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Applicability analysis of truncated mooring system based on static and damping equivalence

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ABSTRACT

Physical model tests of floating facilities in deep and ultra-deep water with full-depth mooring system present obstacles because no wave basin is sufficiently large to perform model testing in reasonable scale. The truncated mooring system needs to be designed to reproduce the statics and mooring-induced damping exerted by the full-depth mooring system. Numerical simulation is developed in this paper to analyse the applicability of an innovative approach which designs truncated mooring system based on static and damping equivalence. Considering the catenary, semi-taut and taut mooring systems used for a semi-submersible platform of 1500 m water depths, equivalent truncated mooring systems are designed by using the innovative approach, respectively. The motion responses of the platform with full-depth and truncated mooring systems are calculated. The applicability of this innovative approach for deepwater model test is discussed.

1. Introduction

Station keeping system is important for any floating offshore structure to maintain its position within allowable offset limits, so that the floater can perform its functions in safe way. The station keeping system is selected based on the service requirements and characteristics of the floaters, including the water depth. As an important station keeping system, mooring system can be categorized as either catenary, semi-taut or taut.

Nowadays, the gas and oil industry is concentrating their efforts in developing fields in deeper waters, cumulatively. Within reasonable model scale, physical model testing of floating oil and gas drilling, production and storage facilities with full-depth mooring system present obstacles because no basin is sufficiently large to perform model testing of floating offshore structure with complete mooring system in 1500–3000 m water depths. The mooring system need to be truncated and reproduced.

In order to deal with the obstacles above, an available method, hybrid approach including combination of model test with truncated set-up and numerical simulation (Stansberg et al., 2002) is proposed. Experimental results from passive truncated mooring system are used for numerical reconstruction and verification in the numerical calculation software. Then the dynamic characteristics of full-depth mooring system could be obtained through the numerical extrapolation (Moxnes and Larsen, 1998). In the hybrid method, the truncated mooring system is designed to reproduce the equivalent static characteristics as the full-depth mooring system. In addition, the compensation of mooring-induced damping and the acquisition of final results are implemented by numerical extrapolation.

Equivalent design of truncated mooring system is the key aspect for model testing technique. Considering the similarity of static characteristics, several computer codes have been developed. MOOROPT-TRUNC (Fylling, 2005) is a special version of MOOROPT combined with MIMOSA and the nonlinear optimization program NLPQL to design truncated mooring and riser system. Zhang et al. (2009), Su et al. (2008), Udoh (2014) and Felix-Gonzalez (Felix-Gonzalez and Mercier, 2016) developed equivalent truncated mooring system design codes using various kinds of approaches to calculate the statics of mooring system and employing different optimization algorithms, respectively.

However, the differences of dynamic characteristics between truncated and full-depth mooring system are reflected in the contribution of mooring-induced damping which has significant influence on floating structure responses. The dynamic of truncated mooring lines has been studied by Chen et al. (2000) and Ferreira et al. (2016).

Once the truncated mooring system can be designed to reproduce both the static and damping characteristics as similar as the full-depth

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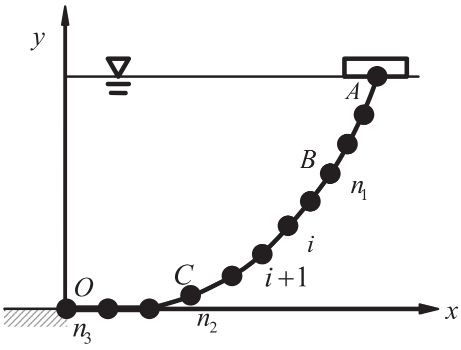

Fig. 1. Elements of mooring line.

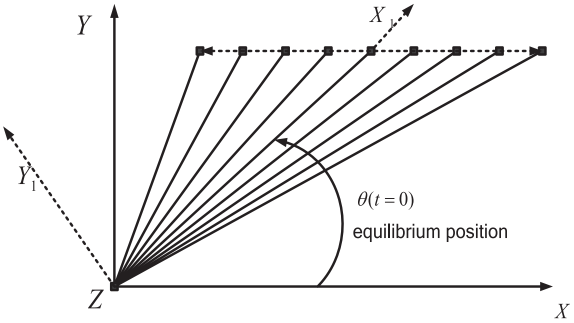

Fig. 2. Top view of the mooring line positions during one surge oscillation.

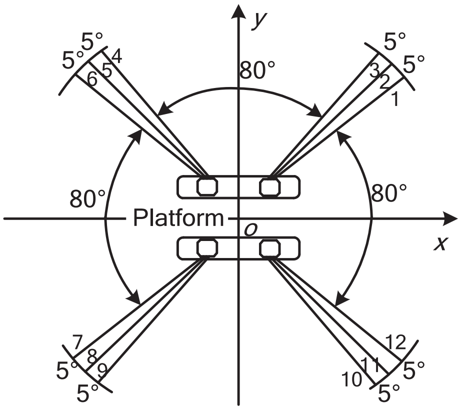

Fig. 3. Layout of the mooring lines.

mooring system, there will be an opportunity that the truncated mooring system could replace the full-depth mooring system equivalently. In another word, when performing model testing by use of this kind of truncated mooring system, the final results could be obtained directly from the test results. With this purpose, an innovative approach to design truncated mooring system has been developed by the author of this paper (Fan et al., 2012, 2014). However, the applicability of this method need to be studied.

In this paper, considering a semi-submersible platform operating in water depth of 1500 m as case study, all the three types (catenary, semi-taut and taut) of mooring systems are chosen as the prototypical full-depth mooring system. By employing the innovative approach mentioned above, truncated mooring systems are designed based on static and damping equivalence, respectively. Coupled analysis on global responses of the semi-submersible platform with each type of full-depth or truncated mooring system is carried out in time domain. The applicability of replacing full-depth mooring system by the truncated mooring system designed based on static and damping equivalence is discussed.

2. Equivalent design of truncated mooring system

2.1. Equivalent design method

Considering the gravity, tension and mooring line extension, the piecewise extrapolating method is employed to the static analysis of the multi-component mooring line. In addition, the quasi-static approach and dissipated energy model are used to figure out the mooring-induced damping of mooring system. Employing genetic algorithm (GA), an optimized design program is developed to design equivalent truncated mooring system based on the similarity of both static and damping characteristics (Fan et al., 2014).

2.1.1. Statics of mooring system

The piecewise extrapolating method is employed to calculate the static of single mooring line (Hao and Teng, 2003). The top chain AB, the middle wire BC, and the bottom chain OC are divided into n_1, n_2, and n_3 elements, respectively, as shown in Fig. 1.

In order to improve the computational efficiency, golden section search method is adopted in this paper to find out the top angle (Fan et al., 2012). It can achieve optimal results by shortening the optimization interval. During each step, the length of new interval is 0.618 times of the former. Thus, this approach has high convergence rate and accuracy.

2.1.2. Mooring-induced damping

Huse and Matsumoto (1988, 1989) and Huse (1991) have studied mooring-induced damping by means of the dissipated energy model.

The dissipated energy E during one Low Frequency (LF) oscillation of period τ is related to the linear coefficient B by the formula

$$E = \int_0^\tau B\left(\frac{dX}{dt}\right)^2 dt \tag{1}$$

Where X refers to the LF component of the surge motions.

Consequently, provided the energy dissipated by the mooring line during one LF surge oscillation can be calculated, the linear damping coefficient can be obtained by

$$B = \frac{E\tau}{2\pi^2 X_0^2} \tag{2}$$

where X_0 is the amplitude of the surge harmonic oscillation.

The improved quasi-static method (Fan et al., 2017) by the author of this paper is employed here to calculate the mooring-induced damping.

Consider a discretization of the period τ with a time step $\Delta t = \tau/2N$. A total of $N+1$ catenary line profiles are computed; the first and the last, respectively, for the near and far positions as shown in Fig. 2.

At each time step, the profile of mooring line could be computed. Consequently, the position of each mooring line element could be considered as a displacement function of time. Then, the velocity and acceleration function can be obtained. Using the Morison Equation, the drag force of each mooring line element can be calculated. Finally, the dissipated energy E, and the damping can be obtained.

2.1.3. Optimized design criteria

The equivalent truncated mooring system should preferably own equivalent static and damping characteristics as the full-depth system. In practice, the design of equivalent truncated mooring system need follow the criteria as below (Stansberg et al., 2002): (1) Model the correct total, horizontal restoring force characteristic. (2) Model representative single line tension characteristics. (3) Model the correct quasi-static coupling between vessel responses. (4) Model a representative level of mooring system damping.