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Numerical study on a hybrid mooring system with clump weights and buoys

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ABSTRACT

A new hybrid mooring system based on the traditional taut mooring lines was proposed in the present study. A series of clump weights were attached to the lower end of each mooring line to form a catenary shape. Some buoys were connected to the upper ends of the lines to reduce the top tension on each mooring line. In order to verify the advantages of this new hybrid system, we investigated the motion responses of a semi-submersible platform moored by the proposed hybrid mooring system. The top tension on the lines was also calculated by using the time domain method. Comparing the results from the taut mooring system, it can be found that the tension on the lines could be reduced by using the present hybrid mooring system, while the motion responses were hardly influenced. Furthermore, a catenary shape was formed at the lower end of each mooring line, which could reduce the requirement of the anti-uplift capacity of the anchors. We also carried out the parametric study to investigate the optimal position and volume of the buoys. The discussions were highlighted on the influence of the water depth.

1. Introduction

Deep-water floating systems are normally composed of three main components: the floating vessel, the mooring system (the mooring lines and the anchors) and the marine risers, all of which are subjected to the environmental loads. As a critical component, the mooring system guarantees the safety of the working condition of the vessel. For the water depths of up to 1000 m, the most common mooring system is the catenary mooring system, which consists of a group of lines combined of chain and wire rope. For exploration and production in water depth beyond 1000 m, the weight of the mooring line starts to become a limiting factor in the design of the floating system, and then the taut leg mooring system comes forth, which adopts synthetic polymeric ropes as the main section of the lines. In addition to these two popular mooring systems, a hybrid mooring system with buoys and catenary lines has been proposed these years.

There are mainly three aspects which can estimate the performance of a mooring system. The first one is the motion responses of the vessel. A smaller movement of the vessel will bring a better working condition for the floating structures. The second one is the tension on the mooring lines. It is obvious that a smaller tension is preferable in the design. But these two aspects are always incompatible. A smaller movement of the vessel can only be achieved when the mooring lines provide enough restoring forces, which requires a larger tension. The third one is the requirement for the anchor's holding capacity. The piles or suction anchor are required to resist significant vertical loads when there is a vertical component force at the anchor points, which will greatly increase the cost.

As for the catenary mooring system, the catenary chains or wires rely heavily on their own weight to provide restoring forces. As a result, it will not only increase the production costs, but also bring an increase to the top tension of the lines and enlarge the vertical loads on the vessel when the line is lifted from the sea bottom (Johanning, et al., 2007). This growth in vertical load can be important as it effectively decreases the vessel's useful payload. The restoring forces provided by catenary chain are not adequate to keep a small platform offset. However, the main advantage is that the anchors are only subjected to the horizontal force component since the lower end of the mooring line is resting on the seabed. As for the taut mooring system, the synthetic polymeric ropes can provide large restoring forces through their axial stiffness, which can reduce mean- and low-frequency platform offsets and improve the drilling condition. Meanwhile, the

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synthetic fiber lines are considerably light, very flexible and can absorb imposed dynamic motions through extension without causing an excessive dynamic tension. But the disadvantage is that the anchors need to handle a very large vertical.

The idea and application of the clump weights on the offshore mooring lines can be found in some previous publications. Finn (1976) proposed a new deep water offshore platform which was called 'the guyed tower', and the platform was held upright by multiple guy lines. Each line has three main portions: (1) A catenary from the fairlead connection at the tower to the clump weight; (2) a clump weight that is relatively massive compared with the cable; and (3) a line and an anchor pile to anchor the line. The clump weight rests almost entirely on the sea bottom during relatively small tower response. However, during the extreme sea state, the clump weights lift off the bottom to form part of an extended catenary from anchor pile to the tower. Morrison and Asce (1983) carried out the analysis for the dynamic properties of the guyed tower mooring lines. However, these researches are limited to the water depth up to 1500 ft. Some other component mooring lines with additional sinkers and buoys are proposed recently. Smith and MacFarlane (2001) used catenary equations to solve a three component mooring made up of two lines, connected at a point buoy or sinker where water depth and fairlead tension were given. Vicente et al. (2011) investigated different mooring configurations with slack chain mooring lines of a floating point absorber with or without additional sinkers or floaters. It was found that the different arrangement of the buoys and weights would bring significant differences in terms of average and maximum tensions on the mooring cables. Hong and Kim (2004) carried out an experimental study for a compliant mooring system keeping a floating OWC device. The compliant buoy mooring system consists of four mooring systems, each of which has a buoy connected to horizontal and vertical mooring lines. However, this wave energy device was damaged by mooring line failure during a severe storm. This study has been made to clarify the mechanism of mooring line failure for future improvements in mooring line design.

Based on the guyed tower mooring lines, Ji et al. (2011) proposed a mooring system integrating catenary with taut mooring for deep water platform. In their study, some clump weights were applied to the lower end of the taut lines at fixed intervals, which could form a catenary end, tangent to the seabed. In that way, the anchor points were only subjected to the horizontal forces. They calculated the hydrodynamic responses for a semi-submersible. The results showed that the vessel's offsets and the line's tensions could be greatly reduced when the new mooring system was used. Besides, a catenary shape was formed at the lower end of the line, which lowered the requirement of the anti-uplift capacity of the anchors. It is also demonstrated by Yuan et al. (2011) that this combined mooring system was applicable for a wide range of water depth. But, as pointed by the author, the maximum tension of the new mooring system turned out to be a little larger when the water depth exceeds 1000 m.

In this paper, a new hybrid mooring system with the clump weights and buoys will be proposed. It is based on the combined mooring system proposed by Ji et al. (2011). In the present work, some improvements are made by attaching some buoys to the previous mooring lines. In this way, the top tension on the lines could be reduced. Meanwhile, this new hybrid system is expected to keep the merits of the previous one since the clump weights are retained.

2. Description of the new mooring system

The design of the present hybrid mooring lines is based on the traditional taut mooring lines. It can be seen from Fig. 1 that the mooring lines are connected to the floating structures and go in a fairly straight line to the bottom. This is only possible with light lines, therefore modern polyester lines are needed to achieve this. These lines have a large axial resistance and good fatigue properties. When the platform drifts horizontally with wind or current, the lines stretch and this sets up an opposing force. The lines usually come in at a 30–45° angle on the seabed where they meet the anchor, which is loaded vertically. Therefore, the suction piles must be used for deep water taut mooring lines to resist the vertical forces. Suction piles can be used in sand, clay and mud soils, but not gravel, as water can flow through the ground during installation, making suction difficult. And also suction piles are usually not allowed to be applied in reefs for the environmental protection. Furthermore, the installation and maintenance of the suction piles is very expensive.

In order to reduce the vertical component of the mooring force at the lower end of the mooring line, a series of clump weights are attached at the lower end of each line, which is shown in Fig. 2. And a couple of these mooring lines with clump weights can constitute a hybrid system, which can be called hybrid mooring system with weights (HMSW). It can be seen from Fig. 2 that the weights are attached to the lines at uniform intervals and the sizes of these weights decrease gradually from the sea bottom upwards. Therefore, the lower end of each line is expected to behavior as a catenary if the weights are arranged properly. When the lines are subjected to the maximum tension, it should be designed to fulfill the following condition: the clump weight (m_1 in Fig. 6) next to the anchor point should never be lifted off from the sea floor. Thus, it can be guaranteed that there is no vertical force at the lower end of the mooring line. When the tension decreases, the weights will be supported by the sea floor, thereby lowering the tension at the fairlead. However, in the numerical simulation (Ji et al., 2011), the tensions could be increased by the gravity of the weights. In order to lower the tension on the line, a buoy is attached to each mooring line, shown in Fig. 3. A couple of mooring lines with weights and buoys constitute a new hybrid system, which can be called the hybrid mooring system with weights and buoys

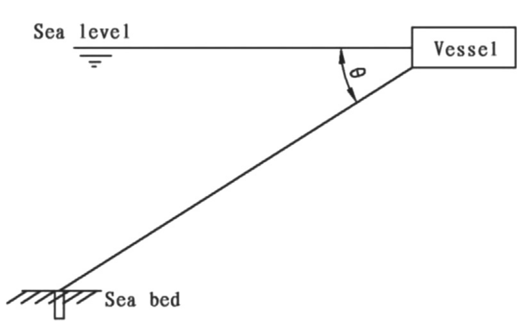

Fig. 1. Taut mooring line (TML).

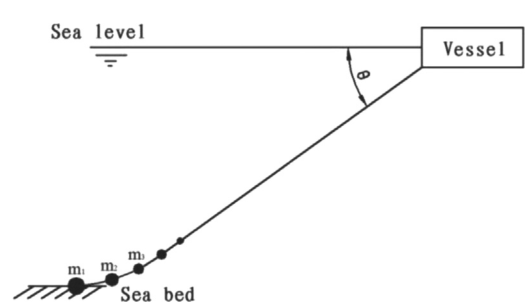

Fig. 2. Hybrid mooring line with clump weights (HMLW).