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Formulas for Variation of Stress Concentration Around Intersection in Tubular Joints

Many of the offshore structures used for oil exploration and exploitation are built of tubular members. The repeated damages in tubular joints have clearly shown that the safety of these structures depends on the safe fatigue design of the joints. The fatigue life of the joint depends very much on the Stress Concentration Factor, SCF. The current practice is to use semi-empirical formulas proposed by various investigators to determine SCF. While some of the formulas give the maximum SCF, others give the SCFs at both the crown and saddle points. The design of fatigue life using the value of maximum SCF is conservative, while using SCFs at crown and saddle is unsafe. The main aim of this paper is to propose a set of formulas for T and Y-joints, which gives not only the magnitude of maximum SCF as in the presently available formulas, but also the variation of SCF around intersection.

Introduction

Many of the offshore structures used for oil exploration and exploitation are built of tubular members. Structural failures in some of the platforms indicate fatigue cracking of tubular joints. The design of tubular joints depends on the stress concentration factor (SCF), since an error of 20 percent in SCF causes an error of as much as 100 percent in fatigue life. The current practice is to use semi-empirical formulas for SCF. While some of the formulas give maximum SCF, others give the magnitude of SCF at both crown and saddle.

The fatigue design of tubular joints is usually carried out at eight points equally spaced around the intersection. Since the joint is subjected to three types of loading, namely axial force, in-plane bending and out-of-plane bending, and the location of hot spot is different for each of the three types of loading, using the value of maximum SCF at all eight points is conservative. The load interaction for three types of loadings based on the crown and saddle SCFs is unsafe, since the location of hot spot does not lie either in the crown or saddle in some cases. This paper presents a new set of formulas, which gives not only the location and magnitude of maximum SCF, but also the variation of SCF around intersection of tubular *T* and *Y*-joints.

Literature Survey

The available formulas for SCF in literature are due to Kuang (1975), Wordsworth and Smedley (1978), Gibstein (1978), Visser (1974), Beale and Toprac (1967), Mitsui (1973), Reber (1973), Kellog (1956) and Efthymiou and Dunkin (1985).

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The formulas proposed by Kuang (1975), Gibstein (1978) and Wordsworth and Smedley (1978) are the most commonly used formulas for SCF. The Kuang formulas are a complete collection of formulas for all types of joints. While the Kuang and Gibstein formulas give the maximum SCF, Wordsworth and Smedley predict the SCF at both crown and saddle. Gulati et al. (1982) have proposed a formula for stress variation around intersection assuming a linear variation of axial load and sinusoidal variation for in-plane and out-of-plane moment.

Finite Element Analysis

The fatigue design of tubular joints requires accurate determination of SCF. The semi-empirical formulas available in literature do not give the variation of SCF around intersection. Finite element analysis of tubular joints is carried out to develop a set of formulas which gives not only magnitude and location of the maximum SCF, but also the variation of SCF. The thin plate and shell element available in Structural Analysis Program SAP IV (1973) is used for the analysis. A preprocessor for SAP IV is developed to discretize the tubular

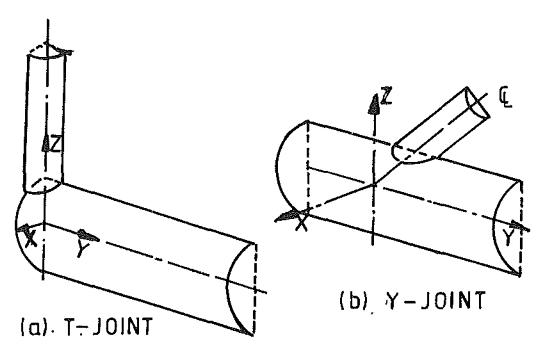

Fig. 1 Coordinate axes

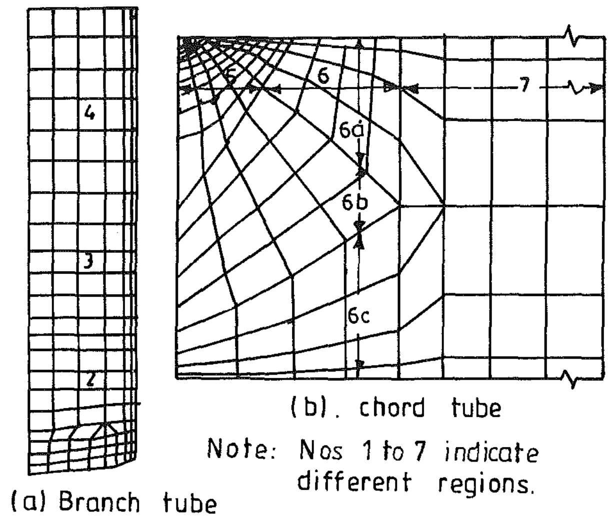

Fig. 2 Discretization of T-joint

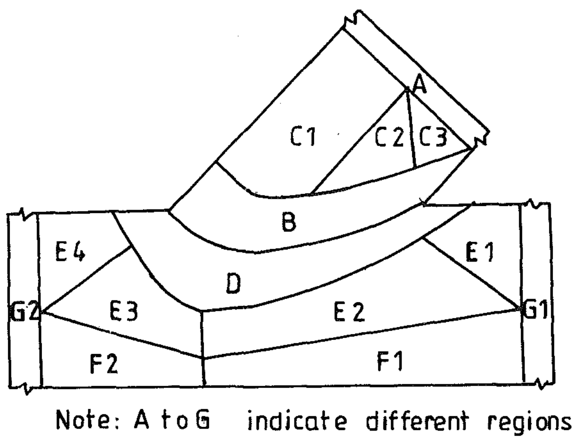

Fig. 3 Y-joint regions

joint into graded mesh. Considering geometric symmetry, one quarter of the tubular T-joint and one-half of the tubular Y-joint (Fig. 1) are discretized using the preprocessor. The discretization on the developed surface of the T-joint is given in Fig. 2, and the different Y-joint regions are given in Fig. 3.

The end conditions at supports, i.e., at chord ends, are assumed as fixed. Hence, at chord ends $u_x = u_y = u_z = \theta_x = \theta_y = \theta_z = 0$.

In addition, the following boundary conditions considering symmetry and/or antisymmetrty of the loading are assumed along the geometric lines of symmetry.

T-Joint

(*a*) Axial force. The loading is symmetric about both x and y-axis. Hence, for all nodes along $X=0$, $u_x=\theta_y=\theta_z=0$; and for all nodes along $Y=0$, $u_y=\theta_x=\theta_z=0$.

(*b*) In-plane moment. The loading is antisymmetric about X-axis and symmetric about Y-axis. Hence, for all nodes along $X=0$, $u_x=\theta_y=\theta_z=0$; and for all nodes along $Y=0$, $u_z=u_x=\theta_y=0$.

(*c*) Out-of-plane moment. The loading is symmetric about X-axis and antisymmetric about Y-axis. Hence, for all nodes along $X=0$, $u_y=u_z=\theta_x=0$; and for all nodes along $Y=0$, $u_y=\theta_x=\theta_z=0$.

Y-Joint

(*a*) Axial force and in-plane moment. The loading is symmetric about Y-axis. Hence, for all nodes along $X=0$, $u_x=\theta_y=\theta_z=0$.

(*b*) Out-of-plane moment. The loading is antisymmetric about both Y-axis. Hence, for all nodes along $X=0$, $u_y=u_z=\theta_x=0$.

The details of preprocessor and comparison of results with those of Chi-Tat-Kwan and Graff (1972) are given in Sundaravadivelu and Ganapathy (1981).

A postprocessor is developed to process the results of SAP IV, i.e., the midpoint membrane and bending stress components. The principal stresses, calculated using the midpoint membrane and bending stress components along the intersection in both the branch and chord tubes are extrapolated linearly to the line of intersection. The stress concentration factor along the intersection is calculated as the ratio of maximum principal stress to the normal stress in the branch. The location of maximum SCF is defined as the hot spot.

Parametric Study

The magnitude and location of maximum SCF and the variation of SCF depend on the type of joint, type of loading, and the diameter and thickness of both branch and chord tubes. Two types of joints (T and Y), and three types of load cases are considered for parametric studies. The diameter of the chord is kept constant and the diameter of the branch and thickness of both the branch and chord are varied in the following ranges:

$$20 \leq D/T \leq 40$$

$$0.35 \leq d/D \leq 1$$

$$0.35 \leq t/T \leq 1$$

$$45 \text{ deg} \leq \alpha \leq 90 \text{ deg}$$

In all 121 joints have been analyzed, the details of which are given in Table 1.

Table 1 Parametric joint details

Type of joint	Load case	No. of joints analysed
T	Axial force	42
T	Inplane moment	29
T	Out-of-plane moment	26
Y	Axial force	8
Y	Inplane moment	8
Y	Out-of-plane moment	8

Nomenclature

d = diameter of branch tube
D = diameter of chord tube
u_x,u_y,u_z = displacements in x, y and z directions, respectively
$\theta_x,\theta_y,\theta_z$ = rotations in x, y and z directions, respectively
t = thickness of branch tube
T = thickness of chord tube
α = angle of inclination of branch with chord
β = angle around the line of intersection

Table 2 T-joint subjected to axial load

Joint	D/T	t/T	d/D	Maximum SCF in branch		Maximum SCF in chord	
				FEM	Author's formula	FEM	Author's formula
TA 1	40	0.35	0.34	6.20	7.6	4.9	5.5
TA 2	40	0.50	0.34	9.35	10.1	8.0	8.2
TA 3	30	0.35	0.34	5.60	6.6	4.1	4.4
TA 4	30	0.50	0.34	8.20	8.5	6.6	6.8
TA 5	20	0.35	0.34	4.80	5.4	3.2	3.6
TA 6	40	0.50	0.45	10.10	9.0	9.5	8.6
TA 7	40	0.75	0.45	14.50	12.0	16.5	15.1
TA 8	35	0.50	0.45	9.50	8.3	8.5	8.1
TA 9	35	0.75	0.45	13.60	11.2	15.4	13.3
TA 10	30	0.35	0.45	6.10	6.1	4.8	4.7
TA 11	30	0.50	0.45	8.80	7.8	7.6	7.2
TA 12	25	0.35	0.45	5.60	5.5	3.9	4.1
TA 13	25	0.50	0.45	8.00	7.0	6.4	6.5
TA 14	20	0.50	0.45	7.00	6.3	5.4	5.7
TA 15	40	0.75	0.56	15.00	11.2	13.7	13.2
TA 16	40	1.00	0.56	17.30	13.8	20.2	18.9
TA 17	35	0.50	0.56	8.50	7.8	6.9	7.4
TA 18	35	0.75	0.56	13.80	10.5	12.0	12.3
TA 19	35	1.00	0.56	15.8	13.0	18.4	17.4
TA 20	30	0.50	0.56	8.8	7.2	5.8	6.0
TA 21	30	0.75	0.56	12.4	9.6	10.7	11.0
TA 22	25	0.35	0.56	5.5	5.3	3.0	4.5
TA 23	25	0.50	0.56	8.0	6.6	4.8	5.9
TA 24	20	0.35	0.56	5.0	4.7	2.4	3.3
TA 25	20	0.50	0.56	7.1	5.9	4.0	5.2
TA 26	40	0.75	0.69	12.1	10.5	9.0	10.0
TA 27	40	1.00	0.69	14.6	12.9	13.9	14.4
TA 28	30	0.50	0.69	6.9	6.9	4.8	5.1
TA 29	30	0.75	0.69	10.3	9.0	7.9	8.4
TA 30	30	1.00	0.69	12.0	11.1	12.1	11.9
TA 31	20	0.35	0.69	3.9	4.5	3.5	2.5
TA 32	20	0.50	0.69	5.7	5.6	4.4	3.3
TA 33	40	1.00	0.85	11.3	11.9	10.4	11.2
TA 34	35	0.75	0.85	8.8	9.3	6.8	7.3
TA 35	35	1.00	0.85	10.6	11.2	7.7	10.2
TA 36	30	0.75	0.85	8.1	8.4	5.4	6.5
TA 37	30	1.00	0.85	9.7	10.4	7.9	9.3
TA 38	25	0.75	0.85	7.2	7.7	5.3	5.8
TA 39	25	1.00	0.85	8.5	9.4	7.6	8.3
TA 40	20	0.35	0.85	3.8	4.8	3.4	2.5
TA 41	20	0.50	0.85	4.6	5.4	3.5	3.1
TA 42	20	0.75	0.85	6.3	6.8	5.3	5.0

For all the joints studies, the chord tube diameter and length are kept constant at 28.35 units and 180 units, respectively.

The results of parametric study for the three load cases are given in Tables 2, 3 and 4 for the *T*-joint. The details of the *Y*-joint analyzed are given in Table 5 and the results in Table 6. The SCF values are normalized with maximum SCF, and a typical normalized curve of SCF is given in Fig. 4.

Formulas for Stress Concentration

The multiple linear regression analysis, MLTR, available in SSP (1977), is used to fit formulas for variation of SCF using the results of the 121 joints analyzed.

T-Joint. Trend analysis is first carried out to fit the maximum SCF and suitable functions are then selected for the following variables: d/D, t/T, D/T and β. The interaction effect is the predominant effect, and hence the semi-empirical formulas are of the form

$$\mathrm{SCF} = f_1(D/T) f_2(t/T) f_3(d/D) f_4(\beta) \tag{1}$$

The formula for SCF is fitted on one-quarter of the T-joint, and hence β varies from 0 to 90 deg only. $\beta = 0$ corresponds to the saddle, and $\beta = 90$ deg the crown.

Axial Load. The graphic fit and other available semi-empirical formulas show the functions f_1, f_3 and f_2 are of the form $(D/T)^m$, $(d/D)^k$ and $(t/T)^n$.

Then the semi-empirical formula for maximum SCF is of the form

$$\mathrm{TAB\ max} = 1(D/T)^m (t/T)^n (d/D)^k \tag{2}$$

Taking logarithms on both sides

$$\log \mathrm{TAB\ max} = \log 1 + m \log(D/T) + n \log(t/T)$$

$$= k \log(d/D) \tag{3}$$

The MLTR program is used to determine the intercept log 1 and regression coefficients m, n, and k. The equation for maximum SCF is obtained as

$$\mathrm{TAB\ max} = 1.73(D/T)^{0.52}(t/T)^{0.89}(d/D)^{-0.5} \tag{4}$$

The multiple correlation is 0.952 and standard error is 0.124 for the foregoing fit.

The variation of SCF, TAB (β) values obtained using the finite element method (FEM) is then normalized with TAB max, the maximum value obtained using the formula

$$F = \mathrm{TAB_{FEM}}(\beta)/\mathrm{TAB\ max} \tag{5}$$

Table 3 T-joint subjected to in-plane moment

Joint	D/T	t/T	d/D	Maximum SCF in branch		Maximum SCF in chord	
				FEM	Author's formula	FEM	Author's formula
TI 1	40	0.35	0.34	1.58	1.73	1.15	1.36
TI 2	40	0.50	0.34	2.03	2.09	1.52	1.95
TI 3	30	0.35	0.34	1.58	1.72	1.07	1.29
TI 4	30	0.50	0.34	1.99	2.10	1.43	1.88
TI 5	20	0.35	0.34	1.59	1.72	0.91	1.21
TI 6	40	0.50	0.45	2.10	1.98	1.98	1.96
TI 7	40	0.75	0.45	2.71	2.49	3.11	3.08
TI 8	30	0.35	0.45	1.65	1.62	1.29	1.29
TI 9	20	0.50	0.45	2.08	1.98	1.67	1.76
TI 10	40	0.75	0.56	2.66	2.39	2.76	3.10
TI 11	40	1.00	0.56	3.06	2.81	3.81	4.30
TI 12	30	0.50	0.56	2.04	1.89	1.69	1.90
TI 13	30	0.75	0.56	2.59	2.97	2.59	2.39
TI 14	25	0.35	0.56	1.64	1.56	1.14	1.27
TI 15	25	0.50	0.56	2.02	1.91	1.62	1.87
TI 16	20	0.35	0.56	1.64	1.56	1.08	1.22
TI 17	20	0.50	0.56	2.00	1.90	0.87	1.77
TI 18	40	0.75	0.69	2.25	2.29	3.20	3.15
TI 19	40	1.00	0.69	2.61	2.69	4.25	4.37
TI 20	30	0.50	0.69	1.75	1.82	1.91	1.92
TI 21	30	0.75	0.69	2.20	3.01	2.30	2.29
TI 22	30	1.00	0.69	2.53	2.68	4.15	4.13
TI 23	20	0.35	0.69	1.45	1.24	1.41	1.49
TI 24	20	0.50	0.69	1.78	1.80	1.76	1.82
TI 25	40	1.00	0.85	2.53	2.58	4.28	4.48
TI 26	30	0.75	0.85	2.14	2.20	2.94	3.10
TI 27	30	1.00	0.85	2.48	2.57	4.12	4.24
TI 28	20	0.50	0.85	1.68	1.86	1.78	1.75
TI 29	20	0.75	0.85	2.07	2.99	2.20	2.23

Table 4 T-joint subjected to out-of-plane moment

Joint	D/T	t/T	d/D	Maximum SCF in branch		Maximum SCF in chord	
				FEM	Author's formula	FEM	Author's formula
TO 1	40	0.35	0.34	2.97	3.68	3.67	4.85
TO 2	40	0.50	0.34	4.22	4.76	5.40	7.14
TO 3	30	0.35	0.34	2.58	3.16	2.94	3.90
TO 4	30	0.50	0.34	3.56	4.14	4.30	5.84
TO 5	20	0.35	0.34	2.12	2.56	2.13	2.83
TO 6	40	0.50	0.45	5.42	5.22	7.50	7.22
TO 7	40	0.75	0.45	7.46	7.18	12.05	11.59
TO 8	30	0.35	0.45	3.28	3.47	4.18	3.94
TO 9	30	0.50	0.45	4.59	4.56	6.04	5.90
TO 10	40	1.00	0.56	9.85	9.65	16.00	15.36
TO 11	30	0.50	0.56	5.38	4.90	5.72	5.77
TO 12	30	0.75	0.56	7.30	6.73	9.27	9.23
TO 13	20	0.35	0.56	3.08	3.02	2.81	2.81
TO 14	20	0.50	0.56	4.14	3.95	4.20	4.19
TO 15	40	0.75	0.69	7.73	8.21	8.90	10.39
TO 16	40	1.00	0.69	9.04	10.29	12.90	14.49
TO 17	30	0.50	0.69	4.86	5.21	4.82	5.29
TO 18	30	0.75	0.69	6.72	7.16	7.62	8.03
TO 19	30	1.00	0.69	7.79	8.87	10.70	11.67
TO 20	20	0.35	0.69	2.89	3.21	2.40	2.58
TO 21	20	0.50	0.69	3.83	4.21	4.57	3.85
TO 22	40	1.00	0.85	9.18	11.04	10.24	11.32
TO 23	30	0.75	0.85	6.78	7.68	6.19	6.62
TO 24	30	1.00	0.85	7.96	9.54	8.58	9.11
TO 25	20	0.50	0.85	3.99	4.51	3.06	3.01
TO 26	20	0.75	0.85	5.35	6.15	4.84	4.76

Assuming the following form for F:

$$F = k_1 + k_2[(d/D)/(t/T)] + k_3\cos^2\beta \qquad (6)$$

the coefficients k_1, k_2 and k_3 are evaluated using MLTR program. The formula for TAB(β) is obtained as

$$\mathrm{TAB}(\beta) = (D/T)^{0.52}(t/T)^{0.89}(d/D)^{-0.5}[0.05 + 0.34(d/D)/(t/T) + 1.25\cos^2\beta] \qquad (7)$$

The maximum SCF in chord is obtained using the same procedure adopted for branch

$$\mathrm{TAC\,max} = (D/T)^{0.63}(t/T)^{1.24}(d/D)^{-0.73} \qquad (8)$$

The trend analysis shows a strong influence of (d/D), not

Table 5 Y-joint details

Joint name for: Axial load	Inplane moment	Out-of-plane moment	D/T	t/T	d/D	Angle of inclination α in degrees
YA 1	YI 1	YO 1	40	1.0	0.56	45
YA 2	YI 2	YO 2	30	0.5	0.56	45
YA 3	YI 3	YO 3	20	1.0	0.56	45
YA 4	YI 4	YO 4	20	0.5	0.45	60
YA 5	YI 5	YO 5	40	1.0	0.56	60
YA 6	YI 6	YO 6	20	0.5	0.85	60
YA 7	YI 7	YO 7	20	0.5	0.45	70
YA 8	YI 8	YO 8	20	0.5	0.85	70

Table 6 Y-joint maximum SCF

Axial load					Inplane moment					Out-of-plane moment				
Joint name	Branch SCF		Chord SCF		Joint name	Branch SCF		Chord SCF		Joint name	Branch SCF		Chord SCF	
	FEM	Author's formula	FEM	Author's formula		FEM	Author's formula	FEM	Author's formula		FEM	Author's formula	FEM	Author's formula
YA1	7.2	7.87	9.6	8.74	YI1	2.70	2.56	3.58	3.46	YO1	5.1	5.22	7.0	6.26
YA2	3.1	3.65	3.5	3.08	YI2	1.80	1.71	1.70	1.65	Y02	2.7	2.67	2.2	2.28
YA3	6.0	5.45	6.7	5.64	YI3	2.60	2.54	3.10	3.13	YO3	4.2	3.63	4.4	3.67
YA4	5.4	4.96	3.6	3.93	YI4	1.92	1.88	1.70	1.64	YO4	2.7	2.75	2.3	2.27
YA5	12.2	11.81	12.6	12.27	YI5	2.60	2.71	4.30	4.07	YO5	7.4	7.18	8.4	8.27
YA6	3.4	3.60	2.0	1.95	YI6	1.59	1.66	1.60	1.60	YO6	3.4	3.37	2.7	2.06
YA7	6.0	5.80	4.4	4.50	YI7	1.80	1.93	1.64	1.68	YO7	3.1	3.12	2.5	2.54
YA8	4.3	4.20	2.5	2.80	YI8	1.65	1.69	1.65	1.65	YO8	3.9	3.83	2.4	2.31

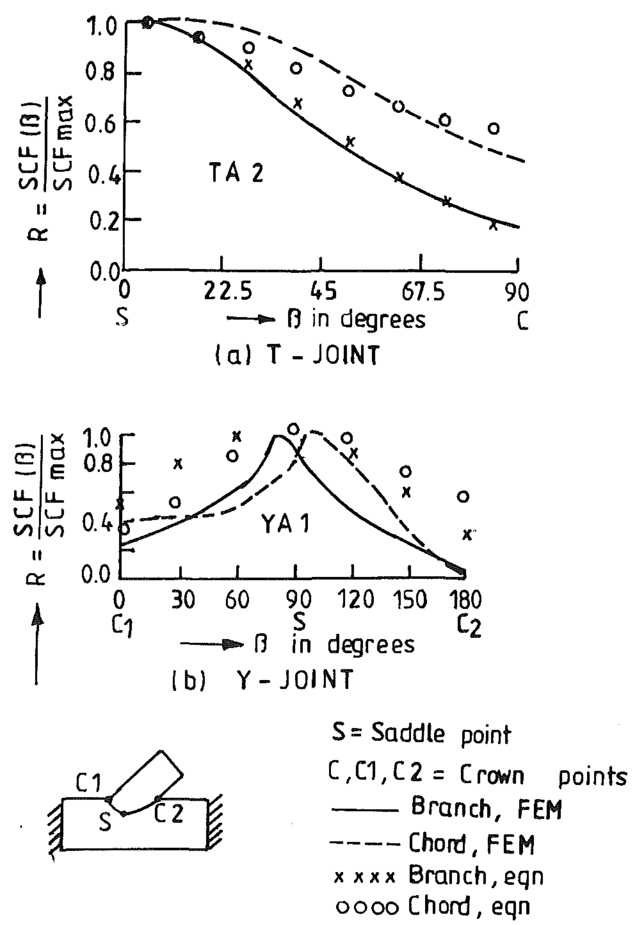

Fig. 4 Comparison of variation of SCF

only on the variation of SCF, but also on the location of hot spot. The influence of (d/D) on the location of hot spot is incorporated using a function

$$\beta_A: \quad \beta_A = \beta - \frac{\pi}{12}(d/D)^3 \tag{9}$$

Assuming the following form for F, representing the variation of SCF around the intersection:

$$F = k_1 + k_2(d/D) + k_3(d/D)^2 + k_4\cos\beta_A + k_5\cos^2\beta_A \tag{10}$$

where

$$F = \mathrm{TAC}_{\mathrm{FEM}}(\beta)/[(D/T)^{0.63}(t/T)^{1.24}] \tag{11}$$

In the expression for F, the term (d/D) is omitted in the denominator, since in the formula for variation of SCF, (d/D) and $(d/D)^2$ terms are included. MLTR program is then used to determine the various coefficients in equation (10). The resulting formula is given in the Appendix.

In-Plane and Out-of-Plane Moment: The same procedure adopted to develop formulas for SCF in T-joint due to axial load is used to develop formulas for SCF in T-joint due to inplane and out-of-plane moment load cases. The resulting formulas are given in the Appendix.

Y-Joint. The parametric study on Y-joint has been carried out on 24 joints for the three types of loadings. Since the T-joint is a special case of Y-joint, the effect of the following parameters (d/D), (t/T) and (D/T) on SCF of Y-joint is considered to be the same as that of T-joint.

The formula for SCF is fit on one-half of the Y-joint, and hence β varies from 0 to 180 deg. $\beta = 0$ corresponds to the crown C_1 and $\beta = 180$ deg the crown C_2 (Fig. 4).

The following form for maximum SCF in Y-joint is assumed:

$$Y_{\max} = T_{\max}\sin^k\alpha \tag{12}$$

The logrithmic ratio of the T-joint maximum SCF,

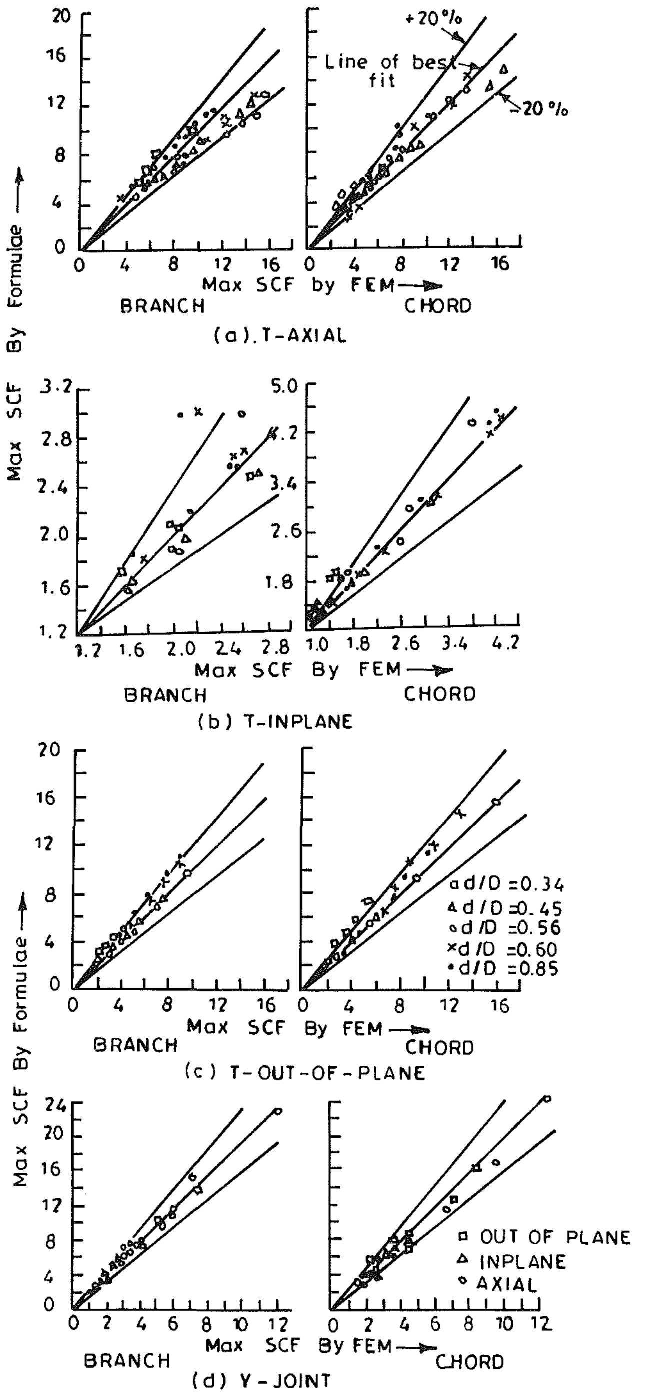

Fig. 5 Comparison of SCF by formula with FEM for T and Y-joints

calculated by the formula and Y-joint maximum SCF, obtained by FEM versus log sinα are plotted. The value of k is determined as the slope of the straight line fit.

The formula for variation of SCF is assumed as

$$Y(\beta) = Y_{\max}(k_1 + k_2 f_1{}^{(\beta) + k_3/2(\beta)} \tag{13}$$

The functions $f_1(\beta)$ and $f_2(\beta)$ are selected after trend analysis. The MLTR program is used to calculate the coefficients k_1, k_2 and k_3. The results are given in the Appendix.

Analysis of Regression. The analysis of regression for the developed formula is given in Table 7. The multiple correlation is above 0.9 for T-joint in all cases except for chord axial loading and branch in-plane moment. The standard error and

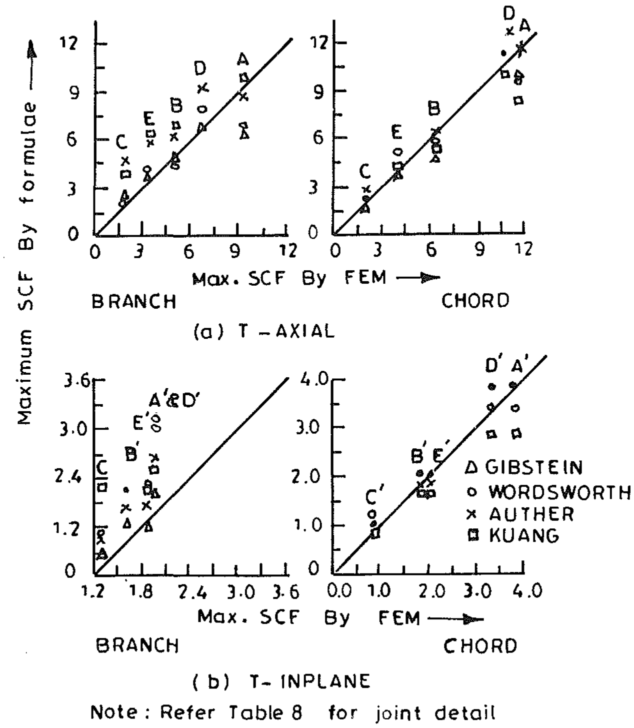

Fig. 6 Comparison of FEM results of commission of European communities with authors' and others' formulas

the comparison of computed and table F values at 99-percent confidence level are also given in Table 7.

An analysis of regression of the developed formula for variation of SCF in Y-joints shows that the formula needs improvement based on more studies on Y-joints.

Comparison

The comparison of maximum SCF developed by formulas with FEM (Tables 2, 3, 4 and 5 and Fig. 5) shows that for 95 percent of the joints studied, the maximum SCF predicted by the formulas is within ±20 percent error band.

The Commission of European Communities have reported results of five T-joints (Table 8) subjected to axial and in-plane loading. The authors' formulas compare well with these results, as well as the formulas developed by Kuang, Gibstein and Wordsworth and Smedley (Fig. 6).

Loading Interaction

The loading interaction for fatigue design of tubular joint is carried out by using one of the following:

(*a*) maximum SCF at all the points;
(*b*) maximum SCF at crown and saddle points;
(*c*) maximum SCFs at crown and saddle, and linear variation for axial load and sinusoidal variation for in-plane and out-of-plane moments as proposed by Gulati et al. (1982)

Case Study. The developed formulas can be used directly to evaluate the loading interaction. The TA 1 joint subjected to 10 MPa of nominal axial stress and TI 1 subjected to 20 MPa of extreme in-plane stress is studied by FEM, and is compared with the present formula and the foregoing three methods (Table 9). The comparison indicates that:

(*i*) Method (*a*) is conservative.
(*ii*) Method (*b*) does not give true location of hot spot, and hence is unsafe.

Table 7 Analysis of regression

Note.:- B refers branch and C refers chord.

Joint	Loading	Tube	Multiple correlation	Standard error	Degrees of freedom		F value	
					Attributable to regression	Deviation from regression	Computed	Table
T	Axial	B	0.94	0.17	2	333	1239	6.9
		C	0.85	0.23	4	331	215	4.6
	Inplane moment	B	0.77	0.15	3	228	113	5.4
		C	0.97	0.07	3	228	1376	5.4
	Out-of-plane moment	B	0.96	0.09	2	205	1120	6.9
		C	0.96	0.06	4	203	592	4.6
Y	Axial	B	0.78	0.21	2	93	52	4.9
		C	0.81	0.15	2	93	58	4.9
	Inplane moment	B	0.69	0.22	2	93	47	4.9
		C	0.71	0.23	2	93	32	4.9
	Out-of-plane moment	B	0.89	0.07	1	94	124	6.9
		C	0.75	0.22	2	93	50	4.9

Table 8 Commission of European communities joint details

All dimensions are in mm

Joint	Diameter		Thickness	
	Chord	Branch	Chord	Branch
A	473	341	22.8	21.5
B	684	342	40.0	22.4
C	1281	343	77.6	22.4
D	949	682	41.6	41.4
E	1280	683	75.0	40.0
A'	472	341	22.3	22.0
B'	685	343	40.0	22.0
C'	1275	343	75.0	22.8
D'	947	683	44.0	43.5
E'	1275	682	76.7	43.5
Y1	472	341	22.3	22.0
Y2	685	343	40.0	22.0
Y3	1275	343	75.0	22.8
Y4	947	683	44.0	43.5
Y5	1275	684	76.7	43.5

(*iii*) Method (*c*) is better than (*a*) and (*b*), but is empirical.
(*iv*) The use of formulas developed by the authors is straightforward and has sound mathematical background.

While the location of hot spot predicted is true location, the magnitude of maximum stress exceeds the stress obtained using the results of finite element analysis by 7 percent.

Conclusions

A parametric study has been carried out by analyzing 121 joints using the finite element method. The multiple linear regression analysis program is used to develop formulas for SCF based on the analytical data which give not only the magnitude and location of hot spot, but also the variation of SCF around the intersection. The developed formulas give a clear picture of stress distribution around intersection, and fills the gap of information lacking in the available parametric equation. A realistic fatigue design, considering load interaction can be carried out using the developed formulas.

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Table 9 Results of case study

Nominal stress for axial load = 10 MPa

Extreme stress for inplane moment = 20 MPa

β in degrees	SCF by present formula		SCF by FEM		Stress around intersection in MPa				
	Axial load	Inplane moment	Axial load	Inplane moment	Formula by authors	FEM	Method a	Method b	Method c
0 Saddle point	5.50	0.00	4.70	0.00	55.0	47.0	55.0	55.0	55.00
22.5	5.06	0.54	4.70	0.32	61.4	53.4	65.6		59.83
45.0	4.29	0.99	4.18	0.84	62.7	58.6	74.2		62.65
67.5	3.41	1.33	3.29	1.15	60.7	55.9	80.0		62.68
90 Crown point	3.19	1.36	2.53	1.15	59.1	48.3	82.2	59.1	59.1

Maximum stress by using SCF obtained by present formula = 4.29 x 10 + 0.99 x 20

= 62.7 MPa

Maximum SCF by FEM = 4.18 x 10 + 0.84 x 20 = 58.6 MPa

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APPENDIX

Formulas for Maximum SCF in Y-Joint

The formula for maximum SCF in Y-joint is given in the following for axial load, in-plane moment and out-of-plane moment in both branch and chord. In YAB, Y represents Y-joint, A axial load, and B branch. Similarly, YOC corresponds to maximum SCF in chord for Y-joint subjected to out-of-plane moment.

$$YAB = 1.73(D/T)^{0.52}(t/T)^{0.89}(d/D)^{0.89}(d/D)^{-0.5}\sin^2\alpha$$

$$YAC = (D/T)^{0.63}(t/T)^{1.24}(d/D)^{-0.73}\sin^{1.67}\alpha$$

$$YIB = 2.34(D/T)^{0.02}(t/T)^{0.57}(d/D)^{-0.2}\sin^{0.29}\alpha$$

$$YIC = 1.85(D/T)^{0.2}(t/T)(d/D)^{-0.05}\sin^{0.4}\alpha$$

$$YOB = 1.6(D/T)^{0.52}(t/T)^{0.77}(d/D)^{0.32}\sin^{1.57}\alpha$$

$$YOC = 0.54(D/T)^{0.77}(t/T)^{1.14}(d/D)^{-0.15}\sin^{1.37}\alpha$$

In the foregoing formulas, if the value of α is substituted as 90 deg, the maximum SCF in T-joint can be obtained.

Formulas for Variation of SCF in T-Joint

$$TAB(\beta) = (D/T)^{0.52}(t/T)^{0.89}(d/D)^{-0.5}[0.05 + 0.34\frac{(d/D)}{(t/T)} + 1.28\cos^2\beta]$$

$$TAC(\beta) = (D/T)^{0.63}(t/T)^{1.24}[0.59 + 2(d/D) - 2.8(d/D)^3 + 0.16\cos\beta_A + 0.7\cos^2\beta_A]$$

where

$$\beta_A = \beta - \frac{\pi}{12}(d/D)^3$$

$$TIB(\beta) = (D/T)^{0.02}(t/T)^{0.57}(d/D)^{-0.2}[0.91 - 0.04(t/T) + 1.46\sin\beta]$$

$$TIC(\beta) = (D/T)^{0.2}(t/T)(d/D)^{-0.06}[0.28(t/T) + 0.31(d/D)^2 + 1.63\sin\beta]$$

$$TOB(\beta) = (D/T)^{0.52}(t/T)^{0.77}(d/D)^{0.32}[1.71 - 1.55\sin\beta]$$

$$TOC(\beta) = (D/T)^{0.77}(t/T)^{1.14}[1.41(d/D) - 1.63(d/D)^2 - 0.28\cos\beta_o + 0.92\cos^2\beta_o]$$

where

$$\beta_o = \beta - \frac{\pi}{6}(d/D)^2$$

In the foregoing formulas, β varies from 0 to 90 deg. $\beta = 0$ corresponds to the saddle and $\beta = 90$ deg the crown.

Formulas for Variation of SCF in Y-Joint

$$\mathrm{YAB}(\beta) = \mathrm{YAB}\left[0.36 + 0.22\sin\beta + 0.42\sin\left(\beta + \frac{\pi}{12}\right)\right]$$

$$\mathrm{YAC}(\beta) = \mathrm{YAC}\left[0.42 + 0.36\sin\left(\beta - \frac{\pi}{6} + 0.25\sin^3\beta\right]$$

$$\mathrm{YIB}(\beta) = \mathrm{YIB}\left[0.11 + 0.8\cos\left(\beta - \frac{\pi}{12}\right.\right.$$

$$\left.+ 0.2\cos\left(\beta + \frac{\pi}{6}\right)\right]$$

$$\mathrm{YIC}(\beta) = \mathrm{YIC}\left[-0.06 + 0.53\cos\left(\beta - \frac{\pi}{6}\right)\right.$$

$$\left.+ 0.67\cos^3\left(\beta + \frac{\pi}{6}\right)\right]$$

$$\mathrm{YOB}(\beta) = \mathrm{YOB}[0.2 + 0.8\sin^2\beta]$$

$$\mathrm{YOC}(\beta) = \mathrm{YOC}\left[0.25 + 0.3\cos\left(\beta + \frac{\pi}{6}\right)\right.$$

$$\left.+ 0.7\sin\left(\beta - \frac{\pi}{6}\right)\right]$$

In the foregoing formulas, β varies from 0 to 180 deg. $\beta = 0$ deg corresponds to the crown C_1, $\beta = 180$ deg the crown C_2 and $\beta = 90$ deg the saddle. Figure 2(*b*) and YAB, YAC, etc., refers to the maximum SCF obtained using the formulas given in "Formulas for Maximum SCF in Y-Joint."