Fatigue Analysis of Welded Tubular Joints

by V. M. RADHAKRISHNAN*

ABSTRACT

Many of the welded structures are of tubes, specially in off-shore applications. Such structures are often subjected to cyclic loads which have to be taken into account at the design stage. Some of the problems connected with the evaluation of fatigue life of tubular structures are discussed in this articles, taking the main body of the data from reports of Commission XIII of other centres.

Introduction

In off-shore structures constructed by tubular members, the fatigue strength of tubular connections is an important factor to be considered in design. Tubular joints are also used in many other constructions where the applied load varies with time. Joints as such, whether welded or not, will introduce stress concentration zones, where the stresses will be much higher than the applied stress. And if the joints are obtained by welding the process itself will introduce residual stresses which will be detrimental to the load carrying capacity of the structure. Welding also introduces many geometry changes which make the determination of the stress concentration factor somewhat more complicated. Coupled with these if the structure is to operate in aggressive environments, as in off-shore construction, chemical plants etc., corrosion has to be taken into consideration while evaluating the design stress.

Tubular joints will be of different forms, like T—joints, Y—joints, +joints, X—joints etc. It will be normally difficult to carry out fatigue tests on all these types of joints, though that will be ideal to have a first hand information for the design purpose. Usually butt welded specimens will be tested to evaluate the basic fatigue properties and crack growth behaviour and these data will be cross checked by conducting fatigue tests on simple joints like T—joints, so that the correlation factors in carrying over the basic data to design level can be established. Number of investigations have been carried out to analyse the fatigue behaviour of tubular joints (1—5) and the following is a review of these studies with comments on their extension to design purposes.

Stress Concentration

Because of the type of welding and the components to be joined stress concentration points will be introduced where the stress σ_D will be much higher than the nominal stress σ_n. The stress concentration factor is given by

$$K_{tD} = \frac{\sigma_D}{\sigma_n} \tag{1}$$

The stress concentration factor K_{tD} is very much dependent on the dimensions of chord and brace (the two tubes to be joined), the angle at which the joint is to be made and finally the type of loading—tension, torsion or bending. So K_{tD} is a function of the different geometrical variables and is given by

$$K_{tD} = f_1(\alpha)\, f_2(\beta)\, f_3(\gamma)\, f_4(\tau)\, f_5(\sin\theta) \tag{2}$$

where $\alpha = L/D$, $\beta = d/D$, $\gamma = D/T$ and $\tau = t/T$.

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*Chairman, Technical Commission XIII
Professor Metallurgy Department, I.I.T., Madras-600006

Among all types of hollow section joints, circular hollow section joint has been studied by many researchers. Typical example for the case of axial force of Y—type joint is shown in Fig. 1a and 1b. The degree of the effect of each parameter can be obtained from these relations. K_{tD} is influenced mostly by the parameter γ which is related to ratio D/T of the main pipe. Evaluation of the stress concentration factors of different types of welded joints will be presented in another article (6).

If reinforcement members are involved with simple joints, stress concentration is obtained by Finite Element Method (FEM) analysis using small elements substituted for the structure. It can also be estimated by measuring stresses in the vicinity of the weld bead in a model test.

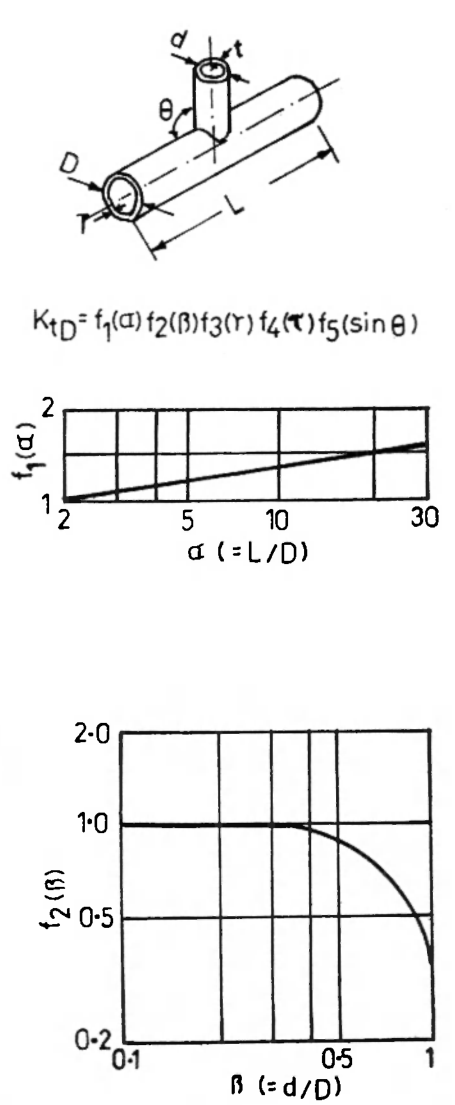

Fig. 1(a) *Y—Joint details and K_{tD} calculation procedure.*

Fatigue Data Analysis

For the Design S—N curve giving the relation between the maximum stress locally occurring in a tubular member connection and the fatigue life, various curves such as X—curve of AWS. Q—curve of BS-153, those of ASME III, Lloyd's basic and DnV, have been proposed. Which curve to be used will be determined according to the requirements by the classification society, the governmental authority and the owner. Generally AWS X-curve is mostly used.

Typical stress range versus number of cycles to failure relation for a T type of joint with the wall thickness T=6.3 mm and 16 mm for a steel (equivalent to ASTM A 441) is shown in Fig. 2. The testing was done under fully reversed axial brace loading with R=−1. It can be seen that when the wall thickness of the chord is increased the fatigue life is reduced.

The stress at the junction of the weld is to be calculated using the stress concentration factor K_{tD} so that

$$\sigma_D = K_{tD}\, \sigma_n$$

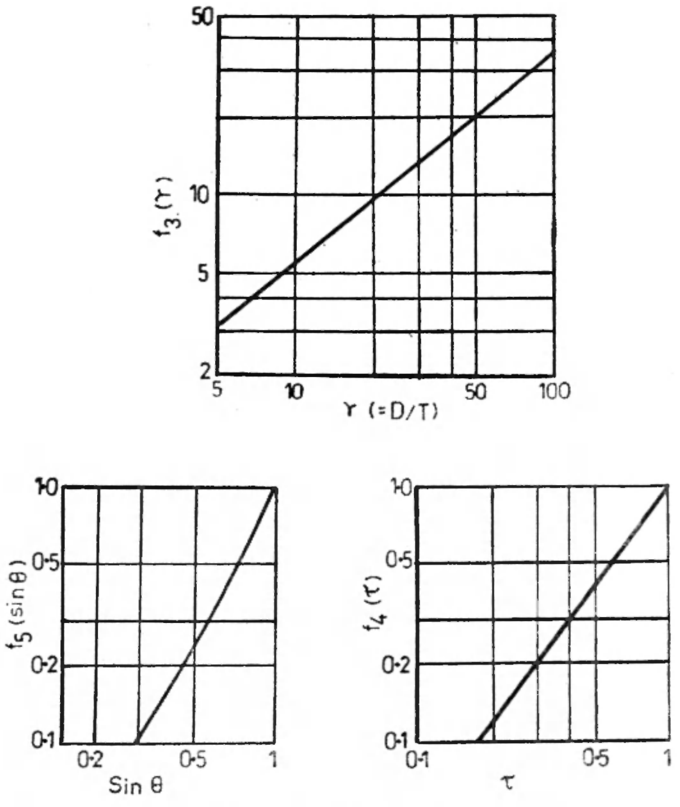

Fig. 1(a) and 1(b) *Y—Joint details and K_{tD} calculation procedure.*

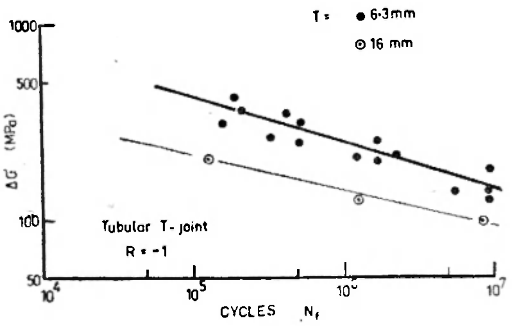

Fig. 2 *Relation between stress range and fatigue life of T—joint. R=—1.*

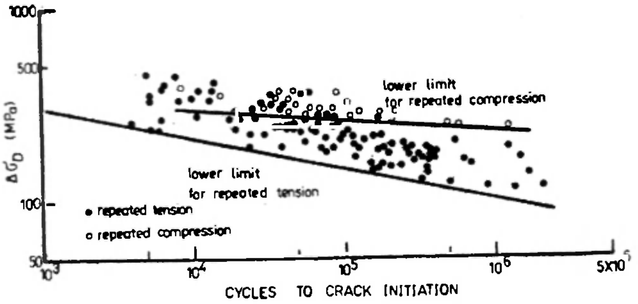

Fig. 3 *Relation between dynamic stress range and number of cycles to crack initiation. Lower limit based on XIII-950.*

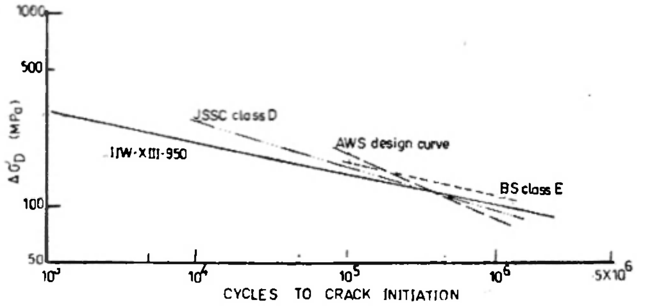

Fig. 4 *Comparison of lower limit XIII-950 with other standard curves.*

K'_{tD} should take into account the toe geometry etc., as discussed previously. However, in the present analysis K'_t has been assumed to be around 2. The S—N relation including the effect of chord wall thickness T can be expressed for R=−1, as

$$\Delta\sigma = 9392\, N_f^{-0.2534}\, (12/T)^{0.25} \quad \text{(MPa)} \qquad (3)$$

The above analysis gives a good correlation with the test data. However, when other variables come into picture, the above equation will not be sufficient and more rigorous method has to be used to evaluate K_{tD}.

Fig. 3. shows the relation between the dynamic stress range σ_D calculated based on K_{tD} and the number of cycles for crack initiation. Cracked points in the tests are at the toe of weld in complicated full penetration cruciform joints, at the toe of weld in complicated non-load carrying fillet welded joints and at the round welded toe in the end of parts.

Evaluation method in the document IIW-XIII-950-80 for fatigue strength is to give the unified S-N. curve and to give the structural stress concentration factor K_{tD} for the effect of structural details. The data points for different conditions come within a scatter band, as seen in Fig. 3, the lower bound of which is given by the equation

$$\sigma_D = 899\, N_i^{-0.159} \qquad (4)$$

Fig. 4. shows the comparison of the lower limit line of XIII-950 with other rules for full penetration cruciform butt welded joints and transverse non-load carrying fillet welded joints. The lower limit line of XIII-950 is almost mean of the current rules.

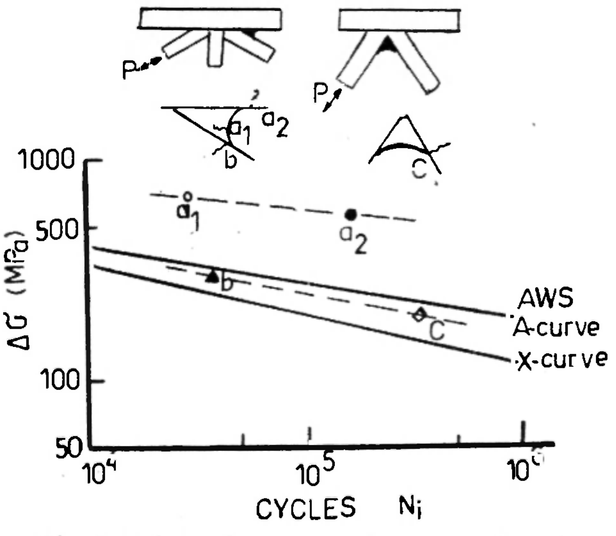

Fig. 5 *Relation between stress range and number of cycles to crack initiation in stiffened or reinforced joints.*

In the case of stiffened or reinforced joints, the analysis is more complicated and the stress concentration has to be obtained by Finite Element Method. A typical result when Y and X shaped joints are reinforced and pulsating load was applied through one of the members is shown in Fig. 5 for crack initiation at points, a_1, a_2, b and C as indicated in the figure. The frequency of load application was between 0.5 to 2.0 Hz. Cracks initiated around the middle of the bracket and at the bracket toe.

The test values have cleared both A—and X—curves of AWS (American Welding Society, Structural Welding Code—Steel AWS D1. 1-79).

Concluding Remarks

From the foregoing presentation it is clear that stress analysis in the welded joints is rather a complicated problem and correlation of the same with fatigue life has to be carefully carried out so that the results will be more meaningful and can be used for design purposes.

Acknowledgement

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