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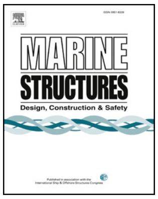

Optimized stiffness combination of a flexible-base hinged connector for very large floating structures

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ABSTRACT

Prototype design of a flexible connector indeed includes the aspects of stiffness arrangement, structural layout, strength analysis, fatigue analysis, and manufacturing constraints etc. This paper focuses on the stiffness design for the flexible-base hinged connector (FBHC). A three-modular platform is used for the case studies. How to layout the connector stiffness in different directions is very much interested in order to gain the most benefit in the reduction of the connector loads as well as module responses. An orthogonal experiment method is thus employed to examine the relationship between the stiffness combination and module responses. It is found that there is a dilemma to gain the both benefits on the minimum for connector load and relative displacement. By suitably relaxing the tolerance on displacement requirements, the optimal stiffness combination for the FBHC is suggested. In the comparison study with a rigid hinged connector (RHC), the FBHC can significantly reduce the connector loads with a confined flexibility.

1. Introduction

More than 70% area of the earth surface is occupied by the ocean, thus humankind has never stopped the pace of expansion to the ocean. In the past three decades, very large floating structures (VLFS) as an exciting and environmentally friendly way for land creation from the sea were widely used in floating airports, floating fuel storage facilities, floating piers and even floating cities [1]. The concept of very large floating structure was proposed in 1920s after Edward R. Armstrong creatively presented a seadrome as stepping stones for aircrafts flying across the oceans [2]. Later, the Japanese scholars started to study the VLFS and they did a lot of researches on pontoon type floating structure which is suitable for use in the sea area sheltered by breakwaters [3]. A major milestone was achieved by the formation of the Technological Research Association of Mega-float (TRAM) in 1995 [4]. The Mega-float is a VLFS test model for floating airport terminals and airstrips. They have constructed a Mega-float in Tokyo bay which was awarded the world's largest man-made floating island in the Guinness book of records in 1999. This Mega-Float is also a precursor to a 3.6 km floating runway for Haneda (Tokyo) airport [5]. In addition, the US navy put forward a mobile offshore base (MOB), which is a semi-submersible type VLFS [6]. Differing from the pontoon type VLFS, MOB can either serve as a floating runway or logistic base in seas away from the coastline [7]. In recent years, the demands for developable land around the coastal cities have increased significantly, for residential purposes as well as industrial and logistic uses [8]. Therefore, the floating farms are concerned by the Canada and Norway's researchers. They focused on the following problems: coastal zone conflicts, economic issues and the Fatigue Damage of the floating cage structure [9,10]. As traditional coastal countries, the Dutch and Belgian even committed to living on the water [1,11].

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Besides those countries, Chinese researchers also have done many works on the hydro-elastic response of the VLFS [12].

Since the VLFS works in the highly complex and rough sea conditions, the safety design based on the hydrodynamic response analysis is important [13]. At first, the VLFS was treated as a single continuum structure. From the comprehensive reviews [14,15], we know that the hydro-elastic analysis [16] was widely used to assess dynamic responses and stresses of the VLFS with big length to height ratio. Then the classical theory of elastic thin plate was employed to simplify floating structures, and the linear wave theory was used to analyze the response of the structures [17]. For those floating structures with non-negligible thickness, they were usually modeled as thick plates by using the Mindlin plate theory [18]. Considering the massive single continuum structure suffers large bending stress as well as results many problems in manufacturing and transportation of floating structures [19], multi-modular floating structures were concerned [20]. For the modularized VLFS, the connection design is a key technology to study. Japanese researchers used the strip method to analyze the rigid joints, they found that rigid joints could induce huge shear forces [21]. In order to reduce the forces, many scholars also studied the hinged or semi-rigid connectors. Some of them found that even if hinged connectors release the pitch motion, the shear forces of the connector are still large in some frequencies [22,23]. The other scholars investigated a semi-rigid connector that could vary rotation stiffness by using a mechanical joint. They found that the stiffness of the connector is a critical parameter in determining the response of the modules [24]. Then, the flexible connectors were discussed. Gao et al. [25] studied the hydro-elastic response of the pontoon-type modules with a flexible line connection. They found that the location of the connector greatly influences the hydro-elastic response and stress resultants of the VLFS. Compared with the pontoon-type modules, semi-submersible type is more suitable to minimize the effect of waves in the open seas where the wave heights are relatively large [3]. Riggs and his co-workers [26] studied the mobile offshore base (MOB) which is consisted of five semi-submersible type modules and flexible connectors that have stiffness in three directions. A comparative study of RMFC (Rigid Module and Flexible Connectors) and FEA (Finite Element Analysis) models had been done in their work, the research results showed that the RMFC model can predict the response as good as the FEA model and it is easier to compute dynamic responses by the RMFC model [27]. Paulling's team [28] studied the semi-submersible type modules with the mechanical joints which have the characteristics of elasticity and damping, and they found that the incident wave angle has great influence on the hydro-elastic responses. Considering the incident wave period and connector stiffness, Zhang et al. [29] analyzed the configuration of the flexible connection based on the network modeling method [30] and found that the compound type connection may deliver better dynamic stability. Wu et al. [31] studied a flexible connector which can restrain the linear displacement of adjacent modules but allow angular rotation through the installation of a linkage in three translational directions, so as to effectively reduce the constraint force on the connectors. Although there is significant effect of reducing the connector load, the flexible connector may still cause large response of modules in some wave frequencies. Haney [32] summarized some compliant connectors that combine with the rigid hinge and flexible part. However, the connectors are more likely to have maintenance and repair problems, and it is too complicated for researchers to do numerical analysis. In addition to the passive connectors mentioned above, Xia et al. [33] invented a kind of air-spring connector in which the stiffness of the connector could be adjusted along with the wave condition and retain the floating structures in a relatively stable state. Nevertheless, because the change of the wave condition is unpredictable, active controlled connector may also encounter troubles in the timeliness and complexity of the sensor signal transmission.

In this paper, we focus on the stiffness design for a flexible-base hinged connector (FBHC). A three-connected-modular platform with an idealized FBHC is modeled for dynamic analysis. The short-term extreme response of the platform is investigated, showing that the stiffness of the connector could significantly affect the connector loads and module responses. For the three-dimensional model of the connector, we are interested that how to layout the connector stiffness in different directions can mostly benefit the reduction of the connector loads as well as module responses. With this motivation, we use the orthogonal experiment method [34,35] to analyze the relationship between the stiffness combination and dynamic responses. An optimization is conducted for determining the stiffness combination of the FBHC with some tolerance on responses. The performance of the FBHC is evaluated in the comparison study on a rigid hinged connector (RHC) in terms of responses of modules and loads of connectors.

This paper is organized as follows. Firstly, the modeling process is briefly introduced. Secondly, the orthogonal experiment method is used to analyze the relationship between the dynamic response and the stiffness combination of the FBHC, and an optimal stiffness combination is suggested. Then, the comparison study is carried out among the RHC and the FBHC. Finally, a conclusion is drawn for the FBHC.

2. Modeling of multi-modular floating platforms

The connector of VLFS is the key component to determine the safety and dynamics of the structures. In order to reduce the connection loads, we do the stiffness design for an idealized FBHC. In the case studies, the FBHC is applied to a three-connected-modular platform where the mathematical model is built by the network modeling method [30] that treats individual floating modules as oscillators and connectors as couplings. Differing from the classical method that treats the connector as a linear spring ignoring the geometry effect of the connector [26], the network modeling method considers the geometrical deformation of the flexible part of connectors [29].

Fig. 1 shows a serially connected floating platform which consists of a number of connected semi-submersible modules. In the global coordinate (x, y, z), the x-y plan is set on the undisturbed free water surface and the z-axis points upwards. The modules are labeled from *1* to *N*. A local coordinate (η, ζ, ξ) is set at the gravity center of each floating module, where $\eta-\zeta$ plan is parallel with the free water surface and ξ-axis points upwards.