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Hydrodynamic performance of a novel semi-submersible platform with nonsymmetrical pontoons

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ABSTRACT

The hydrodynamic performance of a novel semi-submersible platform (SEMI) was investigated in the present study. This new type of SEMI, which features two nonsymmetrical pontoons and no horizontal connection braces, can serve as a semi-submersible crane vessel. For a comparative study, two conventional SEMI models, i.e., one SEMI having both twin symmetric pontoons and horizontal braces and the other SEMI having twin symmetric pontoons with no horizontal braces, were established. The hydrodynamic characteristics were first investigated and compared with a special focus on the heave, roll and pitch motions. Furthermore, the motion response of the novel SEMI was studied under normal operation in eight different wave directions. The numerical results demonstrate that there exists significant heave-roll/heave-pitch coupling effects in the novel SEMI due to the nonsymmetrical pontoon shapes. These coupling effects require that more attention be paid to long waves whose periods are close to the heave resonance period. The motion responses of the novel SEMI are generally satisfactory for a typical normal sea state.

1. Introduction

With the rapid development of hydrocarbon exploration and exploitation in deepwater ocean, floating crane vessels play an increasingly important role in the operation of offshore installations. Basically, there are three different types of floating crane vessels around the world (Clauss and Vannahme, 1999). One type is the semisubmersible crane vessel (SSCV) that has a semi-submersible hull shape and revolving cranes. SSCVs have favorable sea-keeping behavior and an immense deckload capacity as compared to other crane ships. These vessels require a sophisticated ballast system for counter ballast in order to operate cranes in different slewing angles. Other types of crane vessels comprise monohull vessels and catamaran-shaped crane vessels, outfitted with revolving cranes. Advantages of monohulls are higher transit speed, associated with lower mobilizing costs. However, they are more weather sensitive compared to SSCVs due to larger water-plane area, and need also strong support and sophisticated ballast system. Shear leg cranes are another type of floating cranes, having a barge-shaped hull with large water-plane area, operating in sheltered waters of harbors where waves are relatively low and in offshore regions at moderate weather conditions.

Among those floating crane vessels, SSCVs are widely employed in all types of heavy lifting at offshore projects around the world. Whereas the monohull crane vessels have excessive response to the wind-driven waves and swell, this limits the workability of the vessel. A semi-submersible obtains its buoyancy from ballasted, watertight pontoons that are fully submerged during operations, supporting four to eight columns that extend through the water plane and in turn support the deck. The vessel is therefore subject to minimum wave loading, and corresponding motions. The semisubmersible concept was first developed for offshore exploratory drilling but the advantages of the semi-submersible vessel stability were soon recognized for offshore construction. Crane vessels and barges operating in the North Sea were quite sensitive to wave action, and this made operations during the winter months virtually impossible. To increase heavy-lift capacity and operability in the North Sea, Heerema Marine Contractors constructed the world's first SSCVs – sister vessels Balder and Hermod In 1978. The SSCVs were much less sensitive to sea swell, therefore it was possible to operate on the North Sea during the winter months. The high stability also allowed for heavier lifts than was possible with a monohull. The larger capacity of the cranes reduced the installation time of a platform from a whole season to a few weeks.

So far, there are several SSCVs in use. The representative of them are DCV Thialf, DCV Balder and HLV Hermod of Heerema Marine Contractors, Saipem7000 of Saipem, DB-101 of J. Ray

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McDermott, etc. (Clauss and Riekert, 1990). Generally, these SSCVs share common structural features such as identical twin pontoons, four/six/eight columns, horizontal braces and large upper deck. And the twin cranes are installed at the left and right parts of the hull deck on the ship bow, respectively. At present, this kind of structure has been regarded as the classic SSCV type. A major consideration of any floating production vessel is the dynamics and performance of these vessels, which is of great importance in overall field development (Söylemez, 1998). Early studies concerned with the stability of the semi-submersibles under intact and damaged conditions (Numata et al., 1976; Dahle, 1981). Later, extensive studies have been investigated on the hydrodynamic performance and motion responses (Wu, 1986; Yilmaz and Incecik, 1996; Wu et al., 1997; Söylemez, 1998; Feng et al., 2009; Ng et al., 2010; Li et al., 2011; Zhu and Ou, 2011; Yang, et al., 2012). As for the SSCV, the nonlinear dynamic responses of moored crane vessels to regular waves are investigated experimentally and theoretically (Ellermann et al., 2002). Both the developed models and the analytical tools can be used to identify the limits of the operating range of floating cranes. Jacobsen and Clauss (2005) investigated the sea-keeping behavior of SSCV Thialf in detail in time and frequency domain deriving definitions of operational limits and the coupling effects with a barge floating nearby. In order to examine the effects of the water depth on heave and pitch motion, model tests accompanied by numerical calculations were conducted on SSCV Thialf (Clauss et al., 2009). Motion behavior of the crane vessel is investigated focusing on the effect of the water depth on the hydrodynamic coefficients, i.e. potential damping, added mass and exciting forces.

From the literature review, one can see that for both the semi drilling rigs and SSCV, the main hull structure of semi-submersible shares common structural features of identical twin pontoons and several columns, connected with braces. An innovative semi-submersible platform, named Explorer Lifter, was designed and constructed by Yantai CIMC Raffles Offshore Ltd., China. This new type of SEMI, which served as a semi-submersible crane & accommodation vessel, integrated the functions of heavy-lifting, storage of cargo, and accommodation. It is the first asymmetric semi-submersible unit without bracing in the world.

As shown in Fig. 1, the novel SSCV has several significant innovations and notable features. One major innovation is the different sizes of the two pontoons. Classic SEMIs commonly have two identical pontoons. However, the external shapes of the two pontoons of this novel SSCV have different dimensions, i.e., one is large and one is small. Accordingly, the two groups of columns also have different dimensions. Another characteristic is that there are no horizontal connection braces between the columns of the SEMI. In addition, both of the lifting cranes are installed on the same side of the upper deck, above the large pontoon. This new SEMI configuration has several advantages. Asymmetric pontoon outline with pneumatic de-ballast system is very useful for quick ballast adjustment to suit heavy lifting operation, and the time for ballast adjustment is reduced from normally 1 h to 15 min. Because the two cranes are placed on the same side as the large pontoon, the new SEMI is able to get closer to the lifting object. Furthermore, the lack of horizontal connection braces results in a reduced towing resistance and dynamic positioning load, which improved the transit speed from about 8–9 knots to more than 11.3 knots.

As a new type of deep-water floating structure, the first asymmetric semi-submersible unit without bracing in the world, the hydrodynamic performance of this novel SEMI is worthy of attention and investigation. To present the results of the investigation, the paper is organized as follows. In Section 2, the theoretical background related to the study is briefly described. The three different SEMI models used for the comparative investigation, including the principal parameters and mooring systems, are introduced in Section 3. In Section 4, the hydrodynamic performances of these SEMIs are investigated and compared, and the conclusions are summarized in Section 5.

2. Theoretical background

Floating structures positioned with mooring systems generally consist of large- and small-scale structures and are subjected to different types of wave forces. In this section, the theoretical basis related to the hydrodynamic analysis is briefly summarized.

2.1. Potential theory

For large-scale structures compared with the wavelength, such as the columns and the pontoons, wave diffraction and radiation force are considered the main wave loads on the structures. The 3-D diffraction-radiation theory can be used to calculate the hydrodynamic loads on the structures. When a floating structure is subjected to wave action, the wave incident upon the floating structure is diffracted to produce a scattered wave field and sets the structure in motion to produce a radiated field. Through linear superposition, the velocity potential can be decomposed into three parts as follows (Faltinsen, 1993):

$$\Phi(x,y,z,t)=\Phi_I(x,y,z,t)+\Phi_D(x,y,z,t)+\Phi_R(x,y,z,t) \tag{1}$$

where potential Φ_I represents the incident wave potential, Φ_D the scattered wave potential, and Φ_R the radiation potential. Each type of potential must satisfy Laplace's equation with the associated boundary conditions throughout the domain of the fluid. After solving the resulting boundary-value problem, the potentials Φ_I,

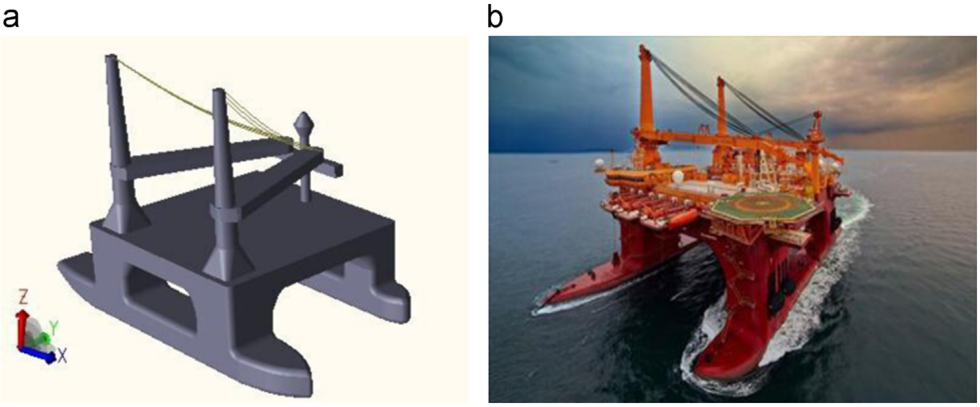

Fig. 1. Geometrical model and stereogram of the novel SEMI. (a) Geometrical model, (b) Photo of Explorer Lifter.