STONE & WEBSTER ENGINEERING CORPORATION

CALCULATION TITLE PAGE

*SEE INSTRUCTIONS ON REVERSE SIDE

NOTED APR 0 9 1986 A. COKONIS

A 5010.84 (FRONT)

CLIENT & PROJECT	PAGE 1 OF 27
[illegible] EMD - GENERIC	

CALCULATION TITLE (indicative of the Objective):	QA CATEGORY (✓)
Stress Intensification Factors for Lateral Branches Fabricated from "Welded-In" Piping to be used in ASME Class [illegible]3 and ANSI B31.1 Pipe Stress Analysis	☒ I - NUCLEAR SAFETY RELATED ☐ II ☐ III ☐ ____ OTHER

CALCULATION IDENTIFICATION NUMBER				OPTIONAL WORK PACKAGE NO.
J.O. OR W.O. NO.	DIVISION & GROUP	CURRENT CALC. NO.	OPTIONAL TASK CODE	
599.470.1.01	NP (B)	75	X6	

NOTED APR 2 1 1982

* APPROVALS - SIGNATURE & DATE			REV. NO. OR NEW CALC NO.	SUPERSEDES * CALC. NO. OR REV. NO.	CONFIRMATION * REQUIRED (✓)	
PREPARER(S)/DATE(S)	REVIEWER(S)/DATE(S)	INDEPENDENT REVIEWER(S)/DATE(S)			YES	NO
L. Raghavan L Raghavan Mar 16, 82	G ARENA G Arena 3-17-82	G ARENA G Arena 3-17-82	Rev. 0	N/A		X
L Raghavan May 5, 1982		G. Arena 5-5-82	REV 1	N/A		X

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	RF Hankinson 245/8	✓ ✓			

Calculation No. 599. 470.1 .01. NP(B) - 75-X6

Calculation Title Stress Intensification Factors for Lateral Branch Conn.

This calculation has been reviewed in accordance with EMTP 8.26 and was found to be adequate. The method of review utilized was (circle one):

a. Comparison with a similar previous Calculation No. ______.

(b.) Review of calculation.

c. Alternate Calculation No. ______.

Guy Orene 3-17-82

Signature of Reviewer Date

______ ______

Signature of Independent Reviewer (where different from Reviewer) Date

REV 1 Guy Orene I/ace 5/5/82

SIGNATURE OF REVIEWER DATE

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REVISION STATUS

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REVISION 1

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REASON FOR CHANGE : DELETED CODE SUBPARAGRAPH REFERENCE IN CONCLUSION NOTE 3 b.

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TABLE OF CONTENTS

Nomenclature

D and R = mean diameter and mean radius, respectively of plane pipes and pipes of connections

d and r = mean diameter and mean radius of branch, respectively

T = thickness of pipe of connection

t = thickness of branch

s/S = elastic hoop stress ratio $(d/t)/(D/T)$

ρ and ρ_c = constant fillet radius of external surface of intersection of tees and fillet radius at external crotch of tee

$A_f = \rho^2(1 - \frac{\pi}{4})$ = crossectional area of reinforcement due to fillet in horizontal plane

ρ_a and ρ_o = external fillet radius of lateral where crotch makes an acute and obtuse angle, respectively

σ_Y = average yield strength of connection in tension

e_{lB}, e_{lP} = theoretical elastic axial strain due to internal pressure of a plane pipe with closed ends having dimensions of branch or pipe, respectively

e_l = referring to e_{lB} or e_{lP}

σ_a/σ_c = elatic stress ratio in thin plane pipe exposed to axial force and bending

σ_{aB}/σ_{IE} = elastic stress ratio in thin branch due to F_E and C_{IE}

D_N = nominal diameter of pipe of welded laterals

p_{LP} and p_L = theoretical limit pressure of plane pipe with open ends and closed ends, respectively

p_E = experimental limit pressure of connection or plane pipe

C_L and C_{BL} = theoretical limit couple of plane pipe and plane branch respectively

p = experimental pressure in connection

C_E = experimental limit couple of plane pipe

C_{IE} = stable experimental in-plane limit couple

C_{OE} = stable experimental out-of-plane limit couple

IC_{OE} = unstable experimental out-of-plane plastic couple

C_{pL} = theoretical limit couple of plane pipe at constant internal pressure

$\sigma_Y(t)$ = yield strength averaged for various types of tensile tests and specimens

e_{hB}, e_{hP} = theoretical elastic hoop strain due to internal pressure of a plane pipe with closed ends having dimensions of the branch or pipe, respectively

e_h = referring to e_{hB} or e_{hP}

e_{hE} = experimental elastic hoop strain due to internal pressure

F_E = axial force acting on branch due to differences in magnitude of forces constituting the limit couple

e_{cB}, e_{cP} = theoretical elastic extremum axial strain due to an external couple having dimensions of branch and pipe, respectively

e_c = referring to e_{cB} or e_{cP}

e_{cE} = experimental axial strain due to external couple measured at 90 deg to neutral axis

F_c = average of magnitude of forces constituting limit couple

STRESS INTENSIFICATION FACTORS (SIF)

FOR UNREINFORCED LATERAL BRANCH CONNECTIONS

1.0 OBJECTIVE:

Paragraph NC 3650 of the ASME Section III, (12)*, code provides a method of analysis of class 2 and 3 piping products. The analysis utilizes Stress Intensification Factors (SIF) along with some simple equations to establish acceptable limits on stresses.

Figure NC 3673.2(b)-1, (12)*, provides SIF's for commonly used standard piping products. For non-standard piping products NC 3673.2(b), (12)*, states that SIF may be taken as $C_2K_2/2$ where C_2 and K_2 are class 1 stress indices given in Table NB 3682.2-1, (12)*. Lateral branch connections are not among the components for which SIF or C_2 and K_2 stress indices are available. Thus, code evaluation of lateral branch connection by simplified analysis is not possible.

The purpose of this calculation is to establish a method to derive an appropriate SIF for use in the evaluation of lateral "stub-in" branches using NC-3650 rules, (12)*, based upon the results of a published literature survey.

* Numbers in () indicate reference numbers listed in Section 3.

3. DIRECT - this indicates the step is to be analyzed in the increments given on the data card, breaking the step into fractions, e.g.,

   0.7, 0.8, 0.9, 0.95, 1.0

   indicates increments will be used applying to 70%, 80%, 90%, 95%, and 100% of the load history (as defined on the loading cards).

4. TIMEP is the period of this analysis step. Default value is one which means that normalized time is used. Note: this time period for static analysis is not accumulated over different steps. The time period must be non-zero.

5. NUMBER - this parameter is used to initiate the automatic load incrementation option and to suggest the increment size. For example, NUMBER = 5 will make the first increment equal to 0.2 of the total time. However, the program will now adjust the time increment based on the number of cycles needed in each increment with the limitation being that the time increments will not be larger than 0.2 of the total time.

   Note: NUMBER and DIRECT are mutually exclusive parameters.

6. CUTMAX - the maximum number to times the suggested uniform increment size may be subdivided.

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2.0 ASSUMPTIONS

	CONFIRMATION REQUIRED (✓) YES	NO
1. It is reasonable to assume that unreinforced lateral branch connection behavior would also be indicative of reinforced lateral branch connection behavior.		X
2. Bending moment stress indices (c_2 and k_2) are same for tubular joints (no hole at the intersection) as well as pipe branch connections.		X
3. All other assumptions are noted in the body of the text.		X

3.0 References:

1. Markl A.R.C., "Fatigue Tests of Piping Components"- Transactions ASME, April 1952, pp. 287-303.

2. Schroeder, J., Srinvasaich, K.R., and Graham, P., " Analysis of test data on branch connections exposed to internal pressure and/or external couples", Bulletin No. 200, Welding Research Council, New York, 1974.

3. Kuang, J.G., Potvin, A.B., and Leick, R.D., "Stress concentrations in Tubular Joints", Paper No. OTC 2205, Off-Shore Technology conference, Houston 1975.

4. Hsiao C. and Kahn. A.S., "Stress intensification effects in unreinforced oblique branch intersections due to external moments" - PVP Volume 50 ASME, New York 1981.

5. Wichman, K.R., Hopper A.G., and Mershon, J.L., "Local Stresses in spherical and cylindrical shells due to External Loadings" Bulletin No. 107, Welding Research Council, New York.

6. Visser W. " On the structural design of tubular joints" OTC 2117 Proc. Sixth Annual Off-Shore Technology Conference, Houston (May 6-8, 1974) Volume II pp. 881-894

7. Reber, J.B. Jr. "Ultimate Strength Design of Tubular Joints" OTC 1664 Proc. Fourth Annual Off-Shore Technology Conference Houston (May 1-3, 1972) Volume I pp. 447-458

8. Beale L.A. and Toprac, A.A. "Analysis of in-plane T,Y, and K Welded Tubular Connections" Welding Research Council Bulletin 125 Oct. 1967 pp. 1-30.

9. Gurner, T.R., "Fatigue of Welded Structures" Second Edition 1979 Cambridge University Press.

10. Khan, A.S. and Hsiao C., "Strain Field in the intersection region of two obliquely inclined straight cylindrical shells, An Experimental Study". Submitted for publication in "Experimental Mechanics".

11. Mukhopadhyay A., Itoh, Y., Bouwkamp, J. G., "Fatigue Behavior of Tubular Joints in Offshore Structures", OTC 2207, Seventh Annual Offshore Technology Conference, Houston (May 5-8, 1975).

12. ASME Boiler and Pressure Vessel Code, Section III, 1980 Edition.

13. ANSI B31.1, American National Standard Code for Pressure Piping, Power Piping, 1977 Edition.

4.0 ANALYSIS

Stress intensification factors (i) for various piping components are, in large part, based upon Markl's (1)* approach and test data generated by his work.

The Markl cyclic moment fatigue tests did not cover lateral branch connections and code does not provide either 'i' factors or C_2, K_2 stress indicies for lateral branch connections. Several authors have investigated this problem and references (2)*, (3)*, and (4)* are some of the significant published reports.

WRC Bulletin 200 (2)* reports and analyzes test data on branch connections including unreinforced laterals exposed to internal pressure and/or external couples. Tests were conducted on plain pipes, tees (normal branch connections) and 45° laterals, to determine "limit loads" of the components when subject to internal pressure, in-plane and out-of-plane bending moments. No fatigue tests were conducted.

Figures 1 and 2,** (2)*, show results of in-plane couple tests on a 45° lateral and a 90° normal branch connection, both of identical dimensions except for the angle of branch connection. Table 1, (2)*, summarizes the data and test results as well. From these figures and table, it is clear that the limit load for the lateral is higher compared to that of 90° tee indicating that the laterals are plastically stronger than tees. The same conclusions are arrived at for out-of-plane couples as observed by test results shown in figures 3, 4, and 5 and Table 2, (2)*. However, as observed in the Pe/P_{1p} column in Table 1, (2)*, the following is concluded:

1. Laterals are plastically stronger than 90° branch connections when subjected to external bending moments.

2. Laterals are plastically weaker compared to tees when exposed to internal pressures.

Conclusion 2 is drawn as a point of interest since in class 2, 3, and B31.1 stress analysis, the pressure loading terms are not intensified. The branch construction need only meet the local pressure reinforcement requirements stated in the applicable codes.

While reference (2)* conducted tests on 45° lateral branch connections only reference (3)* reports results of tests conducted on tubular joints laterals with angle of branch connections ranging from 0° to 90°. Reference (3)* presents the finite element model analytical results as well as results of experimental investigations and provides stress concentration factor (SCF) for radial thrusts loads, in-plane, out-of-plane bending moments applied to both normal and lateral branch connections. The SCF value reported does not represent maximum or peak stress in the joint, but rather the equivalent of the maximum primary plus secondary membrane plus bending stresses as represented by the C_2 stress indices of NB 3650.

* Numbers in () indicate reference numbers listed in Section 3.

** FIGS. & TABLES FOLLOW CONCLUSION SECTION

J.G. Kuang, et al, (3)* performed a parametric study to best fit the experimental results to those arrived at by finite element analysis. The following parameters that govern the stress distribution in branch connections were chosen: the run thickness to diameter ratio T/D, the branch the run pipe thickness ration t/T, the branch to run diameter ratio d/D, and most significantly to our current investigation, the angle of branch connection. The T/D and t/T ratios govern the stress distribution by influencing the radial flexibility of the run pipe (Figure 6), (3)*, and by bending stress in the branch at the intersection. The d/D ratio and the angle of branch connection influence the stress distribution by the load transfer mechanism.

When a tee is subjected to axial branch loading, the load is transferred to the run primarily via local bending and punching shear. As a result if the branch is inclined at other than 90° only the component of the load normal to the run wall is of primary concern, as the horizontal component is transferred by compression or tension in the run.

Reference (3)* developes empirical equations to derive SCF's based on the parameters discussed above. The applicability and accuracy of the empirical equations developed were verified by comparing the test results to results obtained by the empirical equations. Figure 7(3)* shows good agreement between the experimental and analytical results. The empirical expression for radial loads, in-plane, and out-of-plane bending loads contain a multiplying term $\sin^a \theta$ where θ is the angle of branch connection, [see Table 3] and 'a' is a constant greater than zero. This indicates that the maximum stress for the branch connection and SCF increases as the angle θ increases, $0° \leq \theta \leq 90°$.

Several other researchers' investigations, (6)*, (7)*, and (8)* have resulted in empirical equations for SCF's that include a $\sin^a \theta$ term reinforcing the conclusion arrived at in reference (3)*. Table 4, (9)*, also indicates the agreement between the results arrived at by various authors.

Reference (3)* imposes a set of limitations on geometric parameters to minimize dispersion between experimental and analytical results. Most important of them are:

- $0.2 \leq t/T \leq 0.8$
- $0.3 \leq d/D \leq 0.8$
- $0° \leq \theta \leq 90°$

As mentioned earilier, the SCF derived in reference (3)* is akin to C_2 stress indices of the code. From reference (3)* it is clear that the SCF and therefore, C_2 for laterals are lower thean 90° branch connections. By considering the geometry, branch and lateral connections must have similar K_2 indices and thus the product of C_2K_2 for laterals will always be lower than that for branches. Therefore stress intensification factor 'i' which is equal to $C_2K_2/2$ (NC 3673.1(b)) for laterals will always be lower than that for 90° branches.

* Numbers in () indicate reference numbers listed in Section 3.

While it is true that Reference (3)* deals with tubular joints, (no hole at the run-branch intersection) the same conclusions are arrived at by C. Hsiao and A.S. Kahn (4)* for piping intersetions. C. Hsiao, et al, present the result of finite element investigation of 6 x 3 branch connections for three branch angles, namely 30°, 60°, and 90°, subjected to in-plane and out-of-plane loads.

The output of the finite element analysis in the form of membrane stresses and bending moments in the local coordinates are properly combined to obtain total stresses at the run/branch pipe intersection. These stresses are divided by "beam type stresses" (= M/Zr) for the known applied in-plane and out-of-plane moment to obtain a "stress ratio". Here M is the applied moment and Zr the elastic section - modules of the run pipe. The stress ratio thus obtained are compared to the experimental data, (10)*, for in-plane and out-of-plane loadings available for 30° and 60° branch connection angles. Figures 8, 9, 10, and 11, (4)*, exhibit good agreement between the experimental and analytical results. Reviewing figures 12 through 20, (4)*, indicate that the stress ratio increases with the increase in the angle of branch connection thus confirming results of reference (3)*.

Reference (11)* provides a basis to evaluate the fatigue capacities of a lateral in comparison to a 90° branch of equal size under equivalent loading conditions. Figure 21 results indicate a trend to initial failure (crack initiation) occurring at 90° branches sooner than at equivalent laterals and complete failure (through-wall crack) predominantly occurring in 90° branch connections. The tests were run using stress ranges above those allowed by the piping codes for a 7,000 cycle life. The laterals withstood greater than 7,000 cycles in all cases. These trends indicate that a lateral is less sensitive to cyclic damage than its equivalent 90° branch.

* Numbers in () indicate reference numbers listed in Section 3.

5.0 SUMMARY OF RESULTS

1. Under a single load to failure, the lateral branch connection is stronger plastically than the normal branch connection.

2. Under cyclic loading the lateral branch connection has greater fatigue strength than a normal branch connection.

3. Laterals are plastically weaker compared to tees when exposed to internal pressure.

4. While reference (3)* tests are on tubular joints the results are applicable to branch connections considering the similar conclusions arrived at in reference (1)* and (4)*.

5. Reference (3)* imposes geometric parameter limitations for the empirical expressions for SCF to be valid. However, it is reasonable to assume that the dispersion between experimental and analytical results for tees and laterals will be in the same direction so that the laterals SCF's will always be lower than that of tees even outside the geometric limitations.

* Numbers in () indicate reference numbers listed in Section 3.

6.0 CONCLUSIONS

1. In a piping analysis a lateral branch connection can be safely analyzed similar to a normal branch connection for class 2 and 3 and non-ASME pipes.

2. In general the results of this investigation indicates that unreinforced fabricated lateral connections are stronger than corresponding 90° connections. It is expected that this same conclusion could be drawn for reinfored lateral connections as well. However, until more data becomes available to confirm this it is recommended that a factor be applied for additional conservatism in the calculation of stress intensification factors (SIF) for laterial connections.

   The SIF for either an unreinforced or reinforced connections may be determined by calculating the SIF for an equivalent 90° connection and increasing it by 25 percent.

3. The above must be subjected to the following restrictions:

   a. The branch connections must meet all the pressure reinforcement requirements of NC 3643 of ASME Section III or ANSI B31.1 Paragraph 104.3.1.

   b. The branch connection angle (the angle between the run and branch pipe axes) is between 45° and 90° both inclusive REV 1

   c. ASME Section III code version is limited to the summer 1981 addenda and earlier. Winter 1981 addenda requires that pressure terms be modified by "B" indices.

4. The use of lateral branch connections would be restricted to ASME Class 2 and 3 and B31.1 systems; insufficient data exists to draw conclusions for Class 1 applications.

* Numbers in () indicate reference numbers listed in Section 3.

TABLE 1 : REF: 2 Tables 1,

—Data on Limit Pressure Tests

Connect. or Pipe No.[1]	$\frac{d}{D}$	$\frac{D}{T}$	$\frac{s}{S}$	$\frac{A_f}{rT}$	p or m	σ_T (ksi)	p_{LP} (ksi)	p_B (ksi)	$\frac{p_B}{p_{LP}}$	No. of dial gages	Fig. No. for test data
T_1	1	33	1	...	...	33.3	2.02	1.45	(0.69)	1	20
T_6	0.63	35	0.9	...	...	31.4	1.80	1.40	(0.78)	3	21
T_4	0.85	26	1	0.32	4T	40.4	3.11	1.88	0.61	3	22
T_7	1	25	1	0.28	4T	36.5	2.92	1.8 ± 0.1	0.62	3	23
P_1	...	31	...	...	...	28.2	1.82	2.1	1.16	...	24
Y_1	1	34.5	1	...	8T	35.0	2.03	0.78	0.39	1	25
Y_3	1	26.8	1	...	8T	30.3	2.25	0.80	0.35	1	26, 27
Y_4	0.63	29	0.94	...	8T	31.6	2.18	1.15	0.51	4	28
Y_{10}	1	26.8	1	...	8T	30.3	2.26	0.87 ± 0.1	0.39	4	29
Y	1	14.6	1	...	...	35.7	4.89	3.4	0.7	4	30, 32
Y	1	17	1	...	...	38.9	4.57	2.1	0.46	4	31, 33
Y	0.77	17.2	0.8	...	...	33.9	3.94	2.6	0.69	4	34
Y	1	17.7	1	...	...	37.7	4.26	1.9	0.47	4	35

[1] The branch-pipe angle α of all laterals is 45 deg. The external reinforcement of T_1 and T_7 was more than a fillet. The limit pressure p_L of P_1 was 2.09 ksi.

TABLE 2 : REF 2 Tables 2 & 3

—Data on Limit Couple Tests of Plain Pipes and In-Plane Couple Tests

Connect. or Pipe No.[1]	$\frac{d}{D}$	$\frac{D}{T}$	$\frac{s}{S}$	$\frac{A_f}{rt}$	p or m	σ_T (ksi)	p_{LP} (ksi)	C_L or C_{IL} (in-kip)	p (ksi)	C_B or C_{IB} (in-kip)	$\frac{C_B}{C_L}$ or $\frac{C_{IB}}{C_{IL}}$	$\frac{p}{p_{LP}}$	No. of dial gages	Fig. No. for test data
P_1	...	21	...	...	...	28.7	...	43.0	...	36.9	0.86	...	2	37
P_3	...	41	...	...	...	28.2	1.38	31.8	0.75	26.5	0.83	0.55	2	38
P_4	...	51	...	...	...	27.7	...	24.6	...	23.5	0.96	...	2	39
T	0.52	24	1	0.14	2T	31.6	...	7.3	0	6.6 ± 0	0.91	0	2	40
T	0.75	25	1	0.37	3.5T	32.4	...	22.1	0	18.5 ± 0	0.84	0	2	41
~~T~~	~~1.0~~	~~25~~	~~1~~	~~0.28~~	~~4T~~	~~25.0~~	~~...~~	~~42.5~~	~~0~~	~~27.0 ± 2~~	~~0.64~~	~~0~~	~~4~~	~~42, 43, 44~~
Y_1	0.75	25	1	...	7T	35.4	...	24.2	0	23.0 ± 0	0.95	0	2	45
~~T~~	~~0.75~~	~~25~~	~~1~~	~~0.27~~	~~4T~~	~~37.5~~	~~3.1~~	~~25.4~~	~~1.0~~	~~12.0 ± 0~~	~~0.47~~	~~0.32~~	~~2~~	~~46~~
T	1.0	27	1	0.25	4T	25.2	1.9	39.6	0.5	19.2 ± 0	0.49	0.26	2	47

[1] The branch-pipe angle α of all laterals is 45 deg. C_{pL} of P_1 is 27.8 in.-kip.

TABLE 2

—Data on Out-of-Plane Limit Couple Tests and Plastically Unstable Out-of-Plane Couple Tests

Connect. or pipe No.[1]	$\frac{d}{D}$	$\frac{D}{T}$	$\frac{s}{S}$	$\frac{A_f}{rT}$	p or m	σ_T (ksi)	p_{LP} (ksi)	C_{0L} (in-kip)	p (ksi)	C_{0B} (in-kip)	$\frac{C_{0B}}{C_{0L}}$	IC_{0B} (in-kip)	$\frac{IC_{0B}}{C_{0L}}$	No. of dial gages	Fig. No. for test data
T_1	0.5	25	1	0.14	2T	33.6	...	7.8	...	5.6	0.72	>7.8	...	2	50
~~T_{10}~~	~~0.7~~	~~34.5~~	~~0.55~~	~~0.22~~	~~3.5T~~	~~29.5~~	~~...~~	~~20.2~~	~~...~~	~~...~~	~~...~~	~~9.7~~	~~0.48~~	~~1~~	~~51~~
→ Y_1	0.63	22	1	...	6T	33.2	...	16.1	...	14.4	0.90			1	52
~~T_4~~	~~1~~	~~25~~	~~1~~	~~0.07~~	~~2T~~	~~31.4~~	~~...~~	~~54.0~~	~~...~~	~~...~~	~~...~~	~~32.0~~	~~0.59~~	~~1~~	~~54~~
T_{16}	1	42	1	0.34	6T	24.1	...	23.1	...	...	...	11.0	0.49	3	55, 57
T_{11}	0.7	34.5	0.55	0.044	5T	31.0	1.8	21.8	1.0	7.0	0.32			2	56

[1] The branch-pipe angle α of all laterals is 45 deg.

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TABLE 3 (REF 3 Table 3)

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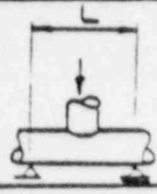
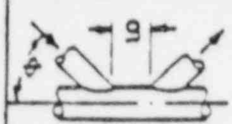
STRESS CONCENTRATION FACTORS FROM SPE 5472, OTC 2205 AUG, 1977



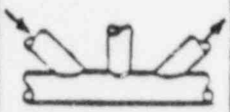
$$T,Y_{Chord} = 1.177 (T/D)^{-0.808} e^{-1.2(d/D)^3} (t/T)^{1.333} (D/L)^{-0.057} \sin^{1.694}\theta \qquad \text{T-1}$$

$$T,Y_{Branch} = 2.784 (T/D)^{-0.55} e^{-1.35(d/D)^3} (t/T) (D/L)^{-0.12} \sin^{1.94}\theta \qquad \text{T-2}$$



$$K_{Chord} = 0.949 (T/D)^{-0.666} (d/D)^{-0.059} (t/T)^{1.104} (g/D)^{0.067} \sin^{1.521}\theta \qquad \text{T-3}$$

$$K_{Branch} = 0.825 (T/D)^{-0.157} (d/D)^{-0.441} (t/T)^{0.560} (g/D)^{0.058} e^{1.440 \sin\theta} \qquad \text{T-5}$$



$$T,K_{Chord} = 1.26 (T/D)^{-0.54} (d/D)^{0.12} (t/T)^{1.068} \sin\theta \qquad \text{T-7}$$

$$T,K_{Branch} = 5.65 (T/D)^{-0.1} (d/D)^{-0.36} (t/T)^{0.68} \left(\frac{g_1+g_2}{D}\right)^{0.126} \sin^{0.5}\theta \qquad \text{T-8}$$

$0 < \theta \leq 45°$

$$T,K_{Branch} = 12.88 (T/D)^{-0.1} (d/D)^{-0.36} (t/T)^{0.68} \left(\frac{g_1+g_2}{D}\right)^{0.126} \sin^{2.38}\theta \qquad \text{T-9}$$

$45° < \theta \leq 90°$

$$T \text{ of } T,K = 4.491 (T/D)^{-0.123} (d/D)^{-0.396} (t/T)^{0.672} \left(\frac{g_1+g_2}{D}\right)^{0.159} \sin^{2.267}\theta \qquad \text{T-10}$$

IN-PLANE BENDING

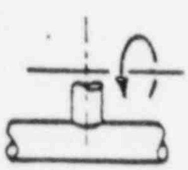
$$T,Y_{Chord} = 0.463 (T/D)^{-0.6} (d/D)^{-0.04} (t/T)^{0.86} \sin^{0.57}\theta \qquad \text{T-11}$$

$$T,Y_{Branch} = 1.109 (T/D)^{-0.23} (d/D)^{-0.38} (t/T)^{0.38} \sin^{0.21}\theta \qquad \text{T-12}$$

IN-PLANE BENDING

$$K_{Chord} = 1.40 (T/D)^{-0.38} (d/D)^{0.06} (t/T)^{0.94} \sin^{0.9}\theta \qquad \text{T-13}$$

$$K_{Branch} = 2.827 (d/D)^{-0.35} (t/T)^{0.35} \sin^{0.5}\theta \qquad \text{T-14}$$



TRANSVERSE BENDING

$$T,Y_{Chord} = 0.507 (T/D)^{-1.014} (d/D)^{0.787} (t/T)^{0.889} \sin^{1.557}\theta \qquad \text{T-15}$$

$0.3 < d/D < 0.55$

$$T,Y_{Chord} = 0.229 (T/D)^{-1.014} (d/D)^{-0.619} (t/T)^{0.889} \sin^{1.557}\theta \qquad \text{T-16}$$

$0.55 \leq d/D \leq 0.75$

$$T,Y_{Branch} = 0.843 (T/D)^{-0.852} (d/D)^{0.801} (t/T)^{0.543} \sin^{2.033}\theta \qquad \text{T-17}$$

$0.3 < d/D < 0.55$

$$T,Y_{Branch} = 0.441 (T/D)^{-0.852} (d/D)^{-0.281} (t/T)^{0.543} \sin^{2.033}\theta \qquad \text{T-18}$$

$0.55 \leq d/D \leq 0.75$

D = Chord Outside Dia. d = Branch Outside Dia

T = Chord Nominal Thickness t = Branch Nominal Thickness

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CALCULATION SHEET

A 5010 65

CALCULATION IDENTIFICATION NUMBER				
J.O. OR W.O. NO.	DIVISION & GROUP	CALCULATION NO.	OPTIONAL TASK CODE	PAGE 16
590.470.1.01	NP(B)	75	X6	

Table 7.2

Formula	SCF in chord $\beta = 0.3$	SCF in chord $\beta = 0.55$	SCF in chord $\beta = 0.8$	SCF in brace $\beta = 0.3$	SCF in brace $\beta = 0.55$	SCF in brace $\beta = 0.8$
			Axial load on the brace			
Gibstein	5.25	5.58	4.08	5.79	6.20	5.24
Kuang	5.92	4.58	3.06	8.36	6.27	3.97
Wordsworth & Smedley	5.87	6.66	4.98	4.70	5.20	4.14
			In-plane bending			
Gibstein	2.03	2.03	1.85	2.03	2.02	1.83
Kuang	1.59	1.55	1.53	2.59	2.06	1.78
Wordsworth & Smedley	2.14	2.23	2.04	2.35	2.40	2.29
			Out-of-plane bending			
Gibstein	2.91	4.60	4.32	2.78	4.64	4.93
Kuang	2.44	3.94	3.10	3.15	5.12	4.60
Wordsworth & Smedley	2.87	5.09	5.87	2.81	4.21	4.70

TABLE: 4

REF: 9 PAGE 188

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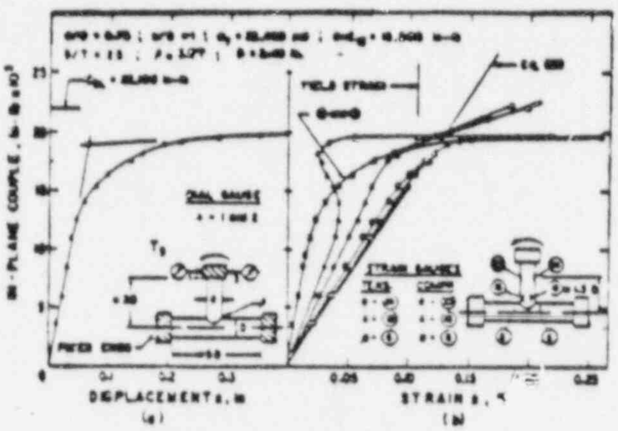
590.470.1.01	NP(B)	75	X6	

REFERENCE 2: Fig. 41



—In-plane limit couple test on T3

TEES

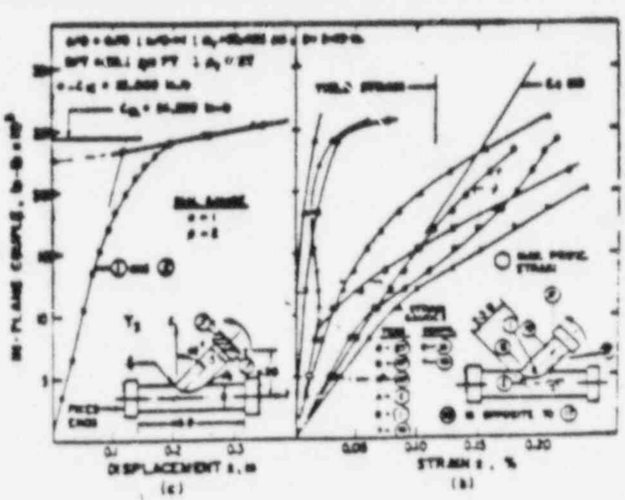
FIGURE: 1

IN-PLANE LIMIT COUPLE

TEES:

EXPERIMENTAL: 18500 IN-LB

THEORETICAL: 22,100 IN-LB



—In-plane limit couple test on Y3

LATERALS

FIGURE: 2 (REF 2 Fig 45)

IN-PLANE LIMIT COUPLES ON 45° LATERAL:

EXPERIMENTAL: 23,000 IN-LB

THEORETICAL: 24,200 IN-LB

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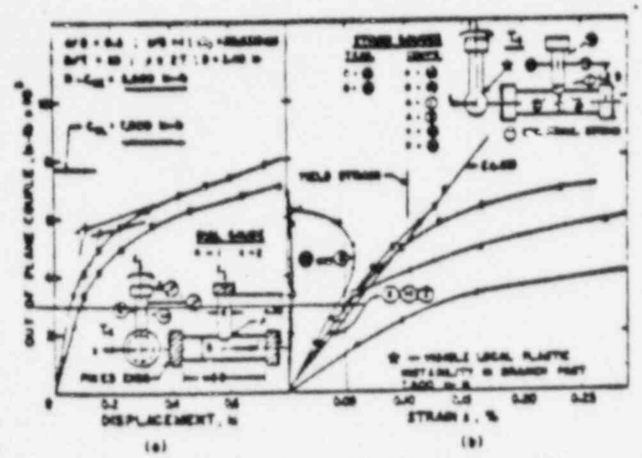
590.470.1.01	NP(B)	75	X6	

OUT-OF PLANE LIMIT COUPLE ON TEES AND LATERALS

(REF: 2 Figs 50, 52, 56)



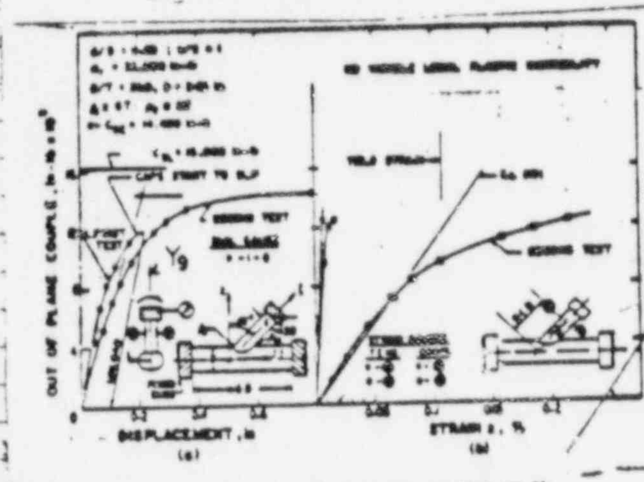
—Out-of-plane limit couple test on T_6

FIGURE: 3

LIMIT COUPLE:

EXPERIMENTAL: 5600 IN LB

THEORETICAL: 7800 INLB

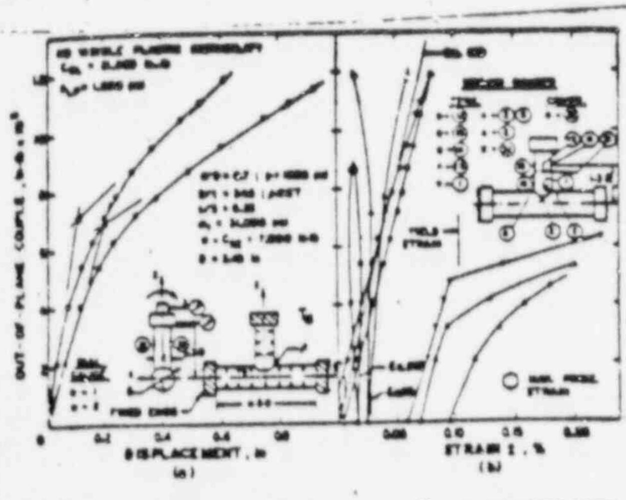


—Out-of-plane limit couple test on Y_9

EXPERIMENTAL: 14,400 INLB

THEORETICAL: 16,060 INLB

FIGURE: 4



—Out-of-plane limit couple test on T_{11} at constant internal pressure

EXPERIMENTAL: 7000 INLB

THEORETICAL: 21,500 INLB

FIGURE: 5

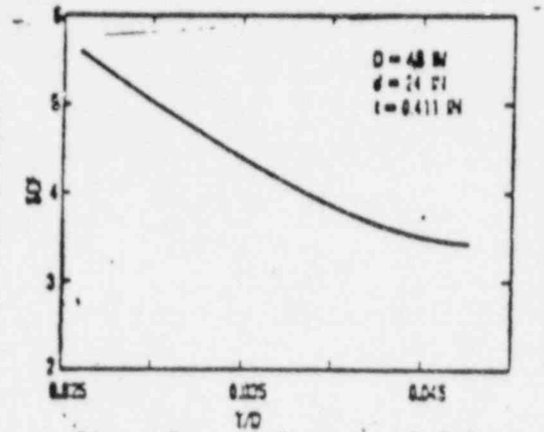


Fig. 10a - Influence of T/D on the SCF of a typical T-joint.

REF: 3
(Fig 10a)

FIGURE 6

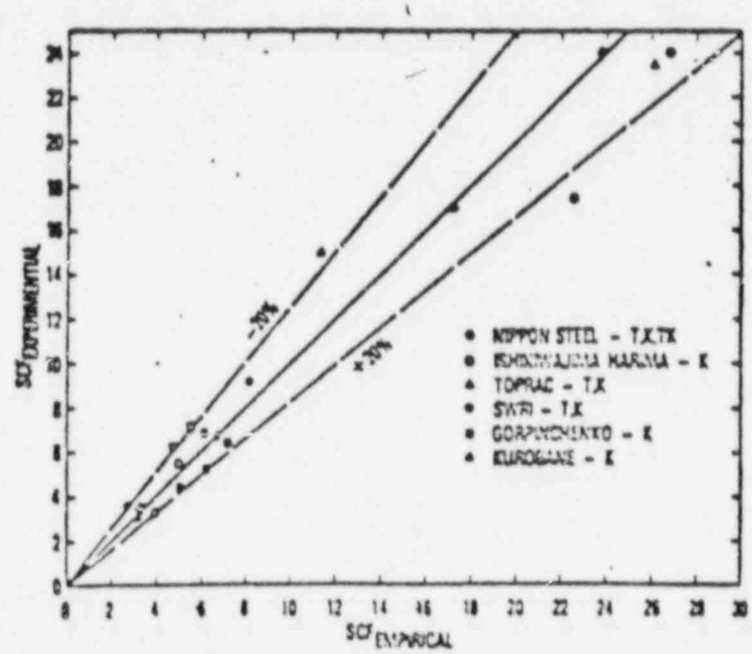


Fig. 11 - Comparison of experimental and empirical SCFs for various joints.

REF: 3
(Fig 11)

FIGURE 7

REF: 4 (Fig 13)

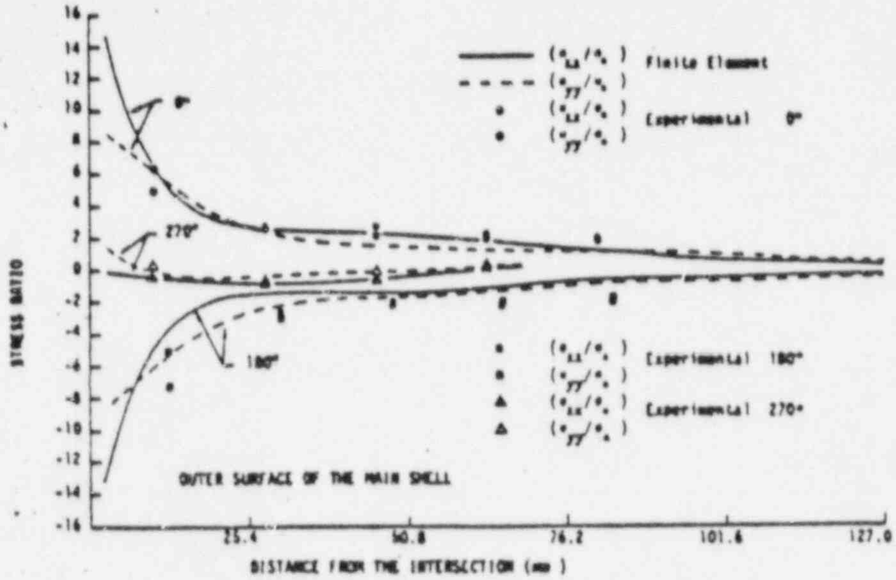


Figure 13. In-plane loading results for 60° intersection (outside surface).

FIGURE 8

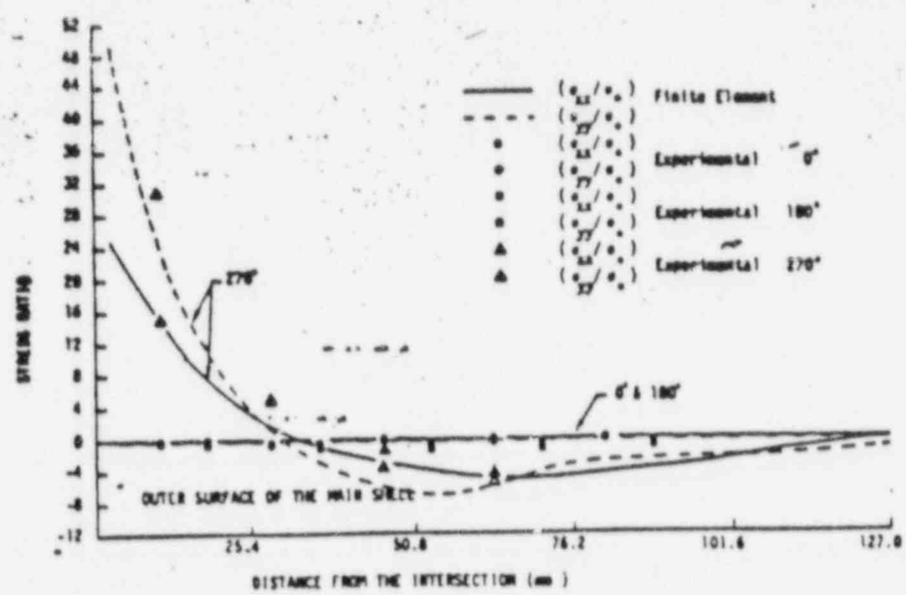


Figure 14. Out-of-plane loading results for 60° intersection (outside surface).

FIGURE 9 (Ref: 4 Fig 14)

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CALCULATION SHEET

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J.O. OR W.O. NO.	DIVISION & GROUP	CALCULATION NO.	OPTIONAL TASK CODE	PAGE 21
590.470.1.01	NPLB)	75	X6	

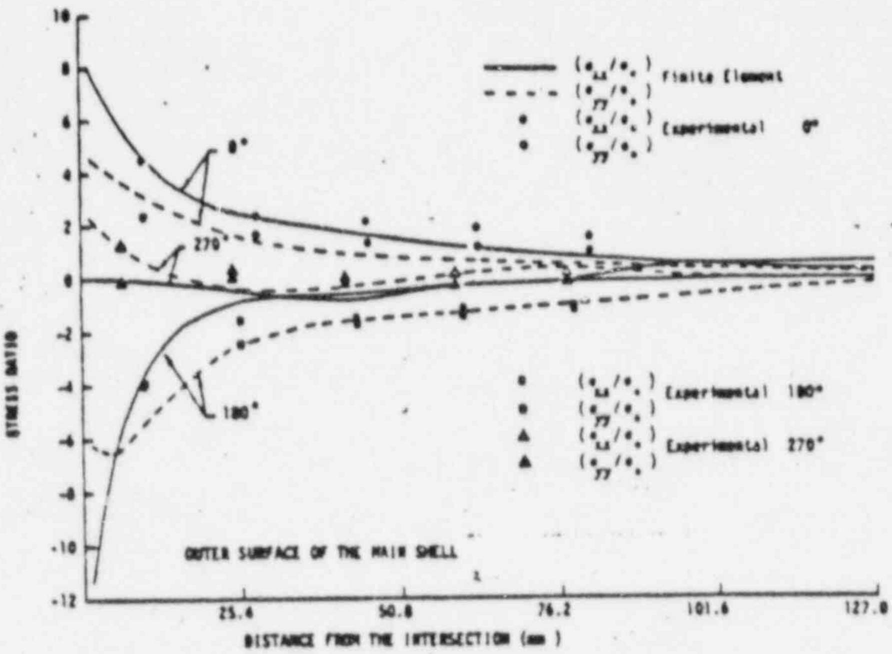

Figure 15. In-plane loading results for 30° intersection (outside surface).

(REF: 4 Fig 15)

FIGURE 10

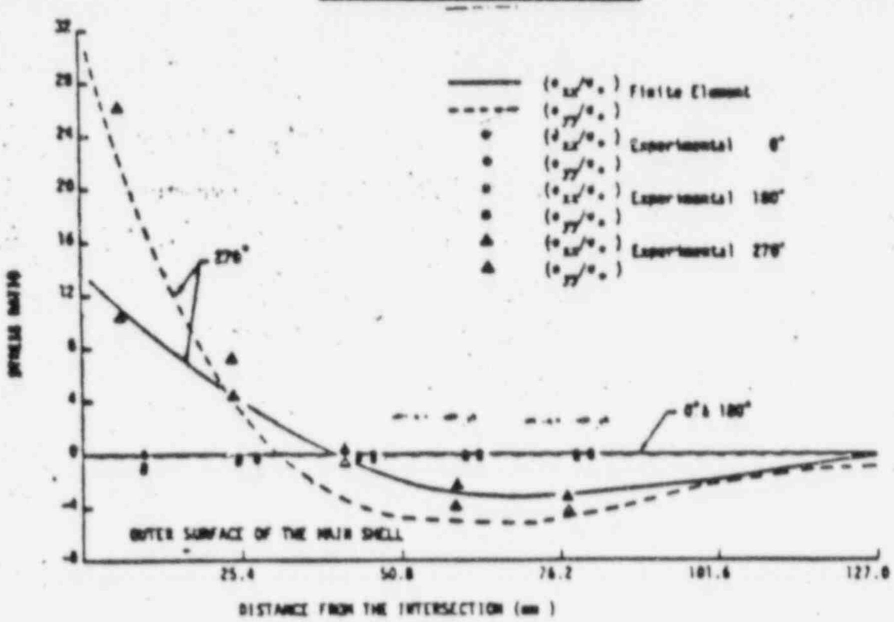

Figure 16. Out-of-plane loading results for 30° intersection (outside surface).

(REF: 4 Fig 16)

FIGURE 11

▲ 5010.65

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J.O. OR W.O. NO. 590.470.1.01	DIVISION & GROUP NP(B)	CALCULATION NO. 75	OPTIONAL TASK CODE X6	

(REF: 4 Fig 11)

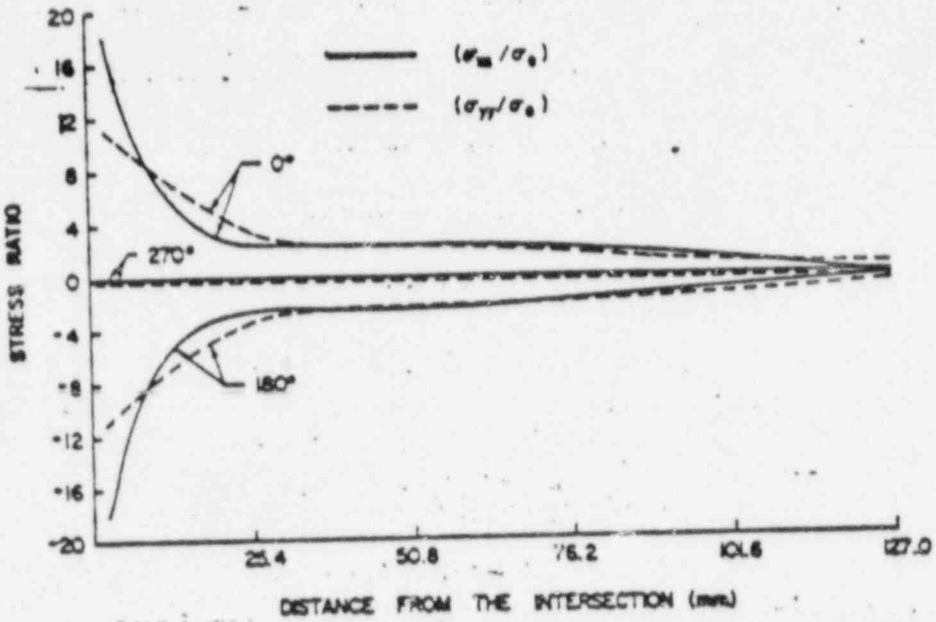
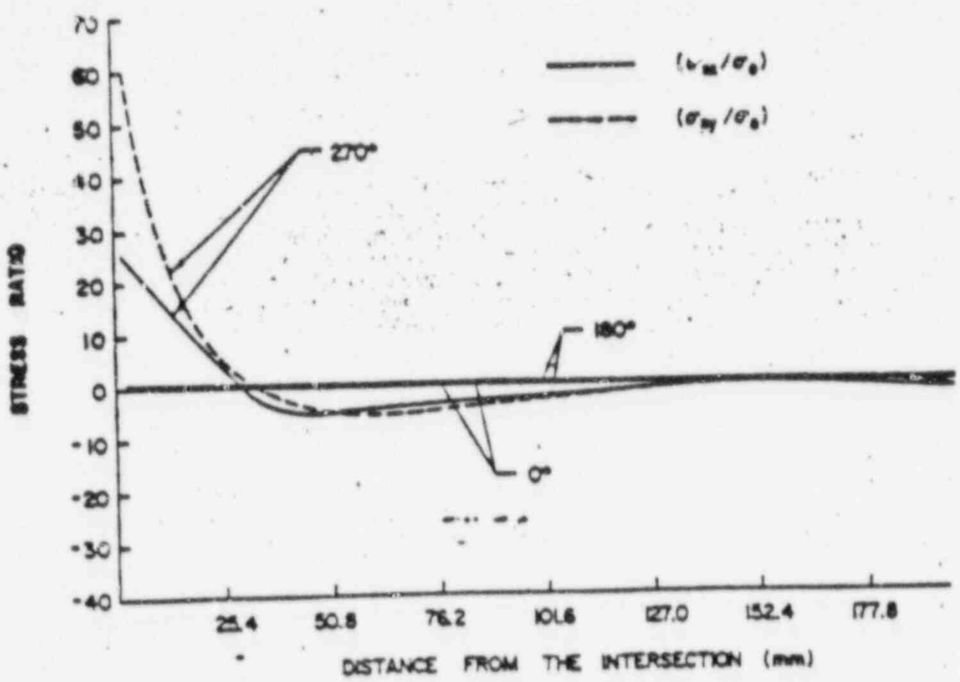


Figure 11. In-plane loading results for 90° intersection (outside surface).

FIGURE 12



(Ref 4 Fig 12)

Figure 12. Out-of-plane loading results for 90° intersection (outside surface).

FIGURE 13

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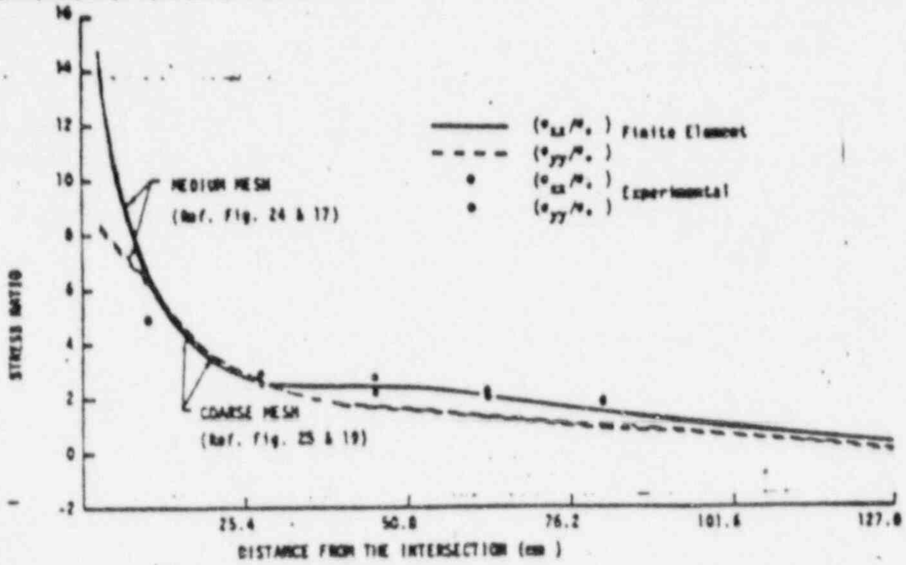
A 5010.66

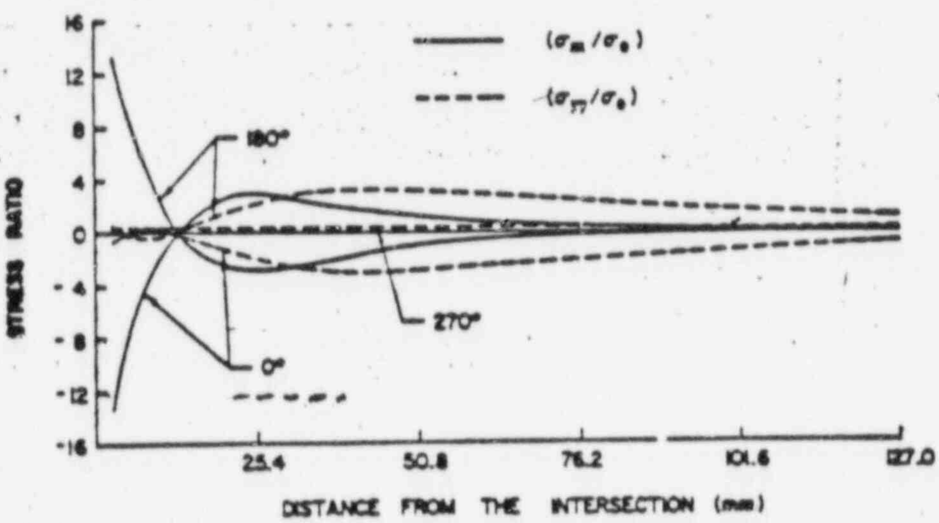
CALCULATION IDENTIFICATION NUMBER				PAGE 23
J.O. OR W.O. NO.	DIVISION & GROUP	CALCULATION NO.	OPTIONAL TASK CODE	
570.470.1.01	NP(B)	75	X6	



REF: 4 (Fig 17)

Figure 17. Comparison of the course and fine meshes for the case of in-plane loading at 0° line.

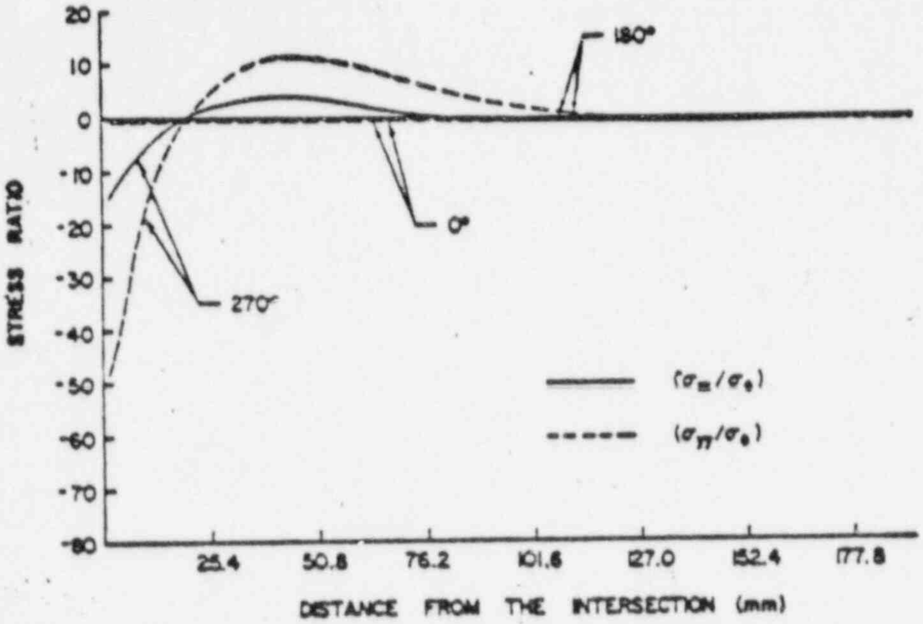
FIGURE 14



(Ref: 4 Fig. 18)

FIGURE 15

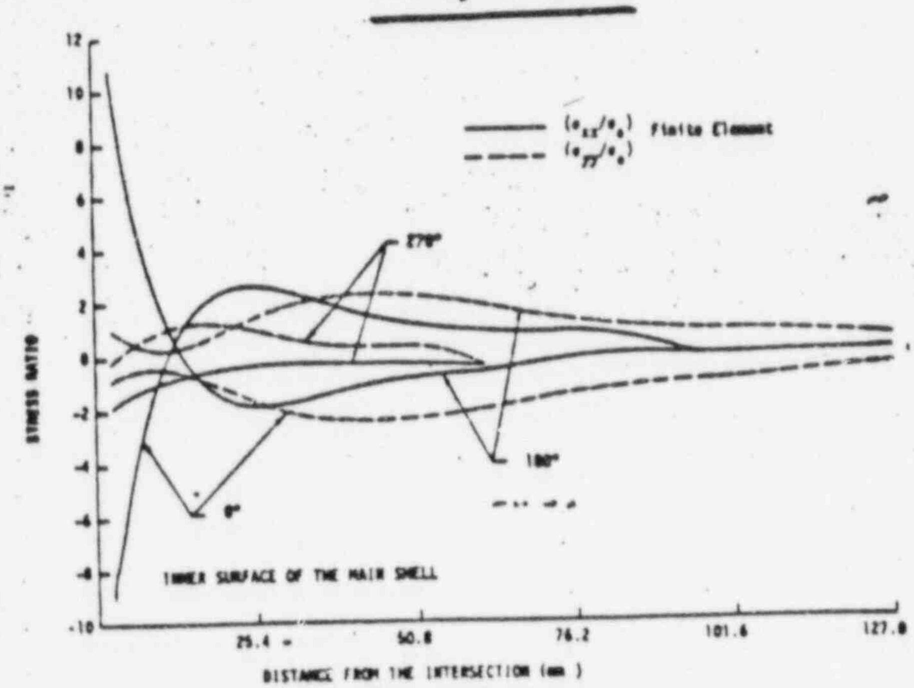
Figure 18. In-plane loading results for 90° intersection (inside surface).



REF: 4 (Fig 19)

Figure 19. Out-of-plane loading results for 90° intersection (inside surface).

FIGURE 16



(REF 4 Fig 20)

FIGURE 17

Figure 20. In-plane loadin, results for 60° intersection (inside surface).

REF 4
(Fig 21)

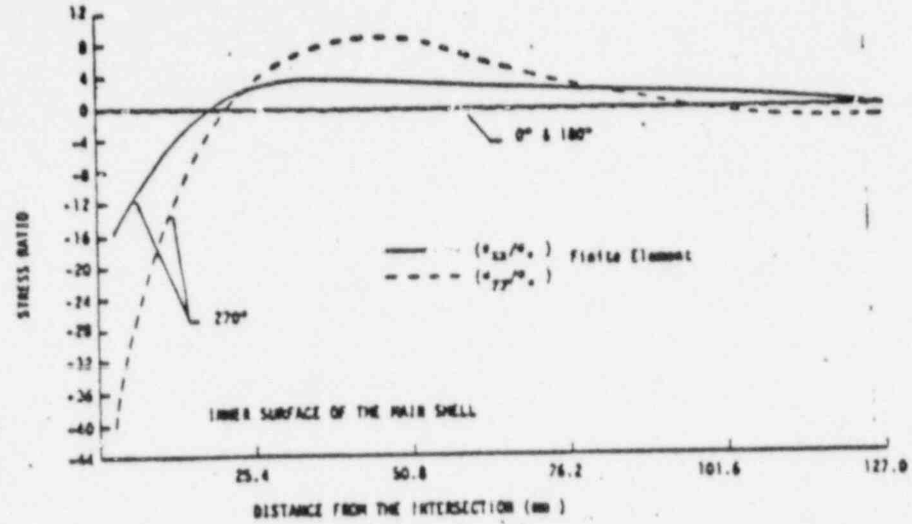


Figure 21. Out-of-plane loading results for 60° intersection (inside surface).

FIGURE 18

REF 4
Fig 22

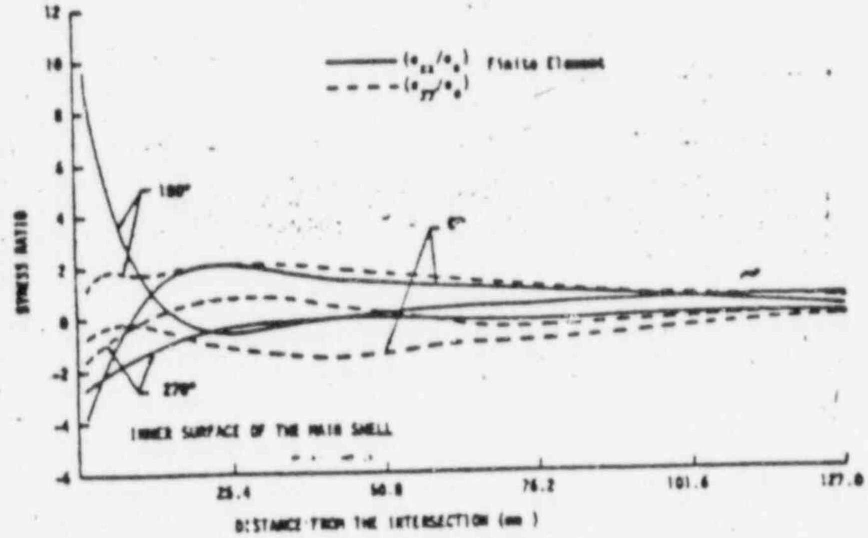


Figure 22. In-plane loading results for 30° intersection (inside surface).

FIGURE 19

A 5010.65

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J.O. OR W.O. NO.	DIVISION & GROUP	CALCULATION NO.	OPTIONAL TASK CODE	
590 470.1.01	NP(B)	75	X6	

FIGURE 20 (REF: 4 Fig 23)

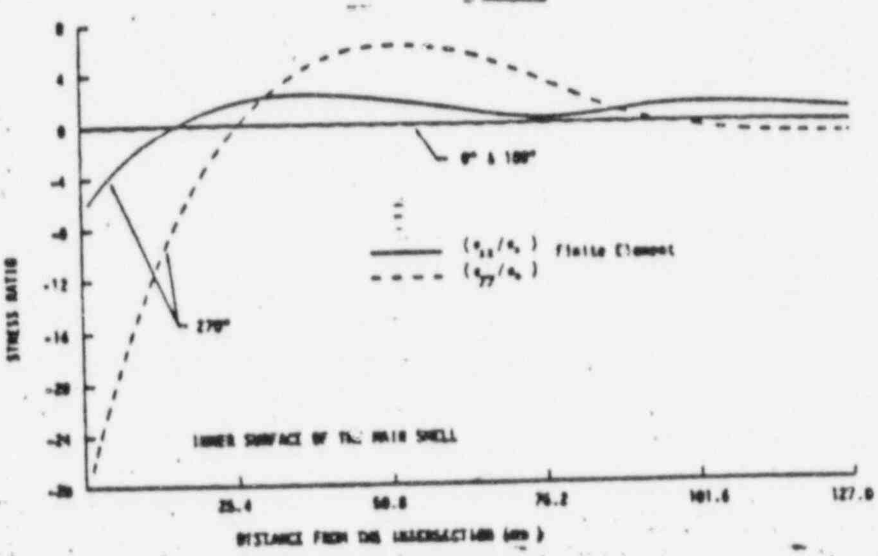

Figure 23. Out-of-plane loading results for 30° intersection (inside surface).

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CALCULATION SHEET

A 5010.65

CALCULATION IDENTIFICATION NUMBER				
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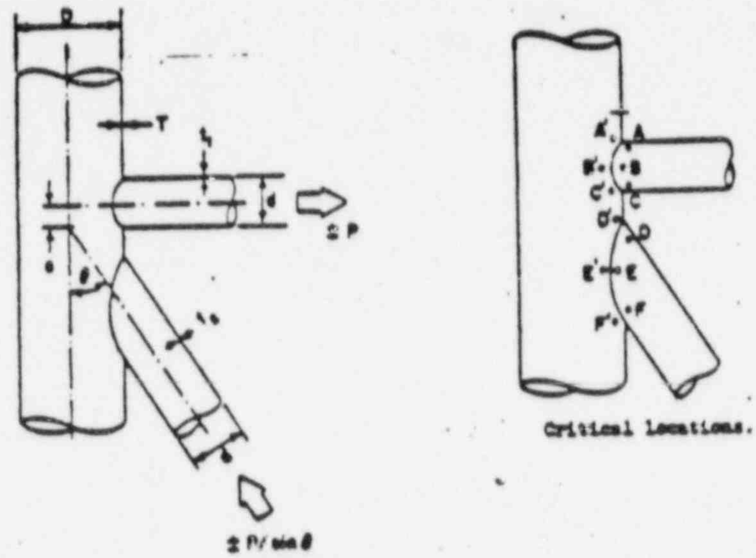
599.470.1.01	NP(B)	75	X6	

FIGURE 21 (REF: 14. Figs 2, 3 & Table 2)



...Test specimen and loading condition.

Critical locations.

- FATIGUE DATA OF K-TYPE TUBULAR JOINTS- C. FATIGUE LIFE AND CRITICAL LOCATIONS FOR FATIGUE FRACTURE

SPECIMEN DESIGNATION	CRACK INITIATION				CYCLES TO COMPLETE FAILURE	FAILURE OCCURRED AT
	HORIZONTAL		DIAGONAL			
	CYCLES	CRITICAL LOCATION	CYCLES	CRITICAL LOCATION		
A-1	14,500	C	20,300	D	34,600	Horiz.
A-2	49,000	C, B', C'	68,500	D	94,900	Horiz.
B-1	6,400	C, B'	12,300	D'	22,600	Horiz.
B-2	7,500	C, B'	None	-	19,000	Horiz.
B-3	48,700	C, B'	35,600	D'	106,500	Horiz.
B-4	160,000	C	150,000	D', D	217,900	Diag.
C-1	9,900	C, B, A	None	-	9,900	Horiz.
C-2	17,700	C	16,100	D	27,700	Horiz.
C-3	27,500	C	None	-	75,900	Horiz.
C-4	67,000	C	None	-	85,600	Horiz.
C-5	382,000	-	None	-	None	-
D-1	60	B', C', A'	None	-	450	Horiz.
D-2	2,580	C', B'	1,400	D'	6,300	Horiz.
B-3	1,200	C', B'	1,520	B', F	6,600	Diag.