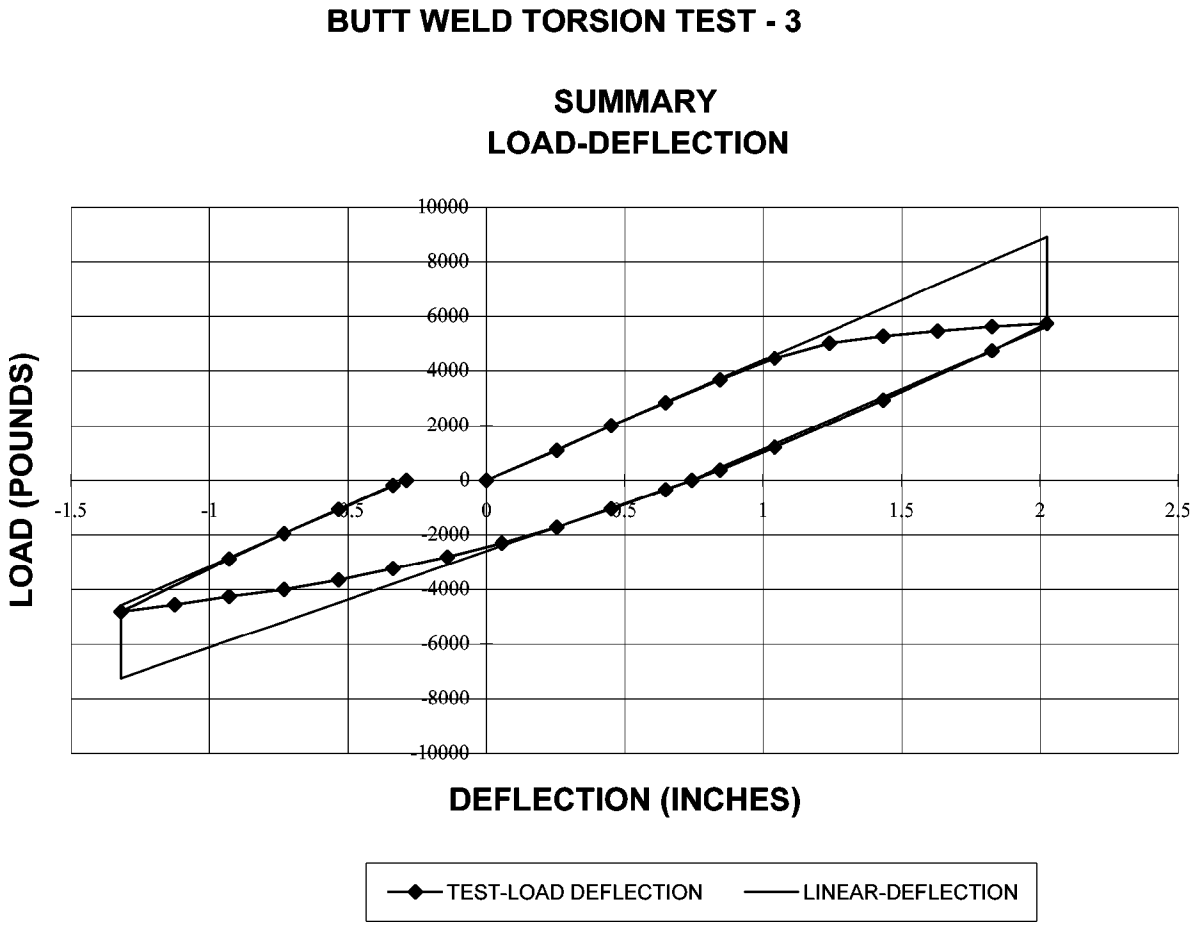


NOTES:


BUTT WELD TORSION TEST - 3
SUMMARY
LOAD-DEFLECTION
LOAD (POUNDS)
10000
8000
6000
4000
2000
0
-2000
-4000
-6000
-8000
-10000
-1.5
-1
-0.5
0
0.5
1
1.5
2
2.5
DEFLECTION (INCHES)
TEST-LOAD DEFLECTION
LINEAR-DEFLECTION

TEST #: **BUTT WELD TORSION TEST - 3**

FATIGUE TEST DATA ANALYSIS

Do (IN) = 4.5 MOMENT ARM (IN)= L = 27.5
t (IN) = 0.237 AVERAGE STIFFNESS (LBS/IN) = 4183
AVERAGE STIFFNESS (LBS/IN) (TEST 1)= 3794

TEST DISPLACEMENT/CYCLE DATA:

CONDITION #	DISPLACEMENT AMPLITUDE (+/-) (mm.) δ_i	DISPLACEMENT AMPLITUDE (+/-) (in.) δ_i	EFFECTIVE APPLIED LOAD (LBS)	NOMINAL STRESS (+/-) (PSI) S	NUMBER OF TEST CYCLES N_i
1	50.0	1.969	8234	70,434	1,500
2	67.3	2.650	11083	94,804	1,000
3	77.5	3.051	12763	109,173	999
4		0.000	-	-	0
5		0.000	-	-	0
6		0.000	-	-	0
7		0.000	-	-	0
8		0.000	-	-	0
				TOTAL CYCLES:	3,499

FOR THE MAXIMUM DISPLACEMENT, δ_{max} (IN) = 3.051 THE EQUIVALENT NUMBER
OF CYCLES USING $N_{eq} = \Sigma(\delta_i/\delta_{max})^5 * N_i$ IS = 1,660

FOR Z(IN^3) = 3.215
$i = 245{,}000 * Neq^{(-0.2)}/S$ = **0.509**

COMMENTS:

1. Failure point was at the fixed end on the pipe side of the weld at 3:00.
2. L is distance from load point to center of pipe.
3. It is assumed that the stresses are calculated by M / Z.
4. Condition 1 was run at a rate of 21 cycles per minute. Condition 2 at 16 cycles per minute. Condition 3 at 13 cycles per minute.
5. Initial temperature was 23°C. Maximum tempertature was 75°C.

Fatigue

TEST #: **BUTT WELD TORSION TEST - 3**

1. FATIGUE USAGE FACTOR EVALUATION ASSUMING Z = 3.215

Condition	S_{nom}= +/- M/Z (ksi)	S_n= 2 C_2 M/Z (ksi)	S_p = 2 K_2C_2M/Z (ksi)	K_e	S_{alt}= K_eS_p/2 (ksi)	$N_{allowable}$	N_{test}	USAGE FACTOR	CUMULATIVE USAGE FACTOR
1	70.43	68.3	122.9	1.28	78.5	23,260	1,500	0.06	0.06
2	94.80	91.9	165.5	2.06	170.76	3,376	1,000	0.30	0.36
3	109.17	105.9	190.5	2.53	240.88	1,562	999	0.64	1.00
4	-	-	-	-	-	-	-	0.00	0.00
5	-	-	-	-	-	-	-	0.00	0.00
6	-	-	-	-	-	-	-	0.00	0.00
7	-	-	-	-	-	-	-	0.00	0.00
8	-	-	-	-	-	-	-	0.00	0.00

INDICES & MATERIAL PROPERTY DATA

C_2 =	**0.485**	S_m (ksi) =	20
K_2 =	**1.80**	m =	3.0
$C_2K_2/2$=	0.44	n =	0.2

TOTAL CUMULATIVE USAGE FACTOR = **1.000**

COMMENTS:

1. The fatigue analysis follows the methodology defined in ASME Section III for Class 1 components (ASME Boiler and Pressure Code, Section III, Nuclear Power Plant Components, ASME, New York, 2001). The definition of the various terms are in accordance with NB-3653 except for the design fatigue which is defined as : $N_{allowable} = (8{,}664/(S_{alt}-21.645))^2$ (from Criteria of the ASME Boiler and Pressure Vessel Code for Design by Analysis in Sections III and VIII, Division 2, The American Society of Mechanical Engineers, 1969). If S_{alt} is less than or equal to 21.645, the expression is not valid and the associated usage factor is taken as 0.0.
2. The usage factor is defined as $N_{test}/N_{allowable}$.
3. The Cumulative Usage Factor is the sum of the usage factors for the particular loading condition and the previous ones.

TEST # : **BUTT WELD TORSION TEST - 4** **TYPE:** **FATIGUE - LOAD DEFLECTION CURVE**

F = Fo + m δ, "m" TO BE BASED ON "N" DATA POINTS, N = 3
THE VALUE OF "m" = 4662
Fo (LBS) = 0
NOMINAL STRESS = M/Z KSI, M=F x L, L(IN) = 27.5

Do (IN) = 4.5
t (IN) = 0.237
$Z(IN^3)$ = 3.215

POSITIVE LOAD - LOADING CONDITION

DATA POINT #	MEASURED DEFLECTION δ (mm)	MEASURED LOAD F (LBS)	MODIFIED DEFLECTION δ (INCHES)	MODIFIED LOAD F (LBS)	SLOPE FOR START TO DATA POINT (LBS/INCH)	F BASED ON "m" (LBS)	NOMINAL STRESS (KSI)
1	0.720	2	0.000	2	N/A	5	0.0
2	10.000	1706	0.365	1706	4,664	1708	14.6
3	15.000	2623	0.562	2623	4,662	2626	22.5
4	20.000	3565	0.759	3565	4,688	3543	30.3
5	25.000	4510	0.956	4510	4,713	4461	38.2
6	30.000	5340	1.153	5340	4,663	5379	46.0
7	35.000	5560	1.350	5560	4,315	6297	53.9
8	40.000	5580	1.546	5580	3,843	7214	61.7
9	45.000	5620	1.743	5620	3,388	8132	69.6
10	50.000	5650	1.940	5650	2,983	9050	77.4
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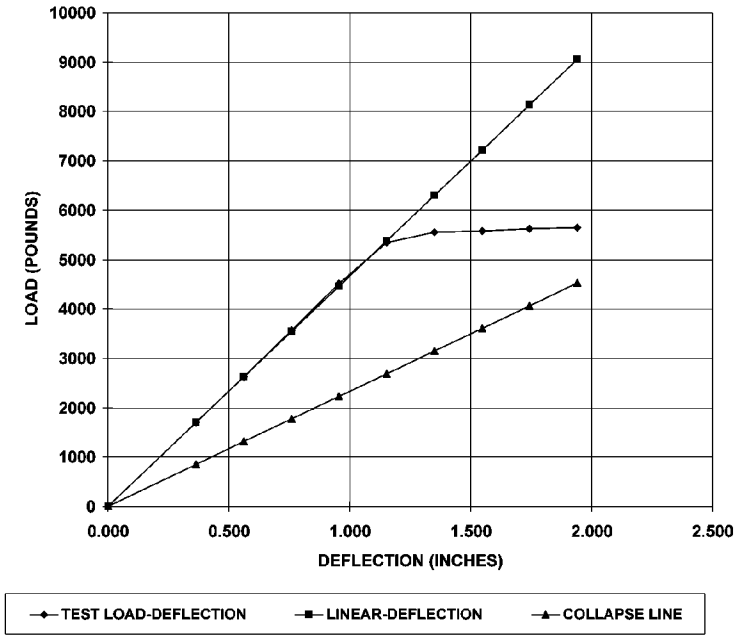

NOTES:
1. Modified data include deflection and load instrumentation adjustments if required.
2. Loading is in a downward direction. For purposes of the evaluation of the stiffness calculation, the directions of loading (e.g. positive load-loading condition) will remain the same. The sign of the deflection will indicate the load direction.

TEST #: **BUTT WELD TORSION TEST - 4** **TYPE:** **FATIGUE - LOAD DEFLECTION CURVE**

F = Fo + m δ, "m" TO BE BASED ON "N" DATA POINTS, N = 2
THE VALUE OF "m" = 4554
Fo (LBS) = -3369
NOMINAL STRESS = M/Z KSI, M=F x L, L(IN) = 27.5 Z(IN^3) = 3.215

DATA POINT #	MEASURED DEFLECTION δ (mm)	MEASURED LOAD F (LBS)	MODIFIED DEFLECTION δ (INCHES)	MODIFIED LOAD F (LBS)	SLOPE FOR START TO DATA POINT (LBS/INCH)	F BASED ON "m" (LBS)	NOMINAL STRESS (KSI)
1	50.000	5650	1.940	5650	4,694	5467	46.8
2	40.000	3670	1.546	3670	4,554	3674	31.4
3	30.000	1825	1.153	1825	4,427	1881	16.1
4	25.000	932	0.956	932	4,339	984	8.4
5	20.000	70	0.759	70	3,629	88	0.8
6	19.510	0	0.740	0	N/A	0	0.0
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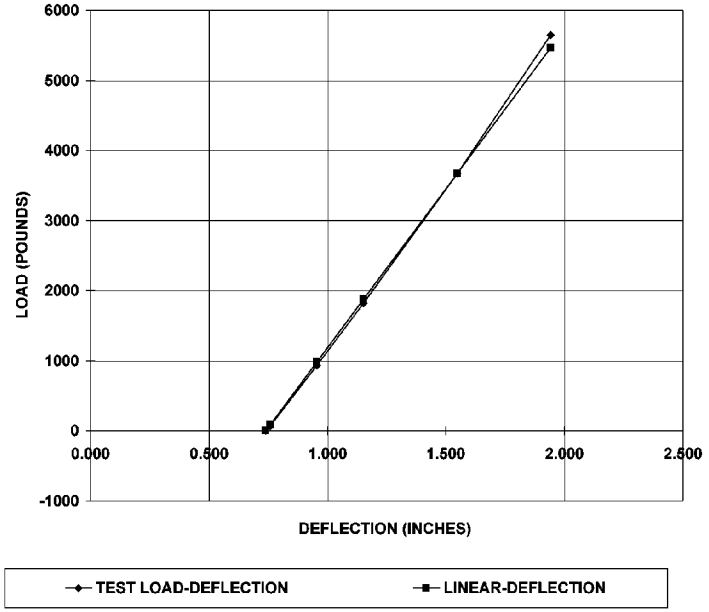
POSITIVE LOAD - UNLOADING CONDITION



NOTES:
1. Modified data include deflection and load instrumentation adjustments if required.

TEST #: **BUTT WELD TORSION TEST - 4** **TYPE:** **FATIGUE - LOAD DEFLECTION CURVE**

F = Fo + m δ, "m" TO BE BASED ON "N" DATA POINTS, N = 4
THE VALUE OF "m" = 4053
Fo (LBS) = 0

NOMINAL STRESS = M/Z KSI, M=F x L, L(IN) = 27.5 $Z(IN^3)$ = 3.215

NEGATIVE LOAD - LOADING CONDITION

DATA POINT #	MEASURED DEFLECTION δ (mm)	MEASURED LOAD F (LBS)	MODIFIED DEFLECTION δ (INCHES)	MODIFIED LOAD F (LBS)	SLOPE FOR START TO DATA POINT (LBS/INCH)	F BASED ON "m" (LBS)	NOMINAL STRESS (KSI)
1	19.510	0	0.740	0	N/A	0	0.0
2	15.000	-713	0.562	-713	4,016	-720	-6.2
3	10.000	-1535	0.365	-1535	4,101	-1517	-13.0
4	5.000	-2307	0.169	-2307	4,053	-2315	-19.8
5	0.000	-2990	-0.028	-2990	3,923	-3113	-26.6
6	-5.000	-3590	-0.225	-3590	3,760	-3911	-33.4
7	-10.000	-4120	-0.422	-4120	3,586	-4708	-40.3
8	-15.000	-4580	-0.619	-4580	3,409	-5506	-47.1
9	-20.000	-5000	-0.816	-5000	3,241	-6304	-53.9
10	-25.000	-5355	-1.013	-5355	3,077	-7101	-60.7
11	-30.000	-5630	-1.209	-5630	2,911	-7899	-67.6
12	-35.000	-5710	-1.406	-5710	2,718	-8697	-74.4
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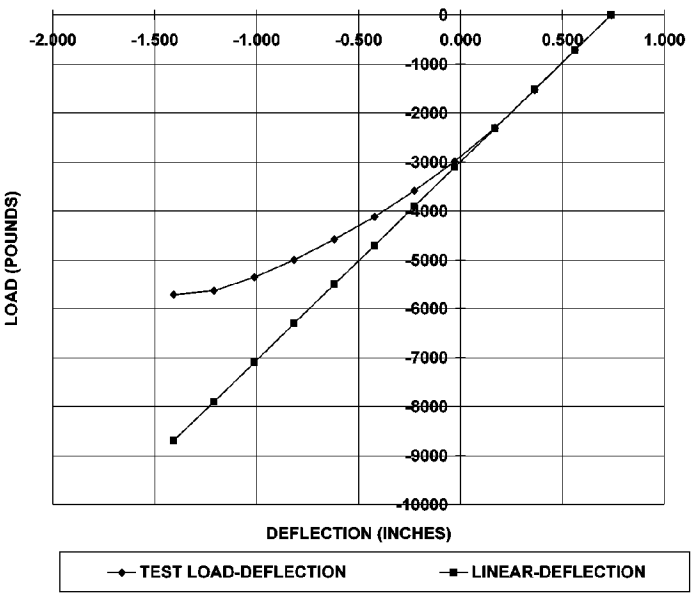

NOTES:
1. Modified data include deflection and load instrumentation adjustments if required.

TEST #: **BUTT WELD TORSION TEST - 4** **TYPE:** **FATIGUE - LOAD DEFLECTION CURVE**

F = Fo + m δ, "m" TO BE BASED ON "N" DATA POINTS, N = 3
THE VALUE OF "m" = 4663 Fo (LBS) = 942

NOMINAL STRESS = M/Z KSI, M=F x L, L(IN) = 27.5 $Z(IN^3)$ = 3.215

NEGATIVE LOAD - UNLOADING CONDITION

DATA POINT #	MEASURED DEFLECTION δ (mm)	MEASURED LOAD F (LBS)	MODIFIED DEFLECTION δ (INCHES)	MODIFIED LOAD F (LBS)	SLOPE FOR START TO DATA POINT (LBS/INCH)	F BASED ON "m" (LBS)	NOMINAL STRESS (KSI)
1	-35.000	-5710	-1.406	-5710	4747	-5616	-48.0
2	-30.000	-4713	-1.209	-4713	4700	-4698	-40.2
3	-25.000	-3760	-1.013	-3760	4663	-3780	-32.3
4	-20.000	-2813	-0.816	-2813	4616	-2862	-24.5
5	-15.000	-1882	-0.619	-1882	4554	-1944	-16.6
6	-10.000	-950	-0.422	-950	4404	-1026	-8.8
7	-5.000	-56	-0.225	-56	2411	-108	-0.9
8	-4.410	0	-0.202	0	N/A	0	0.0
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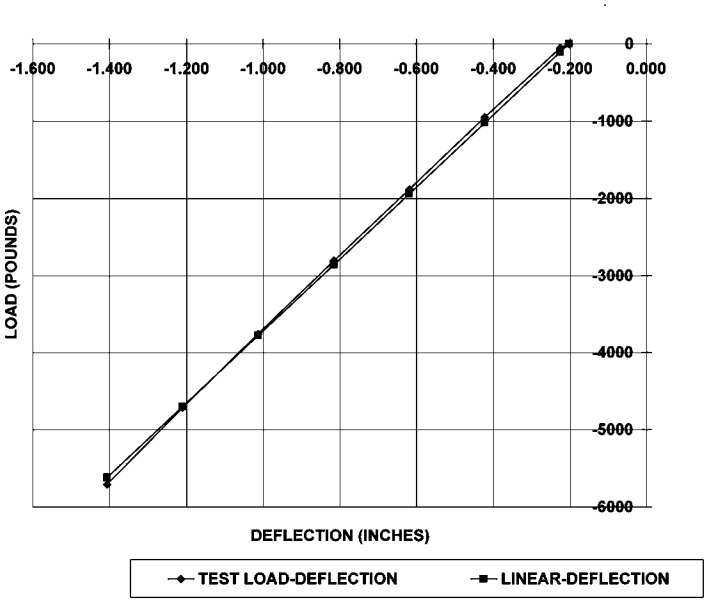
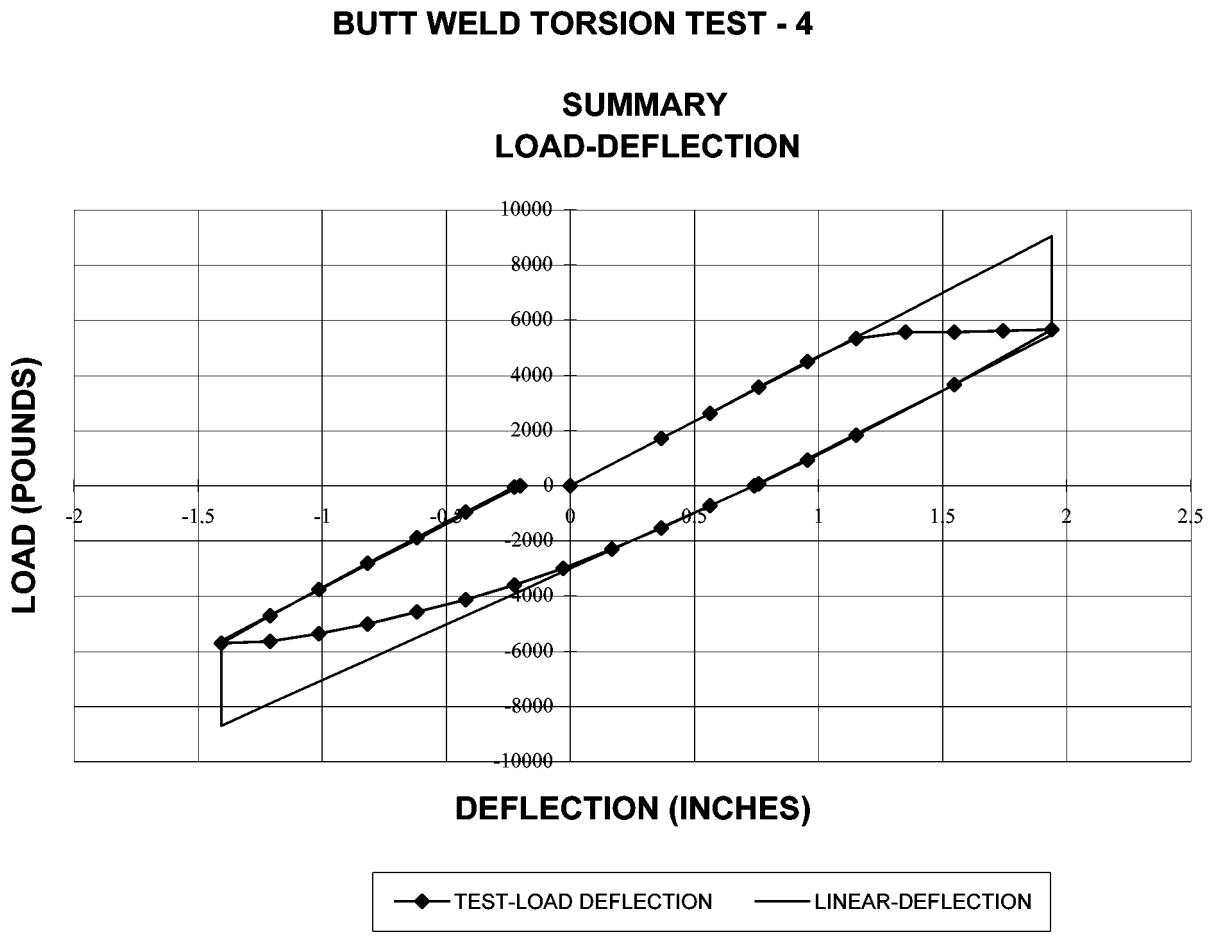


NOTES:


BUTT WELD TORSION TEST - 4
SUMMARY
LOAD-DEFLECTION
LOAD (POUNDS)
10000
8000
6000
4000
2000
0
-2000
-4000
-6000
-8000
-10000
-2
-1.5
-1
-0.5
0
0.5
1
1.5
2
2.5
DEFLECTION (INCHES)
TEST-LOAD DEFLECTION
LINEAR-DEFLECTION

TEST #: **BUTT WELD TORSION TEST - 4**

FATIGUE TEST DATA ANALYSIS

Do (IN) = 4.5 MOMENT ARM (IN)= L = 27.5
t (IN) = 0.237 AVERAGE STIFFNESS (LBS/IN) = 4483
AVERAGE STIFFNESS (LBS/IN) (TEST 1)= 3794

TEST DISPLACEMENT/CYCLE DATA:

CONDITION #	DISPLACEMENT AMPLITUDE (+/-) (mm.) δ_i	DISPLACEMENT AMPLITUDE (+/-) (in.) δ_i	EFFECTIVE APPLIED LOAD (LBS)	NOMINAL STRESS (+/-) (PSI) S	NUMBER OF TEST CYCLES N_i
1	72.1	2.839	12725	108,848	2,242
2		0.000	-	-	0
3		0.000	-	-	0
4		0.000	-	-	0
5		0.000	-	-	0
6		0.000	-	-	0
7		0.000	-	-	0
8		0.000	-	-	0
				TOTAL CYCLES:	2,242

FOR THE MAXIMUM DISPLACEMENT, δ_{max} (IN) = 2.839 THE EQUIVALENT NUMBER
OF CYCLES USING $N_{eq} = \Sigma(\delta_i/\delta_{max})^5 * N_i$ IS = 2,242

For $Z(IN^3)$ = 3.215

$i = 245{,}000 * Neq^{(-0.2)}/S =$ **0.481**

COMMENTS:

1. Failure point was at the fixed end at the weld on the pipe side at 3:00.
2. L is distance from load point to center of pipe.
3. It is assumed that the stresses are calculated by M / Z.
4. Condition 1 was run at a rate of 13 cycles per minute.
5. Initial temperature was 26°C. Maximum tempertature was 72°C.

Fatigue

TEST #: **BUTT WELD TORSION TEST - 4**

1. FATIGUE USAGE FACTOR EVALUATION ASSUMING Z (IN^3) = 3.215

Condition	S_{nom}= +/- M/Z (ksi)	S_n= 2 C_2 M/Z (ksi)	S_p = 2 K_2C_2M/Z (ksi)	K_e	S_{alt}= K_eS_p/2 (ksi)	$N_{allowable}$	N_{test}	USAGE FACTOR	CUMULATIVE USAGE FACTOR
1	108.85	98.9	178.1	2.30	204.6	2,242	2,242	1.00	1.00
2	-	-	-	-	-	-	-	0.00	0.00
3	-	-	-	-	-	-	-	0.00	0.00
4	-	-	-	-	-	-	-	0.00	0.00
5	-	-	-	-	-	-	-	0.00	0.00
6	-	-	-	-	-	-	-	0.00	0.00
7	-	-	-	-	-	-	-	0.00	0.00
8	-	-	-	-	-	-	-	0.00	0.00

INDICES & MATERIAL PROPERTY DATA

C_2 =	**0.454**	S_m (ksi) =	20
K_2 =	**1.80**	m =	3.0
$C_2K_2/2$=	0.41	n =	0.2

TOTAL CUMULATIVE USAGE FACTOR = **1.000**

COMMENTS:

1. The fatigue analysis follows the methodology defined in ASME Section III for Class 1 components (ASME Boiler and Pressu Code, Section III, Nuclear Power Plant Components, ASME, New York, 2001). The definitions of the various terms are in accordance with NB-3653 except for the design fatigue which is defined as : $N_{allowable} = (8{,}664/(S_{alt}-21.645))^2$ (from Criteria of the ASME Boiler and Pressure Vessel Code for Design by Analysis in Sections III and VIII, Division 2, The American Society of Mechanical Engineers, 1969). If S_{alt} is less than or equal to 21.645, the expression is not valid and the associated usage factor is taken as 0.0.
2. The usage factor is defined as $N_{test}/N_{allowable}$.
3. The Cumulative Usage Factor is the sum of the usage factors for the particular loading condition and the previous ones.

TEST # : **BUTT WELD BENDING TEST - 5** **TYPE:** **FATIGUE - LOAD DEFLECTION CURVE**

F = Fo + m δ, "m" TO BE BASED ON "N" DATA POINTS, N = 8
THE VALUE OF "m" = 5929 Do (IN) = 4.5
Fo (LBS) = 0 t (IN) = 0.237
NOMINAL STRESS = M/Z KSI, M=F x L, L(IN) = 39.375 $Z(IN^3)$ = 3.215

POSITIVE LOAD - LOADING CONDITION

DATA POINT #	MEASURED DEFLECTION δ (mm)	MEASURED LOAD F (LBS)	MODIFIED DEFLECTION δ (INCHES)	MODIFIED LOAD F (LBS)	SLOPE FOR START TO DATA POINT (LBS/INCH)	F BASED ON "m" (LBS)	NOMINAL STRESS (KSI)
1	-0.870	3	0.000	3	N/A	5	0.1
2	0.290	283	0.046	283	6,131	275	3.4
3	1.260	514	0.084	514	6,095	502	6.1
4	2.240	746	0.122	746	6,068	730	8.9
5	3.400	1015	0.168	1015	6,022	1001	12.3
6	4.500	1268	0.211	1268	5,982	1258	15.4
7	5.510	1501	0.251	1501	5,956	1494	18.3
8	6.620	1753	0.295	1753	5,929	1753	21.5
9	7.660	1992	0.336	1992	5,910	1996	24.4
10	8.840	2257	0.382	2257	5,888	2271	27.8
11	9.940	2503	0.426	2503	5,866	2528	31.0
12	11.030	2744	0.469	2744	5,844	2782	34.1
13	12.140	2990	0.512	2990	5,824	3041	37.2
14	13.530	3291	0.567	3291	5,798	3366	41.2
15	15.450	3694	0.643	3694	5,759	3814	46.7
16	16.960	3993	0.702	3993	5,712	4166	51.0
17	17.860	4189	0.737	4189	5,680	4376	53.6
18	19.980	4608	0.821	4608	5,634	4871	59.7
19	21.810	4819	0.893	4819	5,531	5298	64.9
20	24.030	4947	0.980	4947	5,341	5816	71.2
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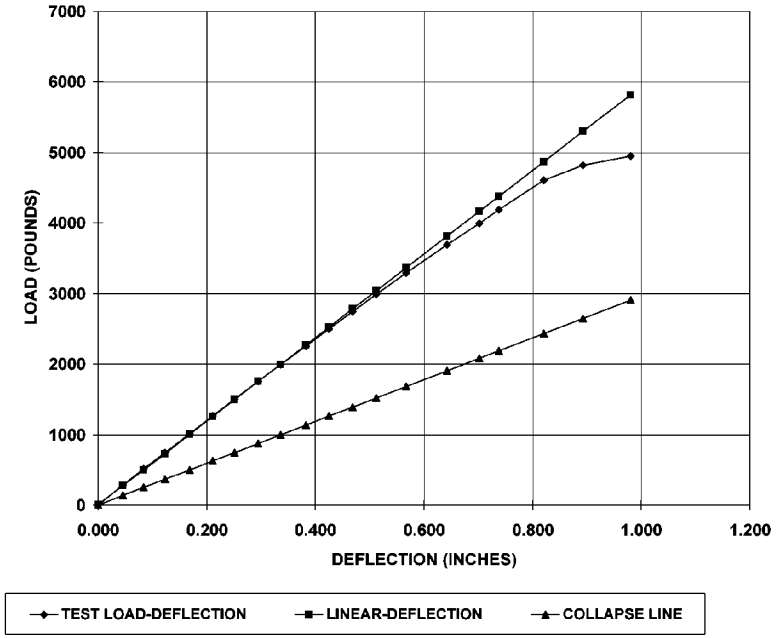

NOTES:
1. Modified data includes deflection and load instrumentation adjustments if required.
2. Loading is in a downward direction. For purposes of the evaluation of the stiffness calculation, the directions of loading (e.g. positive load-loading condition) will remain the same. The sign of the deflection will indicate the load direction.

TEST #: **BUTT WELD BENDING TEST - 5** **TYPE:** **FATIGUE - LOAD DEFLECTION CURVE**

F = Fo + m δ, "m" TO BE BASED ON "N" DATA POINTS, N = 6
THE VALUE OF "m" = 5810
Fo (LBS) = -894
NOMINAL STRESS = M/Z KSI, M=F x L, L(IN) = 39.375 Z(IN^3) = 3.215

DATA POINT #	MEASURED DEFLECTION δ (mm)	MEASURED LOAD F (LBS)	MODIFIED DEFLECTION δ (INCHES)	MODIFIED LOAD F (LBS)	SLOPE FOR START TO DATA POINT (LBS/INCH)	F BASED ON "m" (LBS)	NOMINAL STRESS (KSI)
1	24.030	4947	0.980	4947	5,953	4802	58.8
2	21.980	4428	0.900	4428	5,912	4333	53.1
3	19.980	3938	0.821	3938	5,879	3875	47.5
4	17.980	3454	0.742	3454	5,850	3418	41.9
5	16.020	2993	0.665	2993	5,831	2970	36.4
6	14.010	2525	0.586	2525	5,810	2510	30.7
7	12.030	2064	0.508	2064	5,784	2057	25.2
8	9.970	1588	0.427	1588	5,752	1586	19.4
9	7.970	1127	0.348	1127	5,710	1128	13.8
10	5.970	671	0.269	671	5,662	671	8.2
11	2.960	0	0.151	0	N/A	-18	-0.2
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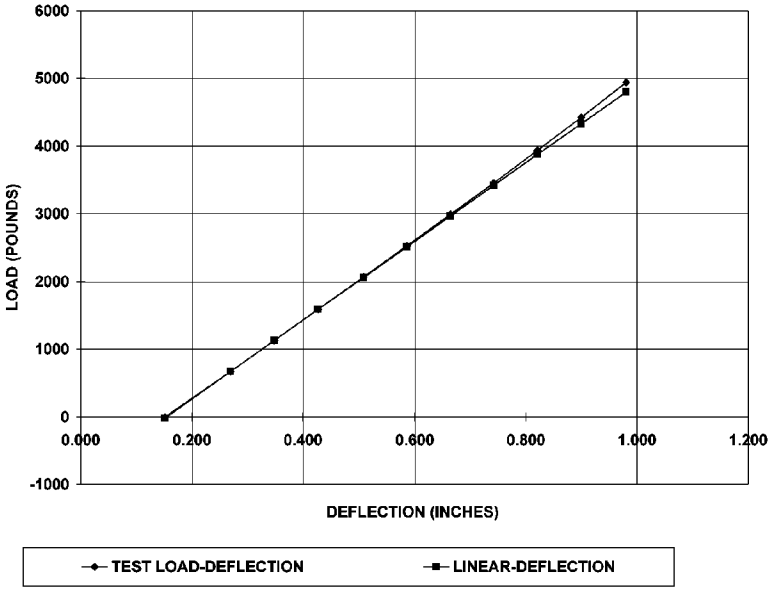
POSITIVE LOAD - UNLOADING CONDITION



NOTES:
1. Modified data includes deflection and load instrumentation adjustments if required.

TEST #: **BUTT WELD BENDING TEST - 5** **TYPE:** **FATIGUE - LOAD DEFLECTION CURVE**

F = Fo + m δ, "m" TO BE BASED ON "N" DATA POINTS, N = 3 1.215

THE VALUE OF "m" = 5160

Fo (LBS) = 0

NOMINAL STRESS = M/Z KSI, M=F x L, L(IN) = 39.375 Z(IN^3) = 3.215

NEGATIVE LOAD - LOADING CONDITION

DATA POINT #	MEASURED DEFLECTION δ (mm)	MEASURED LOAD F (LBS)	MODIFIED DEFLECTION δ (INCHES)	MODIFIED LOAD F (LBS)	SLOPE FOR START TO DATA POINT (LBS/INCH)	F BASED ON "m" (LBS)	NOMINAL STRESS (KSI)
1	2.960	0	0.151	0	N/A	0	0.0
2	-1.010	-782	-0.006	-782	5,003	-807	-9.9
3	-3.000	-1217	-0.084	-1217	5,160	-1211	-14.8
4	-5.030	-1653	-0.164	-1653	5,252	-1623	-19.9
5	-7.010	-2064	-0.242	-2064	5,282	-2026	-24.8
6	-9.090	-2492	-0.324	-2492	5,286	-2448	-30.0
7	-11.000	-2880	-0.399	-2880	5,277	-2836	-34.7
8	-13.030	-3277	-0.479	-3277	5,250	-3249	-39.8
9	-15.110	-3670	-0.561	-3670	5,208	-3671	-45.0
10	-17.140	-4042	-0.641	-4042	5,158	-4084	-50.0
11	-19.070	-4372	-0.717	-4372	5,097	-4476	-54.8
12	-21.080	-4660	-0.796	-4660	5,008	-4884	-59.8
13	-22.990	-4890	-0.871	-4890	4,896	-5272	-64.6
14	-25.040	-5087	-0.952	-5087	4,755	-5689	-69.7
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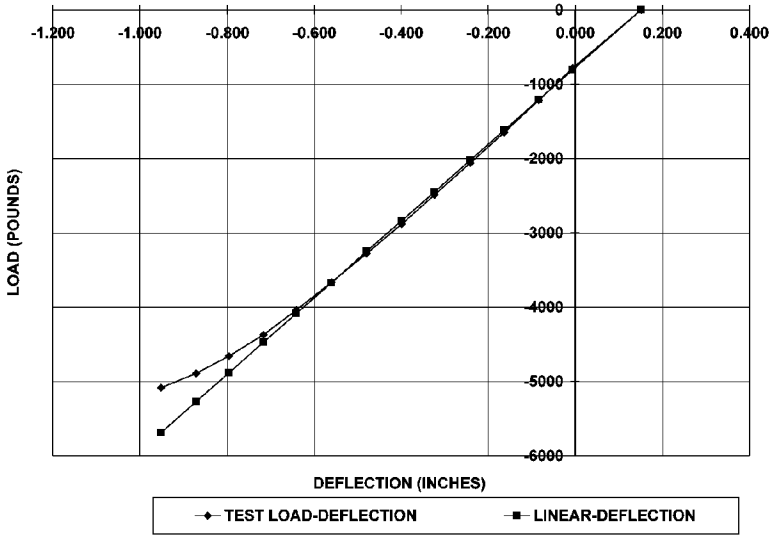

NOTES:

1. Modified data includes deflection and load instrumentation adjustments if required.

TEST #: **BUTT WELD BENDING TEST - 5** **TYPE:** **FATIGUE - LOAD DEFLECTION CURVE**

F = Fo + m δ, "m" TO BE BASED ON "N" DATA POINTS, N = 3

THE VALUE OF "m" = 5618 Fo (LBS) = 500

NEGATIVE LOAD - UNLOADING CONDITIO

NOMINAL STRESS = M/Z KSI, M=F x L, L(IN) = 39.375 $Z(IN^3)$ = 3.215

DATA POINT #	MEASURED DEFLECTION δ (mm)	MEASURED LOAD F (LBS)	MODIFIED DEFLECTION δ (INCHES)	MODIFIED LOAD F (LBS)	SLOPE FOR START TO DATA POINT (LBS/INCH)	F BASED ON "m" (LBS)	NOMINAL STRESS (KSI)
1	-25.040	-5087	-0.952	-5087	5713	-4846	-59.3
2	-20.930	-3945	-0.790	-3945	5557	-3937	-48.2
3	-16.960	-3154	-0.633	-3154	5618	-3059	-37.5
4	-12.910	-2226	-0.474	-2226	5519	-2163	-26.5
5	-9.030	-1343	-0.321	-1343	5334	-1305	-16.0
6	-4.980	-443	-0.162	-443	4708	-409	-5.0
7	-2.590	0	-0.068	0	N/A	120	1.5
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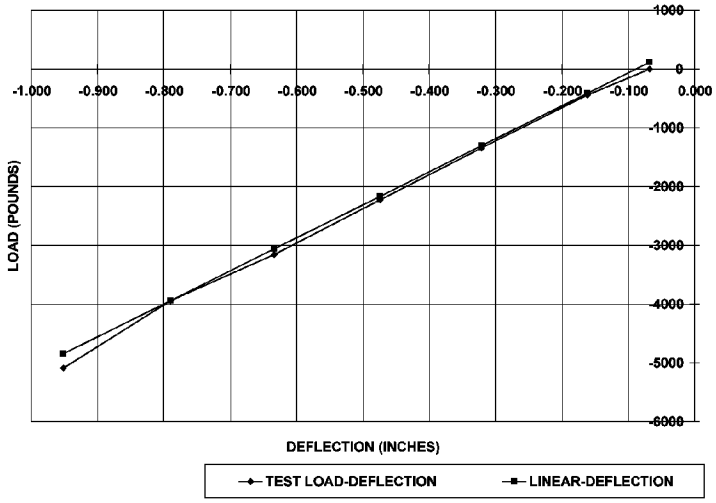
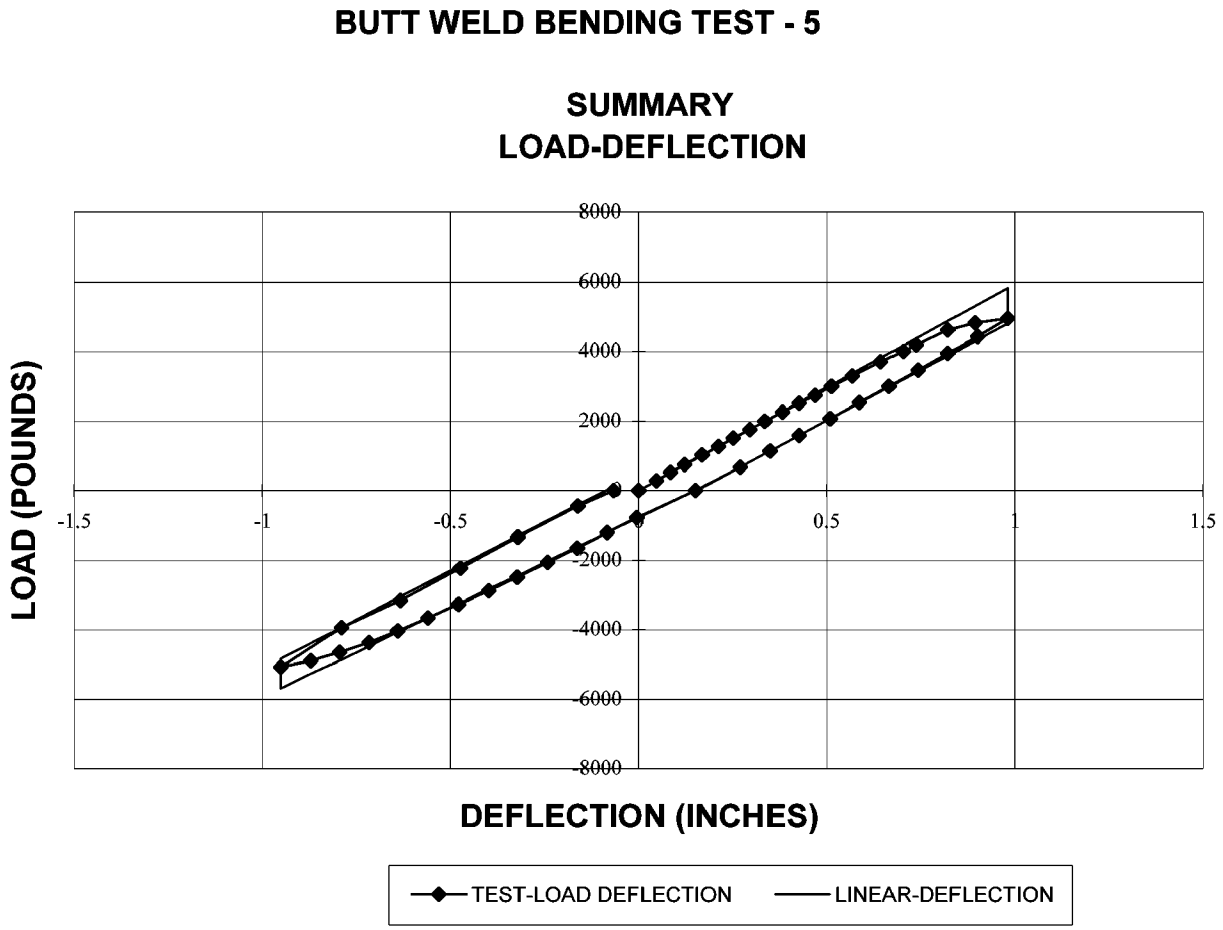


NOTES:


BUTT WELD BENDING TEST - 5
SUMMARY
LOAD-DEFLECTION
LOAD (POUNDS)
8000
6000
4000
2000
-2000
-4000
-6000
-8000
-1.5
-1
-0.5
0
0.5
1
1.5
DEFLECTION (INCHES)
TEST-LOAD DEFLECTION
LINEAR-DEFLECTION

TEST #: **BUTT WELD BENDING TEST - 5**

FATIGUE TEST DATA ANALYSIS

Do (IN) = 4.5 MOMENT ARM (IN)= L = 39.375
t (IN) = 0.237 AVERAGE STIFFNESS (LBS/IN) = 5629
AVERAGE STIFFNESS (LBS/IN) (TEST 1)= 3794

TEST DISPLACEMENT/CYCLE DATA:

CONDITION #	DISPLACEMENT AMPLITUDE (+/-) (mm.) δ_i	DISPLACEMENT AMPLITUDE (+/-) (in.) δ_i	EFFECTIVE APPLIED LOAD (LBS)	NOMINAL STRESS (+/-) (PSI) S	NUMBER OF TEST CYCLES N_i
1	20.0	0.787	4433	54,286	2,321
2		0.000	-	-	0
3		0.000	-	-	0
4		0.000	-	-	0
5		0.000	-	-	0
6		0.000	-	-	0
7		0.000	-	-	0
8		0.000	-	-	0
				TOTAL CYCLES:	2,321

FOR THE MAXIMUM DISPLACEMENT, δ_{max} (IN) = 0.787 THE EQUIVALENT NUMBER
OF CYCLES USING $N_{eq} = \Sigma(\delta_i/\delta_{max})^5 * N_i$ IS = 2,321

FOR $Z(N^3)$ = 3.215
$i = 245{,}000 * Neq^{(-0.2)}/S$ = **0.958**

COMMENTS:

1. Failure point was at the weld at fixed end of the pipe.
2. L is distance from load point to failure point.
3. It is assumed that the stresses are calculated by M / Z.
4. Condition 1 was run at a rate of 45 cycles per minute.
5. Cracks started on top at about 2000 cycles.
6. Water leaked at about 2300 cycles.

Fatigue

TEST #: **BUTT WELD BENDING TEST - 5**

1. FATIGUE USAGE FACTOR EVALUATION ASSUMING Z = 3.215

Condition	S_{nom}= +/- M/Z (ksi)	S_n= 2 C_2 M/Z (ksi)	S_p = 2 K_2C_2M/Z (ksi)	K_e	S_{alt}= K_eS_p/2 (ksi)	$N_{allowable}$	N_{test}	USAGE FACTOR	CUMULATIVE USAGE FACTOR
1	54.29	98.3	177.0	2.28	201.5	2,321	2,321	1.00	1.00
2	-	-	-	-	-	-	-	0.00	0.00
3	-	-	-	-	-	-	-	0.00	0.00
4	-	-	-	-	-	-	-	0.00	0.00
5	-	-	-	-	-	-	-	0.00	0.00
6	-	-	-	-	-	-	-	0.00	0.00
7	-	-	-	-	-	-	-	0.00	0.00
8	-	-	-	-	-	-	-	0.00	0.00

INDICES & MATERIAL PROPERTY DATA

C_2 =	**0.906**	S_m (ksi) =	20
K_2 =	**1.80**	m =	3.0
$C_2K_2/2$=	0.81	n =	0.2

TOTAL CUMULATIVE USAGE FACTOR = **1.000**

COMMENTS:

1. The fatigue analysis follows the methodology defined in ASME Section III for Class 1 components (ASME Boiler and Pressure Code, Section III, Nuclear Power Plant Components, ASME, New York, 2001). The definition of the various terms are in accordance with NB-3653 except for the design fatigue which is defined as : $N_{allowable} = (8{,}664/(S_{alt}-21.645))^2$ (from Criteria of the ASME Boiler and Pressure Vessel Code for Design by Analysis in Sections III and VIII, Division 2, The American Society of Mechanical Engineers, 1969). If S_{alt} is less than or equal to 21.645, the expression is not valid and the associated usage factor is taken as 0.0.
2. The usage factor is defined as $N_{test}/N_{allowable}$.
3. The Cumulative Usage Factor is the sum of the usage factors for the particular loading condition and the previous ones.

TEST # : **BUTT WELD BENDING TEST - 6** **TYPE:** **FATIGUE - LOAD DEFLECTION CURVE**

F = Fo + m δ, "m" TO BE BASED ON "N" DATA POINTS, N = 8
THE VALUE OF "m" = 5804 Do (IN) = 4.5
Fo (LBS) = 0 t (IN) = 0.237
NOMINAL STRESS = M/Z KSI, M=F x L, L(IN) = 39.375 $Z(IN^3)$ = 3.215

POSITIVE LOAD - LOADING CONDITION

DATA POINT #	MEASURED DEFLECTION δ (mm)	MEASURED LOAD F (LBS)	MODIFIED DEFLECTION δ (INCHES)	MODIFIED LOAD F (LBS)	SLOPE FOR START TO DATA POINT (LBS/INCH)	F BASED ON "m" (LBS)	NOMINAL STRESS (KSI)
1	-6.910	0	0.000	0	N/A	5	0.1
2	-4.970	460	0.076	460	6,023	448	5.5
3	-2.960	932	0.156	932	5,993	907	11.1
4	-0.950	1395	0.235	1395	5,947	1366	16.7
5	1.080	1859	0.315	1859	5,909	1830	22.4
6	3.010	2298	0.391	2298	5,880	2271	27.8
7	5.020	2745	0.470	2745	5,845	2731	33.4
8	7.030	3183	0.549	3183	5,804	3190	39.1
9	9.040	3600	0.628	3600	5,749	3649	44.7
10	10.970	3965	0.704	3965	5,671	4090	50.1
11	13.030	4310	0.785	4310	5,562	4561	55.9
12	15.050	4575	0.865	4575	5,412	5022	61.5
13	17.140	4790	0.947	4790	5,224	5500	67.4
14	19.000	4930	1.020	4930	5,020	5925	72.6
15	21.060	5033	1.101	5033	4,790	6396	78.3
16	23.190	5075	1.185	5075	4,534	6882	84.3
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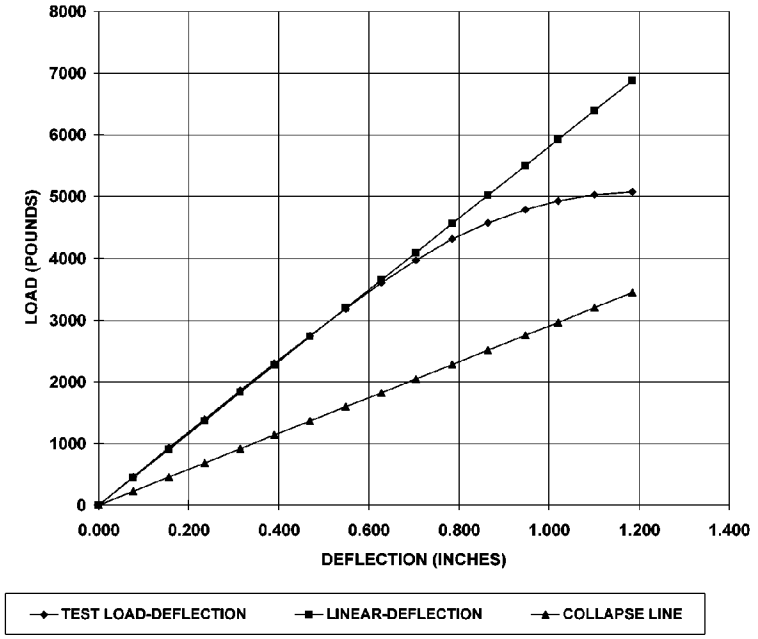

NOTES:
1. Modified data includes deflection and load instrumentation adjustments if required.
2. Loading is in a downward direction. For purposes of the evaluation of the stiffness calculation, the directions of loading (e.g. positive load-loading condition) will remain the same. The sign of the deflection will indicate the load direction.

TEST #: **BUTT WELD BENDING TEST - 6** **TYPE:** **FATIGUE - LOAD DEFLECTION CURVE**

F = Fo + m δ, "m" TO BE BASED ON "N" DATA POINTS, N = 4
THE VALUE OF "m" = 5626
Fo (LBS) = -1800
NOMINAL STRESS = M/Z KSI, M=F x L. L(IN) = 39.375 $Z(IN^3)$ = 3.215

DATA POINT #	MEASURED DEFLECTION δ (mm)	MEASURED LOAD F (LBS)	MODIFIED DEFLECTION δ (INCHES)	MODIFIED LOAD F (LBS)	SLOPE FOR START TO DATA POINT (LBS/INCH)	F BASED ON "m" (LBS)	NOMINAL STRESS (KSI)
1	23.190	5075	1.185	5075	5,826	4867	59.6
2	20.030	4257	1.061	4257	5,737	4168	51.0
3	17.040	3539	0.943	3539	5,679	3505	42.9
4	14.020	2836	0.824	2836	5,626	2836	34.7
5	10.740	2085	0.695	2085	5,565	2110	25.8
6	8.030	1473	0.588	1473	5,501	1509	18.5
7	4.930	782	0.466	782	5,392	823	10.1
8	1.320	12	0.324	12	3,387	23	0.3
9	1.230	0	0.320	0	N/A	3	0.0
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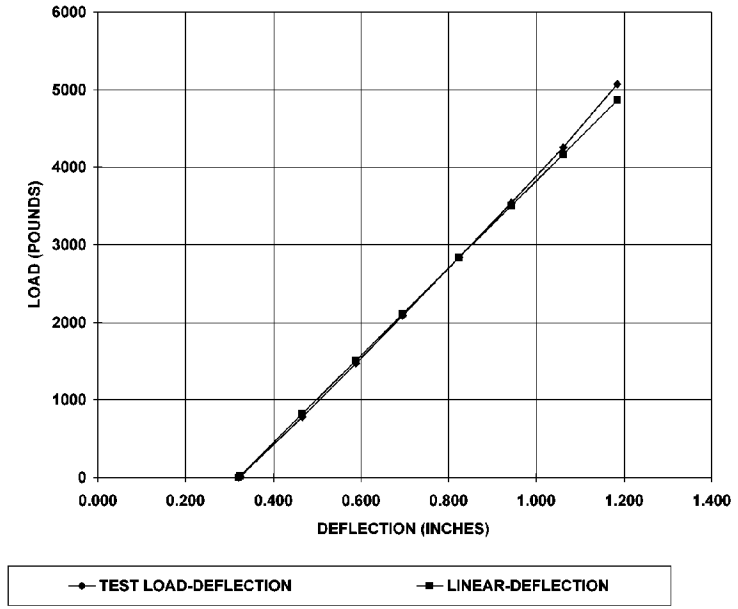
POSITIVE LOAD - UNLOADING CONDITION



NOTES:
1. Modified data includes deflection and load instrumentation adjustments if required.

TEST #: **BUTT WELD BENDING TEST - 6** **TYPE:** **FATIGUE - LOAD DEFLECTION CURVE**

F = Fo + m δ, "m" TO BE BASED ON "N" DATA POINTS, N = 3 1.215

THE VALUE OF "m" = 4958

Fo (LBS) = 0

NOMINAL STRESS = M/Z KSI, M=F x L, L(IN) = 39.375 $Z(IN^3) = \pi r_n^2 t = 3.215$

NEGATIVE LOAD - LOADING CONDITION

DATA POINT #	MEASURED DEFLECTION δ (mm)	MEASURED LOAD F (LBS)	MODIFIED DEFLECTION δ (INCHES)	MODIFIED LOAD F (LBS)	SLOPE FOR START TO DATA POINT (LBS/INCH)	F BASED ON "m" (LBS)	NOMINAL STRESS (KSI)
1	1.230	0	0.320	0	N/A	0	0.0
2	-2.990	-813	0.154	-813	4,893	-824	-10.1
3	-5.010	-1221	0.075	-1221	4,958	-1218	-14.9
4	-7.060	-1624	-0.006	-1624	4,979	-1618	-19.8
5	-9.030	-1990	-0.083	-1990	4,948	-2003	-24.5
6	-11.010	-2360	-0.161	-2360	4,915	-2389	-29.3
7	-13.110	-2740	-0.244	-2740	4,871	-2799	-34.3
8	-15.100	-3080	-0.322	-3080	4,813	-3188	-39.0
9	-17.010	-3400	-0.398	-3400	4,753	-3561	-43.6
10	-19.010	-3710	-0.476	-3710	4,680	-3951	-48.4
11	-21.080	-4015	-0.558	-4015	4,598	-4355	-53.3
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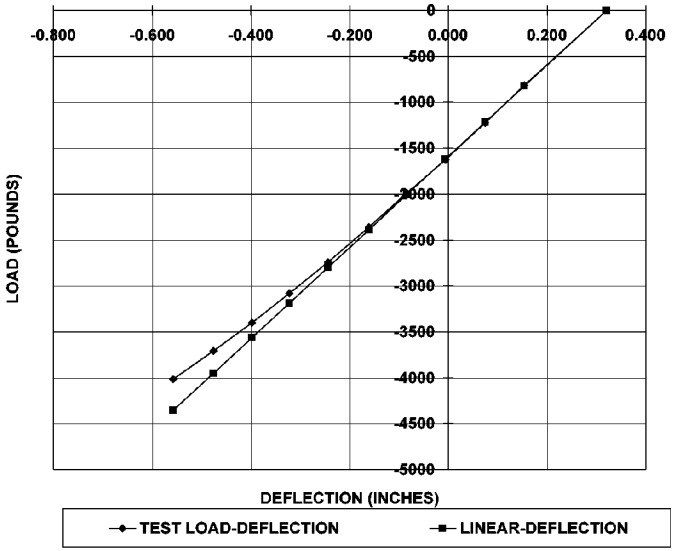

NOTES:

1. Modified data includes deflection and load instrumentation adjustments if required.

TEST #: **BUTT WELD BENDING TEST - 6** **TYPE:** **FATIGUE - LOAD DEFLECTION CURVE**

F = Fo + m δ, "m" TO BE BASED ON "N" DATA POINTS, N = 3
THE VALUE OF "m" = 5514 Fo (LBS) = -745

NEGATIVE LOAD - UNLOADING CONDITION

NOMINAL STRESS = M/Z KSI, M=F x L, L(IN) = 39.375 $Z(IN^3) = \pi r_n^2 t =$ 3.215

DATA POINT #	MEASURED DEFLECTION δ (mm)	MEASURED LOAD F (LBS)	MODIFIED DEFLECTION δ (INCHES)	MODIFIED LOAD F (LBS)	SLOPE FOR START TO DATA POINT (LBS/INCH)	F BASED ON "m" (LBS)	NOMINAL STRESS (KSI)
1	-21.080	-4015	-0.558	-4015	5708	-3821	-46.8
2	-18.060	-3264	-0.439	-3264	5600	-3165	-38.8
3	-14.950	-2543	-0.317	-2543	5514	-2490	-30.5
4	-12.050	-1885	-0.202	-1885	5410	-1861	-22.8
5	-8.860	-1172	-0.077	-1172	5221	-1168	-14.3
6	-6.050	-552	0.034	-552	4851	-558	-6.8
7	-3.160	0	0.148	0	N/A	69	0.8
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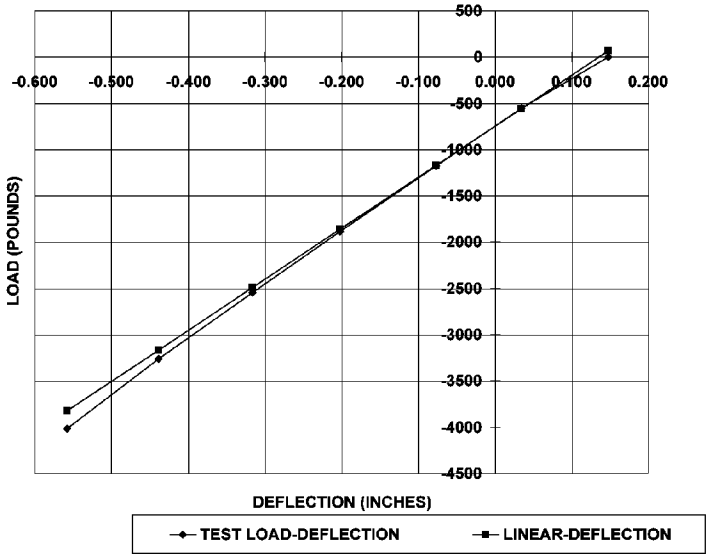
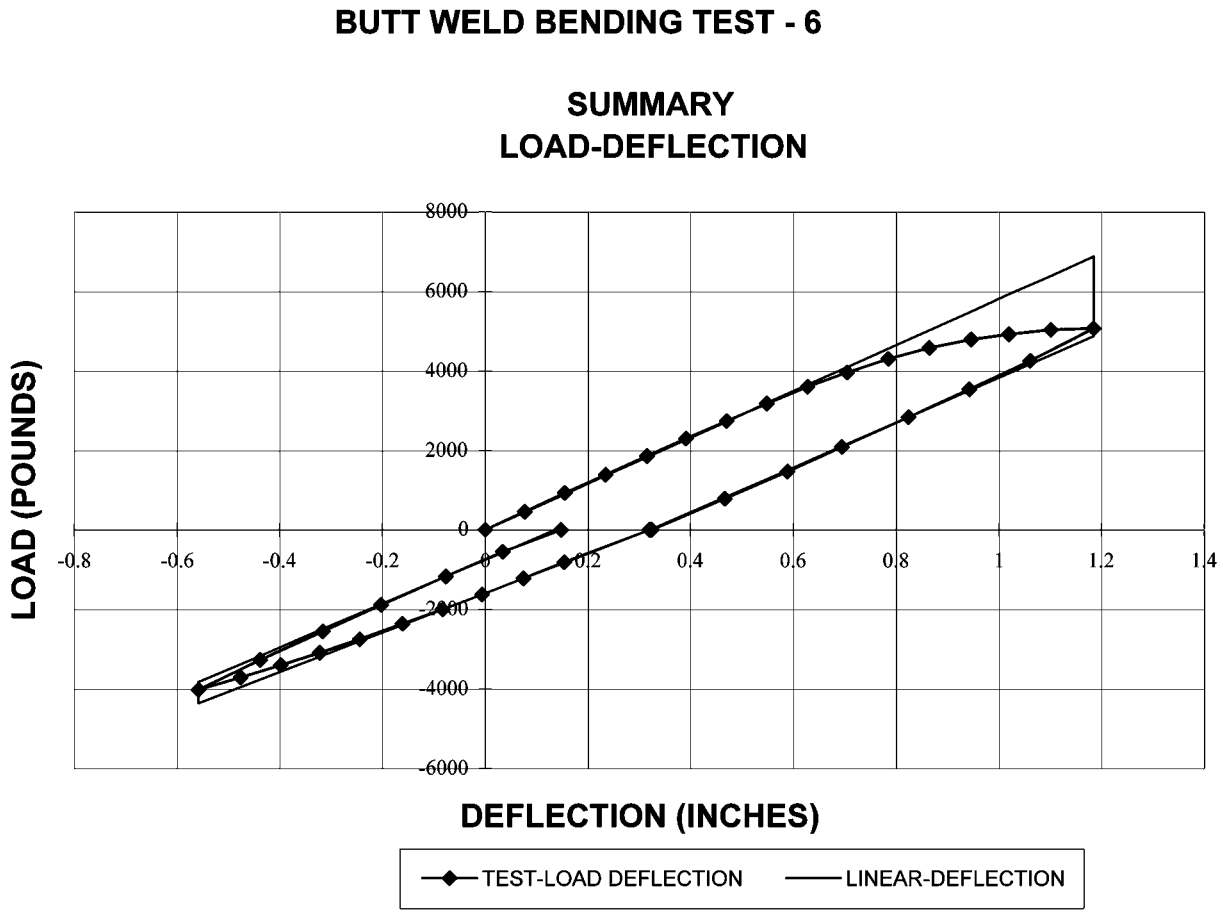


NOTES:


BUTT WELD BENDING TEST - 6
SUMMARY
LOAD-DEFLECTION
LOAD (POUNDS)
8000
6000
4000
2000
0
-2000
-4000
-6000
-0.8
-0.6
-0.4
-0.2
0
0.2
0.4
0.6
0.8
1
1.2
1.4
DEFLECTION (INCHES)
TEST-LOAD DEFLECTION
LINEAR-DEFLECTION

TEST #: **BUTT WELD BENDING TEST - 6**

FATIGUE TEST DATA ANALYSIS

Do (IN) = 4.5 MOMENT ARM (IN)= L = 39.375
t (IN) = 0.237 AVERAGE STIFFNESS (LBS/IN) = 5476
AVERAGE STIFFNESS (LBS/IN) (TEST 1)= 3794

TEST DISPLACEMENT/CYCLE DATA:

CONDITION #	DISPLACEMENT AMPLITUDE (+/-) (mm.) δ_i	DISPLACEMENT AMPLITUDE (+/-) (in.) δ_i	EFFECTIVE APPLIED LOAD (LBS)	NOMINAL STRESS (+/-) (PSI) S	NUMBER OF TEST CYCLES N_i
1	20.0	0.787	4312	52,805	1,943
2		0.000	-	-	0
3		0.000	-	-	0
4		0.000	-	-	0
5		0.000	-	-	0
6		0.000	-	-	0
7		0.000	-	-	0
8		0.000	-	-	0
				TOTAL CYCLES:	1,943

FOR THE MAXIMUM DISPLACEMENT, δ_{max} (IN) = 0.787 THE EQUIVALENT NUMBER
OF CYCLES USING $N_{eq} = \Sigma(\delta_i/\delta_{max})^5 * N_i$ IS = 1,943

For $Z(IN^3)$ = 3.215
$i = 245{,}000 * Neq^{(-0.2)}/S$ = **1.020**

COMMENTS:

1. Failure point was at the weld at fixed end of the pipe.
2. L is distance from load point to failure point.
3. It is assumed that the stresses are calculated by M / Z.
4. Condition 1 was run at a rate of 25 cycles per minute.
5. Cracks started on top at about 1600 cycles.
6. Water leaked at 1943.

Fatigue

TEST #: **BUTT WELD BENDING TEST - 6**

1. FATIGUE USAGE FACTOR EVALUATION ASSUMING Z = 3.215

Condition	S_{nom}= +/- M/Z (ksi)	S_n= 2 C_2 M/Z (ksi)	S_p = 2 K_2C_2M/Z (ksi)	K_e	S_{alt}= K_eS_p/2 (ksi)	$N_{allowable}$	N_{test}	USAGE FACTOR	CUMULATIVE USAGE FACTOR
1	52.80	101.6	182.9	2.39	218.2	1,943	1,943	1.00	1.00
2	-	-	-	-	-	-	-	0.00	0.00
3	-	-	-	-	-	-	-	0.00	0.00
4	-	-	-	-	-	-	-	0.00	0.00
5	-	-	-	-	-	-	-	0.00	0.00
6	-	-	-	-	-	-	-	0.00	0.00
7	-	-	-	-	-	-	-	0.00	0.00
8	-	-	-	-	-	-	-	0.00	0.00

INDICES & MATERIAL PROPERTY DATA

C_2 =	**0.962**	S_m (ksi) =	20
K_2 =	**1.80**	m =	3.0
$C_2K_2/2$=	0.87	n =	0.2

TOTAL CUMULATIVE USAGE FACTOR = **1.000**

COMMENTS:

1. The fatigue analysis follows the methodology defined in ASME Section III for Class 1 components (ASME Boiler and Pressure Code, Section III, Nuclear Power Plant Components, ASME, New York, 2001). The definition of the various terms are in accordance with NB-3653 except for the design fatigue which is defined as : $N_{allowable} = (8{,}664/(S_{alt}-21.645))^2$ (from Criteria of the ASME Boiler and Pressure Vessel Code for Design by Analysis in Sections III and VIII, Division 2, The American Society of Mechanical Engineers, 1969). If S_{alt} is less than or equal to 21.645, the expression is not valid and the associated usage factor is taken as 0.0.
2. The usage factor is defined as $N_{test}/N_{allowable}$.
3. The Cumulative Usage Factor is the sum of the usage factors for the particular loading condition and the previous ones.

TEST # : **BUTT WELD BENDING TEST - 7** **TYPE:** **FATIGUE - LOAD DEFLECTION CURVE**

F = Fo + m δ, "m" TO BE BASED ON "N" DATA POINTS, N = 8
THE VALUE OF "m" = 5660 Do (IN) = 4.5
Fo (LBS) = 0 t (IN) = 0.237
NOMINAL STRESS = M/Z KSI, M=F x L, L(IN) = 39.375 $Z(IN^3)$ = 3.215

POSITIVE LOAD - LOADING CONDITION

DATA POINT #	MEASURED DEFLECTION δ (mm)	MEASURED LOAD F (LBS)	MODIFIED DEFLECTION δ (INCHES)	MODIFIED LOAD F (LBS)	SLOPE FOR START TO DATA POINT (LBS/INCH)	F BASED ON "m" (LBS)	NOMINAL STRESS (KSI)
1	-1.370	-1	0.000	-1	N/A	5	0.1
2	0.000	315	0.054	315	5,859	310	3.8
3	2.010	774	0.133	774	5,822	758	9.3
4	4.020	1229	0.212	1229	5,795	1206	14.8
5	5.990	1663	0.290	1663	5,748	1645	20.1
6	8.010	2115	0.369	2115	5,725	2095	25.7
7	9.990	2545	0.447	2545	5,694	2536	31.1
8	12.010	2978	0.527	2978	5,660	2986	36.6
9	14.010	3400	0.606	3400	5,624	3432	42.0
10	16.020	3800	0.685	3800	5,573	3880	47.5
11	17.980	4150	0.762	4150	5,499	4316	52.9
12	20.010	4490	0.842	4490	5,407	4769	58.4
13	22.010	4765	0.920	4765	5,287	5214	63.9
14	24.000	4915	0.999	4915	5,116	5658	69.3
15	26.020	4998	1.078	4998	4,900	6108	74.8
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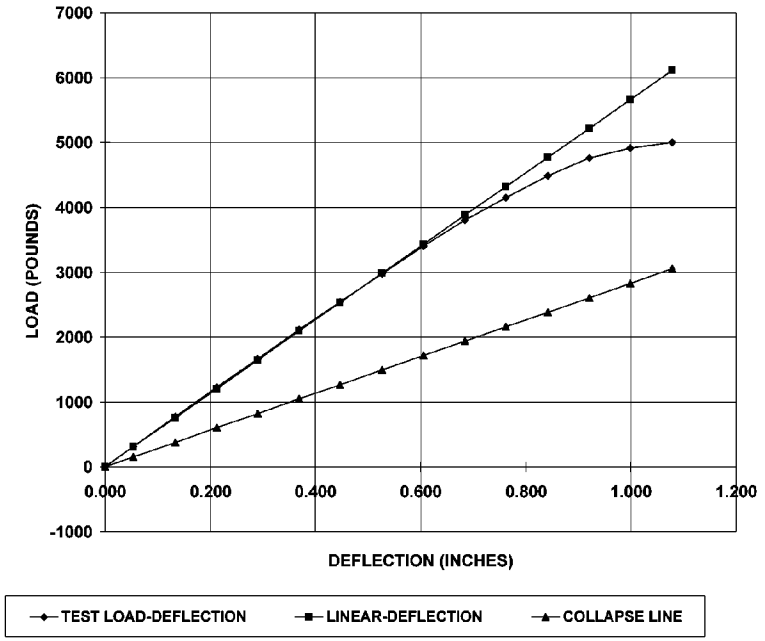

NOTES:
1. Modified data includes deflection and load instrumentation adjustments if required.
2. Loading is in a downward direction. For purposes of the evaluation of the stiffness calculation, the directions of loading (e.g. positive load-loading condition) will remain the same. The sign of the deflection will indicate the load direction.

TEST #: **BUTT WELD BENDING TEST - 7** **TYPE:** **FATIGUE - LOAD DEFLECTION CURVE**

F = Fo + m δ, "m" TO BE BASED ON "N" DATA POINTS, N = 4
THE VALUE OF "m" = 5621
Fo (LBS) = -1230
NOMINAL STRESS = M/Z KSI, M=F x L. L(IN) = 39.375 $Z(IN^3)$ = 3.215

POSITIVE LOAD - UNLOADING CONDITION

DATA POINT #	MEASURED DEFLECTION δ (mm)	MEASURED LOAD F (LBS)	MODIFIED DEFLECTION δ (INCHES)	MODIFIED LOAD F (LBS)	SLOPE FOR START TO DATA POINT (LBS/INCH)	F BASED ON "m" (LBS)	NOMINAL STRESS (KSI)
1	26.020	4998	1.078	4998	5,778	4832	59.2
2	22.990	4224	0.959	4224	5,700	4161	51.0
3	19.990	3511	0.841	3511	5,653	3497	42.8
4	17.000	2830	0.723	2830	5,621	2835	34.7
5	14.000	2150	0.605	2150	5,584	2172	26.6
6	11.010	1483	0.487	1483	5,549	1510	18.5
7	8.000	818	0.369	818	5,500	844	10.3
8	5.010	165	0.251	165	5,239	182	2.2
9	4.210	0	0.220	0	N/A	5	0.1
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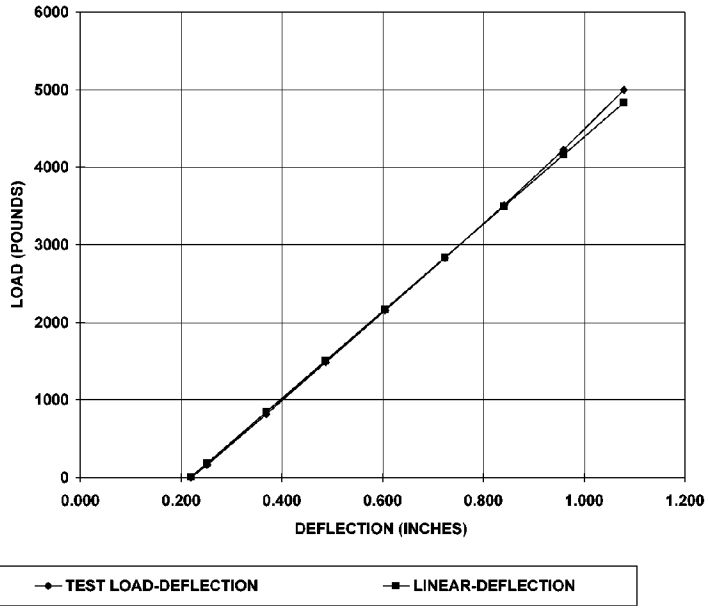

NOTES:
1. Modified data includes deflection and load instrumentation adjustments if required.

TEST #: **BUTT WELD BENDING TEST - 7** **TYPE:** **FATIGUE - LOAD DEFLECTION CURVE**

F = Fo + m δ, "m" TO BE BASED ON "N" DATA POINTS, N = 6 1.215

THE VALUE OF "m" = 5077

Fo (LBS) = 0

NOMINAL STRESS = M/Z KSI, M=F x L, L(IN) = 39.375 Z(IN^3) = 3.215

NEGATIVE LOAD - LOADING CONDITION

DATA POINT #	MEASURED DEFLECTION δ (mm)	MEASURED LOAD F (LBS)	MODIFIED DEFLECTION δ (INCHES)	MODIFIED LOAD F (LBS)	SLOPE FOR START TO DATA POINT (LBS/INCH)	F BASED ON "m" (LBS)	NOMINAL STRESS (KSI)
1	4.210	0	0.220	0	N/A	0	0.0
2	1.980	-403	0.132	-403	4,590	-446	-5.5
3	-0.100	-818	0.050	-818	4,818	-861	-10.5
4	-2.020	-1230	-0.026	-1230	5,014	-1245	-15.2
5	-4.030	-1635	-0.105	-1635	5,077	-1647	-20.2
6	-6.011	-2020	-0.183	-2020	5,077	-2043	-25.0
7	-8.010	-2385	-0.261	-2385	5,030	-2442	-29.9
8	-10.030	-2770	-0.341	-2770	4,995	-2846	-34.9
9	-12.020	-3130	-0.419	-3130	4,952	-3244	-39.7
10	-14.020	-3480	-0.498	-3480	4,903	-3643	-44.6
11	-16.000	-3795	-0.576	-3795	4,837	-4039	-49.5
12	-18.040	-4110	-0.656	-4110	4,763	-4447	-54.5
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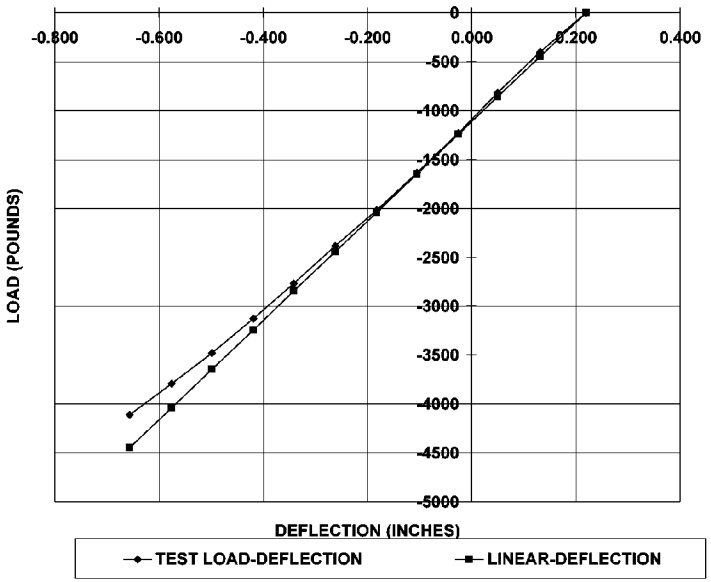

NOTES:
1. Modified data includes deflection and load instrumentation adjustments if required.

TEST #: **BUTT WELD BENDING TEST - 7** **TYPE:** **FATIGUE - LOAD DEFLECTION CURVE**

F = Fo + m δ, "m" TO BE BASED ON "N" DATA POINTS, N = 3
THE VALUE OF "m" = 5482 Fo (LBS) = -400

NEGATIVE LOAD - UNLOADING CONDITION

NOMINAL STRESS = M/Z KSI, M=F x L, L(IN) = 39.375 $Z(IN^3)$ = 3.215

DATA POINT #	MEASURED DEFLECTION δ (mm)	MEASURED LOAD F (LBS)	MODIFIED DEFLECTION δ (INCHES)	MODIFIED LOAD F (LBS)	SLOPE FOR START TO DATA POINT (LBS/INCH)	F BASED ON "m" (LBS)	NOMINAL STRESS (KSI)
1	-18.040	-4110	-0.656	-4110	5615	-3998	-49.0
2	-16.020	-3613	-0.577	-3613	5544	-3562	-43.6
3	-14.000	-3138	-0.497	-3138	5482	-3126	-38.3
4	-11.990	-2677	-0.418	-2677	5417	-2692	-33.0
5	-9.990	-2229	-0.339	-2229	5343	-2260	-27.7
6	-8.010	-1784	-0.261	-1784	5241	-1833	-22.4
7	-6.010	-1344	-0.183	-1344	5111	-1401	-17.2
8	-4.000	-910	-0.104	-910	4922	-968	-11.9
9	-1.990	-485	-0.024	-485	4614	-534	-6.5
10	0.680	0	0.081	0	N/A	42	0.5
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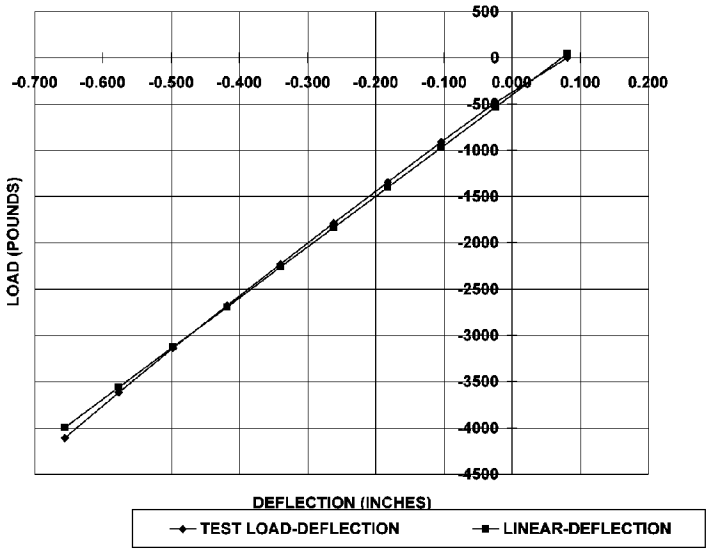
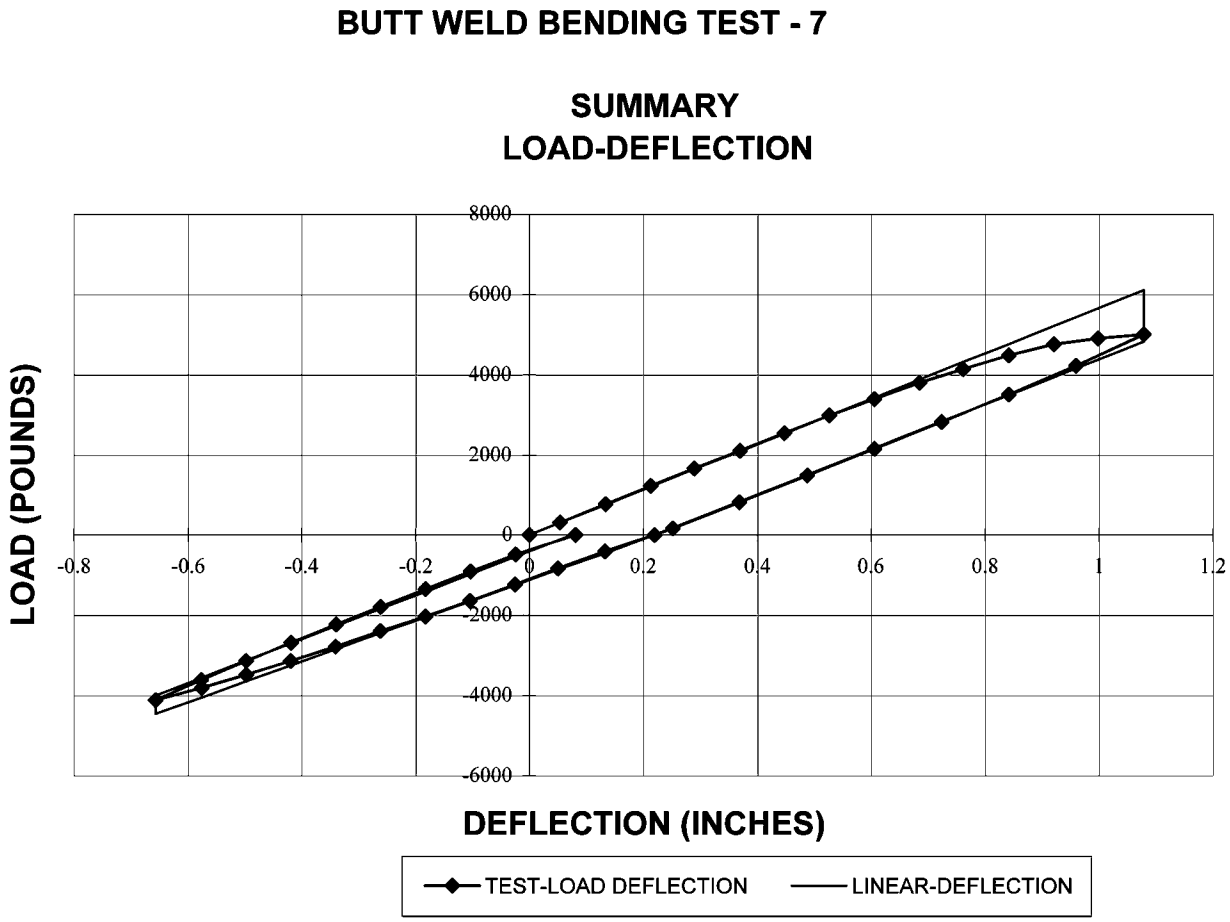


NOTES:


BUTT WELD BENDING TEST - 7
SUMMARY
LOAD-DEFLECTION
LOAD (POUNDS)
8000
6000
4000
2000
0
-2000
-4000
-6000
-0.8
-0.6
-0.4
-0.2
0
0.2
0.4
0.6
0.8
1
1.2
DEFLECTION (INCHES)
TEST-LOAD DEFLECTION
LINEAR-DEFLECTION

TEST #: **BUTT WELD BENDING TEST - 7**

FATIGUE TEST DATA ANALYSIS

Do (IN) = 4.5 MOMENT ARM (IN)= L = 39.375
t (IN) = 0.237 AVERAGE STIFFNESS (LBS/IN) = 5460
AVERAGE STIFFNESS (LBS/IN) (TEST 1)= 3794

TEST DISPLACEMENT/CYCLE DATA:

CONDITION #	DISPLACEMENT AMPLITUDE (+/-) (mm.) δ_i	DISPLACEMENT AMPLITUDE (+/-) (in.) δ_i	EFFECTIVE APPLIED LOAD (LBS)	NOMINAL STRESS (+/-) (PSI) S	NUMBER OF TEST CYCLES N_i
1	20.0	0.787	4299	52,652	2,790
2		0.000	-	-	0
3		0.000	-	-	0
4		0.000	-	-	0
5		0.000	-	-	0
6		0.000	-	-	0
7		0.000	-	-	0
8		0.000	-	-	0
				TOTAL CYCLES:	2,790

FOR THE MAXIMUM DISPLACEMENT, δ_{max} (IN) = 0.787 THE EQUIVALENT NUMBER
OF CYCLES USING $N_{eq} = \Sigma(\delta_i/\delta_{max})^5 * N_i$ IS = 2,790

For Z(IN^3) = 3.215
$i = 245{,}000 * Neq^{(-0.2)}/S$ = **0.952**

COMMENTS:

1. Failure point was at the weld at the fixed end of the pipe.
2. L is distance from load point to failure point.
3. It is assumed that the stresses are calculated by M / Z.
4. Condition 1 was run at a rate of 25 cycles per minute.
5. The weld at the bottom was thick and "bumpy".
6. Water leaked at about 2790 cycles at the bottom near the "bump".

Fatigue

TEST #: **BUTT WELD BENDING TEST - 7**

1. FATIGUE USAGE FACTOR EVALUATION ASSUMING Z(IN^3) = 3.215

Condition	S_{nom}= +/- M/Z (ksi)	S_n= 2 C_2 M/Z (ksi)	S_p = 2 K_2C_2M/Z (ksi)	K_e	S_{alt}= K_eS_p/2 (ksi)	$N_{allowable}$	N_{test}	USAGE FACTOR	CUMULATIVE USAGE FACTOR
1	52.65	95.1	171.2	2.17	185.7	2,790	2,790	1.00	1.00
2	-	-	-	-	-	-	-	0.00	0.00
3	-	-	-	-	-	-	-	0.00	0.00
4	-	-	-	-	-	-	-	0.00	0.00
5	-	-	-	-	-	-	-	0.00	0.00
6	-	-	-	-	-	-	-	0.00	0.00
7	-	-	-	-	-	-	-	0.00	0.00
8	-	-	-	-	-	-	-	0.00	0.00

INDICES & MATERIAL PROPERTY DATA

C_2 =	**0.90**	S_m (ksi) =	20
K_2 =	**1.80**	m =	3.0
$C_2K_2/2$=	0.81	n =	0.2

TOTAL CUMULATIVE USAGE FACTOR = **1.000**

COMMENTS:

1. The fatigue analysis follows the methodology defined in ASME Section III for Class 1 components (ASME Boiler and Pressure Code, Section III, Nuclear Power Plant Components, ASME, New York, 2001). The definition of the various terms are in accordance with NB-3653 except for the design fatigue which is defined as : $N_{allowable} = (8{,}664/(S_{alt}-21.645))^2$ (from Criteria of the ASME Boiler and Pressure Vessel Code for Design by Analysis in Sections III and VIII, Division 2, The American Society of Mechanical Engineers, 1969). If S_{alt} is less than or equal to 21.645, the expression is not valid and the associated usage factor is taken as 0.0.
2. The usage factor is defined as $N_{test}/N_{allowable}$.
3. The Cumulative Usage Factor is the sum of the usage factors for the particular loading condition and the previous ones.

TEST # : **BUTT WELD BENDING TEST - 8** **TYPE:** **FATIGUE - LOAD DEFLECTION CURVE**

F = Fo + m δ, "m" TO BE BASED ON "N" DATA POINTS, N = 8
THE VALUE OF "m" = 5593 Do (IN) = 4.5
Fo (LBS) = 0 t (IN) = 0.237
NOMINAL STRESS = M/Z KSI, M=F x L, L(IN) = 39.375 $Z(IN^3) = \pi r_n^2 t =$ 3.220

POSITIVE LOAD - LOADING CONDITION

DATA POINT #	MEASURED DEFLECTION δ (mm)	MEASURED LOAD F (LBS)	MODIFIED DEFLECTION δ (INCHES)	MODIFIED LOAD F (LBS)	SLOPE FOR START TO DATA POINT (LBS/INCH)	F BASED ON "m" (LBS)	NOMINAL STRESS (KSI)
1	-8.270	0	0.000	0	N/A	5	0.1
2	-6.020	507	0.089	507	5,723	500	6.1
3	-4.000	961	0.168	961	5,717	945	11.6
4	-1.960	1408	0.248	1408	5,672	1394	17.0
5	0.000	1847	0.326	1847	5,666	1825	22.3
6	2.060	2287	0.407	2287	5,630	2279	27.9
7	4.050	2727	0.485	2727	5,615	2717	33.2
8	5.990	3140	0.561	3140	5,593	3144	38.5
9	7.960	3555	0.639	3555	5,567	3578	43.8
10	10.000	3970	0.719	3970	5,531	4027	49.2
11	12.070	4355	0.801	4355	5,474	4483	54.8
12	13.980	4670	0.876	4670	5,394	4904	60.0
13	16.000	4905	0.956	4905	5,265	5349	65.4
14	18.020	4990	1.035	4990	5,063	5793	70.8
15	20.040	5040	1.115	5040	4,821	6238	76.3
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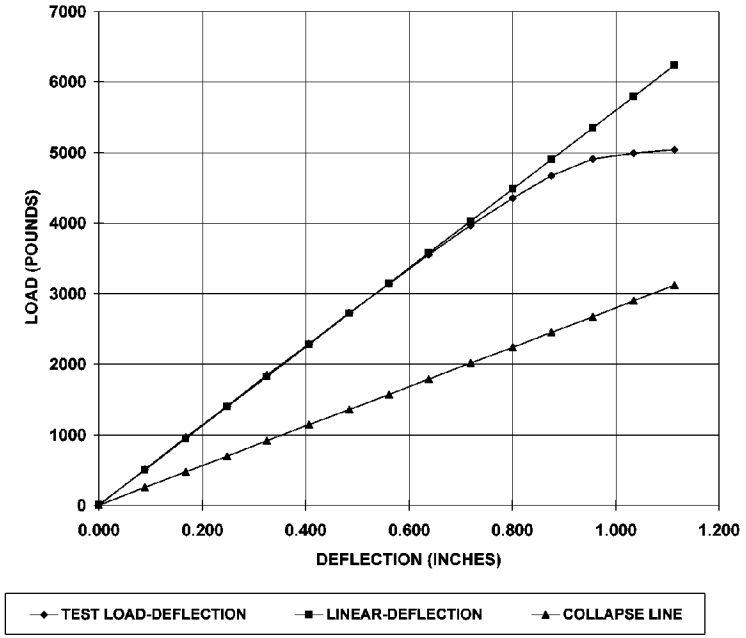

NOTES:
1. Modified data includes deflection and load instrumentation adjustments if required.
2. Loading is in a downward direction. For purposes of the evaluation of the stiffness calculation, the directions of loading (e.g. positive load-loading condition) will remain the same. The sign of the deflection will indicate the load direction.

TEST #: **BUTT WELD BENDING TEST - 8** **TYPE:** **FATIGUE - LOAD DEFLECTION CURVE**

F = Fo + m δ, "m" TO BE BASED ON "N" DATA POINTS, N = 6
THE VALUE OF "m" = 5437
Fo (LBS) = -1260
NOMINAL STRESS = M/Z KSI, M=F x L. L(IN) = 39.375 $Z(IN^3) = \pi r_n^2 t = 3.220$

POSITIVE LOAD - UNLOADING CONDITION

DATA POINT #	MEASURED DEFLECTION δ (mm)	MEASURED LOAD F (LBS)	MODIFIED DEFLECTION δ (INCHES)	MODIFIED LOAD F (LBS)	SLOPE FOR START TO DATA POINT (LBS/INCH)	F BASED ON "m" (LBS)	NOMINAL STRESS (KSI)
1	20.040	5040	1.115	5040	5,750	4800	58.7
2	16.980	4254	0.994	4254	5,656	4145	50.7
3	14.020	3548	0.878	3548	5,594	3512	42.9
4	10.970	2850	0.757	2850	5,542	2859	35.0
5	8.020	2186	0.641	2186	5,491	2227	27.2
6	5.000	1520	0.522	1520	5,437	1581	19.3
7	1.960	860	0.403	860	5,376	930	11.4
8	1.020	659	0.366	659	5,365	729	8.9
9	-2.100	0	0.243	0	N/A	61	0.7
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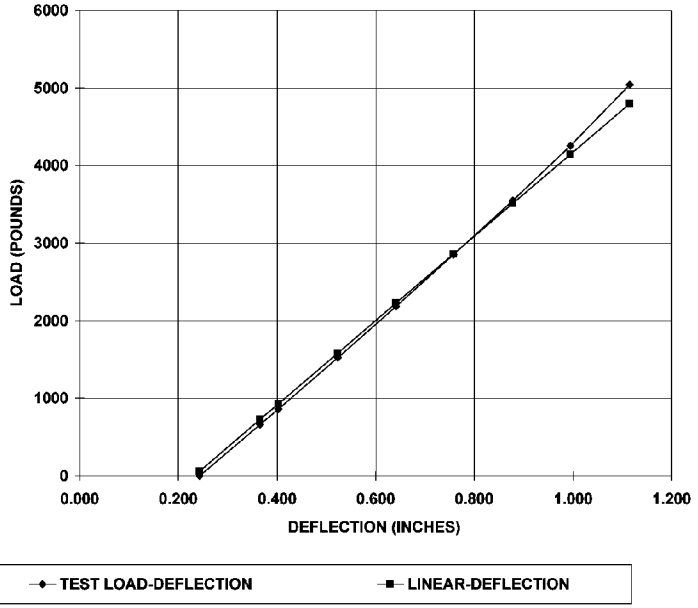

NOTES:
1. Modified data includes deflection and load instrumentation adjustments if required.

TEST #: **BUTT WELD BENDING TEST - 8** **TYPE:** **FATIGUE - LOAD DEFLECTION CURVE**

F = Fo + m δ, "m" TO BE BASED ON "N" DATA POINTS, N = 4 1.215

THE VALUE OF "m" = 4887

Fo (LBS) = 0

NOMINAL STRESS = M/Z KSI, M=F x L, L(IN) = 39.375 $Z(IN^3) = \pi r_n^2 t =$ 3.220

NEGATIVE LOAD - LOADING CONDITION

DATA POINT #	MEASURED DEFLECTION δ (mm)	MEASURED LOAD F (LBS)	MODIFIED DEFLECTION δ (INCHES)	MODIFIED LOAD F (LBS)	SLOPE FOR START TO DATA POINT (LBS/INCH)	F BASED ON "m" (LBS)	NOMINAL STRESS (KSI)
1	-2.100	0	0.243	0	N/A	0	0.0
2	-3.990	-320	0.169	-320	4,301	-364	-4.4
3	-6.020	-732	0.089	-732	4,748	-754	-9.2
4	-8.040	-1135	0.009	-1135	4,887	-1143	-14.0
5	-9.980	-1515	-0.067	-1515	4,931	-1516	-18.5
6	-12.010	-1900	-0.147	-1900	4,927	-1907	-23.3
7	-14.010	-2270	-0.226	-2270	4,901	-2292	-28.0
8	-15.980	-2630	-0.304	-2630	4,869	-2671	-32.7
9	-18.010	-2982	-0.383	-2982	4,822	-3061	-37.4
10	-19.980	-3318	-0.461	-3318	4,772	-3440	-42.1
11	-22.000	-3647	-0.541	-3647	4,716	-3829	-46.8
12	-24.030	-3965	-0.620	-3965	4,654	-4220	-51.6
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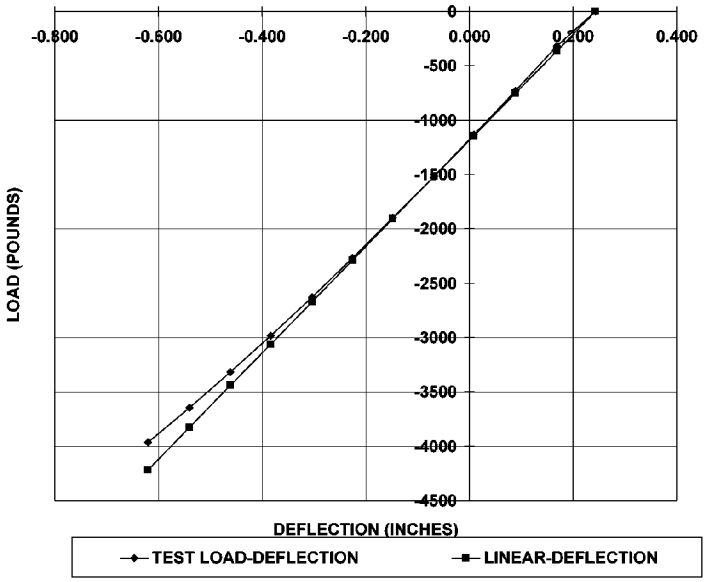

NOTES:

1. Modified data includes deflection and load instrumentation adjustments if required.

TEST #: **BUTT WELD BENDING TEST - 8** **TYPE:** **FATIGUE - LOAD DEFLECTION CURVE**

F = Fo + m δ, "m" TO BE BASED ON "N" DATA POINTS, N = 2
THE VALUE OF "m" = 5529 Fo (LBS) = -400

NEGATIVE LOAD - UNLOADING CONDITION

NOMINAL STRESS = M/Z KSI, M=F x L, L(IN) = 39.375 $Z(IN^3) = \pi r_n^2 t =$ 3.220

DATA POINT #	MEASURED DEFLECTION δ (mm)	MEASURED LOAD F (LBS)	MODIFIED DEFLECTION δ (INCHES)	MODIFIED LOAD F (LBS)	SLOPE FOR START TO DATA POINT (LBS/INCH)	F BASED ON "m" (LBS)	NOMINAL STRESS (KSI)
1	-24.030	-3965	-0.620	-3965	5613	-3831	-46.8
2	-21.020	-3241	-0.502	-3241	5529	-3175	-38.8
3	-17.990	-2543	-0.383	-2543	5455	-2516	-30.8
4	-15.050	-1888	-0.267	-1888	5383	-1876	-22.9
5	-12.030	-1225	-0.148	-1225	5269	-1218	-14.9
6	-9.010	-575	-0.029	-575	4989	-561	-6.9
7	-7.020	-148	0.049	-148	3797	-128	-1.6
8	-6.050	-3	0.087	-3	N/A	83	1.0
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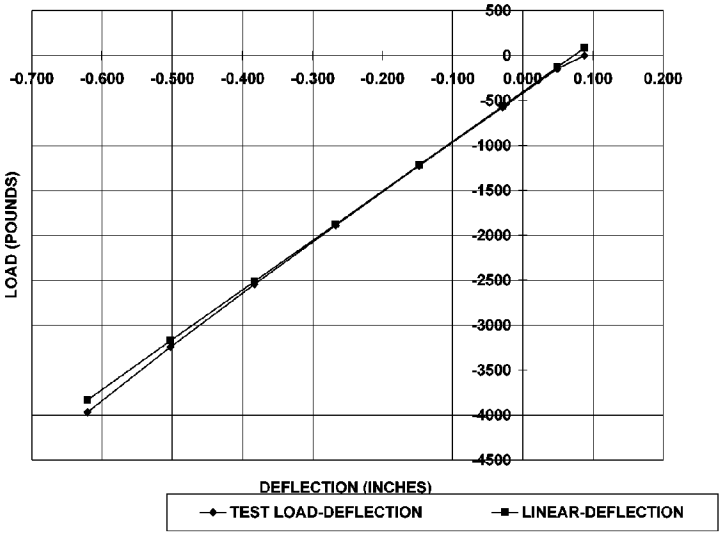
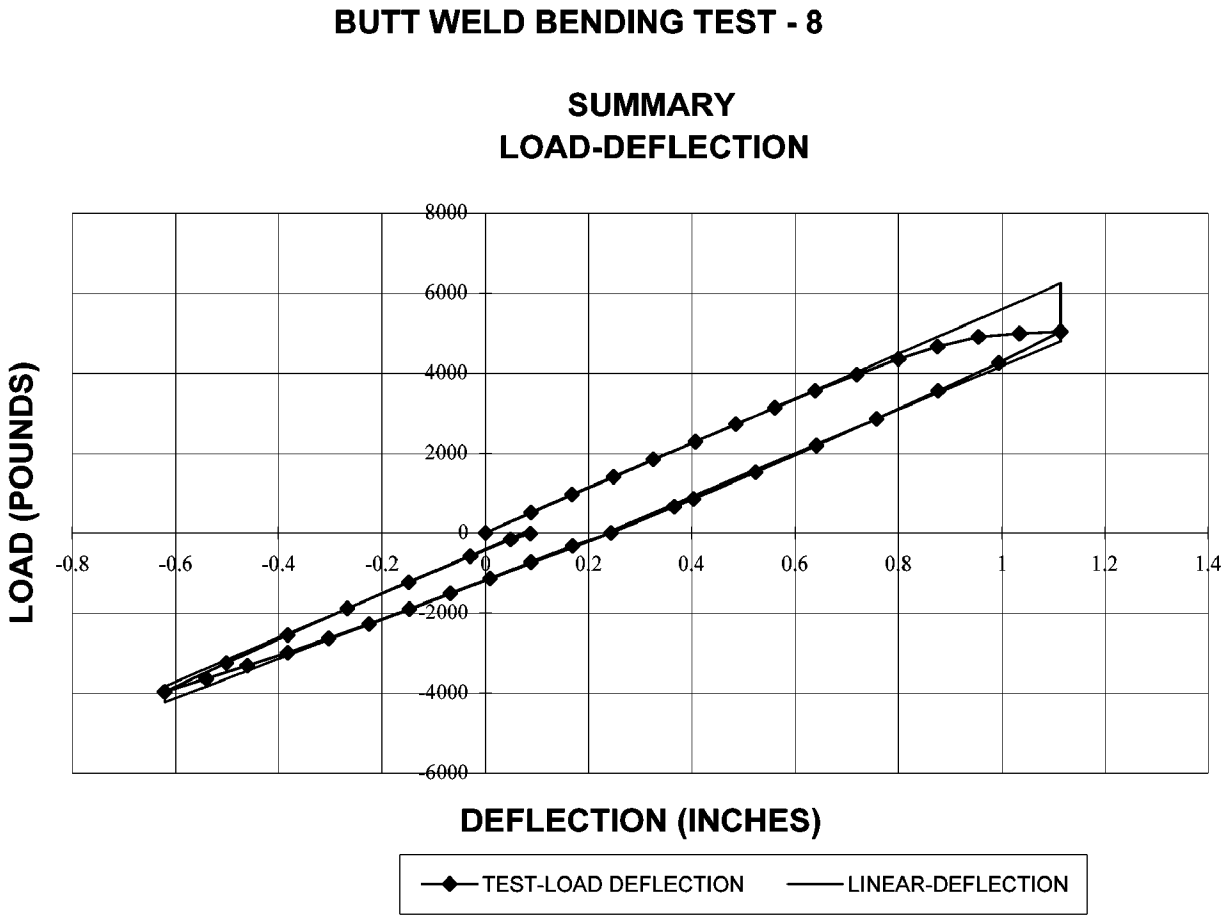


NOTES:


BUTT WELD BENDING TEST - 8
SUMMARY
LOAD-DEFLECTION
LOAD (POUNDS)
8000
6000
4000
2000
0
-2000
-4000
-6000
-0.8
-0.6
-0.4
-0.2
0
0.2
0.4
0.6
0.8
1
1.2
1.4
DEFLECTION (INCHES)
TEST-LOAD DEFLECTION
LINEAR-DEFLECTION

TEST #: **BUTT WELD BENDING TEST - 8**

FATIGUE TEST DATA ANALYSIS

Do (IN) = 4.5 MOMENT ARM (IN)= L = 39.375
t (IN) = 0.237 AVERAGE STIFFNESS (LBS/IN) = 5362
AVERAGE STIFFNESS (LBS/IN) (TEST 1)= 3794

TEST DISPLACEMENT/CYCLE DATA:

CONDITION #	DISPLACEMENT AMPLITUDE (+/-) (mm.) δ_i	DISPLACEMENT AMPLITUDE (+/-) (in.) δ_i	EFFECTIVE APPLIED LOAD (LBS)	NOMINAL STRESS (+/-) (PSI) S	NUMBER OF TEST CYCLES N_i
1	20.0	0.787	4222	51,705	2,139
2		0.000	-	-	0
3		0.000	-	-	0
4		0.000	-	-	0
5		0.000	-	-	0
6		0.000	-	-	0
7		0.000	-	-	0
8		0.000	-	-	0
				TOTAL CYCLES:	2,139

FOR THE MAXIMUM DISPLACEMENT, δ_{max} (IN) = 0.787 THE EQUIVALENT NUMBER
OF CYCLES USING $N_{eq} = \Sigma(\delta_i/\delta_{max})^5 * N_i$ IS = 2,139

For $Z(IN^3)$ = 3.215
$i = 245{,}000 * Neq^{(-0.2)}/S$ = **1.022**

COMMENTS:

1. Failure point was at the weld at fixed end of the pipe.
2. L is distance from load point to failure point.
3. It is assumed that the stresses are calculated by M / Z.
4. Condition 1 was run at a rate of 25 cycles per minute.
5. Cracks were observed on the top at 1560 cycles.
6. Water leaked at about 2139 cycles at the top on the pipe side of the weld.

Fatigue

TEST #: **BUTT WELD BENDING TEST - 8**

1. FATIGUE USAGE FACTOR EVALUATION ASSUMING Z (IN^3)= 3.215

Condition	S_{nom}= +/- M/Z (ksi)	S_n= 2 C_2 M/Z (ksi)	S_p = 2 K_2C_2M/Z (ksi)	K_e	S_{alt}= K_eS_p/2 (ksi)	$N_{allowable}$	N_{test}	USAGE FACTOR	CUMULATIVE USAGE FACTOR
1	51.70	99.8	179.6	2.33	209.0	2,139	2,139	1.00	1.00
2	-	-	-	-	-	-	-	0.00	0.00
3	-	-	-	-	-	-	-	0.00	0.00
4	-	-	-	-	-	-	-	0.00	0.00
5	-	-	-	-	-	-	-	0.00	0.00
6	-	-	-	-	-	-	-	0.00	0.00
7	-	-	-	-	-	-	-	0.00	0.00
8	-	-	-	-	-	-	-	0.00	0.00

INDICES & MATERIAL PROPERTY DATA

C_2 =	**0.965**	S_m (ksi) =	20
K_2 =	**1.80**	m =	3.0
$C_2K_2/2$=	0.87	n =	0.2

TOTAL CUMULATIVE USAGE FACTOR = **1.000**

COMMENTS:

1. The fatigue analysis follows the methodology defined in ASME Section III for Class 1 components (ASME Boiler and Pressure Code, Section III, Nuclear Power Plant Components, ASME, New York, 2001). The definition of the various terms are in accordance with NB-3653 except for the design fatigue which is defined as : $N_{allowable} = (8{,}664/(S_{alt}-21.645))^2$ (from Criteria of the ASME Boiler and Pressure Vessel Code for Design by Analysis in Sections III and VIII, Division 2, The American Society of Mechanical Engineers, 1969). If S_{alt} is less than or equal to 21.645, the expression is not valid and the associated usage factor is taken as 0.0.
2. The usage factor is defined as $N_{test}/N_{allowable}$.
3. The Cumulative Usage Factor is the sum of the usage factors for the particular loading condition and the previous ones.

Target:
Nuclear Power

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