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On Fatigue Damage Assessment for Offshore Support Structures with Tubular Joints

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Abstract

The hot spot stress approach is commonly used for fatigue lifetime estimation of tubular joints. The standard approach consists of the linear superposition of stress components from axial, in-plane, and out of plane action, leading to 8 hot spot stresses equally divided along the circumference of each tubular joint. The fatigue lifetime for a joint is calculated by accumulating the fatigue damage over several load cases. The fatigue damage used per load case is commonly the maximum fatigue damage out of the 8 hot spots. In this study, another approach has been evaluated. Fatigue lifetime is estimated by accumulation of fatigue damage over load cases for each hot spot individually, instead of taking the maximum out of the 8 hot spots. The proposed approach is compared with the commonly used approach using a generic lattice type support structure for offshore wind turbines. In addition, the number of hot spots along the circumference of the joint is increased to 32 points in order to study the influence on the fatigue lifetime estimation. Results show a difference in the fatigue lifetime estimation for individual joints up to 26% when using the proposed approach for estimating the fatigue lifetime. Furthermore, it is shown that the consideration of 32 points along the circumference of tubular joints lead to more precise fatigue damage. Differences up to 11% were detected.

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Keywords: Offshore wind energy; jacket support structure; hot spot stress; fatigue analysis; fatigue lifetime estimation

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1. Introduction

Lattice type support structures, such as jackets, are a preferred solution for offshore wind turbines (OWTs) in a water depth up to 50m. Designing this type of support structures is a non-trivial task, since they are highly dynamic and tightly coupled to the wind turbine [1]. Thus, the structure is exposed to a large number of quasi-periodic excitations caused by the rotor. In addition, the support structure experiences excitation from oscillating waves resulting in additional quasi-periodic motions. These excitations are usually less dominant compared to the effects by the wind turbine due to the typically small diameters of the support structure, but have to be considered in the structural analysis of an OWT. Experiencing this type of loading during the lifetime, a lattice type support structure is usually prone to fatigue damage. Critical locations for fatigue damage are the joints, where two or more elements of the structure are welded together. The design lifetime of a lattice type support structure is, therefore, determined by the fatigue lifetime of joints of the structure.

Fatigue life for welded joints is typically analyzed using the hot spot stress (HSS) approach. In this approach the fatigue lifetime is estimated comparing the intensity of the stresses at critical points with the endurance limit given by S-N curves. The critical points are spots along the circumferences of the tubular joint with high stress concentration, where a fatigue crack is expected to occur. These spots are referred to as hot spots and HSSs can be measured with strain gauges or determined with finite element analysis or empirical formulas when used for design evaluation [2]. For design purposes, the finite element analysis is the more accurate method to determine HSS, thereby estimating the fatigue lifetime. However, performing a detailed finite element analysis for each joint of the support structure and applying it in the design process where several iterations and a numerous amount of simulations are needed is computationally expensive and time consuming. Hence, guidelines for the fatigue design of offshore steel structures recommend deriving HSSs with empirical formulas using nominal stresses and stress concentration factors (SCFs) [3]. According to guidelines, the HSSs should be evaluated at 8 spots equally located around the circumference of the joint, including the crown and saddle points. It is common practice to calculate fatigue damage for different load situations (load cases) at each of these 8 hot spots and to take the highest fatigue damage value out of the 8 hot spots in order to determine the fatigue damage per load case. The fatigue lifetime of a joint is estimated by accumulating these maximal fatigue damage values per load case based on its probability of occurrence. This implies that different hot spots can contribute to the fatigue lifetime of a joint.

This study investigates a different approach. Here, the fatigue lifetime is estimated for each hot spot individually instead of taking the highest fatigue damage value per load case. The lowest fatigue lifetime out of these hot spots determines the fatigue life for each joint. In addition, HSS and fatigue damage is calculated for intermediate points between the 8 hot spots recommended by guidelines, since these might be higher. The main objectives of this study is to assess the differences between (1) the proposed approaches regarding fatigue lifetime estimation for tubular joints and (2) the extended use of hot spots around the circumference of the joints compared to the standard approach recommended by guidelines.

2. Estimating fatigue lifetime for lattice type support structures

2.1. Fatigue analysis

The fatigue lifetime of a lattice type support structure may be predicted based on the fatigue damage analysis for structural details such as joints. Fatigue damage per joint is calculated using HSSs as briefly described in the previous section. In a structure, the term hot spot refers to critical points where the stresses are typically higher than in other parts. For welded tubular joints, these points are positioned along the circumference of the joint, and fatigue calculations should be performed on each side of the weld (see Fig. 1). Fig. 2 shows the positions of the 8 hot spots for fatigue analysis recommended by guidelines [3] including the position of crown and saddle.

HSSs are reference stresses calculated at hot spots using empirically based equations. Inputs for these equations are nominal stresses and SCFs [3-4].

$$\sigma_{HSS} = SCF \cdot \sigma_{nominal} \tag{1}$$