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Mesh Parametric Study for Fatigue Assessment of Tubular K-joints using Numerical Methods

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Abstract

Wind turbine jacket structures are complex structures, whose joints design is generally driven by fatigue. These joints, along with their complex welds, are of special interest in terms of cost reduction. Therefore, a thorough analysis and understanding of the background behind the assessment proposed in guidelines is motivated. The paper presents a study of the influence of meshing for the assessment of tubular K-joints following the hot-spot approach using numerical methods. The accuracy of the results is discussed for several mesh layouts. The influence of the mesh density, element shape and element type are investigated. Furthermore, a parametric study is performed in order to see the variation of the results for several diameters, thicknesses and brace inclination combinations. The hot-spot method is proved to be robust regarding mesh regularity. However, the efficiency of irregular mesh models is very low and a high number of elements is needed in order to find an asymptotic behaviour that tends to a constant solution for increasing mesh refinement. Conclusions can be drawn for which cases it is worth to invest time in semi-automatic meshing. A discussion is done regarding which element size and type is better regarding accuracy and computational time.

Keywords: Offshore; Jacket; K-joint; hot-spot; FEM; mesh

1. Introduction

Jacket support structures are a preferred solution for Offshore Wind Turbines (OWT) in deeper waters. The lattice structure has advantages over other types of support structures, such as high strength to weight ratio and the inherent property of the tubular members minimizing hydrodynamic forces. Extensive knowledge exists in relation to its construction technique as well as its crucial components, but due to considerable cost pressure, continued optimization is essential for future competitiveness of jacket structures as a support structure for OWT. A significant share of the overall production costs of jacket structures is related to the joints connecting the tubular members. Hence, these joints along with their complex welds are of special interest in terms of cost reduction.

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The design of tubular joints is generally driven by fatigue resistance. The hot-spot method, as described in standards such as DNV-GL [1] or IIW [2] is commonly used in practice. Parametric formulae have been developed by several authors for the most common joint types [3,4]. Efthymiou equations [3] have been widely used due to the adoption in standards like DNV-GL [1]. His formulation introduced the influence function concept, taking care of the carry-over effect, i.e. the influence in the Stress Concentration Factor (SCF) at a reference brace due to loading in another member of the joint. However, results are quite conservative in general terms and poorly correlated to the FEM results at some cases [5]. Structural stress is found as a linear superposition of axial, in-plane and out-of-plane actions. The hot-spot stress is the maximum of structural stresses evaluated at at least eight positions around the weld. Despite this, it is demonstrated that, under different basic load combinations, the maximum peak can be found at any position along the intersection [6]. This may yield underconservative results, i.e. higher SCF can be found if evaluating the results at more than eight positions around the weld [7].

The fatigue damage of steel tubular joints is proportional to ΔS^3, given by the recommended Wöhler exponent $m = 3$ tabulated in guidelines. This means that an uncertainty of 20% on the SCF yields approximately a 70% uncertainty in fatigue life. The size, complexity, and cost of these joints lead engineers to perform analyses with detailed FEM models in order to assess their fatigue resistance.

FEM models require the definition of a mesh of discrete elements and nodes where continuum mechanics equations are to be evaluated. Different features of a mesh have to be correctly selected in order to obtain solutions with the desired accuracy. Standards suggest the use of relatively coarse regular meshes for the hot-spot stress method, with an element size in the order of the members wall thicknesses. However, these meshes are not automatically generated by commercial softwares and therefore, in engineering general practice, fine irregular meshes generated by black-box algorithms are a preferred solution. This yields higher computational time but not necessarily better results. Stress evaluation close to the weld toe is affected by the element size and type [8].

The present study was performed in order to investigate the use of automatically generated fine irregular meshes. Various meshes for several K-joint geometries were defined in the commercial software ANSYS© in order to assess their impact on the accuracy of the solution. Geometries of the simulated cases were defined for varying chord and braces diameters, thicknesses and relative angle. It should be noted that K-joints are the most common joint type in jacket support structures for OWT, but not the only one present. The analysis in this work will focus exclusively on them. It is assumed that conclusions drawn for K-joints can be extrapolated to X- and Y-joints. Further analysis should follow to validate that assumption.

Results show that automatically generated irregular fine meshes yield high computational times and for some types and positions generate significant errors. The study shows both quantitative and qualitative ideas of the relevance of meshing when performing FEM analysis in fatigue assessment using the hot-spot method. The different conceptual meshes defined were categorized regarding accuracy and computational time.

2. Description of the mathematical model

The parametric analysis of the influence of meshing in the computation of hot-spot stresses is done for three features that are assumed to be most relevant: (1) Number of elements; (2) Regularity of the mesh (and thereby the shape of the elements); (3) Element type. Furthermore, influence of the geometry of the joint is studied by varying the non-dimensional parameters defined in Fig. 1.(a) within the ranges given in Eq. (1). First of all, the FEM model is described in Section 2.1. Afterwards, in Section 2.2, the scope of the parametric investigation is defined.

The SCF is computed as the ratio between the hot-spot stress (HSS) and the nominal stress σ_n, i.e. SCF = $\frac{\text{HSS}}{\sigma_n}$. The nominal stress is defined as the stress at the same cross-section point where the hot-spot stress is evaluated, obtained by using general theories such as beam or plate theories, i.e. disregarding the peak due to local geometry. Far from the joint influence, the SCF is equal to one. The hot-spot stress is computed, according to DNV-GL [1], as the linear extrapolation to the weld toe from stresses at positions a and b, cf. Fig. 1. These positions are defined in the same guideline as a function of the brace radius and thickness. Only maximum principal stress S_1 is used for the sake of simplicity. S_1 is defined as the maximum component of the stress tensor when the reference is rotated such that the shear components become zero. It is found that this approximation is accurate enough, being the differences between the principal stress and the stress normal to the weld negligible at the crown position [9,10].