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RESEARCH PAPER

Hydrodynamic response for flexible connectors of mobile offshore base at rough sea states

WU Linjian[1, 2], WANG Yuanzhan[1, 2, *], XIAO Zhong[1, 2], LI Yi[3]

1. State Key Laboratory of Hydraulic Engineering Simulation and Safety, Tianjin University, Tianjin 300072, China;
2. Collaborative Innovation Center for Advanced Ship and Deep-Sea Exploration, Tianjin 300072, China;
3. School of River and Ocean Engineering Chongqing Jiaotong University, Chongqing 400074, China

Abstract: Mobile offshore base (MOB) was treated as a research object, and a simplified algorithm was developed for determining the dynamic constraint forces on flexible connectors of MOB at rough sea states. The algorithm was adopted to calculate and analyze the fluctuation laws between dynamic constraint forces and different parameters. The wave loads on MOB structures were evaluated based on the revised Morison equation instead of potential flow theory, and the conventional computational methods were simplified. The numerical results of the simplified algorithm were compared to those of the algorithm based on potential flow theory for validating the correctness and reasonability of the simplified algorithm. The simplified algorithm was used to estimate the dynamic constraint forces on flexible connectors of MOB under different sea states, wave incident directions, and connector stiffness values. The results show as the wave angle increases, the dynamic constraint force decreases in the *x* direction, while increases first and then decreases in the *y* and *z* directions; the dynamic constraint force increases as the sea state increases, and shows a trend of linear increasing with the connector stiffness increasing; the dynamic forces on different connectors are well even in the same conditions.

Key words: mobile offshore base (MOB); semi-submersible platform; flexible connector; dynamic constraint force; rough sea state

Introduction

With advantages like excellent hydrodynamic performance, strong storm resistance, large deck area and loading capacity, wide water adaptability depth range, etc, the semi-submersible platform has become important equipment for offshore oil and gas field development and vital infrastructure for offshore oil engineering[1–2]. Given many merits of semi-submersible platform, it was proposed by some researchers to join several semi-submersible platforms with self-propelled devices working independently together into a semi-submersible type very large floating structure with multiple functions like oil drilling, mining, refining and storage, and use it as an integrated military base for cargo aircrafts and military helicopters landing, refueling, navigation and maintenance. The Defense Advanced Research Projects Agency (DARPA) firstly initiated the conceptual design for this type of semi-submersible structure, and named it the mobile offshore base (MOB)[3]. The final conceptual design scheme for MOB was connecting several semi-submersible modules with individual functions by specially designed connectors to form a built-up floating structure[4]. Obviously, the connectors between two adjacent semi-submersible modules are the weak points of the entire MOB structure. Very large hydrodynamic constraint force would be occurred on the flexible connectors when the MOB is stimulated by external marine environment loads, and excessive hydrodynamic constraint force could threaten the safety of the entire MOB structure. Thus, the hydrodynamic performance of connectors should be evaluated in the design process of MOB structure.

Currently, research on hydrodynamic response of "modules & connectors" of MOB is mainly based on the rigid modules and flexible connectors (RMFC) model[5]. This model assumes that the modules of MOB do not have flexible deformation, only have rigid displacement (translation and rotation) when these modules are stimulated by external loads. Meanwhile, the connectors would have flexible deformations and generate constraint force due to relative motion of the modules connected by them. On the basis of RMFC model, the mainstream research method for dynamic constraint force on flexible connectors of MOB is based on linear potential flow

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*** Corresponding author.** E-mail: yzwang@tju.edu.cn
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theory (2D or 3D), to analyze the frequency-domain or time-domain hydrodynamic performance of MOB and its connectors[6–10]. The method of potential flow theory, with the advantages of mature theory and procedure, high computational precision and wide application range, has been widely used, but involving sophisticated iterative solution, it needs large computer memory and takes long computational time. In the preliminary design stage of MOB, a large number of computational results under different load cases need to be quickly and high-efficiently obtained, therefore, in this study, a simplified algorithm for evaluating the dynamic constraint force on flexible connectors of MOB based on RMFC model and Morison theory has been proposed, to calculate and analyze the variation pattern of dynamic constraint force on flexible connectors with wave angle, and stiffness of connectors at rough sea states.

1. Theoretical derivation and calculation flow

1.1. Theoretical derivation

Fig. 1 shows the conceptual design sketch of MOB structure and its connectors[4]. A single semi-submersible module includes a top platform, several columns and pontoons. Flexible connectors (C_1, C_2, C_3, and C_4 in Fig. 1) are commonly used to restrain the linear displacement of adjacent modules but allow angular rotation through the installation of a linkage (springs with stiffness are set into a linkage) in three translational directions, so as to effectively reduce the constraint force on the connectors. Specific designs of the flexible connectors are introduced in reference [4].

To effectively estimate the dynamic constraint force on flexible connectors of MOB under external loads (this paper only considers the random and irregular wave loads), the flexible connectors of MOB are treated as a simplified spring model along three directions (Fig. 2) according to the structural characteristics of connectors shown in Fig. 1. The dynamic constraint force on the connectors can be calculated by Hook's Law, expressed as follows:

$$\begin{cases} F_{cx}(t) = k_x \Delta x(t) \\ F_{cy}(t) = k_y \Delta y(t) \\ F_{cz}(t) = k_z \Delta z(t) \end{cases} \tag{1}$$

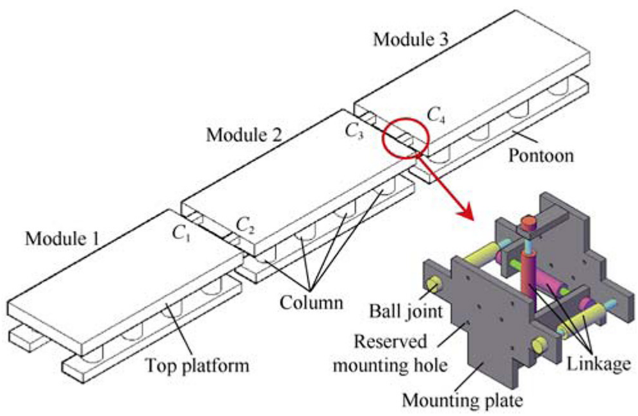

Fig. 1. Conceptual design sketch of MOB and connector.

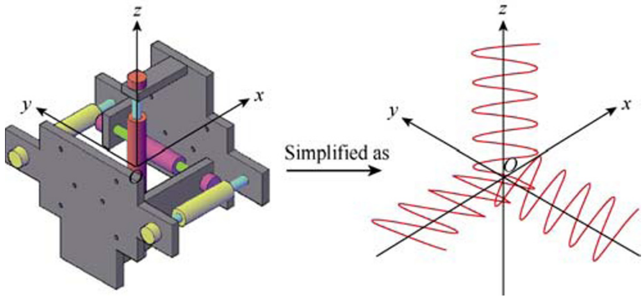

Fig. 2. Simplified model of flexible connectors.

In Eq. (1), the stiffness of the connectors is known. Therefore, the key problem when evaluating the dynamic constraint force is calculating the relative deformation of the connectors.

Relative deformation occurs on flexible connectors of MOB because two adjacent modules have relative motion (translation and rotation) under external loads, thus, the precondition for obtaining the relative deformation of flexible connectors is to get the hydrodynamic response displacement of connectors between two adjacent modules. Therefore, a multi-modules MOB structure is simplified as a multi-degree-of-freedom system model in this study. According to D'Alembert's principle, the dynamic balance equation for the entire MOB structural system is as follows:

$$\boldsymbol{m}\ddot{\boldsymbol{\lambda}} + \boldsymbol{c}\dot{\boldsymbol{\lambda}} + \boldsymbol{k}\boldsymbol{\lambda} = \boldsymbol{SF} \tag{2}$$

Eq. (2) represents the hydrodynamic balance relationship of the entire MOB structure, and the isolation method is adopted to obtain the motion equation of a single MOB module in order to calculate the motion behaviors of each single module. The structural global stiffness matrix $\boldsymbol{k}_\mathrm{s}$=0 due to disconnect the entire structure from the positions of the connectors, and the constraint force of flexible connectors changes from internal force to external force. Meanwhile, the random and irregular wave field always changes with time, therefore:

$$\left[\boldsymbol{m}_\mathrm{s} + \boldsymbol{m}_\mathrm{f}(t)\right]\ddot{\boldsymbol{\lambda}}(t) + \boldsymbol{c}(t)\dot{\boldsymbol{\lambda}}(t) + \boldsymbol{k}_\mathrm{f}(t)\boldsymbol{\lambda}(t) = \boldsymbol{SF}(t) + \boldsymbol{F}_\mathrm{c}(t) \tag{3}$$

In Eq. (3), the detailed derivation process and specific expression of the hydrodynamic coefficient matrixes of each single module ($\boldsymbol{m}_\mathrm{s}$, $\boldsymbol{m}_\mathrm{f}$, $\boldsymbol{c}$, $\boldsymbol{k}_\mathrm{f}$), random and irregular wave force matrix $\boldsymbol{SF}$ and dynamic constraint force matrix of connectors $\boldsymbol{F}_\mathrm{c}$ are shown in reference [11].

According to Code of Hydrology for Sea Harbour (JTS 145-2-2013)[12], various components (columns, pontoons etc.) of MOB structure can be regarded as small scale components by comparing them with wavelengths at rough sea states. Therefore, the random and irregular wave loads on MOB structures are evaluated based on the revised floating body Morison equation instead of relative complicated 3D potential flow theory, in order to improve the computation efficiency. Since the interaction between MOB modules under wave excitations can not be neglected, the shielding effect between front and rear columns of different modules is considered, which is similar to the method for evaluating the wave loads on pile group effect. Thus, the wave force on a single column