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A STATE-OF-THE-ART REVIEW ON LOCAL FATIGUE DESIGN OF SUPPORT STRUCTURES FOR OFFSHORE WIND TURBINES

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ABSTRACT

The scientific community is devoting more attention to the wide scope of offshore wind turbine structures. Since such structures are subjected to high level of fatigue loads as well as a large number of load cycles caused by wind, waves and turbine operation, the fatigue performance of welded connections is usually a design driving criteria. In this paper, a brief revision on load simulation and strength analysis procedures as well as local fatigue design methods of support structures for offshore wind turbines is presented. In order to face some of the challenges in this area of expertise, a research project is introduced, aiming to exploit residual capacities in the fatigue design of tubular joints of support structures for offshore wind turbines.

NOMENCLATURE

FEA	=	Finite Element Analysis
FM	=	Fracture Mechanics
HSS	=	Hot spot stress
LEFM	=	Linear Elastic Fracture Mechanics
NSA	=	Notch Stress Approach
OWT	=	Offshore Wind Turbine
SCF	=	Stress Concentration Factor
SIF	=	Stress Intensity Factors
SSA	=	Structural Stress Approach

INTRODUCTION

Wind energy has become a mainstream source of energy due to the growing energy demands, the imposed limits of greenhouse gases emissions (Kyoto Protocol) and the desired diversification of energy supply related to the fossil fuels dependence, the aversion to the traditional fission nuclear power and the lack of progression in the application of fusion nuclear power [1].

In the last two decades wind turbines moved offshore due to the limited in-land space for the development of onshore wind farms, the possibility to accommodate even more wind power under significant steadier wind conditions, and the lower environmental impact inherent to an Offshore Wind Turbine (OWT). The support

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structure of an offshore wind turbine has a great contribution to the overall cost-effectiveness of the all system, especially in deep waters. As current practice, monopiles are the preferred type of support structures for water depths up to 30 m [2]. Thus, monopile diameters up to 10 m are subject of latest design concepts, leading to manufacturing, transportation and erection challenges. However, more attention have been payed to the use of jacket structures to larger water depths. The design of jacket substructures for offshore wind turbines is still in an early stage of development although the use of such substructures has the potential to become the dominant solution due to the expected optimization of design methods, fabrication techniques (in particular with respect to the connection between members), transportation and erection [3, 4].

Since OWTs are subjected to high level of fatigue loads as well as a large number of load cycles caused by wind, waves and turbine operation, the fatigue performance of welded connections is usually a design driving criteria. The fatigue behaviour of welded tubular joints is a well-recognised problem in the design of tubular structures [5]. The fatigue strength of such joints depends on the absolute and relative size of its members (size effect), on the load case, on the initial crack-like imperfections, and on the welding residual stress fields [6]. Research addressing these fatigue issues has been carried out during the last 35 years, mainly by the offshore industry [5, 6].

In this paper, a brief revision on load simulation and strength analysis procedures as well as local fatigue design methods of support structures for OWT is made, with the aim of contextualize the fatigue problematic within the entire design process and to emphasize the importance of local fatigue design assessment. Finally, a research plan within the framework of the Innovative Training Network (ITN) AEOLUS4FUTURE is introduced, aiming to exploit residual capacities in the fatigue design of tubular joints of support structures for offshore wind turbines.

LOCAL FATIGUE DESIGN OF OWT SUPPORT STUCTURES

The number of load cycles generated from the rotor of an OWT within its design life time (usually 20 years) may reach more than 1x 10^9 load cycles [7]. Furthermore, geometric discontinuities lead to stress concentrations that must be considered within the fatigue assessment [8].

Tubular joint design is a well-known field of research of the offshore industry. For fatigue verifications, it is common practice to evaluate the calculated damage based on hot spot stresses (HSSs) in combination with related S-N curves [9]. However; the geometrical characteristic of tubular joints, especially with respect to multiplanar joints, has a complicated influence to the HSS. Extensive researches have been undertaken using numerical tools to generate data in HSS distribution, Stress Concentration Factors (SCFs) and Stress Intensity Factors (SIFs) for tubular joints, with focus on the uniplanar tubular joints such as T joints and K joints [10].

Regarding the type of OWT support structure, nominal stress approach may be used to determine the damage values for monopile structures. For tubular joints of jacket structures, the nominal stress approach is not applicable. An alternative method is the Structural Stress Approach (SSA) which can be carried out using parametric formulas or numerical methods [11]. Furthermore, sophisticated concepts like the Notch Stress Approach (NSA) can be used for fatigue assessment [12]. Schematization of this different stress approaches is given in Figure 2, for an exemplificative geometry discontinuity, where a fatigue crack is expect to grow.

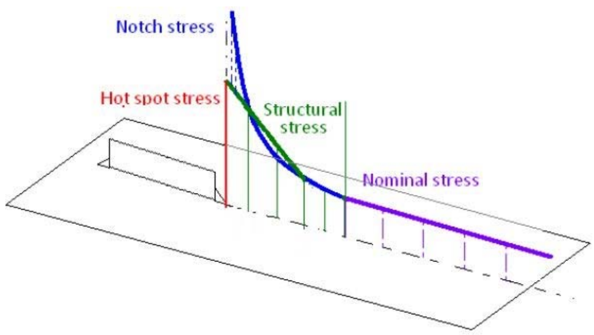


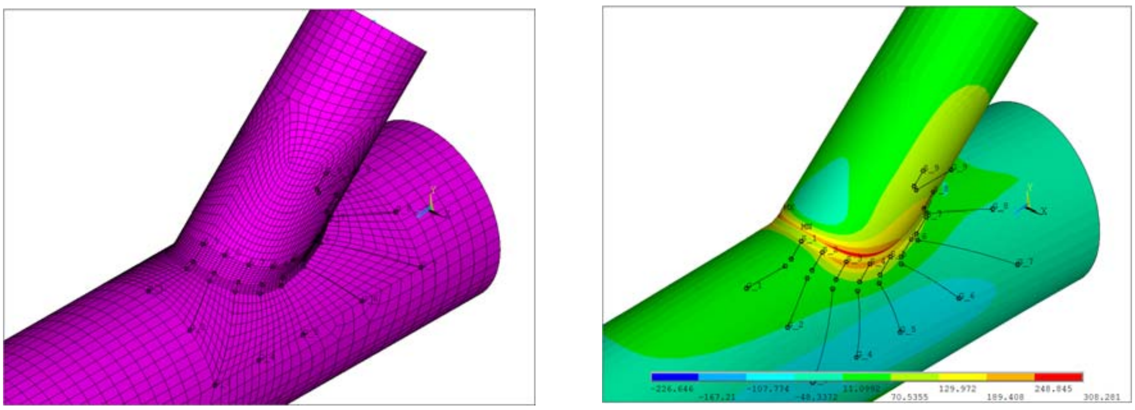
Figure 2. Nominal Stress vs Structural Stress; Hot Spot Stress vs Notch stress [13].

RESEARCH ON WELDED TUBULAR JOINTS

The fatigue performance of welded connections is usually a design driving criteria of support structures for OWTs, due to high level of fatigue loads as well as a large number of load cycles. Components with load cycles of this magnitude can hardly be analysed by means of experimental research and, for that fact, the development of improved numerical models is an important area of fatigue research. In order to push superior risk and cost considerations to a new level, a research project within the framework of the Innovative Training Network (ITN) AEOLUS4FUTURE is under development, in the topic of local fatigue design methods of support structures for OWTs.

The research project proposes an experimental and numerical investigation on the fatigue performance of large scale tubular X joints, with automated Tandem MIG/MAG welds. Automated welding technologies have already been development, for the production of tubular joints [14]. The production automation allows the delivery of standardized components and the application of dual wired welding processes (Tandem MIG/MAG), which can only be applied by robotic welding due to the required precision in positioning. Therefore, there is a need to investigate the fatigue behavior of the assembled joints, as such technology allows welding from both sides of the steel tubes (as strategy to improve fatigue behavior), higher weld deposition rates, lower welding time and overall cost reduction.

Up to now, the large scale experimental investigation is under planning and preliminary numerical models have already been developed by use of SSA, as shown in Figure 9 (a). The aim of these models was to simulate and evaluate the experimental test setup. The finite element model was developed in Ansys© environment, by means of the dedicated tool Falcos©, developed at the Institute for Steel Construction of the Leibniz University Hannover. A 20-node solid element (SOLID95) is used. This element type has a high degree of accuracy as result of midside nodes. The influence of mesh refinement and boundary conditions on SCFs is discussed in the extended version of this paper. The hot spot stresses were located, as shown in Figure 9 (b), and the stress concentration factors were calculated. The maximum SCF equal to 4,10 was estimated for the load case scenario of a unitary axial load (1 N/mm^2).



(a) (b)

Figure 9. (a) X-Joint finite element model; (b) Load simulation and hotspot stress location.

CONCLUSIONS

In this paper, a brief revision of the scope of standard fatigue design procedures as well as local fatigue design methods of support structures for offshore wind turbines is made. In order to push superior risk and cost considerations to a new level, a research plan related to the work package 4 of the Innovative Training Network (ITN) AEOLUS4FUTURE was introduced.

The research work developed so far, proved that it is possible to perform fatigue testing of large scale tubular X joints, with automated Tandem MIG/MAG welds. However, there are still challenges to overcome, concerning the experimental planning, in order to make the ambitious experimental investigation possible. If successful, the results of the experimental campaign will be used to validate numerical models. Furthermore, a numerical investigation will be performed by use of local concepts to achieve a deeper understanding of the damage mechanism. For fatigue verifications, the Structural Stress Approach (SSA) will be applied, combining parametric formulas and numerical methods. Furthermore, global models will be combined with sub-modelled crack regions and more sophisticated concepts like the Notch Stress Approach (NSA) will be used for fatigue assessment. Finally, parametrical studies and differences on fatigue life will be quantified between the standard and the advanced methods. Parameters such as loading, diameter/thickness ratio and steel grades will be investigated.

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