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A Model for Fatigue Life Prediction of Offshore Welded Stiffened Steel Tubular Joints Using FM Approach

D.S. Ramachandra Murthy*, P. Gandhi and A.G. Madhava Rao
Structural Engineering Research Centre, Madras, India

ABSTRACT

Welded steel tubular structures commonly used for offshore platforms are susceptible to fatigue failure due to stress concentration at welded joints and environmental loading which is cyclic in nature. Internally ring stiffened steel tubular joints are found to be efficient in reducing stress concentration and improving ultimate and fatigue strengths. Based on the crack growth data obtained from fatigue tests conducted on seven internally ring stiffened T and Y joints under constant amplitude loading in air, a model has been developed for fatigue crack growth prediction in internally ring stiffened tubular joints using fracture mechanics.

INTRODUCTION

Fatigue is one of the principal modes of failure to be considered in the design of offshore structures. Due to the repetitive action of wave forces and corrosive environment, fatigue cracks can develop at the welded joints of steel tubular jacket platforms which are commonly used for offshore production of oil. Due to this and other causes, maintaining structural integrity for these structures has been a major concern for the oil industry. The objective is to ensure an economical and safe operation.

Fatigue cracks need to be discovered and sized to maintain structural integrity. The significance of cracks discovered in service must also be assessed. Several non-destructive testing (NDT) inspection techniques are available for locating and sizing fatigue cracks. One such technique is the crack microgauge developed by University College, London, which uses the alternating current potential drop (ACPD) technique and is found to be highly reliable. ACPD is a crack sizing NDT system which can be used for monitoring fatigue crack length and depth, periodic measurement of crack size, or investigations of crack size for defects found in service. If the cracks are located and sized properly, fracture mechanics can be used to assess the significance of cracks and the remaining fatigue life of the critical joints and therefore the structural integrity can be assessed. Fracture mechanics can be a useful tool for several aspects of fatigue analysis. It has been recommended as an alternative to the conventional stress-life (SN) curve method popularly used at present for fatigue analysis of tubular joints. Fracture mechanics is more useful and is the only method to assess the remaining fatigue life of tubular joints which is dictated by crack growth.

One of the main impediments to the development of a fracture mechanics model for tubular joints has been the determination of stress intensity factors (SIF) for tubular joints. Due to the complexities of geometry and loading, difficulties are experienced in determining analytically the SIF, which requires stress distribution both around the intersection and through the thickness as the crack advances. For tubular joints, surface flaws initiate at the weld toe of the tubular intersection areas and propagate under environmental loads along the thickness and surface directions. The shape of a propagating flaw is influenced by both the local stress state and the material properties near the tubular intersection area. An understanding of the detailed stress distribution through the tubular thickness, as well as along the surface near the tubular intersection is required. Marshall (1987) observed that because of the severe notch effect peak stresses are three times higher than the hot-spot stress calculated in a 3-D model of a ring-stiffened tubular joint. As the surface defect (which is initially planar when the size is small) grows, the crack surface tends to warp, due to the inhomogeneity of material toughness and stress distribution, to result in a very complicated crack surface shape.

The two most important features of a fracture mechanics study for tubular joints are the mixed mode crack tip material behaviour and the complicated crack shape. Mixed mode fatigue crack propagation problems are not well understood. Though there are special elements with built-in crack tip singularities which are suitable for mixed mode problems, their applicability to practical problems is very limited. Computer programs with these types of elements are not easily available for general use. The warping of a crack face while it propagates makes stress intensity factor evaluation involved and expensive (Rhee et al., 1985).

Therefore, attempts have been made to develop empirical models based on crack growth data obtained from fatigue tests on tubular joints. One such model is the two-phase model developed by Kam et al. (1990), which is found to predict remaining fatigue life close to the experimental values for unstiffened tubular joints.

Kam's model has been developed from crack growth data obtained from constant amplitude fatigue tests conducted in air on seven unstiffened welded steel tubular T, Y and X joints at University College, London. The ratio of brace and chord diameters (β) varied from 0.48 to 0.76 for the joints. All three loading cases — namely axial loading, in-plane bending and out-of-plane bending — were considered. The crack growth was considered in two phases, the so-called early crack growth phase till the crack depth reaches 0.25 times the tube thickness, and the displacement controlled propagation phase thereafter. An empirical model was fitted to obtain the geometric correction factor, **Y**, from experimental crack growth data. The remaining life is then obtained using Paris equation. The controlling parameters considered in this model are hot-spot stress range, average stress parameter (the ratio of the hot-spot stress and average stress around the intersec-

*ISOPE Member.

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