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Weld toe stress concentrations in multi-planar stiffened tubular KK joints

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ABSTRACT

This paper reports a parametric stress analysis of various configurations of rack plate stiffened multi-planar welded KK joints using the finite element method. The KK joint finds application in the leg structure of offshore oil and gas jack-up platforms. The rack plate works as a stiffener which reduces the stress concentration at the brace/chord intersection. This could be an immense contribution to the increase in fatigue life of the joint, but other hot spot sites are introduced into the joint. The rack is also used for raising and lowering of the jack-up hull which gives the jack-up platform its jacking capability. Over 120 models using a combination of shell and solid elements have been built and analysed with ABAQUS. Non-dimensional joint geometric parameters (β, γ and Ω) are employed in the study, with the new parameter Ω being defined as the ratio of rack thickness to chord diameter. Stress concentration factors (SCFs) are calculated under applied axial and OPB (out-of-plane bending) loading. Three critical SCF locations are identified for each load case, with each location becoming the most critical based on the combination of the non-dimensional parameters selected for the joint. This is important as careful design can shift the critical SCF from an area inaccessible to NDT to one that can be easily inspected. The SCF values extracted from the models are used to derive six parametric equations through multiple regression analysis performed using MINITAB. The equations describe the SCF at the different locations as a function of the non-dimensional ratios. The equations not only allow the rapid optimisation of multi-planar joints but also can be used to quickly identify the location of maximum stress concentration and hence the likely position of fatigue cracks. This in itself is an invaluable tool for planning NDT procedures and schedules.

1. Introduction

Longitudinally stiffened tubulars find their greatest application in the legs of jack-up platforms. The stiffeners are usually found as rack plates which aid in the raising and lowering of the jack-up via a rack and pinion mechanism. A survey of available literature reveals that considerable research effort has been directed towards an understanding of the effect of internal ring stiffeners in tubular joints as opposed to the effect of longitudinal stiffeners, nevertheless the rack plate has been observed to reduce the stress concentration at the brace/chord intersection of stiffened joints. Stiffeners which reduce the stress concentration in certain locations are suspected of introducing hot spots in other locations and this justifies the need for research into the effect of rack plates in jack-up chords.

Extensive stress analyses of uni-planar tubular joints have been carried out in the past while most studies of multi-planar joints have focused on an ultimate strength analysis. Furthermore, study of the effect of stiffeners has mostly focused on their application to uni-planar joints. This parametric study involves a stress analysis of a rack plate stiffened multi-planar KK joint as shown in Fig. 1.

The stiffened multi-planar KK joint under investigation is an integral part of the lattice legs of a jack-up platform as can be observed from Fig. 2. Each leg is a critical component of the jack-up as failure of one leg will lead to the collapse of the whole structure. An extensive understanding of possible crack sites in the KK joint, which is to be achieved by this study, is a first step to prevent an eventual collapse of the platform.

A finite element analysis of over 120 models utilizing a combination of 3D solid elements and 2D shell elements was employed for the purpose of this work with the ultimate goal of developing parametric stress concentration factor (SCF) equations to represent the hot spot stress at the brace/chord intersection and any other location identified as a potential hot spot. The study has been restricted to axial and out-of-plane bending (OPB) loading modes while only three non-dimensional joint geometric parameters (β, γ and Ω) were varied.

The circular chord in Fig. 1 has been split to accommodate the continuous rack plate and is described as the opposed pinion leg configuration of a jack-up wherein the KK joint is repeated throughout the legs. Other leg configurations exist, but this study shall focus on the split tubular with a continuous central rack.

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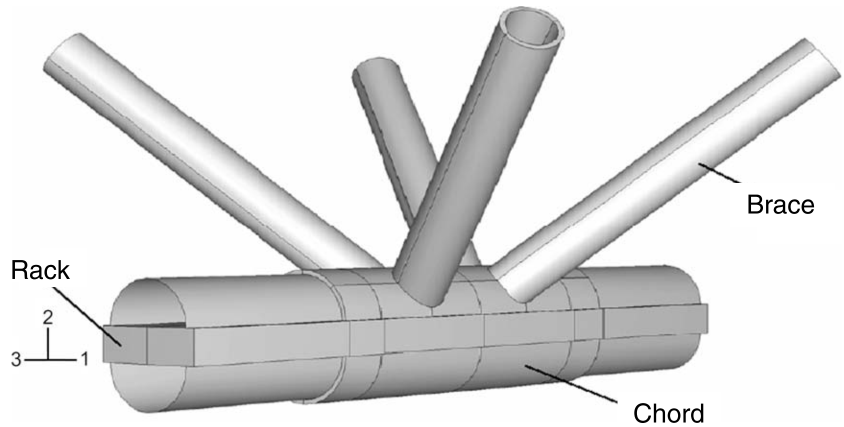

D = chord diameter

z = rack thickness $\Omega = z/D$

d = brace diameter $\beta = d/D$

T = chord wall thickness $\gamma = D/2T$

Fig. 1. 3D view of stiffened KK joint.

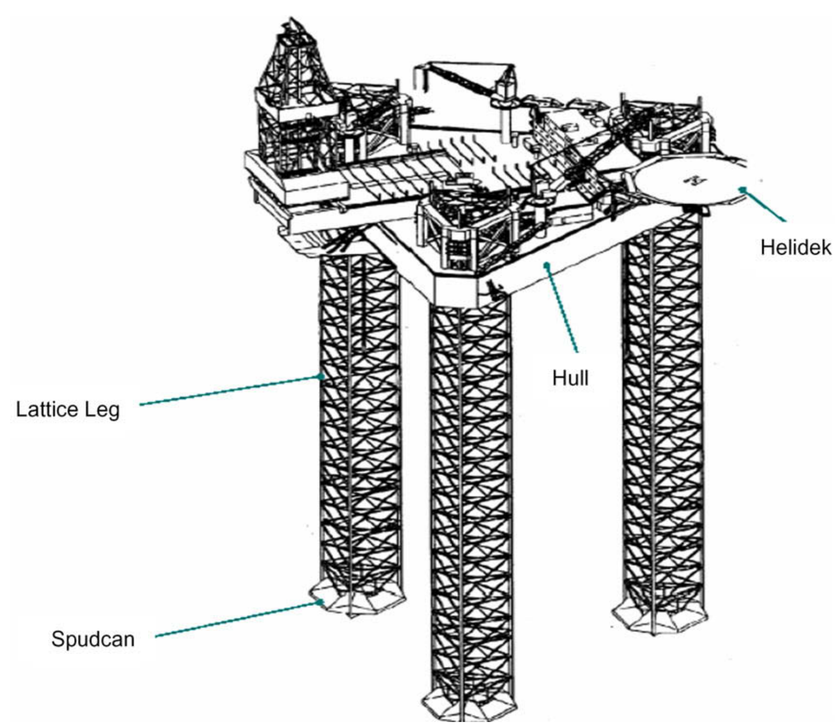

Fig. 2. General view of a jack-up.

Consideration of in-plane bending (IPB) loads has been omitted from this study because of the negligible effect of the stiffener on the SCFs under IPB [1].

Other non-dimensional parameters to describe tubular joint geometry exist but the non-dimensional parameters selected for this study are believed to have the greatest effect on the SCFs in the joint under investigation.

2. Background

The Jack-up Platform is better described as a Mobile Offshore Drilling Unit (MODU) and has been a part of the offshore oil industry exploration fleet since the 1950s. Many units in use today are over 20 years old which makes them very susceptible to fatigue failure.

The Jack-up was originally designed for intermittent use in shallow waters with periodic dry dock inspection and repair but the unit is re-usable as well as being simple and quick to install compared to fixed platforms, thus it finds increased application in the prolonged exploration of reservoirs in the harsher environments of deeper waters. This increased period of use implies less frequent inspection. Jack-ups are also being used as fixed production facilities, thus they are subjected to less frequent and expensive underwater inspection. This infrequent inspection requires that inspection schedules must be cost effective when carried out, pos-