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On the Fatigue Design of K-Joint Tubular Girders

S. A. Karamanos
Department of Mechanical & Industrial Engineering, University of Thessaly, Volos, Greece

A. Romeijn and J. Wardenier*
Faculty of Civil Engineering and Geosciences, Delft University of Technology, Delft, The Netherlands

ABSTRACT

The fatigue design of welded tubular lattice structures is preferably based on the hot-spot stress method, combining nominal stresses and Stress Concentration Factors (SCF). In the present paper, the fatigue design of K-joint tubular girders is investigated through an extensive numerical study, with emphasis on the effects of joint flexibility. It is shown that these effects are quite significant, especially for nominal bending stresses. Results are reported with respect to both the nominal stress level and the hot-spot stress level (through the use of appropriate SCFs). The results of the present study are summarized in a simple and efficient design methodology.

INTRODUCTION

The hot-spot stress method is widely used for the design of welded tubular connections against fatigue. A hot spot is a point with a high stress, usually a weld toe location, where fatigue crack initiation is expected and joint failure starts. The hot-spot stress (S) is calculated from nominal stresses (σ_{nom}), which are combined with the corresponding stress concentration factors (SCFs). In other words and for a single-load condition, the SCF is the ratio of the hot-spot stress over the nominal stress on the loaded member ($SCF = S/\sigma_{nom}$). During the last 25 years, significant effort has been devoted to the development of quite accurate SCFs for welded tubular joints under various loading conditions. On the other hand, a limited number of investigations has been conducted to determine the nominal stresses within a tubular lattice structure, to be used in a fatigue design procedure.

In tubular lattice structures, a simple frame analysis (using beam elements exclusively) may be conducted for design purposes, assuming rigid joints, to obtain nominal axial and bending stresses. The bending stresses at the chords and the braces are sometimes referred to as secondary because they are not necessary for equilibrium in a lattice structure. These secondary stresses are a contributing factor to hot-spot stress and, therefore, they need to be considered in fatigue design. However, there have been some doubts concerning the accuracy of such a model, especially regarding bending stresses at the brace ends. These doubts are substantiated by the fact that tubular joints do not remain rigid but deform similarly to a shell (joint flexibility), resulting in nominal stresses quite different from those obtained through a rigid-joint assumption.

Det Norske Veritas (1977) was the first to report flexibility coefficients for tubular T-joints under in-plane and out-of-plane bending, based on Finite Element analyses. The effects of tubular joint flexibility on the structural response of offshore structures have been examined by Bouwkamp et al. (1980). The research employed shell finite elements and rigidly connected beam elements, and aimed at computing deflections, force and moment distributions as well as dynamic characteristics of offshore structures. The analyses were repeated using the assumption of rigidly connected beam elements. Results showed that deflections and distribution of bending moments within the structure obtained from a shell-element model are generally larger than those obtained from a beam-element model.

The UEG (1984) report presented a study on the effects of joint flexibility on the response of offshore jackets, with respect to deflections, axial force, buckling length and dynamic characteristics, using as a basis the work by Fessler and Spooner (1981) on Araldite model joints. A methodology was proposed in the UEG report in order to form a stiffness matrix which takes into account joint flexibility effects.

Fessler et al. (1986a, b) presented improved equations for flexibility coefficients in terms of the joint parameters, in Y, X and gap-K joints. The difference between single and multi-braced joints is the interaction between two braces, i.e., flexibility coefficients that relate displacement and rotations of a certain brace to the forces and moments at another brace.

Efthymiou (1985) published parametric equations for the local rotational stiffness of T, Y and K joints, in terms of joint parameters. Buitrago et al. (1993) presented new equations for local joint flexibility coefficients and pointed out the difficulty of incorporating these coefficients in a structural analysis program; instead, they proposed two models, referred to as the spring model and the flex model.

The present study aims at examining the particularities of local joint behavior and investigating its effects on the overall behavior of a K-joint lattice structure against fatigue. The effects are considered at both the nominal and the hot-spot stress level. A finite element analysis has been conducted to tackle the problem in a rigorous manner and tubular joints are modeled through shell finite elements. Special emphasis is given on the reliable estimate of bending (secondary) stresses at the brace and chord members.

The paper concerns uniplanar tubular lattice girders with concentric gap K-joints. To the authors' knowledge, reliable measurements of nominal stresses from real tests on CHS K-joint girders

*ISOPE Member.

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KEY WORDS: Tubular joint, welded connection, fatigue design, hot-spot stress, stress concentrations.