Stress Intensification Factors and Flexibility Factors for Pad-Reinforced Branch Connections

TR-110755

Final Report
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REPORT SUMMARY

This report presents the results of an investigation into the effects of pad reinforcement on the flexibility and fatigue life of fabricated tees. Equations are provided, based on analyses and test data, for determining stress intensification factors and flexibility factors. The expressions presented in this report significantly improve the evaluation of the fatigue life of pad-reinforced branch connections.

Background

Fatigue is an important concern in the design and engineering of piping systems. The ASME Section III Class 2 & 3, and B31 piping design codes use factors such as stress intensification factors to account for fatigue effects produced by reversing loads. These factors are known to **often** be conservative. The present version of the ASME Code does not clearly define the flexibility factors for all configurations of branch connections.

Objectives

- To derive expressions for stress intensification factors (SIF) for pad-reinforced branch connections

- To derive expressions for flexibility factors for accurately modeling the behavior of pad-reinforced branch connections in a piping analysis

Approach

A detailed investigation of the behavior of unreinforced fabricated branch connections has been documented in EPRI report TR-110996. Researchers conducted fatigue tests on pad-reinforced branch connections and compared the results to the predicted behavior of the unreinforced branch connections. The differences in results were used to quantify the effects of pad reinforcement.

Results

Adjustments were made to the SIF equations in TR-110996. An adjusted thickness term, T*, was introduced to account for the pad reinforcement. This term accounts for the reduction in SIF due to reinforcement. This new equation is valid for both in-plane and

out-of-plane bending and is valid for all loading conditions on the branch and run pipe. Parameter limitations were established for the results to be applicable to various pad configurations.

Regarding flexibility factors, the T* term was also applied to previously derived equations in TR-110996 to evaluate the branch pipe. However, it was determined that there does not appear to be sufficient data to justify adjusting the flexibility of the run pipe for the effect of the pad-reinforced branch connection.

EPRI Perspective

Design for fatigue is a major concern for any power or process facility. Accurate methods of engineering for fatigue are important for cost-effective design, for root cause failures, and for evaluating remaining fatigue life of plant designs. The work being done under EPRI's SIF optimization program continues to establish the technical justification to allow for reductions in current Code stress intensification factors. The results of this program can provide a basis to reduce the scope of ongoing pressure boundary component testing and inspection programs in operating nuclear power plants. Examples include reductions in the inspection scope of postulated high- and moderate-energy line break locations and reduction of snubber testing.

TR-110755

Interest Categories

Piping, reactor vessel, and internals

ABSTRACT

This report was prepared under the auspices of the EPRI (Electric Power Research Institute) project on Stress Intensification Factor Optimization. The fatigue life of branch connections is a major consideration in the design and evaluation of piping systems. This report presents the results of an investigation of the effects of pad reinforcement on the flexibility and fatigue life of fabricated tees subject to various moments. The report reviews existing test data and develops expressions for estimating SIFs and flexibility factors. The expressions presented in this report significantly improve the evaluation of the fatigue life of pad-reinforced branch connections.

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INTRODUCTION

The configuration of a pad-reinforced fabricated branch connection is shown in Figures 1-1 and 1-2. A pad-reinforced branch connection can be visualized as an unreinforced fabricated branch connection with a collar added at the base of the branch segment. A detailed investigation of the behavior of unreinforced fabricated branch connections has been conducted under this EPRI-sponsored research effort [1]. This study presents the results of fatigue tests conducted on pad-reinforced branch connections, and compares the results to the predicted behavior of an unreinforced fabricated branch connection. The differences in results are used to quantify the effects of pad reinforcement.

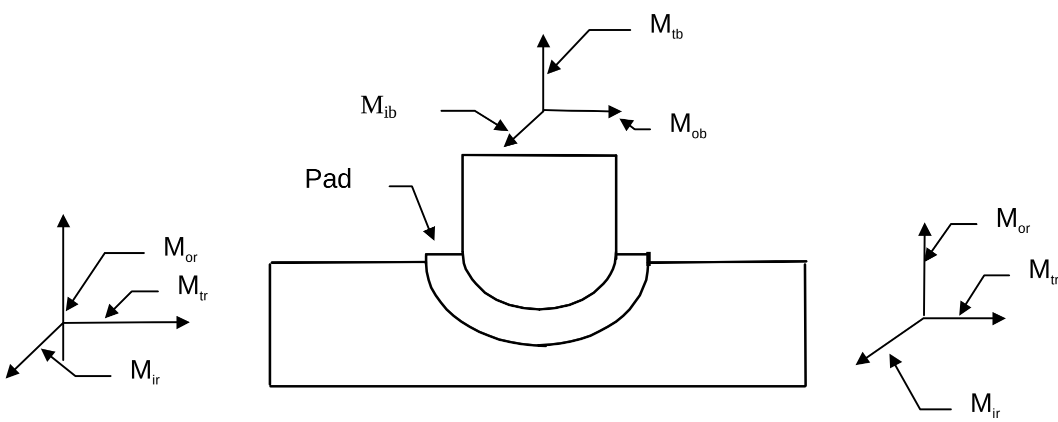

Figure 1-1
Pad-Reinforced Fabricated Branch Connection

1.1 Nomenclature

A_o = constant used in expression for SIFs

B_o = constant used in expression for flexibility

D = mean diameter of run pipe, inches

d = mean diameter of the branch pipe, inches

D_o = outside diameter of the run pipe, inches

D_{op} = diameter of pad, inches

d_o = outside diameter of the branch pipe, inches

F = force applied to test specimens, pounds

K = overall stiffness of test configurations, pounds/inch

n_1, n_2, and n_3 = constants

T = wall thickness of the run pipe, inches

T* = adjusted wall thickness of the run pipe, inches

t = wall thickness of the branch pipe, inches

t_r = thickness of reinforcement pad, inches

t_e = effective fitting thickness, inches

R = mean radius of the run pipe, $R = (D_o\text{-}T)/2$, inches

r = mean radius of the branch pipe, $r = (d_o\text{-}t)/2$, inches

R/T = characteristic of the run pipe

r/t = characteristic of the branch pipe

r/R = characteristic of the connection

t/T = characteristic of the connection

Z = approximate section modulus of the run pipe, in^3, $=\pi R^2 T$

z = approximate section modulus of the branch pipe, in^3, $=\pi r^2 t$

M_{ir} = in-plane bending moments on the run, in-lb.

M_{or} = out-of-plane bending moments on the run, in-lb.

M_{tr} = torsion moments on the run, in-lb.

M_{ib} = in-plane bending moment on the branch, in-lb.

M_{ob} = out-of-plane bending moment on the branch, in-lb.

M_{tb} = torsion moment on the branch, in-lb.

i_{ib} = Stress Intensification Factor for in-plane bending moments on the branch pipe

i_{ob} = Stress Intensification Factor for out-of-plane bending moments on the branch pipe

i_{tb} = Stress Intensification Factor for torsion moments on the branch pipe

i_{ir} = Stress Intensification Factor for through-run in-plane bending moments on the run pipe

i_{or} = Stress Intensification Factor for through-run, out-of-plane bending moments on the run pipe

i_{tr} = Stress Intensification Factor for through-run torsion moments on the run pipe

k_{ib} = Flexibility Factor for in-plane bending moments on the branch pipe

k_{ob} = Flexibility Factor for out-of-plane bending moments on the branch pipe

k_{tb} = Flexibility Factor for torsion moments on the branch pipe

k_{ir} = Flexibility Factor for through-run in-plane bending moments on the run pipe

k_{or} = Flexibility Factor for through-run, out-of-plane bending moments on the run pipe

k_{tr} = Flexibility Factor for through-run, torsion moments on the run pipe

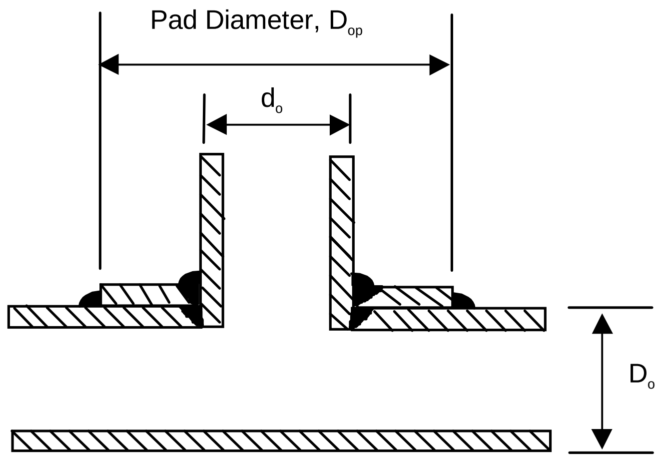

Figure 1-2
Cross-section of Pad-Reinforced Fabricated Tee

1.2 Current Code Factors

The current Code expression [2,3] for the Stress Intensification Factor for a pad-reinforced branch connection is:

$i = 0.9/h^{2/3}$ (eq. 1-1)

where:

$h = (T + t_r/2)^{3/2} / (Rt_r^{3/2})$ (eq. 1-2)

Equation 1-1 values are applied to the resultant moment on each of the three sides of the tee connection.

These expressions are based on Markl's work [4]. Markl began with the premise that the i-factor was of the form:

$i=0.9/h^{2/3} \geq 1$

where

$h=c(t_e/R)$ and $c=(t_e/T)^{1.5}$

Markl called h, the *effective flexibility factor*, and said that c *takes account of the increased section modulus*. Both of these factors are a function of the *effective fitting thickness* at the juncture, t_e, which Markl saw to be the average of the thickness of the run pipe and the thickness of the branch pipe (t_e=(T+t)/2). For a pad thickness, t_r, and for a connection with t=T, then $t_e=(T+t_r+T)/2= T+t_r/2$. Thus, Markl determined t_e to be the pipe wall thickness increased by one half the excess thickness, t_r, provided in either the run or branch, by use of thicker piping, or pad, or saddle. Note that Markl's statement is for t=T.

In 1965, ANSI Code Case 53 [5] introduced rules for evaluation of reduced branch outlet tee connections. These rules use $z=\pi r^2 t_s$ where t_s is the lesser of T or i*t, instead of $z=\pi r^2 t$, for evaluation of the branch side resultant moment. The Code Case is now incorporated in the sections of the Code on determination of moments and section modulus of tee connections. The effect of the Code Case is to change Equation 1-1 to the following two equations:

$$i_{run} = 0.9R^{2/3} [T/(T+t_r/2)^{5/3}] \geq 1.0 \qquad \text{(eq. 1-3)}$$

$$i_{branch} = 0.9R^{2/3} [T/(T+t_r/2)^{5/3}](t/T) \geq 1.0 \qquad \text{(eq. 1-4)}$$

Equation 1-3, is used with $Z=\pi R^2 T$ to evaluate the resultant moments on the run sides of the tee connection, and Equation 1-4 is used with $z=\pi r^2 t$ to evaluate the resultant moment on the branch side of the tee connection. Equations 1-3 and 1-4 are applied over the entire range of $0<r/R\leq 1.0$. The current Code expression for the i-factor is independent of any reinforcement pad dimension other than the thickness of the pad.

2

EXPERIMENTAL RESULTS

2.1 Markl Tests

Markl tested 4x4 pad-reinforced branch connections with the following results. All branch connections had an outside diameter, $D_o = d_o = 4.5$ inches and wall thicknesses were either T= t=0.237 inches, or T=t=0.12 inches. The reinforcement pads were either elliptical or circular in shape.

Test	Pad thickness, t_r	Pad Outside Diameter	Load Direction	i_{test}
1	0.237 inches	7 inches	in-plane branch	1.78
2	0.237 inches	7 inches	out-of-plane branch	1.83
3	0.120 inches	8 inches	in-plane branch	2.21
4	0.120 inches	8 inches	out-of-plane branch	2.43

Markl also cited a fatigue test by Blair [6] conducted on a $D_o = d_o = 6.5$ inches, t=T=0.26 inches, pad-reinforced tee with the following result:

Test	Pad thickness, t_r	Pad Outside Diameter	Load Direction	i_{test}
5	0.312 inches	10.75 inches	in-plane branch	2.58

Markl computed i-factors for these specimens, using Equation 1-1, of

Test	i_{test}	Eq. 1-1 i-factor	% Difference
1	1.78	1.98	11%
2	1.83	1.98	8%
3	2.21	3.17	44%
4	2.43	3.17	31%
5	2.58	2.16	-16%

2.2 EPRI Tests

2.2.1 Objectives

The most obvious void in Markl's information is the lack of fatigue tests on reduced branch outlet tees. To fill this void, fatigue tests on reduced branch outlet fabricated branch connections were conducted under this research effort.

2.2.2 Specimens

In-plane bending of the branch fatigue tests were conducted on four 8x4 inch NPS fabricated tees reinforced with 0.25 inch thick circular pads. The specimens were manufactured by Wilson Welding Service, Inc., of Decatur, GA. The reinforcement pad outside diameter was varied among the four specimens to examine the effect of this dimension. The specimen configurations are illustrated in Figure 2-1.

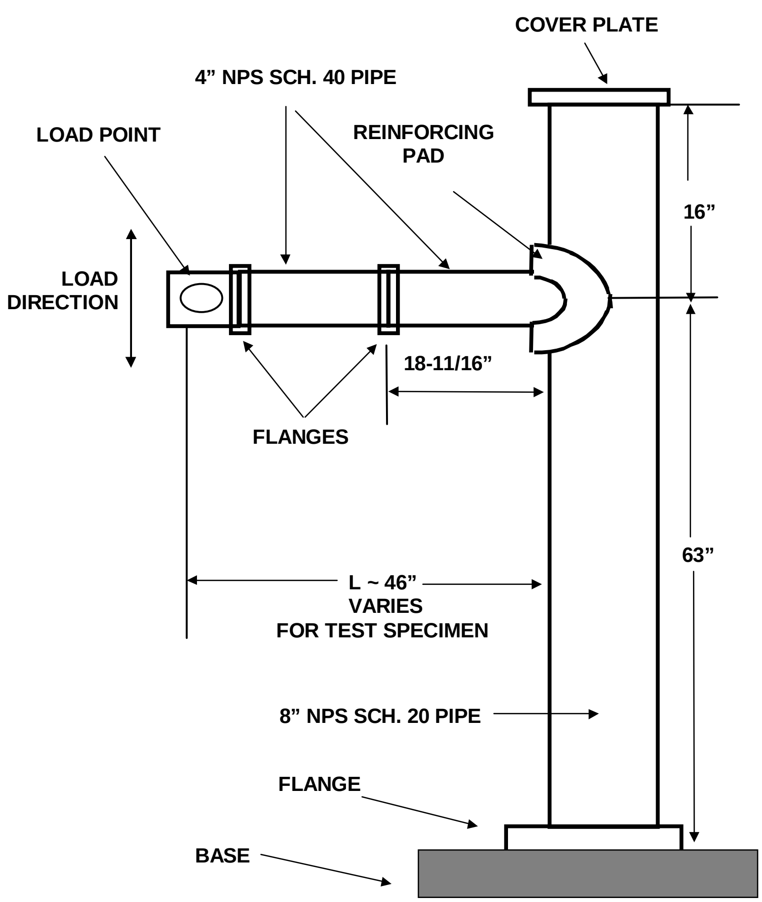

Figure 2-1
Test Configuration

2.2.3 Testing

The testing was performed at the Ohio State University. See reference [7] for a description of the test equipment and methodology.

The test distance from the load point to the surface of the pipe (~46 inches) varies slightly for each test specimen. The measured distance that is dependent on the installation is included in the test data.

The test data, results, and other information are provided in Appendix C. The tests were displacement-controlled cantilever bending tests. The tests followed the standard approach corresponding to Markl type tests [4]. Each specimen was first tested to determine the load deflection curve for that particular specimen. 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 loading directions (down and up). 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 to determine the fatigue life. Failure was detected when throughwall cracks formed at the toe of the filet weld in the longitudinal plane and water leaked through the crack.

2.2.4 Fatigue Test Results

Testing was conducted at Ohio State University. The test report is provided in Appendix C of this report. The fatigue test results for each specimen were as follows:

Specimen	Pad OD	Nominal Stress (M/z)	Cycles to Failure	i_{test}
E	6	26,773	1,260	2.20
F	7	23,997	1,901	2.26
G	9.5	28,752	1,366	2.01
H	7.5	28,133	1,075	2.16

The value of i is calculated from $i = 245{,}000\ N^{-0.2}/S$, where N = cycles to failure, and S = M/z = FL/z. The value of z in the calculation of the nominal stress is given by the expression $z=\pi r^2 t$ for consistency with the i-factors determined for unreinforced branch connections.

2.2.5 Stiffness Results

As discussed above**,** the stiffness of each of the four EPRI test specimens was determined experimentally and is given below. The width of the pad, D_{op}-d_o, divided by the “attenuation length” $2(D_o t_r)^{0.5}$ is also given for comparison.

Specimen	Stiffness (lbs / in)	D_{op} (in)	$(D_{op}-d_o)/(2(D_o t_r)^{0.5})$
E	1963	6.0	0.51
F	2018	7.0	0.85
G	2109	9.5	1.70
H	2092	7.5	1.02

The average stiffness is 2046 lbs / in. The range from this average value is +4 to -3%. This test series suggests that if the pad width divided by the attenuation length $2(D_o t_r)^{0.5}$ is greater than approximately 0.5, further increases in pad outside diameter, D_{op}, have no effect on i-factors or k- factors.

3

STRESS INTENSIFICATION FACTORS

3.1 Discussion

Pad-reinforced branch connections are similar to unreinforced branch connections. It is expected that, with an adjustment to account for the effects of the pad, the equations for the SIFs should be very similar. Consequently, the approach used in this study is to compare the data for the pad-reinforced branch connections to the results from the study on unreinforced branch connections and determine if an adjustment considering the reinforcement would result in a methodology that would be applicable to the pad-reinforced connections.

3.2 Unreinforced Fabricated Branch Connections

Reference [1] provides a detailed study of the SIFs for unreinforced fabricated branch connections. The equations for SIFs are developed based upon test data and extensive finite element analysis. The conclusions of the report contain the equations for the SIFs for different loading conditions, discussion on the combination of moments, and the applicability of the results. This information is summarized below:

For individual loadings, for example, torsion, in-plane and out-of-plane bending, the stress intensification factors for the branch and run pipe ends are given by:

$$i_{xy} = A_o (R/T)^{n1} (r/t)^{n2} (r/R)^{n3} \geq 1.0 \qquad \text{(eq. 3-1)}$$

	Part	SIF	A_o	n_1	n_2	n_3
In-plane bending	Branch	i_{ib}	0.515	1.05	-0.387	0.49
	Run	i_{ir}	0.985	-0.137	0.482	0.241
Out-of-plane bending	Branch	i_{ob}	Note 1	1.40	-0.558	0.406
	Run	i_{or}	0.605	-0.237	0.528	1.42
Torsion	Branch	i_{tb}	0.850	1.00	-0.50	2.10
	Run	i_{tr}	0.864	-0.0473	0.543	0.609

Note 1: Replace A_o with $1.28[1.28(r/R)-(r/R)^4]$

For combination of stresses due to different moments, the various code committees are considering changes at this time. Until these changes are finalized, the evaluation of the stresses must be based on the maximum i-factor for the branch and the maximum i-factor of the run. If Section III is the Code of record (for Class 2 or 3 piping), Equation 3-2 should be used for evaluating the branch connections where the branch and each end of the run pipe are evaluated.

$$S = \frac{i(M_i^2 + M_o^2 + M_t^2)^{1/2}}{Z_i} \quad \text{(eq. 3-2)}$$

The values of the moments and section modulus are appropriate for the location. The value of Z_i for the branch is given by the equation :

$$z = \pi r^2 t \quad \text{(eq. 3-3)}$$

For the run pipe, Z_i is:

$$Z = \pi R^2 T \quad \text{(eq. 3-4)}$$

For the branch, the value of i is the maximum of i_{ib}, i_{ob}, or i_{tb}. For the run, the value of i is the maximum of i_{ir}, i_{or}, or i_{tr}.

If B31.1 is the Code of record, a less conservative approach is permitted. This is discussed in reference [1].

The equations specified above in Equation 3-1 are applicable to the following range of parameters [1]:

$$3.75 \le R / T \le 49.5 \quad \text{(eq. 3-5)}$$
$$3.75 \le r / t \le 99 \quad \text{(eq. 3-6)}$$
$$0.125 \le r / R \le 1.0 \quad \text{(eq. 3-7)}$$

3.3 Extension to Pad-Reinforced Branch Connections

Table 3-1 lists the fatigue test results for pad-reinforced branch connections. The tests labeled 1, 2, 3, 4, and 5 were conducted or cited by Markl. The tests labeled E, F, G, and H are the EPRI-sponsored tests. The tests labeled K1, K2, K3, and K4 are from Khan [8]. The type of loading (in-plane or out-of-plane loading) is indicated. All loads were applied to the branch. The column titled "i_{test}" lists the experimentally determined i-factors.

Table 3-2 contains a comparison of the test i-factors to those derived from the present Code (labeled i_{Code}) and to the expressions for the unreinforced fabricated branch connections given in Equation 3-1 above (labeled i_{uft}). The columns marked “% Diff” contain the percentage differences between the test data and either i_{Code} or i_{uft}. Note that the form of the equation for i_{uft} used in Table 3-2 corresponds to the type of loading, in other words, loading on the branch, either in-plane or out-of-plane.

The average, maximum, and minimum percentage differences are also listed in Table 3-2.

Table 3-1
Test Data for Pad-Reinforced Fabricated Tees

Test	Load Direction	D_o (in.)	T (in.)	d_o (in.)	t (in.)	t_r (in.)	t_e (in.)	Pad OD D_{op} (in.)	R (in.)	r (in.)	R/T	r/t	r/R	t/T	t_r/T	i_{test}
1	in-plane	4.500	0.237	4.500	0.237	0.237	0.356	7.00	2.132	2.132	8.99	8.99	1.000	1.000	1.00	1.78
2	out-of-plane	4.500	0.237	4.500	0.237	0.237	0.356	7.00	2.132	2.132	8.99	8.99	1.000	1.000	1.00	1.83
3	in-plane	4.500	0.120	4.500	0.120	0.120	0.180	8.00	2.190	2.190	18.25	18.25	1.000	1.000	1.00	2.21
4	out-of-plane	4.500	0.120	4.500	0.120	0.120	0.180	8.00	2.190	2.190	18.25	18.25	1.000	1.000	1.00	2.43
5	in-plane	6.500	0.260	6.500	0.260	0.312	0.416	10.75	3.120	3.120	12.00	12.00	1.000	1.000	1.20	2.58
E	in-plane	8.625	0.250	4.500	0.237	0.250	0.375	6.00	4.188	2.132	16.75	8.99	0.509	0.948	1.00	2.20
F	in-plane	8.625	0.250	4.500	0.237	0.250	0.375	7.00	4.188	2.132	16.75	8.99	0.509	0.948	1.00	2.26
G	in-plane	8.625	0.250	4.500	0.237	0.250	0.375	9.50	4.188	2.132	16.75	8.99	0.509	0.948	1.00	2.01
H	in-plane	8.625	0.250	4.500	0.237	0.250	0.375	7.50	4.188	2.132	16.75	8.99	0.509	0.948	1.00	2.16
K1	out-of-plane	8.625	0.322	3.500	0.216	0.322	0.483	6.00	4.152	1.642	12.89	7.60	0.396	0.671	1.00	1.95
K2	out-of-plane	8.625	0.322	6.625	0.280	0.322	0.483	12.00	4.152	3.173	12.89	11.33	0.764	0.870	1.00	2.78
K3	out-of-plane	12.75	0.375	6.625	0.280	0.375	0.563	12.00	6.188	3.173	16.50	11.33	0.513	0.747	1.00	3.47
K4	out-of-plane	12.75	0.375	8.625	0.322	0.375	0.563	15.00	6.188	4.152	16.50	12.89	0.671	0.859	1.00	3.91

Notes:
1. This table is produced on a spreadsheet using EXCEL. The number of significant figures is greater than indicated.
2. All loads are on the branch.

Table 3-2
Comparison to Unreinforced Branch Connections and Code Expressions

Test	Load Direction	R/T	r/t	r/R	i_{test}	i_{uft}	%Diff	i_{Code}	%Diff
1	in-plane	8.99	8.99	1.000	1.78	2.20	19.1	1.98	11.2
2	out-of-plane	8.99	8.99	1.000	1.83	2.28	19.7	1.98	8.2
3	in-plane	18.25	18.25	1.000	2.21	3.51	37.1	3.17	43.6
4	out-of-plane	18.25	18.25	1.000	2.43	4.13	41.2	3.17	30.6
5	in-plane	12.00	12.00	1.000	2.58	2.66	3.1	2.16	-16.5
E	in-plane	16.75	8.99	0.509	2.20	3.04	27.7	2.84	29.5
F	in-plane	16.75	8.99	0.509	2.26	3.04	25.7	2.84	26.0
G	in-plane	16.75	8.99	0.509	2.01	3.04	33.8	2.84	41.3
H	in-plane	16.75	8.99	0.509	2.16	3.04	29.0	2.84	31.8
K1	out-of-plane	12.89	7.60	0.396	1.95	2.18	10.4	1.69	-13.4
K2	out-of-plane	12.89	11.33	0.764	2.78	2.57	-8.1	2.19	-21.3
K3	out-of-plane	16.50	11.33	0.513	3.47	2.74	-26.6	2.22	-36.1
K4	out-of-plane	16.50	12.89	0.671	3.91	2.97	-31.5	2.55	-34.8
						AVE =	13.9	AVE =	22.9
						MAX=	41.2	MAX=	43.6
						MIN=	-31.5	MIN=	-16.5

Notes:
1. This table is produced on a spreadsheet using EXCEL.
The number of significant figures is greater than indicated.
2. i_{uft} is determined by Equation 3-1 in this report.

3.4 Adjusted Thickness

It appears reasonable to assume that the pad thickness effectively increases the thickness of the run pipe and hence should act to reduce the SIF. Markl [4] considered this by using a larger "effective thickness" in determining SIFs for pad-reinforced branch connections. Following this approach, the use of an "effective thickness" will be considered.

The expressions derived for unreinforced branch connections are in terms of the parameters: (R/T), (r/t), and (r/R). The effectiveness of the reinforcement of the run pipe is perhaps best reflected in the (R/T) term. Thus (R/T) term will be replaced by (R/T*) where

$$T^* = T + Ct_r \qquad \text{(eq. 3-8)}$$

"C" is a constant to be determined.

The value of "C" was selected based on an evaluation of the percentage difference (% Diff) between the modified values of i and the test data. Table 3-3 shows the effects of adjusting the thickness on the SIFs (labeled i-pad in Table 3-3). It was determined that for C = 1/2, the average percentage difference was 0.9%. The range was from -37% to +42%.

Thus, Equation 3-1 should be replaced by:

$$i_{xy} = A_o\,(R/T^*)^{n1}(r/t)^{n2}(r/R)^{n3} \geq 1.0 \qquad \text{(eq. 3-9)}$$

where

$$T^* = T + t_r/2 \qquad \text{(eq. 3-10)}$$

While the test data is primarily for in-plane bending of the branch, it is reasonable to assume that the use of T* is valid for all loading conditions on the branch since the SIFs are based on the same theoretical approach. The same assumptions should also be applicable to the SIFs for the loads on the run pipe.

Table 3-3
Effects of Adjusted Thickness

Test	Load	T	T*=T+C tr	R/T	R/T*	r/t	r/R	i-pad	i_{test}	%Diff	i-pad/i-test
1	in-plane	0.237	0.356	8.99	6.00	8.99	1.000	1.44	1.78	-19.3	0.81
2	out-of-plane	0.237	0.356	8.99	6.00	8.99	1.000	1.29	1.83	-29.4	0.71
3	in-plane	0.120	0.180	18.25	12.17	18.25	1.000	2.29	2.21	3.8	1.04
4	out-of-plane	0.120	0.180	18.25	12.17	18.25	1.000	2.34	2.43	-3.6	0.96
5	in-plane	0.260	0.416	12.00	7.50	12.00	1.000	1.62	2.58	-37.0	0.63
E	in-plane	0.250	0.375	16.75	11.17	8.99	0.509	1.98	2.20	-9.7	0.90
F	in-plane	0.250	0.375	16.75	11.17	8.99	0.509	1.98	2.26	-12.1	0.88
G	in-plane	0.250	0.375	16.75	11.17	8.99	0.509	1.98	2.01	-1.4	0.99
H	in-plane	0.250	0.375	16.75	11.17	8.99	0.509	1.98	2.16	-8.0	0.92
K1	out-of-plane	0.322	0.483	12.89	8.60	7.60	0.396	2.77	1.95	42.2	1.42
K2	out-of-plane	0.322	0.483	12.89	8.60	11.33	0.764	3.83	2.78	37.9	1.38
K3	out-of-plane	0.375	0.563	16.50	11.00	11.33	0.513	4.24	3.47	22.3	1.22
K4	out-of-plane	0.375	0.563	16.50	11.00	12.89	0.671	4.92	3.91	26.1	1.26
									AVE =	0.9	
									MAX=	42.2	
									MIN=	-37.0	
Notes:											
1. This table is produced on a spreadsheet using EXCEL.											
The number of significant figures is greater than indicated.											
2. The value of "i-pad" is calculated from Equation 3-1 using the adjusted thickness T*.											

3.5 Applicability

In addition to the limits of applicability of the expressions for the SIFs for unreinforced branch connections, (Equations 3-5 to 3-7), there are limits for pad configurations for which the use of the adjusted thickness are valid. Based upon the test configurations, it is suggested that these results are applicable when:

$$0 \leq t_r/T \leq 1.25 \qquad \text{(eq. 3-11)}$$

$$0 \leq D_{op}/d_o \leq 2.0 \qquad \text{(eq. 3-12)}$$

where D_{op} is the outside diameter of the pad.

4

FLEXIBILITY OF PAD-REINFORCED BRANCH CONNECTIONS

4.1 Discussion

In piping design, the flexibility of the piping components can be as significant as the SIFs. Reference [1] discusses the impact of including the flexibility of unreinforced branch connections in an analysis and shows that the loads and stresses can be significantly reduced. The impact of the flexibility of pad-reinforced branch connections can be as significant.

The present Code does not clearly define flexibility factors for all configurations of branch connections. For ASME Class 1, the Code does provide some direction, however, it is not complete. Configurations with $r/R > 0.5$ are not covered. For Class 2 piping, the flexibility factor is defined to be 1.0 which, as discussed in [1], is misleading at best.

Reference [1] provides guidance (equations) for the determination of flexibility factors for branch connections. As with the SIFs, these equations should be valid for pad-reinforced branch connections with an adjustment to consider the effects of the pad.

4.2 Unreinforced Fabricated Branch Connections

Reference [1] provides the results of a detailed study of the flexibility factors for unreinforced fabricated branch connections. The equations are based on extensive finite element analyses. The conclusions of the report contain the equations for the flexibility factors for the various loading conditions and the applicability of the results. This information is summarized below:

The flexibility modeling of the branch connection should be based on Figure 4-1 for branch loading. Point springs are assumed to exist to represent the flexibility of the connection. For branch loading, it is assumed there is a rigid link from the centerline of the run pipe to its outer surface. At this point, it is assumed that a point spring exists. The flexibility factors of the point springs are given by:

$$k_{xy} = B_o (D/T)^{n1}(d/D)^{n2}(d/t)^{n3} \qquad \text{(eq. 4-1)}$$

	Part	k	B_o	n_1	n_2	n_3
In-plane bending	Branch	k_{ib}	0.488	1.279	0.391	-0.602
	Run	k_{ir}	0.995	0.675	3.78	-0.250
Out-of-plane bending	Branch	k_{ob}	Note 1	1.72	0.5057	-0.717
	Run	k_{or}	0.0771	-0.159	4.096	1.305
Torsion	Branch	k_{tb}	2.43	0.751	2.11	-0.553
	Run	k_{tr}	0.813	0.982	4.328	-0.349

Note 1: Replace B_o with $0.828\,(3.0\,(d/D) - 3.75(d/D)^2 + (d/D)^3)$

Note 2: For $d/D < 0.5$, values of k_{ir}, k_{or}, and k_{tr} are small and should be set to zero. The equations for k_{ir}, k_{or}, and k_{tr} are valid only for $d/D \geq 0.5$.

The equations specified above are applicable to the following range of parameters [1]:

$3.75 \leq R/T \leq 49.5$ (eq. 3-5)

$3.75 \leq r/t \leq 99$ (eq. 3-6)

$0.125 \leq r/R \leq 1.0$ (eq. 3-7)

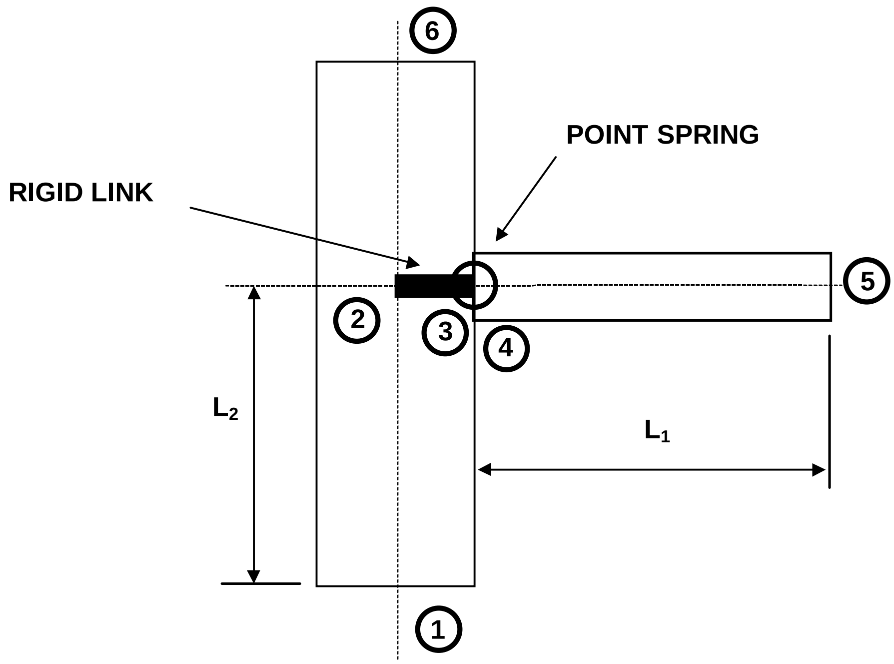

Figure 4-1
Beam Model for Branch Loading

4.3 Comparison to Test Data

In a limited manner, the test data from the SIF tests performed for this study can be used to evaluate the applicability of these equations (at least for in-plane loading of the branch connection). It should be noted that these tests were not specifically designed for evaluation of the flexibility factors. For this evaluation, it is assumed that the branch will act as a continuous straight section of pipe. In reality, as indicated in Figure 2-1, the section consists of a section of pipe, pipe flanges, and a "loading point" section, which is made from a flat plate.

The model depicted in Figure 4-1 will be used as the basis for evaluating the test results and determining the flexibility of the branch connection. In this case, the bottom of the run pipe (point 1) is fixed and the top (point 6) is free. The in-plane load is applied on the branch at point 5. As discussed earlier, the "stiffness", K, was determined experimentally from the load deflection data to be, on the average, K = 2046 lbs / in. The range was very small.

The rotation at point 2, with respect to the fixed end (point 1) is given by:

$$\phi_{2\text{-}1} = F\, L_1\, L_2 / (EI_r) \qquad \text{(eq. 4-2)}$$

where F is the applied force.

The deflection at point 5 due to this rotation is:

$$\delta_a = \phi_{2\text{-}1} L_1 = F L_1^2 L_2 / (EI_r) \qquad \text{(eq. 4-3)}$$

The rotation in the point spring is:

$$\phi_{3\text{-}4} = k_{ib} M_4 d_o / EI_b = k_{ib} F L_1 d_o / EI_b \qquad \text{(eq. 4-4)}$$

where M_4 is the moment at point 4,

The deflection at point 5 due to this rotation is:

$$\delta_b = \phi_{3\text{-}4} L_1 = k_{ib} F L_1^2 d_o / EI_b \qquad \text{(eq. 4-5)}$$

The deflection at point 5 due to the bending of the branch is:

$$\delta_c = FL_1^3 / (3EI_b)$$

The total deflection is $\delta = \delta_a + \delta_b + \delta_c$, or:

$$\delta = F L_1^2 L_2 / (EI_r) + k_{ib} F L_1^2 d_o / EI_b + FL_1^3 / (3EI_b) \qquad \text{(eq. 4-6)}$$

The deflection is also given by:

$$\delta = F / K \qquad \text{(eq. 4-7)}$$

Substituting Equation 4-7 into Equation 4-6 and solving for k_{ib} yields:

$$k_{ib} = [1 / K - L_1^2 L_2 / (EI_r) - L_1^3 / (3EI_b)] EI_b / (L_1^2 d_o) \qquad \text{(eq. 4-8)}$$

Using K = 2046 lbs./in. (the average of the test data), D_o = 8.625 in., d_o = 4.5 in., L_1 = 46 in.,
L_2 = 63 in. E = 30 E6 psi, I_r = 57.7 in^3, and I_b = 7.23 in.^{3} yields k_{ib} = 5.97. As discussed earlier, because test configuration included flanges, etc., this is considered to be a very rough estimate of the flexibility of the test configuration.

Reference [9] lists experimental flexibility data from several sources. Khan [10] also provides experimental flexibility data. This information is summarized in Table 4-1 along with the average data for the tests performed for this study as described above.

When investigating SIFs it was determined that more accurate values could be obtained by using adjusted values of T, in other words, T* = T + t_r / 2 (Equation 3-10) in the equations for SIFs. Table 4-1 lists the values for k_{ib} and k_{ob} calculated using this adjusted value for $T^* = T + t_r/2$ in Equation 4-1. A comparison to the test data is also provided.

For out-of-plane bending using Equation 4-1 with the adjusted value of T yields results that are reasonably close with an average difference of 10.2%. For in-plane bending, the results are different. The differences on a percentage basis are much greater, however, it should be noted that the magnitudes of the flexibilities are much smaller. The average value of k_{ib} is 3.8 versus 16.9 for k_{ob}. It is more difficult to experimentally determine flexibility factors that are small than it is to determine larger values. Also, the potential impact of this order of magnitude difference would not significantly affect the results.

Based upon the overall results, it is deemed reasonable to use Equation 4-1 with the adjusted value of $T^* = T + t_r/2$ for k_{ib} and k_{ob}. In addition, since the theoretical basis is the same, it is reasonable to extend the same approach for the torsional stiffness of the branch, k_{tb}.

However, there does not appear to be sufficient data to justify adjusting flexibility of the run pipe for the effect of the pad-reinforced branch connection. Consequently, until more data is available, it is suggested that no additional flexibility be added to the run pipe for pad-reinforced branch connections.

Table 4-1
Test Data for Pad-Reinforced Branch Connections

Test	D_o	T	d_o	t	t_r	$T^*=T+t_r/2$	D/T*	d/D	d/t	k_{ob}	k_{test}	% Diff	k_{ib}	k_{test}	% Diff
	(in.)	(in.)	(in.)	(in.)	(in.)	(in.)									
1. EFGH (Ave)	8.625	0.250	4.50	0.237	0.250	0.375	22.33	0.509	17.99	10.65	N/A	N/A	3.50	5.97	-41.4
2. 24 x 12	24.00	0.312	12.75	0.250	0.375	0.500	47.42	0.528	50.00	18.98	18.0	5.5	5.02	5.60	-10.4
3. 24 x 4	24.00	0.312	4.50	0.237	0.375	0.500	47.42	0.180	17.99	14.19	20.0	-29.1	6.10	4.70	29.8
4. 24 x 8	24.00	0.312	8.625	0.250	0.375	0.500	47.42	0.354	33.50	19.16	28.0	-31.6	5.46	3.60	51.7
5. 16 x 6	16.00	0.500	6.625	0.280	0.500	0.750	20.67	0.409	22.66	6.88	8.40	-18.1	2.53	1.50	68.7
6. 48 x 6	49.25	0.625	6.625	0.280	0.625	0.938	51.87	0.130	22.66	9.27	10.0	-7.3	5.25	1.60	228.1
7. K1	8.625	0.322	3.500	0.216	0.322	0.483	17.19	0.396	15.20	6.49	3.9	66.4	2.51	N/A	N/A
8. K2	8.625	0.322	6.625	0.280	0.322	0.483	17.19	0.764	22.66	5.64	4.6	22.6	2.55	N/A	N/A
9. K3	12.75	0.375	6.625	0.280	0.375	0.563	22.00	0.513	22.66	8.82	5.8	52.1	2.99	N/A	N/A
10. K4	12.75	0.375	8.625	0.322	0.375	0.563	22.00	0.671	25.79	8.40	6.4	31.3	3.08	N/A	N/A
										AVERAGE =		10.2		AVE =	54.4
										MAXIMUM=		66.4		MAX =	228.1
										MINIMUM =		-31.6		MIN =	-41.4
Notes:															
1. This table is produced on a spreadsheet using EXCEL. The number of significant figures is greater than indicated.															
2. Test "EFGH (Ave)" refers to the average results from the four tests performed as a part of this study.															
3. Tests 2 through 6 are from Reference 9, NUREG/CR-4785.															
4. Tests 7 through 10 are from Khan (Reference 10).															

5

CONCLUSIONS

For reinforced branch connections, the conclusions derived from the tests and analysis described in this report are listed below.

5.1 Stress Intensification Factors

For individual loadings, for example, torsion, in-plane and out-of-plane bending, the stress intensification factors for the branch and run pipe ends are given by:

$$i_{xy} = A_o (R/T^*)^{n1} (r/t)^{n2} (r/R)^{n3} \geq 1.0$$

	Part	SIF	A_o	n_1	n_2	n_3
In-plane bending	Branch	i_{ib}	0.515	1.05	-0.387	0.49
	Run	i_{ir}	0.985	-0.137	0.482	0.241
Out-of-plane bending	Branch	i_{ob}	Note 1	1.40	-0.558	0.406
	Run	i_{or}	0.605	-0.237	0.528	1.42
Torsion	Branch	i_{tb}	0.850	1.00	-0.50	2.10
	Run	i_{tr}	0.864	-0.0473	0.543	0.609

Note 1: Replace A_o with $1.28[1.28(r/R)-(r/R)^4]$
Note 2: $T^* = T + t_r/2$

5.2 Combination Of Moments

For combination of stresses due to different moments, the various code committees are considering changes at this time. Until these changes are finalized, the evaluation of the stresses must be based on the maximum i-factor for the branch and the maximum i-factor of the run. If Section III is the Code of record (for Class 2 or 3 piping), Equation 3-2 should be used for evaluating the branch connections where the branch and each end of the run pipe are evaluated.

$$S = \frac{i(M_i^2 + M_o^2 + M_t^2)^{1/2}}{Z_i} \qquad \text{(eq. 3-2)}$$

The values of the moments and section modulus are appropriate for the location. The value of Z_i for the branch is given by equation :

$$z = \pi r^2 t \qquad \text{(eq. 3-3)}$$

For the run pipe, Z_i is:

$$Z = \pi R^2 T \qquad \text{(eq. 3-4)}$$

For the branch, the value of i is the maximum of i_{ib}, i_{ob}, or i_{tb}. For the run, the value of i is the maximum of i_{ir}, i_{or}, or i_{tr}.

If B31.1 is the Code of record, a less conservative approach is permitted. This is discussed in detail in reference [1].

5.3 Flexibility Factors

The flexibility modeling of the branch connection should be based on Figure 4-1 for the branch. As indicated in the figure, it assumed that a point spring represents the connection. The flexibility factors of the point spring are given by:

$$k_{xy} = B_o\,(D / T^*)^{n1}(d / D)^{n2}(d / t)^{n3} \qquad \text{(eq. 4-1)}$$

	Part	k	B_o	n_1	n_2	n_3
In-plane bending	Branch	k_{ib}	0.488	1.279	0.391	-0.602
Out-of-plane bending	Branch	k_{ob}	Note 1	1.72	0.5057	-0.717
Torsion	Branch	k_{tb}	2.43	0.751	2.11	-0.553

Note 1. Replace B_o with $0.828\,(3.0\,(d / D) - 3.75(d / D)^2 + (d / D)^3)$
Note 2. $T^* = T + t_r / 2$
Note 3. It is assumed that pad-reinforced branch connection has no effect on the flexibility of the run pipe. The values of k for the point spring for the run pipe are set equal to zero.

5.4 Applicability of Results

The equations specified above in 5.1 and 5.3 are applicable to the following range of parameters:

$3.75 \leq R / T \leq 49.5$ (eq. 3-5)

$3.75 \leq r / t \leq 99$ (eq. 3-6)

$0.125 \leq r / R \leq 1.0$ (eq. 3-7)

This is discussed in detail in reference [1].

In addition, the following limitations are specified for the pad configuration:

$0 \leq t_r/T \leq 1.25$ (eq. 3-11)

$0 \leq D_{op}/d_o \leq 2.0$ (eq. 3-12)

5.5 B Indices

This report is focused on SIFs and flexibility factors for ASME Section III Class 2 or 3 and ANSI B31.1 piping. Certain editions of ASME Section III require the use of B indices for the qualification of Class 2 or 3 piping. The scope of this report did not address the B indices.

If B indices are required in the qualification process, it is suggested that the existing plant-specific Code of record be followed.

5.6 Comparison to Present Code

As discussed in reference [1], the equations developed for SIFs for unreinforced fabricated tees are more conservative than the present Code for certain geometry parameters. This is intended to cover certain unconservatism in the Code, which has been documented in various previous studies. This unconservatism has been addressed by the equations developed in reference [1] and used as the basis for the equations herein.

The use of the expressions defined in this report will result in a more realistic evaluation of pad-reinforced branch connections.

6

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2. *ASME Boiler and Pressure Vessel Code, Section III, Nuclear Power Plant Components*, American Society of Mechanical Engineers, New York, 1995

3. *Code for Pressure Piping, B31.1, Power Piping,* American National Standards Institute (ANSI), American Society of Mechanical Engineers, New York.

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5. ANSI Code Case 53, June 1965, American Society of Mechanical Engineers, New York, New York.

6. Blair, J. S., "Reinforcement of Branch Pieces", *Engineering*, London, England, 1947.

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8. Khan, Akhtar S., "A Study of Stress Intensification Factors of Integrally Reinforced Shell to Shell Intersections", *Int. J. Pres. Ves. & Piping*, Vol. 29, pgs. 83-94 (1987).

9. NUREG/CR-4785, ORNL-6339, "Review and Evaluation of Design Analysis Methods for Calculating Flexibility of Nozzles and Branch Connections", Moore, S. E., Rodabaugh, E. C., Mokhtarian, K., and Gwaltney, R. C., Oak Ridge National Laboratory, December 1987.

10. Khan, Akhtar S., "A Study of Flexibility Factors of Integrally Reinforced Shell to Shell Intersections", *Int. J. Pres. Ves. & Piping,* Vol. 29, pgs. 23-31 (1987).

A

MATERIAL CERTIFICATIONS

Steel Tubular Products Company

SHIPPER'S NUMBER: 6801-20553

CERTIFICATE OF TESTS

SALES ORDER NO.: 217176 00

BILL OF LADING NUMBER: 6801-20553

PUR. ORD. DATE: 5/10/96

PURCHASE ORDER NO.:

SOLD TO:
PIPING & EQUIPMENT CO
PO BOX 1377
2251 PLUNKETT ROAD
CONYERS GA 30207

CONSIGNED TO:
PIPING & EQUIPMENT CO
2291 PLUNKETT ROAD
CONYERS GA 30207-3433

SHIP DATE: 6/10/96 FROM: COUNCE

I HEREBY CERTIFY THAT THE MATERIAL LISTED HEREIN HAS BEEN INSPECTED AND TESTED IN ACCORDANCE WITH THE METHODS PRESCRIBED IN THE GOVERNING SPECIFICATIONS AND BASED UPON THE RESULTS OF SUCH INSPECTION AND TESTING HAS BEEN APPROVED FOR CONFORMANCE TO THE SPECIFICATIONS.

L. J. Deeb
Product/Process Metallurgist

ITEM	ITEM DESCRIPTION / SPECIFICATION	QTY SHIPPED
01	ERW STANDARD PIPE 4.500 OD .237W CUT 21' PE BEV REG MILL COAT Itm-001 P/N: 028416 ASTM A53-95 GRADE B	98 PC 2069.0 FT 22326 LB

HEAT NO.	LOT	✓		C	MN	P	S	SI	CU	NI	CR	MO	V	AL	CB	CA	SN	B	CO	N	TI
D64014				190	108	014	004	020	04	00	035	002	000	049			003				
D64022				200	99	008	005	010	02	00	039	006	000	046			014				

HEAT NO.	LOT NO.	I D	YIELD STR PSI	TENSILE STR PSI	WELD UTS PSI	TENSILE SAMPLE SZ (IN)	ELONG % IN 2"	HARDNESS	HYDRO PSI	
D64014	A	1	63600	73800		L S 1.00	32.0		2210	5 Sec Hydro Flatten Test OK
D64022	A	1	53300	74500		L S 1.00	32.0		2210	5 Sec Hydro Flatten Test OK
D64022	B	1	61900	73400		L S 1.00	33.0		2210	5 Sec Hydro Flatten Test OK

RECEIVED JUN 21 1996 CONYERS

MET 0049 (11/92) T - TRANSVERSE L - LONGITUDINAL T - TUBE S - STRIP

Figure A-1
Certificate of Tests

Steel Tubular Products Company

CERTIFICATE OF TESTS

6801-16978

175249 00

6801-16978

3/28/95

50-8-49996

MARMON/KEYSTONE CORP
10700 MARMON DRIVE
BOLINGBROOK IL 60440

MARMON/KEYSTONE CORP
10700 MARMON DRIVE
BOLINGBROOK IL 60440

I HEREBY CERTIFY THAT THE MATERIAL LISTED HEREIN HAS BEEN INSPECTED AND TESTED IN ACCORDANCE WITH THE METHODS PRESCRIBED IN THE GOVERNING SPECIFICATIONS AND BASED UPON THE RESULTS OF SUCH INSPECTION AND TESTING HAS BEEN APPROVED FOR CONFORMANCE TO THE SPECIFICATIONS.

L. J. Deeb
Product/Process Metallurgist
By T Rich
Metallurgical Technician

ITEM	ITEM DESCRIPTION / SPECIFICATION	QTY SHIPPED
02	ERW STANDARD PIPE 8.625 OD .250W DRL PE BEV REG MILL COAT Itm-002 P/N: 001697 API 5L ASTM A53-94 GRADE B ASME SA53-92 GRADE B A93 ADDENDA	21 PC 920.0 FT 20571 LB

Attn: Scott

Piping And Equipment Co.
Conyers, Georgia
(770) 922-0300

HEAT NO.		C	MN	P	S	SI	CU	NI	CR	MO	V	AL	CB	CA	SN	B	CO	N	TI
D52570		.100	203	013	003	.210	.01	.00	.023	.001	.000	.038			005				
0947853		.180	103	010	008	.237	.01	.00	.020	.000	.004	.053	.001		017	0002			

HEAT NO.	LOT NO.		YIELD STR PSI	TENSILE STR PSI	WELD UTS PSI	[illegible]	ELONG %	HARDNESS	HYDRO PSI	
D52570	A	1	53700	71600	74700	T 1.50	33.0		2195	5 Sec Hydro Flatten Test OK
0947853	A	1	49700	65600	70400	T 1.50	39.0		2195	5 Sec Hydro Flatten Test OK
0947853	B ✓	1	49600	65100	71000	T 1.50	38.0		2195	5 Sec Hydro Flatten Test OK

Q.C. REVIEWED
LB 4 28 95

MARMON/KEYSTONE CORPORATION
The record to which this stamp is affixed is a copy of the original supplier's test report. There is no record that the contents of this record agree with the requirements of the second order as shown in this record, except for the items which are noted. The identity however of the material supplied by us is completely identifiable by this document.
Cust. P.O. 0158117
MKC Order No. 5183
Date 5-1-96
Signed
FOR THE QUALITY CONTROL DEPARTMENT

USY 0040 (1/86)   T = TRANSVERSE L = LONGITUDINAL T = TUBE S = STRIP

Figure A-2
Certificate of Tests

TIV Steel Tubular Products Company

6801-19907

CERTIFICATE OF TESTS

213906 00

6801-19907

4/01/96 | 20-03476 REPLACE

MARMON/KEYSTONE CORP
4250 BLUE RIDGE INDUSTRIAL
PARKWAY
NORCROSS GA 30071

MARMON/KEYSTONE CORP
4250 BLUE RIDGE INDUSTRIAL
PARKWAY
NORCROSS GA 30071

4/02/96 COUNCE

I HEREBY CERTIFY THAT THE MATERIAL LISTED HEREIN HAS BEEN INSPECTED AND TESTED IN ACCORDANCE WITH THE METHODS PRESCRIBED IN THE GOVERNING SPECIFICATIONS AND BASED UPON THE RESULTS OF SUCH INSPECTION AND TESTING HAS BEEN APPROVED FOR CONFORMANCE TO THE SPECIFICATIONS.

L. J. Dean
Product/Process Metallurgist
By T Rich
Metallurgical Technician

ITEM	ITEM DESCRIPTION / SPECIFICATION	QTY SHIPPED
02	ERW STANDARD PIPE 8.625 OD .250W DRL PE UBV REG MILL COAT Itm-002 P/N: 001699 API 5L ASTM A53-95 GRADE B ASME SA53-92 GRADE B A99 ADDENDA	11 PC 474.0 FT 10693 LB

RECEIPT LOGGED
INIT. 16
DATE 4-16-96

HEAT NO.	C	MN	P	S	SI	CU	NI	CR	MO	V	AL	CB	CA	RN	B	CO	N	TI
0950276	.190	.94	.019	.011	.013	.06	.01	.040	.000	.004	.059	.	.001	.006	.0001	.	.	.

HEAT NO.	LOT NO.	YIELD STR	TENSILE STR	WELD UTS	ELONG	HARDNESS	HYDRO	
0950276	C	48800	65800	70000	1.50 40.0		1830	5 SEC HYDRO FLATTEN TEST OK

. WELD TYPE . . . T = TRANSVERSE L = LONGITUDINAL . . . T = TUBE S = STRIP

Artha Scott

Piping And Equipment Co.
Conyers, Georgia
(770) 922-0800

MARMON/KEYSTONE CORPORATION
This report to which this stamp is affixed, is a copy of the original supplier's test report. There is no record of the complete identification of this material, but it is typical of stock made in accordance with specifications requirements, except items marked on this report. These items which are marked as to piece or having been received with the material, shipped to you is completely identified by this document.
Cust. P.O. 0155807
MKC Order No. 51 RT
Date 7-19-96
Signed
FOR THE QUALITY CONTROL DEPARTMENT

8.625 X .250

Figure A-3
Certificate of Tests

B

CALIBRATION RECORD

Calibration Record

MTS Systems Corporation
14000 Technology Drive
Eden Prairie, MN 55344-2290

Calibration Report

Page 1 of 2

Customer: Name Ohio State University — System No. 870.54
System ID Axial-torsion — Location Composite lab — Site No. C84006-M05

Equipment
Device Type: Displacement — X Force — _ Pressure — _ Extensometer: Gage Length n/a — _ Other n/a
Device Model No. 6483 — Serial No. 175
Controller/Conditioner Model 458.11 — Serial No. 107 — Calibration Data File Name n/a
Readout Device Model No: n/a — Serial No. n/a — Channel n/a

Procedure
MTS Procedure No. 1234 — Rev B
Calibration has been performed in accordance with: _ ASTM E4- 94 — _ Other n/a — _ Not Required
Method of verification: Set the force

Calibration Equipment Asset NO.* DVM 13475 — Indicator 10976 — Standardizer 10559 — Temp Readout 13477
Additional Equipment n/a

Conditions Ambient Temperature 68 deg. F — Retraction X Positive — _ Negative — Bidirectional: _ Yes X No
Ref Voltage: Initial 10.000 V — Final 10.000 V — Other n/a

Range 4 — Full Scale 10 Percent

Asset No. (Standard) 12501
Class A Loading Range 1106.96
Data Mode X Ascending _ Decending

	Initial		Final
Excitation	10.998		10.998
Gain	n/a		n/a
ΔK	On In / Off	On / Off	In
Shunt Cal +	6.943	+	6.943
Shunt Cal -	n/a	-	n/a
Cal Factor	n/a		n/a
Phase	n/a		n/a
Zero Offset	n/a		n/a

Run No. 1 - As Found, Within Tolerance: x yes _ no; Run No. 1 - As Adjusted (If required); Run No. 2

Percent	Custom Percent	Run 1 As Found Indicated Reading	Run 1 As Found Error % of Reading	As Adjusted Indicated Reading	As Adjusted Error % of Reading	Run 2 Indicated Reading	Run 2 Error % of Reading
100		9.967 V	-0.33%			9.986 V	-0.14%
80		7.992 V	-0.10%			7.994 V	-0.08%
60		5.992 V	-0.13%			5.996 V	-0.07%
40		3.997 V	-0.08%			3.999 V	-0.02%
20	22.13	2.211 V	-0.09%			2.211 V	-0.09%
Start 0		0.000 V				0.000 V	
Ret 0		0.000 V				0.000 V	
Ret 0		0.000 V				0.000 V	
Start 0		0.000 V				0.000 V	
-20	-22.13	-2.223 V	+0.45%			-2.223 V	+0.45%
-40		-4.016 V	+0.40%			-4.013 V	+0.32%
-60		-6.020 V	+0.43%			-6.016 V	+0.27%
-80		-8.026 V	+0.32%			-8.023 V	+0.29%
-100		-10.034 V	+0.34%			-10.033 V	+0.33%

Range 3 — Full Scale 20 Percent

Asset No. (Standard) 12501
Class A Loading Range 1106.96
Data Mode X Ascending _ Decending

	Initial		Final
Excitation	10.993		10.993
Gain	n/a		n/a
ΔK	On In / Off	On / Off	In
Shunt Cal +	6.939	+	6.939
Shunt Cal -	n/a	-	n/a
Cal Factor	n/a		n/a
Phase	n/a		n/a
Zero Offset	n/a		n/a

Run No. 1 - As Found, Within Tolerance: x yes _ no; Run No. 1 - As Adjusted (If required); Run No. 2

Percent	Custom Percent	Run 1 As Found Indicated Reading	Run 1 As Found Error % of Reading	As Adjusted Indicated Reading	As Adjusted Error % of Reading	Run 2 Indicated Reading	Run 2 Error % of Reading
100		9.971 V	-0.29%			9.970 V	-0.30%
80		7.977 V	-0.29%			7.975 V	-0.31%
60		5.983 V	-0.28%			5.982 V	-0.30%
40		3.988 V	-0.30%			3.989 V	-0.28%
20		1.994 V	-0.30%			1.994 V	-0.30%
Start 0		0.000 V				0.000 V	
Ret 0		0.000 V				0.000 V	
Ret 0		0.000 V				0.000 V	
Start 0		0.000 V				0.000 V	
-20		-2.004 V	+0.20%			-2.003 V	+0.16%
-40		-4.008 V	+0.20%			-4.006 V	+0.15%
-60		-6.015 V	+0.25%			-6.009 V	+0.15%
-80		-8.016 V	+0.20%			-8.013 V	+0.16%
-100		-10.017 V	+0.17%			-10.016 V	+0.16%

Notes:

Performed by: ______________________ Print — Date: 6/28/95

______________________ Signature — Next Recommended Calibration Due Date: 6/28/96

* MTS Measurement Standards are Traceable to the National Institute of Standards and Technology.
MTS Force Standards are temperature compensated in the range specified by the manufacturer.

Form Number 114093-11D (04-94)-PC

Figure B-1
Calibration Report

Moke.

MTS Systems Corporation
14000 Technology Drive
Eden Prairie, MN 55344-2290

Calibration Report

Page 2+B26 of 2

Customer Name: Ohio State University — System No. 870.54
System ID: Axial-torsion — Location: Composite lab — Site No. C84009-M05

Equipment Device Type: x Displacement _ Force _ Pressure _ Extensometer; Gage Length n/a _ Other n/a
Device Model No. 309.30 — Serial No. 148
Controller/Conditioner Model 458.13 — Serial No. 181 — Calibration Data File Name n/a
Readout Device Model No. n/a — Serial No. n/a — Channel n/a

Procedure MTS Procedure No. 1254 Rev A
Calibration has been performed in accordance with: _ ASTM E4. _ Other n/a _ Not Required
Method of verification: Set the displacement

Calibration Equipment Asset NO.* DVM 13475 Indicator 12089 Standardizer n/a Temp Readout 13477
Additional Equipment n/a

Conditions Ambient Temperature 68 deg. F — Polarization x Positive _ Negative — Bidirectional: _ Yes X No
Ref Voltage: Initial 10.000 V Final 10.000 V Other n/a

Range 3 Full Scale 20 Percent — Run No. 1 - As Found, Within Tolerance: x yes _ no — Run No. 1 - As Adjusted (If required) — Run No. 2

Asset No. (Standard) 12089
Class A Loading Range n/a
Data Mode X Ascending _ Decending

	Initial	Final
Excitation	n/a	n/a
Gain	n/a	n/a
ΔK	_ On In / _ Off	On In / _ Off
Shunt Cal +	n/a	n/a
Shunt Cal -	n/a	n/a
Cal Factor	x0x000	x0x000
Phase	n/a	n/a
Zero Offset	0	0

Percent	Custom Percent	Run No. 1 Indicated Reading	Run No. 1 Error % of Reading	As Adjusted Indicated Reading	As Adjusted Error % of Reading	Run No. 2 Indicated Reading	Run No. 2 Error % of Reading
100		10.035 V	+0.35%				
80		8.020 V	+0.25%				
60		6.005 V	+0.08%				
40		3.998 V	-0.05%				
20		2.010 V	+0.50%				
Start 0		0.000 V					
Ret 0		0.000 V					
Ret 0		0.000 V					
Start 0		0.000 V					
-20		-2.016 V	+0.80%				
-40		-4.024 V	+0.60%				
-60		-6.023 V	+0.38%				
-80		-7.998 V	-0.02%				
-100		-10.040 V	+0.40%				

Range 4 Full Scale 10 Percent — Run No. 1 - As Found, Within Tolerance: x yes _ no — Run No. 1 - As Adjusted (If required) — Run No. 2

Asset No. (Standard) 12089
Class A Loading Range n/a
Data Mode X Ascending _ Decending

	Initial	Final
Excitation	n/a	n/a
Gain	n/a	n/a
ΔK	_ On In / _ Off	On In / _ Off
Shunt Cal +	n/a	n/a
Shunt Cal -	n/a	n/a
Cal Factor	x0x000	x0x000
Phase	n/a	n/a
Zero Offset	n/a	n/a

Percent	Custom Percent	Run No. 1 Indicated Reading	Run No. 1 Error % of Reading	As Adjusted Indicated Reading	As Adjusted Error % of Reading	Run No. 2 Indicated Reading	Run No. 2 Error % of Reading
100		10.035 V	+0.35%				
80		8.022 V	+0.28%				
60		6.022 V	+0.37%				
40		4.029 V	+0.72%				
20		2.021 V	+1.05%				
Start 0		0.000 V					
Ret 0		0.000 V					
Ret 0		0.000 V					
Start 0		0.000 V					
-20		-2.019 V	+0.95%				
-40		-4.033 V	+0.83%				
-60		-6.029 V	+0.48%				
-80		-8.023 V	+0.29%				
-100		-10.012 V	+0.12%				

Performed by: Don BERNOW
Print
Don Brown
Signature

Date: 6/29/95

Next Recommended Calibration Due Date: 6/28/96

* MTS Measurement Standards are Traceable to the National Institute of Standards and Technology.
MTS Force Standards are temperature compensated in the range specified by the manufacturer.

Form Number 114093-11D (04-94)-PC

Figure B-2
Calibration Report

C

TEST DATA AND RESULTS

Overview of Appendix C

The description of the testing is contained in Section 2. Sections 2.2.4 and 2.2.5 contain a summary of the results. This Appendix contains more detail regarding the test data. For each of the four tests (E, F, G, H), the following is provided:

1. Standard sheets containing load-displacement data

   Data sheets are provided for the two loading directions: “Positive Loading” and “Negative Loading”, (for example, up and down). Both the “Loading” and “Unloading” conditions for each of the directions are included for a total of four data sheets. The sheets are used to determine the linear slopes of the load-deflection curves for the four loading conditions.

   The data includes loads, deflections, and so on. The columns identified as “modified” are for the case where adjustments are required to the data, such as resetting a dial gauge, and so on. No modifications were required for these tests.

2. Summary Load Deflection Sheet

   This sheet contains a plot of the load defection curve and the four straight lines determined from the load-displacement data (item 1 above). This plot indicates the reasonableness of the slope of the load deflection curves.

3. Fatigue Test Data Analysis

   This sheet contains the displacements and number of cycles at each displacement (if more than one displacement is used.) The calculations of the SIF are included. The stiffness used in the calculation is the average value of the four loading conditions (in item 1). Equivalent cycles are also calculated.

Test Specimen E
Test Report

TEST #: REINFORCED BRANCH-E

TYPE: FATIGUE - LOAD DEFLECTION CURVE

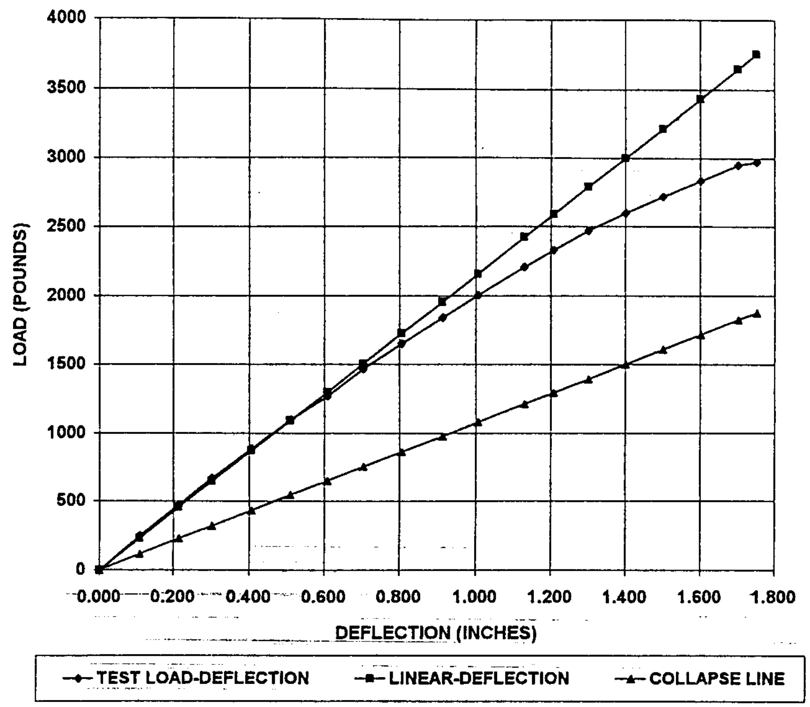
$F = Fo + m\,\delta$ "m" TO BE BASED ON N DATA POINTS, N = 6

THE VALUE OF "m" = 2144 0

POSITIVE LOAD - LOADING CONDITION

NOMINAL STRESS = M/Z KSI, M=F x L, L(IN) = 46.125 $Z(IN^3) = \pi r_n^2 t =$ 3.383

DATA POINT	MEASURED DEFLECTION	LOAD	MODIFIED DEFLECTION	LOAD	SLOPE FOR START TO DATA POINT	F BASED ON "m"	NOMINAL STRESS
	δ	F	δ	F			
#	(INCHES)	(LBS)	(INCHES)	(LBS)	(LBS/INCH)	(LBS)	(KSI)
1	0.00	0	0.000	0	N/A	0	
2	0.11	249.54	0.108	250	2,311	232	3.2
3	0.21	476.59	0.213	477	2,238	457	6.2
4	0.30	667.02	0.301	667	2,212	645	8.8
5	0.41	886.75	0.406	887	2,181	871	11.9
6	0.51	1091.8	0.509	1092	2,144	1091	14.9
7	0.61	1267.6	0.606	1268	2,097	1299	17.7
8	0.70	1465.4	0.703	1465	2,073	1507	20.6
9	0.81	1648.5	0.805	1648	2,042	1726	23.5
10	0.91	1838.9	0.911	1839	2,012	1953	26.6
11	1.01	2000	1.006	2000	1,983	2157	29.4
12	1.13	2205.1	1.129	2205	1,950	2421	33.0
13	1.21	2329.6	1.206	2330	1,923	2586	35.3
14	1.30	2468.8	1.300	2469	1,894	2787	38.0
15	1.40	2593.3	1.400	2593	1,859	3002	40.9
16	1.50	2717.8	1.499	2718	1,823	3214	43.8
17	1.60	2835	1.601	2835	1,784	3433	46.8
18	1.70	2952.2	1.702	2952	1,745	3649	49.8
19	1.75	2974.2	1.751	2974	1,709	3754	51.2
20							
21							
22							
23							
24							
25							



NOTES:
Loading is in an upward 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 #: REINFORCED BRANCH-E **TYPE:** FATIGUE - LOAD DEFLECTION CURVE

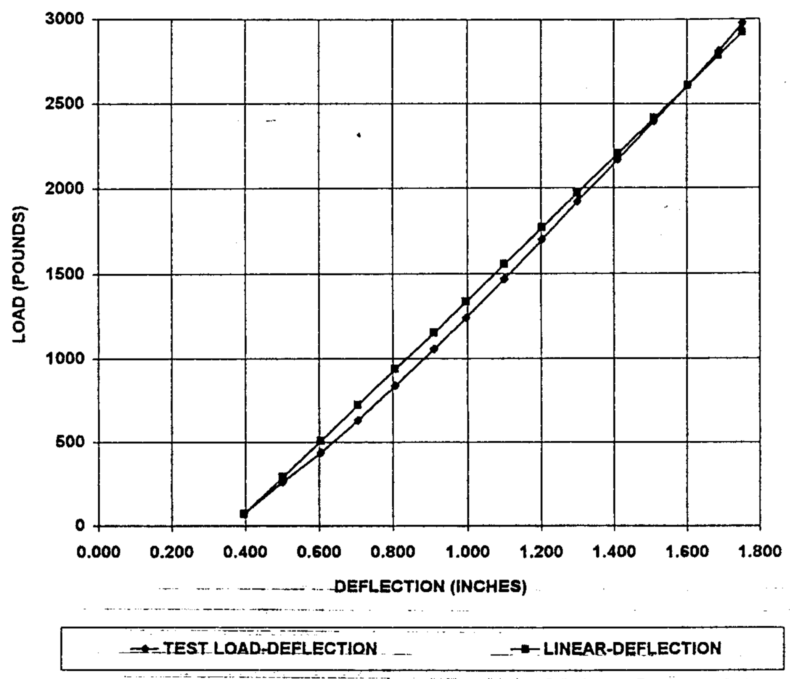
$F = F_o + m\,\delta$ "m" TO BE BASED ON N DATA POINTS, N = 4
THE VALUE OF "m" = 2100 Fo (LBS) = 74

NOMINAL STRESS = M/Z KSI, M=F x L, L(IN) = 46.125 $Z(IN^3) = \pi r_n^2 t =$ 3.383

DATA POINT	MEASURED DEFLECTION	LOAD	MODIFIED DEFLECTION	LOAD	SLOPE FOR START TO DATA POINT	F BASED ON "m"	NOMINAL STRESS
#	δ (INCHES)	F (LBS)	δ (INCHES)	F (LBS)	(LBS/INCH)	(LBS)	(KSI)
1	1.75	2974.2	1.751	2974	2,159	2921	39.8
2	1.69	2813	1.686	2813	2,140	2785	38.0
3	1.60	2607.9	1.602	2608	2,120	2609	35.6
4	1.51	2395.5	1.509	2396	2,100	2413	32.9
5	1.41	2168.5	1.410	2168	2,076	2205	30.1
6	1.30	1919.5	1.299	1919	2,047	1972	26.9
7	1.20	1699.7	1.203	1700	2,014	1771	24.1
8	1.10	1465.4	1.100	1465	1,977	1554	21.2
9	1.00	1238.3	0.995	1238	1,941	1334	18.2
10	0.91	1055.2	0.908	1055	1,904	1151	15.7
11	0.81	835.48	0.805	835	1,849	935	12.7
12	0.70	630.4	0.703	630	1,801	721	9.8
13	0.60	439.97	0.602	440	1,769	508	6.9
14	0.50	264.19	0.501	264	1,797	296	4.0
15	0.40	73.762	0.395	74	N/A	74	1.0
16							
17							
18							
19							
20							
21							
22							
23							
24							
25							

NOTES:

POSITIVE LOAD - UNLOADING CONDITION



TEST #: **REINFORCED BRANCH-E** **TYPE:** **FATIGUE - LOAD DEFLECTION CURVE**

NEGATIVE LOAD - LOADING CONDITION

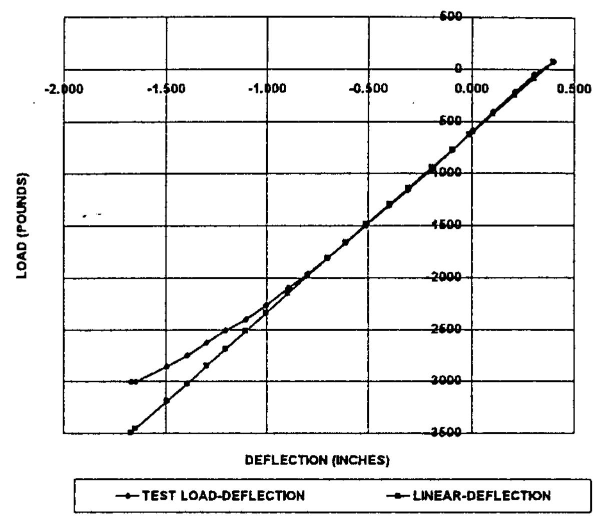
$F = F_0 + m\,\delta$ "m" TO BE BASED ON N DATA POINTS, N = 5

THE VALUE OF "m" = 1725 F_0 (LBS) = 73.762

NOMINAL STRESS = M/Z KSI, M=F x L, L(IN) = 46.125 $Z(IN^3) = \pi r_n^2 t =$ 3.383

DATA POINT #	MEASURED DEFLECTION δ (INCHES)	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	0.40	73.762	0.395	74	N/A	74	1.0
2	0.30	-50.75	0.302	-51	1,339	-87	-1.2
3	0.21	-219.207	0.209	-219	1,575	-247	-3.4
4	0.10	-409.636	0.102	-410	1,668	-432	-5.9
5	0.00	-592.742	0.004	-593	1,725	-601	-8.2
6	-0.01	-622.039	-0.013	-622	1,739	-630	-8.6
7	-0.10	-775.847	-0.096	-776	1,757	-773	-10.5
8	-0.20	-958.953	-0.196	-959	1,774	-946	-12.9
9	-0.31	-1156.71	-0.309	-1157	1,780	-1140	-15.5
10	-0.40	-1310.52	-0.399	-1311	1,779	-1296	-17.7
11	-0.51	-1500.95	-0.512	-1501	1,772	-1491	-20.3
12	-0.61	-1669.4	-0.611	-1669	1,766	-1661	-22.7
13	-0.70	-1808.56	-0.698	-1809	1,756	-1811	-24.7
14	-0.80	-1962.37	-0.798	-1962	1,743	-1984	-27.0
15	-0.90	-2101.53	-0.895	-2102	1,727	-2151	-29.3
16	-1.01	-2269.99	-1.006	-2270	1,710	-2342	-31.9
17	-1.11	-2401.82	-1.107	-2402	1,690	-2517	-34.3
18	-1.21	-2511.69	-1.206	-2512	1,665	-2687	-36.6
19	-1.30	-2628.88	-1.300	-2629	1,641	-2850	-38.9
20	-1.40	-2753.39	-1.399	-2753	1,618	-3020	-41.2
21	-1.50	-2855.93	-1.499	-2856	1,593	-3193	-43.5
22	-1.65	-3002.41	-1.653	-3002	1,561	-3458	-47.2
23	-1.68	-3002.41	-1.675	-3002	1,534	-3496	-47.7
24							
25							

NOTES:



TEST #: REINFORCED BRANCH-E **TYPE:** FATIGUE - LOAD DEFLECTION CURVE

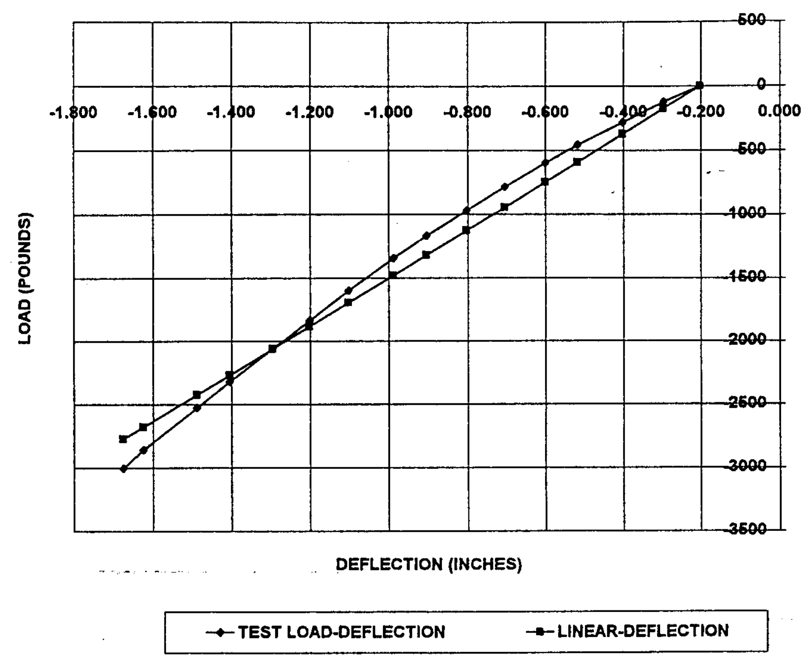
F = Fo + m δ "m" TO BE BASED ON N DATA POINTS, N = 5
THE VALUE OF "m" = 1885 Fo (LBS) = 1

NOMINAL STRESS = M/Z KSI, M=F x L, L(IN) = 46.125 $Z(IN^3) = \pi r_n^2 t =$ 3.383

DATA POINT	MEASURED DEFLECTION δ	MEASURED LOAD F	MODIFIED DEFLECTION δ	MODIFIED LOAD F	SLOPE FOR START TO DATA POINT	F BASED ON "m"	NOMINAL STRESS
#	(INCHES)	(LBS)	(INCHES)	(LBS)	(LBS/INCH)	(LBS)	(KSI)
1	-1.68	-3002.41	-1.675	-3002.4	2063	-2772	-37.8
2	-1.63	-2855.93	-1.625	-2855.9	2024	-2678	-36.5
3	-1.49	-2526.34	-1.49	-2526.3	1979	-2424	-33.0
4	-1.41	-2321.26	-1.407	-2321.3	1935	-2267	-30.9
5	-1.30	-2057.59	-1.297	-2057.6	1885	-2060	-28.1
6	-1.20	-1837.86	-1.203	-1837.9	1834	-1883	-25.7
7	-1.10	-1603.48	-1.103	-1603.5	1776	-1694	-23.1
8	-0.99	-1347.14	-0.99	-1347.1	1717	-1481	-20.2
9	-0.91	-1171.36	-0.906	-1171.4	1671	-1323	-18.0
10	-0.80	-973.601	-0.804	-973.6	1621	-1131	-15.4
11	-0.71	-790.496	-0.707	-790.5	1568	-948	-12.9
12	-0.60	-600.066	-0.602	-600	1512	-750	-10.2
13	-0.52	-460.906	-0.519	-461	1474	-593	-8.1
14	-0.40	-285.125	-0.403	-285	1437	-375	-5.1
15	-0.30	-123.992	-0.298	-124	1325	-177	-2.4
16	-0.20	0.52	-0.204	1	N/A	1	0.0
17							
18							
19							
20							
21							
22							
23							
24							
25							

NOTES:
Deflection is in an upward direction.

NEGATIVE LOAD - UNLOADING CONDITION



TEST #: **REINFORCED BRANCH-E**

COMPONENT: REINFORCED BRANCH CONNECTION

STIFFNESS (lbs/in) = 1963 MOMENT ARM (in)= 46.125

D (in) = 4.5 t (in) = 0.237 $Z(IN^3) = \pi r_n^2 t =$ 3.383

TEST DISPLACEMENT/CYCLE DATA:

CONDITION #	DISPLACEMENT AMPLITUDE (+/-) (in.) δ_i	EFFECTIVE APPLIED LOAD (lbs)	NOMINAL STRESS (+/-) (psi) S	NUMBER OF TEST CYCLES N_i
1	1.00	1963	26,773	1,260
2	0.00	0	0	0
3	0.00	0	0	0
4	0.00	0	0	0
5	0.00	0	0	0
6	0.00	0	0	0
7	0.00	0	0	0
8	0.00	0	0	0
			TOTAL CYCLES:	1,260

THE EQUIVALENT NUMBER OF CYCLES, BASED ON A DISPLACEME $\delta_{max} =$ 1 INCHES

IS: $N_{eq} = SUM(\delta_i/\delta_{max})^5 * N_i =$ 1,260

$i = 245{,}000 * N_{eq}^{(-0.2)}/S =$ **2.195**

FOR NOMINAL DIMENSIONS: $Z(IN^3) =$ 3.215 i = **2.309**

COMMENTS:

1. HT # 0947853 (Branch), #D947853B (Run)
2. L is distance to weld on branch. Distance to center of weld on branch is 46-1/8 in. Distance to center of weld on large pipe was 46-7/8 in.

Test Specimen F
Test Report

TEST #: REINFORCED BRANCH-F TYPE: FATIGUE - LOAD DEFLECTION CURVE

$F = Fo + m\,\delta$ "m" TO BE BASED ON N DATA POINTS, N = 7
THE VALUE OF "m" = 2083 0

NOMINAL STRESS = M/Z KSI, M=F x L, L(IN) = 46.25 Z(IN3) $=\pi r_{n2}t=$ 3.383

DATA POINT #	MEASURED DEFLECTION δ (INCHES)	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	0	0.000	0	N/A	0	
2	0.102	219.82	0.102	220	2,155	212	2.9
3	0.202	439.55	0.202	440	2,176	421	5.8
4	0.308	659.27	0.308	659	2,146	642	8.8
5	0.4	849.7	0.400	850	2,126	833	11.4
6	0.51	1069.4	0.510	1069	2,100	1062	14.5
7	0.601	1252.5	0.601	1253	2,083	1252	17.1
8	0.698	1435.6	0.698	1436	2,060	1454	19.9
9	0.808	1640.7	0.808	1641	2,034	1683	23.0
10	0.899	1809.2	0.899	1809	2,013	1872	25.6
11	1.003	2006.9	1.003	2007	1,995	2089	28.6
12	1.108	2182.7	1.108	2183	1,972	2308	31.6
13	1.201	2343.8	1.201	2344	1,951	2502	34.2
14	1.304	2512.3	1.304	2512	1,929	2716	37.1
15	1.401	2658.8	1.401	2659	1,904	2918	39.9
16	1.501	2805.3	1.501	2805	1,878	3126	42.7
17	1.619	2929.8	1.619	2930	1,840	3372	46.1
18	1.621	2907.8	1.621	2908	1,812	3376	46.2
19	1.624	2878.5	1.624	2879	1,787	3383	46.2
20	1.675	2981.1	1.675	2981	1,770	3489	47.7
21	1.806	3164.2	1.806	3164	1,749	3762	51.4
22	1.848	3171.5	1.848	3171	1,725	3849	52.6
23	1.848	3142.2	1.848	3142	1,705	3849	52.6
24							
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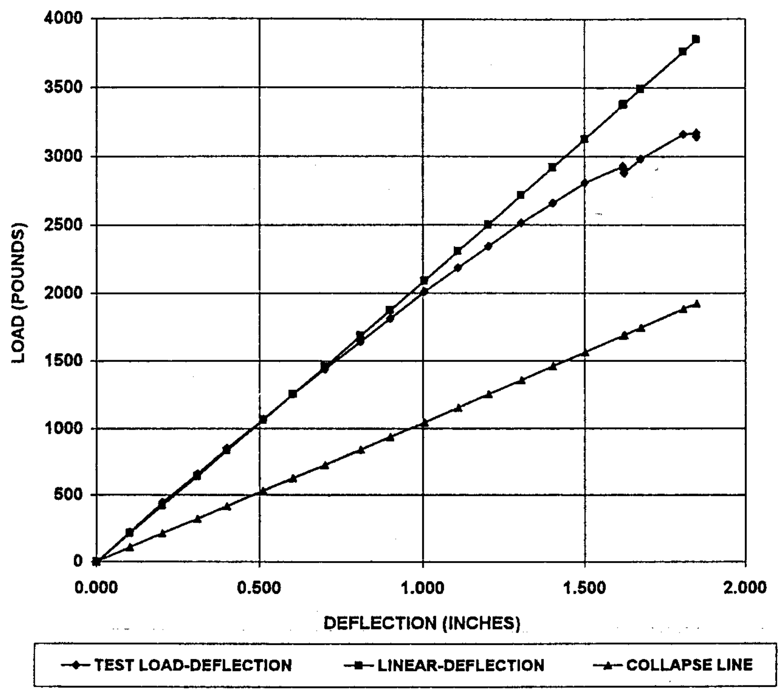
POSITIVE LOAD - LOADING CONDITION



NOTES:
Loading is in an upward 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 #: **REINFORCED BRANCH-F** **TYPE:** **FATIGUE - LOAD DEFLECTION CURVE**

F = Fo + m δ "m" TO BE BASED ON N DATA POINTS, N = 4
THE VALUE OF "m" = 2061 Fo (LBS) = 154

NOMINAL STRESS = M/Z KSI, M=F x L, L(IN) = 46.25 Z(IN3) = $\pi r_{n2} t$ = 3.383

DATA POINT #	MEASURED DEFLECTION δ (INCHES)	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	1.848	3142.2	1.848	3142	2,133	3070	42.0
2	1.694	2776	1.694	2776	2,107	2752	37.6
3	1.618	2600.2	1.618	2600	2,087	2596	35.5
4	1.514	2365.8	1.514	2366	2,061	2381	32.6
5	1.389	2065.5	1.389	2066	2,026	2124	29.0
6	1.295	1853.1	1.295	1853	1,999	1930	26.4
7	1.199	1655.4	1.199	1655	1,966	1732	23.7
8	0.999	1215.9	0.999	1216	1,867	1320	18.0
9	0.814	820.41	0.814	820	1,735	939	12.8
10	0.689	578.71	0.689	579	1,661	681	9.3
11	0.574	395.6	0.574	396	1,714	444	6.1
12	0.433	153.9	0.433	154	N/A	154	2.1
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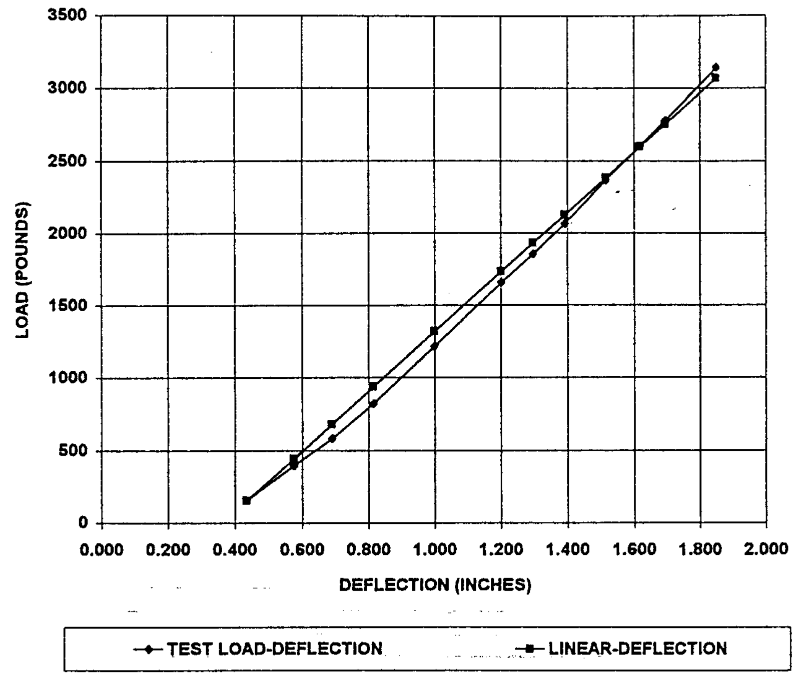
NOTES:

POSITIVE LOAD - UNLOADING CONDITION



TEST #: REINFORCED BRANCH-F **TYPE:** FATIGUE - LOAD DEFLECTION CURVE

NEGATIVE LOAD - LOADING CONDITION

F = Fo + m δ "m" TO BE BASED ON N DATA POINTS, N = 7
THE VALUE OF "m" = 1861 Fo (LBS) = 153.903

NOMINAL STRESS = M/Z KSI, M=F x L, L(IN) = 46.25 Z(IN3) = $\pi r_n^2 t$ = 3.383

DATA POINT #	MEASURED DEFLECTION δ (INCHES)	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	0.433	153.903	0.433	154	N/A	154	2.1
2	0.31	-43.851	0.310	-44	1,608	-75	-1.0
3	0.227	-190.335	0.227	-190	1,666	-229	-3.1
4	0.12	-395.413	0.120	-395	1,753	-428	-5.9
5	-0.018	-666.409	-0.018	-666	1,827	-685	-9.4
6	-0.114	-842.191	-0.114	-842	1,845	-864	-11.8
7	-0.232	-1069.24	-0.232	-1069	1,861	-1083	-14.8
8	-0.324	-1245.02	-0.324	-1245	1,870	-1255	-17.2
9	-0.424	-1420.8	-0.424	-1421	1,868	-1441	-19.7
10	-0.511	-1581.94	-0.511	-1582	1,866	-1603	-21.9
11	-0.6	-1735.75	-0.600	-1736	1,860	-1768	-24.2
12	-0.7	-1889.55	-0.700	-1890	1,845	-1954	-26.7
13	-0.803	-2058.01	-0.803	-2058	1,829	-2146	-29.3
14	-0.908	-2219.14	-0.908	-2219	1,810	-2341	-32.0
15	-1.011	-2387.6	-1.011	-2388	1,793	-2533	-34.6
16	-1.104	-2519.44	-1.104	-2519	1,774	-2706	-37.0
17	-1.21	-2687.89	-1.210	-2688	1,757	-2903	-39.7
18	-1.304	-2819.73	-1.304	-2820	1,740	-3078	-42.1
19	-1.407	-2958.89	-1.407	-2959	1,721	-3270	-44.7
20	-1.502	-3083.4	-1.502	-3083	1,701	-3446	-47.1
21	-1.573	-3163.97	-1.573	-3164	1,682	-3579	-48.9
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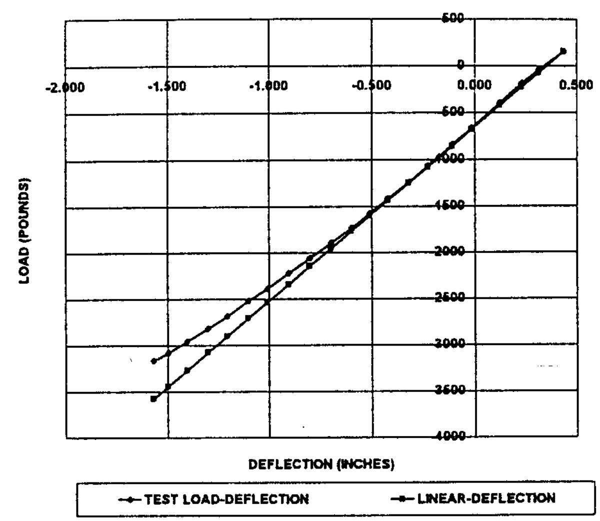

NOTES:

TEST #: **REINFORCED BRANCH-F** **TYPE:** **FATIGUE - LOAD DEFLECTION CURVE**

$F = Fo + m\,\delta$ "m" TO BE BASED ON N DATA POINTS, N = 4

THE VALUE OF "m" = 2066 Fo (LBS) = -15

NOMINAL STRESS = M/Z KSI, M=F x L, L(IN) = 46.25 Z(IN3) = $\pi r_{n2} t$ = 3.383

DATA POINT #	MEASURED DEFLECTION δ (INCHES)	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	-1.573	-3163.97	-1.573	-3164	2172	-2996	-41.0
2	-1.507	-2951.57	-1.507	-2951.6	2136	-2860	-39.1
3	-1.409	-2709.87	-1.409	-2709.9	2103	-2657	-36.3
4	-1.299	-2438.87	-1.299	-2438.9	2066	-2430	-33.2
5	-1.202	-2197.17	-1.202	-2197.2	2029	-2230	-30.5
6	-1.109	-1977.45	-1.109	-1977.4	1992	-2038	-27.9
7	-1.006	-1735.75	-1.006	-1735.7	1950	-1825	-24.9
8	-0.901	-1494.05	-0.901	-1494	1907	-1608	-22.0
9	-0.809	-1296.29	-0.809	-1296.3	1870	-1418	-19.4
10	-0.699	-1061.92	-0.699	-1061.9	1826	-1190	-16.3
11	-0.605	-871.488	-0.605	-871.49	1792	-996	-13.6
12	-0.502	-673.734	-0.502	-674	1766	-783	-10.7
13	-0.408	-505.277	-0.408	-505	1759	-589	-8.1
14	-0.351	-402.738	-0.351	-403	1753	-471	-6.4
15	-0.195	-131.741	-0.195	-132	1803	-149	-2.0
16	-0.13	-14.554	-0.13	-15	N/A	-15	-0.2
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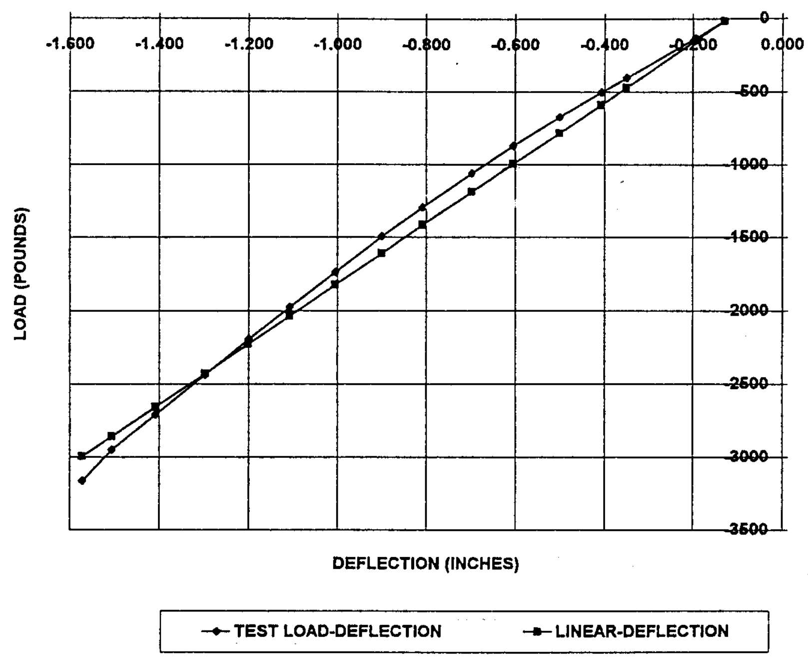
NOTES:
Deflection is in an upward direction.

NEGATIVE LOAD - UNLOADING CONDITION



FATIGUE TEST DATA ANALYSIS

TEST #: **REINFORCED BRANCH-F**

COMPONENT: REINFORCED BRANCH CONNECTION

STIFFNESS (lbs/in) = 2018 MOMENT ARM (in)= 46.25

D (in) = 4.5 t (in) = 0.237 Z(IN3) = $\pi r_{n2} t$= 3.383

TEST DISPLACEMENT/CYCLE DATA:

CONDITION #	DISPLACEMENT AMPLITUDE (+/-) (in.) δ_i	EFFECTIVE APPLIED LOAD (lbs)	NOMINAL STRESS (+/-) (psi) S	NUMBER OF TEST CYCLES N_i
1	0.80	1614	22,067	2,216
2	0.87	1755	23,997	444
3	0.00	0	0	0
4	0.00	0	0	0
5	0.00	0	0	0
6	0.00	0	0	0
7	0.00	0	0	0
8	0.00	0	0	0
			TOTAL CYCLES:	2,660

THE EQUIVALENT NUMBER OF CYCLES, BASED ON A DISPLACEMENT δ_{max} = 0.87 INCHES

IS: $N_{eq} = SUM(\delta_i/\delta_{max})^5 * N_i$ = 1,901

$i = 245,000 * N_{eq}^{(-0.2)}/S$ = **2.255**

FOR NOMINAL DIMENSIONS: Z(IN^3) = 3.215 i = **2.373**

COMMENTS:

1. HT # 0947853 (Branch), #D947853B (Run)
2. At 0 deflection the load is 110 pounds.
3. Cracks were visible at the toe of the weld on the branch at the bottom.

Test Specimen G
Test Report

TEST #: REINFORCED BRANCH-G TYPE: FATIGUE - LOAD DEFLECTION CURVE

$F = F_o + m\,\delta$ "m" TO BE BASED ON N DATA POINTS, N = 6

THE VALUE OF "m" = 2181 0

NOMINAL STRESS = M/Z KSI, M=F x L, L(IN) = 46.125 Z(IN3) $=\pi r_n^2 t=$ 3.383

DATA POINT #	MEASURED DEFLECTION δ (INCHES)	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	0	0.000	0	N/A	0	
2	0.103	223.23	0.103	223	2,167	225	3.1
3	0.201	442.96	0.201	443	2,203	438	6.0
4	0.303	662.69	0.303	663	2,192	661	9.0
5	0.405	882.41	0.405	882	2,182	883	12.0
6	0.502	1094.8	0.502	1095	2,181	1095	14.9
7	0.606	1314.5	0.606	1315	2,172	1321	18.0
8	0.705	1519.6	0.705	1520	2,161	1537	21.0
9	0.81	1732	0.810	1732	2,146	1766	24.1
10	0.903	1915.1	0.903	1915	2,129	1969	26.8
11	1.008	2105.6	1.008	2106	2,105	2198	30.0
12	1.1	2281.3	1.100	2281	2,085	2399	32.7
13	1.203	2449.8	1.203	2450	2,057	2623	35.8
14	1.304	2625.6	1.304	2626	2,030	2843	38.8
15	1.402	2801.4	1.402	2801	2,007	3057	41.7
16	1.441	2845.3	1.441	2845	1,985	3142	42.8
17	1.441	2808.7	1.441	2809	1,965	3142	42.8
18	1.5	2918.5	1.500	2919	1,948	3271	44.6
19	1.546	2977.1	1.546	2977	1,931	3371	46.0
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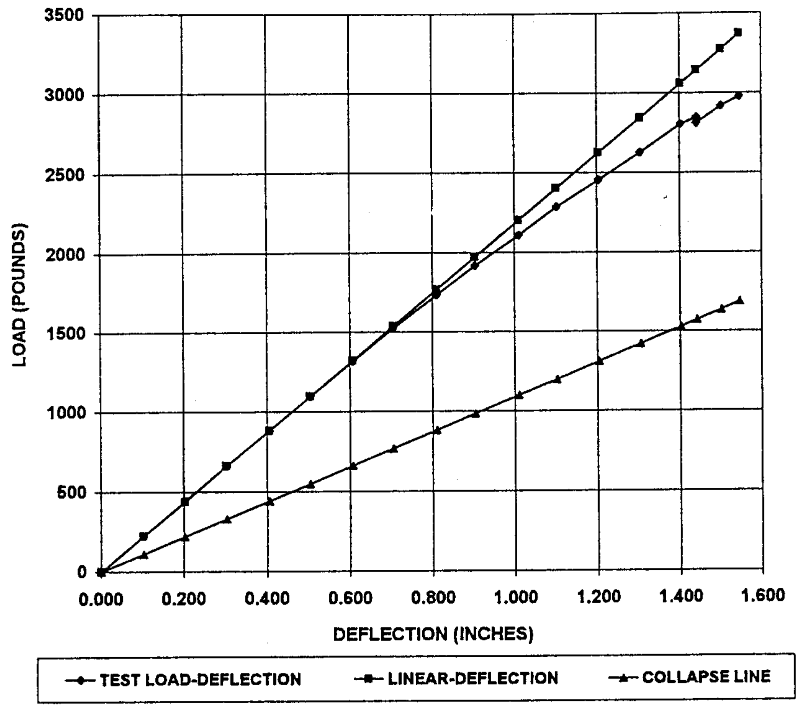
POSITIVE LOAD - LOADING CONDITION



NOTES:
Loading is in an upward 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 #: REINFORCED BRANCH-G

TYPE: FATIGUE - LOAD DEFLECTION CURVE

$F = Fo + m\,\delta$

"m" TO BE BASED ON N DATA POINTS, N = 4

THE VALUE OF "m" = 2194

Fo (LBS) = 135

NOMINAL STRESS = M/Z KSI, M=F x L, L(IN) = 46.125 Z(IN3) $=\pi r_n^2 t=$ 3.383

DATA POINT	MEASURED DEFLECTION		MODIFIED DEFLECTION		SLOPE FOR START TO DATA POINT	F BASED ON "m"	NOMINAL STRESS
#	δ (INCHES)	LOAD F (LBS)	δ (INCHES)	LOAD F (LBS)	(LBS/INCH)	(LBS)	(KSI)
1	1.546	2977.1	1.546	2977	2,273	2864	39.1
2	1.401	2559.7	1.401	2560	2,230	2546	34.7
3	1.303	2325.3	1.303	2325	2,212	2331	31.8
4	1.203	2090.9	1.203	2091	2,194	2112	28.8
5	1.105	1863.9	1.105	1864	2,172	1897	25.9
6	1.006	1636.8	1.006	1637	2,145	1680	22.9
7	0.901	1387.8	0.901	1388	2,107	1449	19.8
8	0.806	1175.4	0.806	1175	2,073	1241	16.9
9	0.721	977.63	0.721	978	2,023	1055	14.4
10	0.604	728.6	0.604	729	1,966	798	10.9
11	0.488	479.58	0.488	480	1,849	543	7.4
12	0.401	311.12	0.401	311	1,776	353	4.8
13	0.302	135.34	0.302	135	N/A	135	1.8
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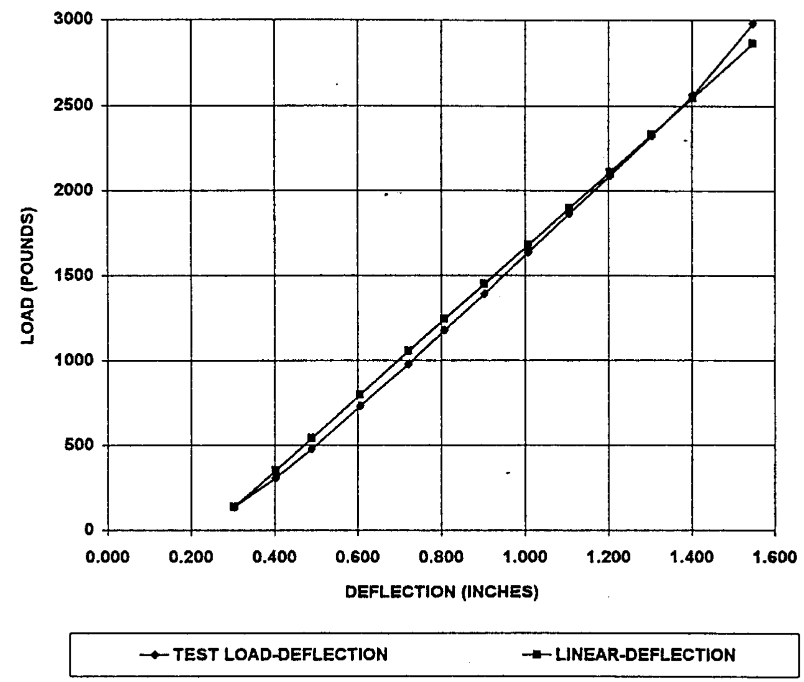
NOTES:

POSITIVE LOAD - UNLOADING CONDITION



TEST #: REINFORCED BRANCH-G | **TYPE:** FATIGUE - LOAD DEFLECTION CURVE

NEGATIVE LOAD - LOADING CONDITION

F = Fo + m δ | "m" TO BE BASED ON N DATA POINTS, N = 7
THE VALUE OF "m" = 1930 | Fo (LBS) = 135.341

NOMINAL STRESS = M/Z KSI, M=F x L, | L(IN) = 46.125 | $Z(IN3) = \pi r_n^2 t =$ 3.383

DATA POINT #	MEASURED DEFLECTION δ (INCHES)	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	0.302	135.341	0.302	135	N/A	135	1.8
2	0.21	-11.143	0.210	-11	1,592	-42	-0.6
3	0.114	-172.276	0.114	-172	1,637	-227	-3.1
4	0.001	-399.327	0.001	-399	1,772	-445	-6.1
5	-0.119	-648.35	-0.119	-648	1,867	-677	-9.2
6	-0.207	-824.132	-0.207	-824	1,906	-847	-11.5
7	-0.306	-1021.89	-0.306	-1022	1,930	-1038	-14.2
8	-0.412	-1226.96	-0.412	-1227	1,940	-1242	-16.9
9	-0.512	-1410.07	-0.512	-1410	1,938	-1435	-19.6
10	-0.607	-1593.18	-0.607	-1593	1,936	-1619	-22.1
11	-0.701	-1761.63	-0.701	-1762	1,930	-1800	-24.5
12	-0.811	-1974.03	-0.811	-1974	1,926	-2012	-27.4
13	-0.914	-2164.46	-0.914	-2164	1,921	-2211	-30.1
14	-1.013	-2340.25	-1.013	-2340	1,913	-2402	-32.8
15	-1.109	-2501.38	-1.109	-2501	1,903	-2587	-35.3
16	-1.219	-2699.13	-1.219	-2699	1,894	-2800	-38.2
17	-1.306	-2830.97	-1.306	-2831	1,881	-2967	-40.5
18	-1.401	-2984.78	-1.401	-2985	1,868	-3151	-43.0
19	-1.478	-3087.32	-1.478	-3087	1,852	-3299	-45.0
20	-1.5	-3123.94	-1.500	-3124	1,841	-3342	-45.6
21	-1.53	-3153.23	-1.530	-3153	1,829	-3400	-46.4
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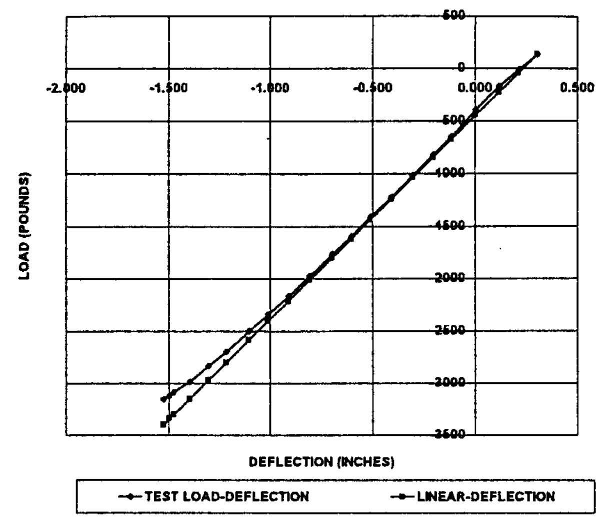
NOTES:



TEST #: REINFORCED BRANCH-G **TYPE:** FATIGUE - LOAD DEFLECTION CURVE

F = Fo + m δ "m" TO BE BASED ON N DATA POINTS, N = 4
THE VALUE OF "m" = 2131 Fo (LBS) = -84

NOMINAL STRESS = M/Z KSI, M=F x L, L(IN) = 46.125 Z(IN3) = $\pi r_n^2 t$ = 3.383

DATA POINT	MEASURED		MODIFIED		SLOPE FOR START TO DATA POINT	F BASED ON "m"	NOMINAL STRESS
#	DEFLECTION δ (INCHES)	LOAD F (LBS)	DEFLECTION δ (INCHES)	LOAD F (LBS)	(LBS/INCH)	(LBS)	(KSI)
1	-1.53	-3153.23	-1.53	-3153.2	2232	-2994	-40.8
2	-1.534	-3072.67	-1.534	-3072.7	2198	-3002	-40.9
3	-1.516	-3014.07	-1.516	-3014.1	2171	-2964	-40.4
4	-1.405	-2728.43	-1.405	-2728.4	2131	-2727	-37.2
5	-1.302	-2464.76	-1.302	-2464.8	2089	-2508	-34.2
6	-1.22	-2259.68	-1.22	-2259.7	2041	-2333	-31.8
7	-1.08	-1915.44	-1.08	-1915.4	1971	-2034	-27.7
8	-0.911	-1512.61	-0.911	-1512.6	1890	-1674	-22.8
9	-0.798	-1248.94	-0.798	-1248.9	1827	-1433	-19.5
10	-0.703	-1043.86	-0.703	-1043.9	1775	-1231	-16.8
11	-0.56	-758.214	-0.56	-758.21	1714	-926	-12.6
12	-0.45	-560.46	-0.45	-560	1685	-692	-9.4
13	-0.297	-296.788	-0.297	-297	1636	-366	-5.0
14	-0.189	-113.682	-0.189	-114	1221	-136	-1.8
15	-0.165	-84.385	-0.165	-84	N/A	-84	-1.2
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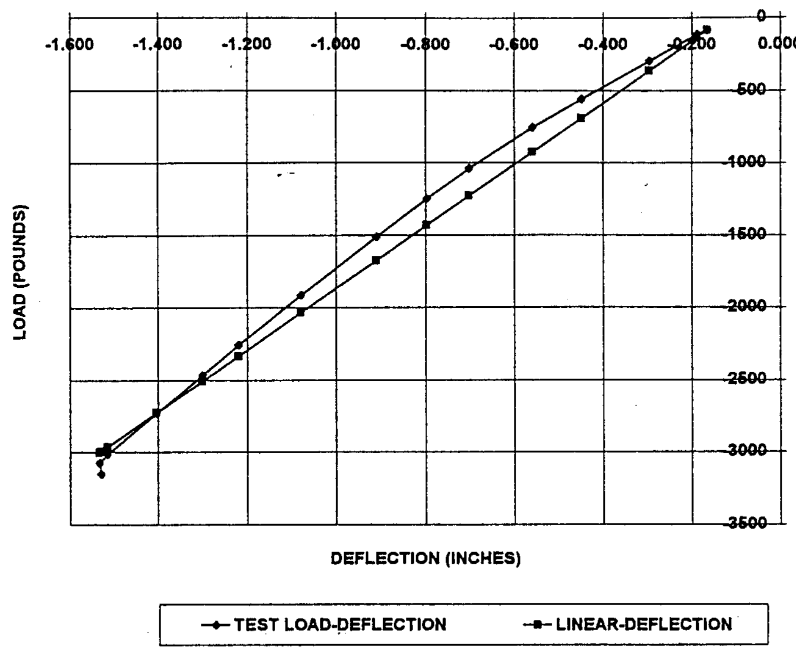
NOTES:
Deflection is in an upward direction.

NEGATIVE LOAD - UNLOADING CONDITION



FATIGUE TEST DATA ANALYSIS

TEST #: **REINFORCED BRANCH-G**

COMPONENT: REINFORCED BRANCH CONNECTION

STIFFNESS (lbs/in) = 2109   MOMENT ARM (in)= 46.125

D (in) = 4.5   t (in) = 0.237   Z(IN3) =$\pi r_n^2 t$= 3.383

TEST DISPLACEMENT/CYCLE DATA:

CONDITION #	DISPLACEMENT AMPLITUDE (+/-) (in.) δ_i	EFFECTIVE APPLIED LOAD (lbs)	NOMINAL STRESS (+/-) (psi) S	NUMBER OF TEST CYCLES N_i
1	1.00	2109	28,752	1,366
2	0.00	0	0	0
3	0.00	0	0	0
4	0.00	0	0	0
5	0.00	0	0	0
6	0.00	0	0	0
7	0.00	0	0	0
8	0.00	0	0	0
			TOTAL CYCLES:	1,366

THE EQUIVALENT NUMBER OF CYCLES, BASED ON A DISPLACEMENT δ_{max} = 1 INCHES

IS: $N_{eq} = SUM(\delta_i/\delta_{max})^5 * N_i$ = 1,366

$i = 245{,}000 * N_{eq}^{(-0.2)}/S$ = **2.011**

FOR NOMINAL DIMENSIONS: Z(IN^3) = 3.215   i = **2.116**

COMMENTS:

1. HT # 0947853 (Branch), #D547853B (Run)
2. L is distance to weld on branch. Distance to center of weld on branch is 46-1/8 in. Distance to center of weld on large pipe was 47-5/8 in.
3. Failure occured at the top <u>and</u> bottom at the same time at the toe of the weld on the branch

Test Specimen H
Test Report

TEST #: REINFORCED BRANCH-H

TYPE: FATIGUE - LOAD DEFLECTION CURVE

$F = F_o + m\,\delta$ "m" TO BE BASED ON N DATA POINTS, N = 6

THE VALUE OF "m" = 2273 0

POSITIVE LOAD - LOADING CONDITION

NOMINAL STRESS = M/Z KSI, M=F x L, L(IN) = 45.5 Z(IN3) = $\pi r_n^2 t$ = 3.383

DATA POINT #	MEASURED DEFLECTION δ (INCHES)	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	0	0.000	0	N/A	0	
2	0.101	263.77	0.101	264	2,612	230	3.1
3	0.2	490.82	0.200	491	2,455	455	6.1
4	0.3	717.87	0.300	718	2,383	682	9.2
5	0.401	930.27	0.401	930	2,312	911	12.3
6	0.505	1157.3	0.505	1157	2,273	1148	15.4
7	0.603	1369.7	0.603	1370	2,248	1371	18.4
8	0.702	1574.8	0.702	1575	2,223	1596	21.5
9	0.806	1787.2	0.806	1787	2,199	1832	24.6
10	0.908	1992.3	0.908	1992	2,176	2064	27.8
11	0.921	2014.3	0.921	2014	2,163	2093	28.2
12	1.001	2168.1	1.001	2168	2,147	2275	30.6
13	1.103	2351.2	1.103	2351	2,124	2507	33.7
14	1.2	2527	1.200	2527	2,099	2728	36.7
15	1.302	2695.4	1.302	2695	2,071	2959	39.8
16	1.4	2827.2	1.400	2827	2,034	3182	42.8
17	1.503	2959.1	1.503	2959	1,991	3416	45.9
18	1.606	3120.2	1.606	3120	1,953	3650	49.1
19	1.642	3164.2	1.642	3164	1,923	3732	50.2
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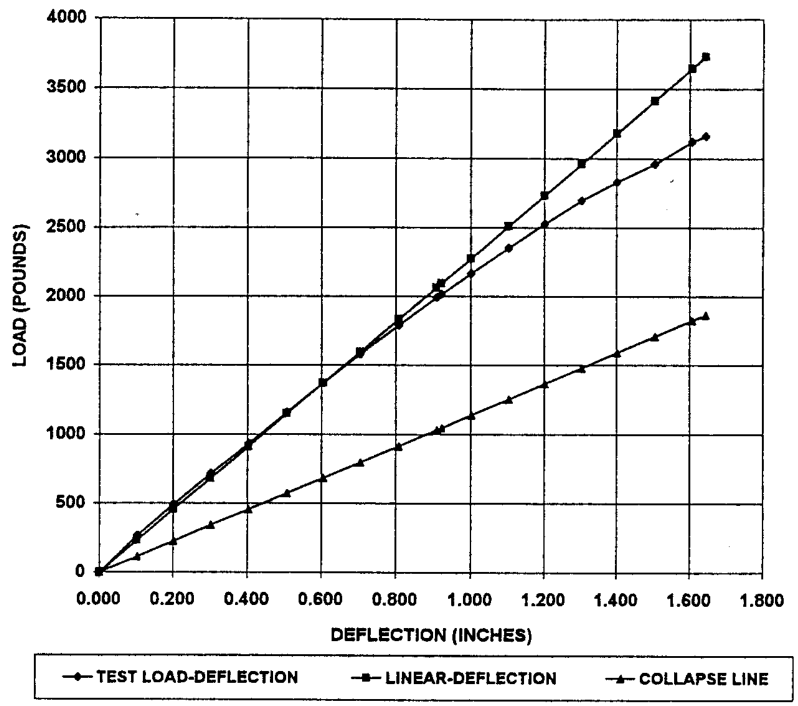
22							
23							
24							
25							



NOTES:

Loading is in an upward 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 #: **REINFORCED BRANCH-H** **TYPE:** **FATIGUE - LOAD DEFLECTION CURVE**

F = Fo + m δ "m" TO BE BASED ON N DATA POINTS, N = 4
THE VALUE OF "m" = 2225 Fo (LBS) = 117

NOMINAL STRESS = M/Z KSI, M=F x L, L(IN) = 45.5 Z(IN3) $=\pi r_n^2 t=$ 3.383

DATA POINT #	MEASURED DEFLECTION δ (INCHES)	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	1.642	3164.2	1.642	3164	2,277	3097	41.6
2	1.503	2812.6	1.503	2813	2,256	2787	37.5
3	1.404	2570.9	1.404	2571	2,240	2567	34.5
4	1.308	2343.8	1.308	2344	2,225	2354	31.7
5	1.201	2087.5	1.201	2087	2,208	2115	28.5
6	1.106	1875.1	1.106	1875	2,193	1904	25.6
7	1.006	1633.4	1.006	1633	2,167	1682	22.6
8	0.9	1399	0.900	1399	2,149	1446	19.4
9	0.802	1172	0.802	1172	2,117	1228	16.5
10	0.709	966.89	0.709	967	2,088	1021	13.7
11	0.593	710.54	0.593	711	2,035	763	10.3
12	0.499	505.47	0.499	505	1,982	553	7.4
13	0.408	329.68	0.408	330	2,023	351	4.7
14	0.303	117.28	0.303	117	N/A	117	1.6
15							
16							
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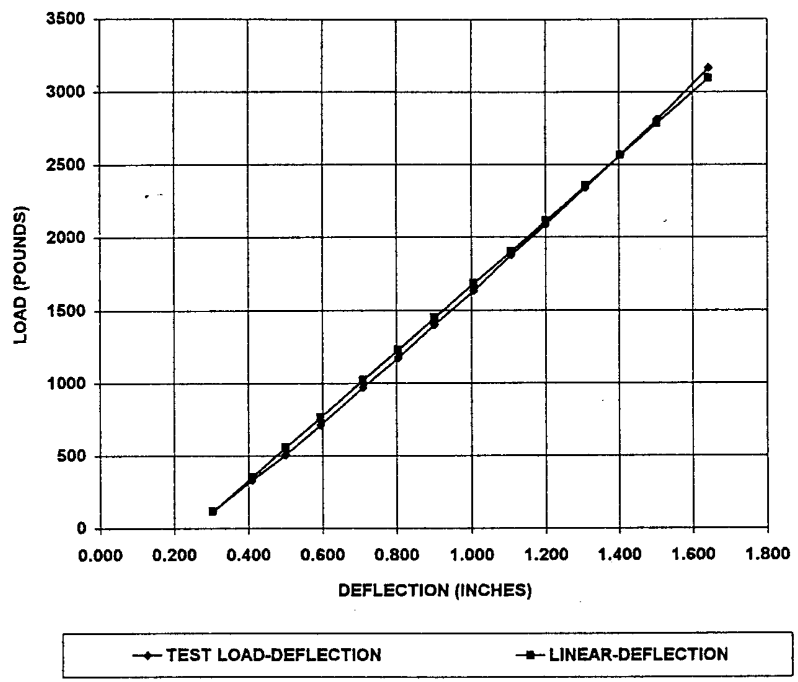
NOTES:

POSITIVE LOAD - UNLOADING CONDITION



TEST #: **REINFORCED BRANCH-H** **TYPE:** **FATIGUE - LOAD DEFLECTION CURVE**

NEGATIVE LOAD - LOADING CONDITION

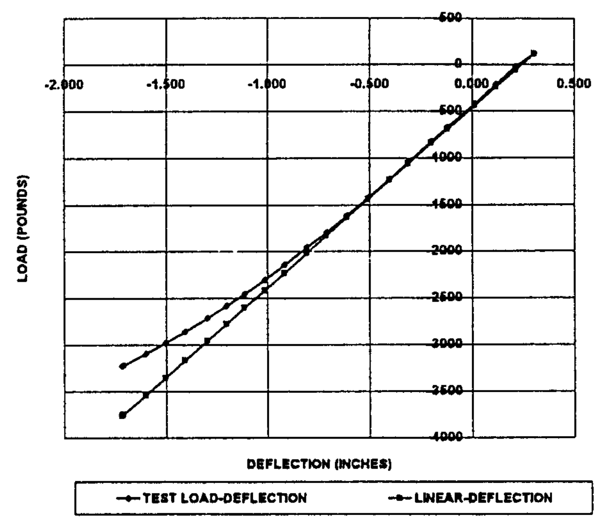
$F = Fo + m\delta$ "m" TO BE BASED ON N DATA POINTS, N = 7

THE VALUE OF "m" = 1918 Fo (LBS) = 117.282

NOMINAL STRESS = M/Z KSI, M=F x L, L(IN) = 45.5 Z(IN3) $=\pi r_n^2 t=$ 3.383

DATA POINT #	MEASURED DEFLECTION δ (INCHES)	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	0.303	117.282	0.303	117	N/A	117	1.6
2	0.21	-21.878	0.210	-22	1,496	-61	-0.8
3	0.113	-219.632	0.113	-220	1,775	-247	-3.3
4	0.01	-424.71	0.010	-425	1,871	-445	-6.0
5	-0.121	-673.734	-0.121	-674	1,897	-696	-9.4
6	-0.199	-827.542	-0.199	-828	1,910	-845	-11.4
7	-0.313	-1047.27	-0.313	-1047	1,918	-1064	-14.3
8	-0.403	-1230.37	-0.403	-1230	1,929	-1237	-16.6
9	-0.508	-1428.13	-0.508	-1428	1,931	-1438	-19.3
10	-0.611	-1611.23	-0.611	-1611	1,924	-1635	-22.0
11	-0.712	-1794.34	-0.712	-1794	1,915	-1829	-24.6
12	-0.811	-1955.47	-0.811	-1955	1,899	-2019	-27.2
13	-0.921	-2145.9	-0.921	-2146	1,884	-2230	-30.0
14	-1.016	-2299.71	-1.016	-2300	1,867	-2412	-32.4
15	-1.116	-2453.52	-1.116	-2454	1,848	-2604	-35.0
16	-1.204	-2578.03	-1.204	-2578	1,827	-2773	-37.3
17	-1.301	-2709.87	-1.301	-2710	1,804	-2959	-39.8
18	-1.409	-2856.35	-1.409	-2856	1,779	-3166	-42.6
19	-1.508	-2980.86	-1.508	-2981	1,754	-3356	-45.1
20	-1.605	-3098.05	-1.605	-3098	1,727	-3542	-47.6
21	-1.713	-3222.56	-1.713	-3223	1,700	-3749	-50.4
22	-1.721	-3229.89	-1.721	-3230	1,679	-3764	-50.6
23							
24							
25							

NOTES:



TEST #: REINFORCED BRANCH-H

TYPE: FATIGUE - LOAD DEFLECTION CURVE

$F = Fo + m\,\delta$

"m" TO BE BASED ON N DATA POINTS, N = 4

THE VALUE OF "m" = 1951

Fo (LBS) = 0

NOMINAL STRESS = M/Z KSI, M=F x L,

L(IN) = 45.5

$Z(IN3) = \pi r_n^2 t =$ 3.383

DATA POINT	MEASURED DEFLECTION	MEASURED LOAD	MODIFIED DEFLECTION	MODIFIED LOAD	SLOPE FOR START TO DATA POINT	F BASED ON "m"	NOMINAL STRESS
#	δ (INCHES)	F (LBS)	δ (INCHES)	F (LBS)	(LBS/INCH)	(LBS)	(KSI)
1	-1.721	-3229.89	-1.721	-3229.9	2093	-2925	-39.3
2	-1.607	-2849.03	-1.607	-2849	2032	-2703	-36.3
3	-1.5	-2578.03	-1.5	-2578	1991	-2494	-33.5
4	-1.4	-2329.01	-1.4	-2329	1951	-2299	-30.9
5	-1.311	-2116.61	-1.311	-2116.6	1913	-2125	-28.6
6	-1.205	-1867.58	-1.205	-1867.6	1872	-1918	-25.8
7	-1.109	-1647.86	-1.109	-1647.9	1836	-1731	-23.3
8	-1.007	-1428.13	-1.007	-1428.1	1806	-1532	-20.6
9	-0.905	-1223.05	-0.905	-1223.1	1785	-1333	-17.9
10	-0.807	-1039.95	-0.807	-1039.9	1773	-1141	-15.4
11	-0.724	-886.136	-0.724	-886.14	1764	-979	-13.2
12	-0.603	-673.734	-0.603	-674	1760	-743	-10.0
13	-0.51	-505.277	-0.51	-505	1745	-562	-7.6
14	-0.412	-329.495	-0.412	-329	1732	-371	-5.0
15	-0.307	-153.714	-0.307	-154	1810	-166	-2.2
16	-0.222	0.094	-0.222	0	N/A	0	0.0
17							
18							
19							
20							
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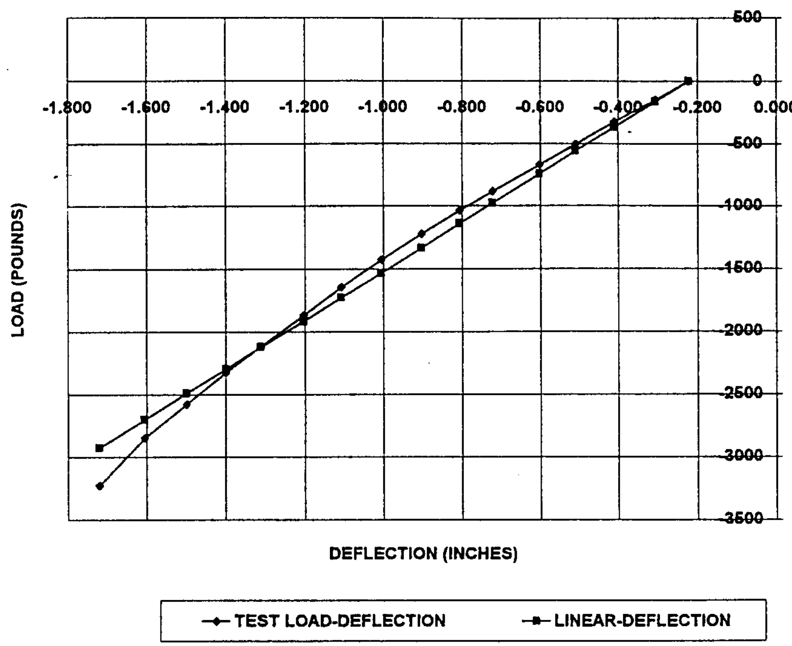
25							

NOTES:
Deflection is in an upward direction.

NEGATIVE LOAD - UNLOADING CONDITION



FATIGUE TEST DATA ANALYSIS

TEST #: **REINFORCED BRANCH-H**

COMPONENT: REINFORCED BRANCH CONNECTION

STIFFNESS (lbs/in) = 2092 MOMENT ARM (in)= 45.5

D (in) = 4.5 t (in) = 0.237 Z(IN3) $=\pi r_n^2 t=$ 3.383

TEST DISPLACEMENT/CYCLE DATA:

CONDITION #	DISPLACEMENT AMPLITUDE (+/-) (in.) δ_i	EFFECTIVE APPLIED LOAD (lbs)	NOMINAL STRESS (+/-) (psi) S	NUMBER OF TEST CYCLES N_i
1	1.00	2092	28,133	1,075
2	0.00	0	0	0
3	0.00	0	0	0
4	0.00	0	0	0
5	0.00	0	0	0
6	0.00	0	0	0
7	0.00	0	0	0
8	0.00	0	0	0
			TOTAL CYCLES:	1,075

THE EQUIVALENT NUMBER OF CYCLES, BASED ON A DISPLACEMENT $\delta_{max}=$ 1 INCHES

IS: $N_{eq} = SUM(\delta_i/\delta_{max})^5 * N_i =$ 1,075

$i = 245{,}000 * N_{eq}^{(-0.2)}/S =$ **2.156**

FOR NOMINAL DIMENSIONS: Z(IN^3) = 3.215 i = **2.269**

COMMENTS:

1. HT # 0947853 (Branch), #D547853B (Run)
2. L is distance to weld on branch. Distance to center of weld on branch is 46 in. Distance to center of weld on large pipe was 46-5/8 in.