Numerical analysis of stress concentration in two-planar tubular K-joints of jacket-type offshore wind turbine foundation subjected to combined loadings

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ABSTRACT

In this paper, the stress concentration of two-planar tubular K-joints under combined loadings is numerically investigated. An approximate model of the actual weld profile, which meets the minimum weld size specified in the AWS D1.1-2010, is proposed. In order to illustrate the accuracy of the proposed model, three-dimensional finite element models of several tubular Y and K-joints are established to calculate the stress concentration factors of the joints. It is shown that the numerical results are in good agreement with the literature data. Subsequently, the effect of combined loadings on hot spot stresses of two-planar tubular K-joint is investigated by using the proposed model. Comparison with the results predicted by two equations recommended respectively by API and Gulati (1982) is conducted, and some useful conclusions for fatigue design of jacket-type offshore wind turbine foundation are presented.

KEY WORDS: offshore wind turbine; two-planar tubular K-joint; weld profile model; stress concentration factor; hot spot stress; combined loadings.

INTRODUCTION

Wind energy has attracted more attention all over the world. Especially, in the past years, offshore wind energy industry has growth rapidly in Europe and China due to its advantages. The supporting structure of offshore wind turbine is constantly subjected to high cyclic loads resulting into fatigue damage. For deeper water depth like 30m~50m, jacket type of foundation is considered to be a more competitive solution for supporting offshore wind turbine. While, tubular joints are the key positions of the jacket foundation, and they are more susceptible to fatigue failure. When assessing the fatigue life of tubular joints, the method combined hot spot stress (HSS) with S-N curve is widely used by structure designers and researchers. Generally, the hot spot stress can be calculated by multiplying the nominal stress by the stress concentration factor (SCF). Then the stress concentration factor (SCF) plays a crucial role in evaluation of the tubular joint’s fatigue life.

In order to predict the SCF distribution along the intersection, Chang and Dover (1999a) conducted systematic thin shell finite element (FE) analyses, then they derived a set of parametric equations. And they (Chang and Dover, 1999b) also proposed several equations to predict the stress distributions of tubular Y and T-joints. The thin shell element cannot reveal the stress variation in thickness direction, but 3D solid element is more suitable to avoid the disadvantage in finite element analysis. Karamanos et al (2002) adopted solid element to numerically analyze the SCFs in DT-joints. Chiew et al (1999) used 3D brick element in finite element models to study the SCFs of multi-planar tubular DX-joints subjected to axial loads. Subsequently, they (Chiew and Soh, 2000) tested a large-scale steel multi-planar tubular DX-joint specimen under axial loading to verify FE models.


Lee (1999) used concentric cylinders to define the extents of the welds, and performed three-dimensional finite element analyses to evaluate stress concentration in offshore tubular K, Y, X and T-joints under axial, in-plane and out-of-plane bending loading. Later on, Ahmadi et al (2011; 2012; 2015a; 2015b), Lotfollahi-Yaghin et al (2010; 2011) used the technique presented in the paper (Lee 1999) to investigate the SCFs of tubular joints. For stress concentration in tubular KT-joints and internally ring-stiffened tubular KT-joints under balanced axial load, in-plane bending and out-of-plane bending, they studied the effect of geometrical parameters on SCF and developed parametric equations for predicting SCFs of the joints. Subsequently, multi-planar tubular KT-joints were also considered in their studies.

In service, joints can be subjected to any combination of the basic load cases. However, a very small number of studies involving combined loadings are available in the literature. The API RP2A code (2000) recommended an elastic superposition equation to calculate the peak hot spot stress (HSS) for fatigue design:

\[
\text{peak HSS} = \left[ SCF_{\alpha} \cdot f_{\alpha} + \sqrt{(SCF_{\beta} \cdot f_{\beta})^2 + (SCF_{\theta} \cdot f_{\theta})^2} \right]
\] (1)