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Structural behaviour prediction for jack-up units during jacking operations

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Abstract

For a self-elevated jack up unit, localized failure and collapse may take place during installation phase under severe sea state conditions. In order to minimize the loss, an innovative method is proposed and incorporated in finite element analysis to predict the structural behaviours before construction. With a full model of a jack-up unit being built, numerical simulations could be carried out under different load and boundary conditions. A lot of information such as displacement and member force etc. during jacking operations could be obtained from simulation results and these valuable data would be much helpful for re-design of the structure and could be used as guidance for site installation as well.

Keywords: Jack-up unit; Finite element method; Numerical simulation; Control algorithm; Seabed fixity; Rack phase difference

1. Introduction

As a very useful and movable tool for drilling operations of oil and gas industry in shallow water (i.e. less than 100 m deep), jack-up units have been used widely for several decades. In general, a jack-up structure consists of a hull and three *K*-lattice legs resting on spudcan footings. Each leg has three chords. When the structure is towed to site and preloaded to the desirable penetration, the hull is then jacked up.

According to the design code [1], attention should be paid to the four particular design conditions such as transit, installation, elevated states and retrieval during conceptual design of a jack-up unit. A lot of effort has been put on the transit and the elevated states in past years. Non-linear dynamic behaviours under various wave and current loading conditions were studied by Spidsøe et al. [2] on an integrated leg-hull system. With a two-dimensional non-linear finite element model being built, dynamic responses of an offshore jack-up unit due to environmental loads have been investigated with parametric study by Williams et al. [3,4]. Non-linear analysis for elevated jack-up units has been carried out by Cassidy et al. [5] with constrained new wave methodology. Karunakaran et al. [6] and Springett et al. [7] have done a lot of analysis on the full-scale measurements obtained from the instrumented jack-up platforms. Graaf et al. [8] examined structural failure or overturning of jack-up units by physical uncertainty in the extreme environmental loads. Furthermore, characteristics of a jack-up platform operating at two different locations in the North Sea and the effects from uncertainty in load and boundary conditions were analyzed by Leira et al. [9]. As a result, a lot of important findings have been obtained from these research works. However, the important installation phase—jacking operations—has been touched rarely by researchers.

The hull is jacked up by motors through pinions rotating along racks on the chords. The pinions are connected to the jack-cases, which are fixed tightly on the

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hull. Normally, there are four pinions supported by each chord. The pinions are motivated by motors through gearboxes. Rack phase difference (RPD), defined as the displacement difference between the averaged position of the pinions on each chord of one leg and that of the lowest pinion group of the same leg, is used to judge the inclination of the leg towards the hull. If RPDs of one or more legs are too high, adjustment should be performed.

In order to protect the structure from damage, guides, i.e. upper guides, lower guides and wear plates, are installed for each chord. Usually, the clearances between guides/wear plates and chords are very small. As a typical problem, guide-to-leg contact and friction may occur, giving some clamping moments and even resulting in some failures.

To analyze a jack-up unit during jacking operations for safety evaluation of a proposed design under the specified conditions, the proposed control elements and gap elements are used for the connections between pinion and chord and the interactions between guide/wear plate and chord, respectively. These two kinds of element are incorporated into finite element analysis with extra control techniques.

The behaviours of a jack-up system during jacking operations vary with the load and boundary conditions. Wind load is one of the factors that affect the system seriously. Sometimes, wind speed is extremely high on the site. Apart from the wind load condition, another important factor is the fixity of the footings. The seabed fixity has been measured, analyzed and discussed by Springett et al. [7], Temperton et al. [10] and Nelson et al. [11] based on the instrumentation data measured on site. Generally, the fixity of a jack-up leg would be somewhere between pinned connection and fixed connection. However, according to the research done by Hoyle et al. [12], Langen [13] and SNAME report [14], legs may even be sliding if the penetrations of the spudcans to seabed are not desirable. Therefore, the effects of wind load and leg fixity on the behaviours of a jack-up unit are investigated.

2. Finite element (FE) model for a jack-up unit

A full three-dimensional finite element model is built based on a practical design. The model consists of three parts, i.e., legs, hull and connections between the legs and the hull. Pipe elements and beam elements are used for all members such as chords, horizontal braces and diagonal braces of the *K*-lattice legs. Comparing to the stiffness of the jack-cases and the legs, the stiffness of the hull is very large. Simplification is made for the hull, which is assumed to be always above the water level. With consideration of both stiffness distribution and mass distribution according to the design, the hull is represented by beam elements. The total mass of the hull is about 14,000 Tonnes. Initial distance measured from seabed to the hull is 47.4 m. The elements proposed for the connections between legs and hull are sorted into two types: control element and gap element. Since the connections between pinions and chords and the interactions between guides/wear plates and chords are varying from time to time, a lot of these two types of element with control switch functions, which will be discussed later, are created in the model.

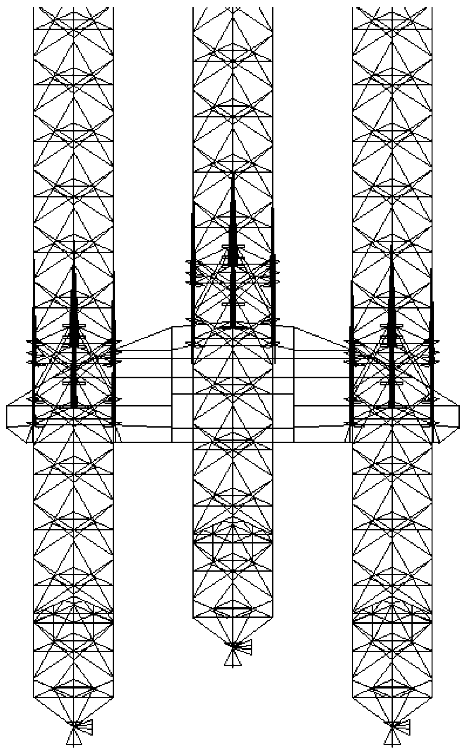

Fig. 1. FE model of the jack-up unit.

To be conservative, all of the three legs are pinned for the basic simulation case. The overall view of the FE model is displayed in Fig. 1. Horizontal force induced by wind is assumed to act on the hull in the direction of port/starboard leg to forward leg as shown in Fig. 2. Maximum value of the wind load is estimated up to 2200 kN according to the site conditions.

3. Connection between pinion and chord

There are four pinions on each chord. Each pinion is driven by one motor. The motor speed varies with the torsion on the pinion. In the model, a motor is represented by a transfer function of moving-up speed versus vertical reaction force of a pinion. The vertical force and the moving-up speed are expressed as follows: