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Experimental validation of network modeling method on a three-modular floating platform model

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ABSTRACT

This paper reports an experimental verification of a network modeling method that is recently proposed for forecasting responses of multi-modular floating platforms in regular waves. A three-dimensional network modeling method is presented, which includes the geometric effect of connectors and permits nonlinear dynamic analysis of the floating system. In the validation study, a three-modular floating platform model is fabricated for experimental test in wave basin. Both the linear model and nonlinear model of the network modeling method are examined in the collation of the hydro-elastic method and experiment test. The responses of modules and loads of connectors are employed for the comparison study. The results show that the linear model of the network modeling method is the closest to the test results and outperforms over the nonlinear model and the hydro-elastic method. The possible reasons of the discrepancy in the results of the different methods are discussed. This work validates that the network modeling method is reliable.

1. Introduction

Very Large Floating Structure (VLFS) is a state-of-art mega equipment for exploring deepwater resources in oceans. VLFS has a scale of multiple kilometers making it different from ship vessels and marine structures. Early in 1920s, Armstrong (1924) proposed to build a seadrome to help aircrafts across the Atlantic Ocean. This idea was too ambitious to carry out until in 1970s the aspiration of building large floating structures in the ocean was revived and a great mount of efforts have been put by researchers worldwide. The Mega-float is a famous pontoon-type VLFS proposed as a floating runway by Japanese (Lamas-Pardo et al., 2015; Suzuki, 2005, 2001), which was successfully built and tested in Yokosuka around 1999. During the same period, the US Navy proposed Mobile Offshore Base (MOB) (McAllister, 1997; Palo, 2005; Rognaas et al., 2001) in order to develop an mobile logistics base in open sea. MOB consists of a number of floating modules with self-propelled capacity. These iconic projects of Mega-float and MOB trigged a great of interests in the field of marine engineering and promotes the research of the development of different types of very large floating structures, such as offshore farms (Chang et al., 2014; Thomassen and Leira, 2012), the Dutch's floating town (Boo, 2005), the Liliypad Floating Ecopolis proposed by the Belgium architect Vincent Callebaut (Wang and Tay, 2011), as well as floating airport (Wu et al., 1993).

Considering the long service life (typically 100 years) and multiple functional requirements of VLFS, the safety design based on the hydrodynamic response analysis is critical (Rognaas et al., 2001). Since VLFS is a typical large flat structure resting on the sea surface, the hydro-elastic method (Wang and Tay, 2010) has been usually used to assess its dynamic responses and structure stresses. The early study dealt with the floating structure of VLFS as a single continuum structure. Thus the classical theory of elastic thin plate was employed to simplify the floating platform, and the linear wave theory was used to analyze floating structures' response (Wu et al., 1995). For those floating structures with non-negligible thickness, the floating platform was usually modeled as thick plate by using the Mindlin plate theory (Watanabe et al., 2006). Owing to the large scale of VLFS, a single continuum structure would result in a large hogging moment in the floating body. Modularizing the floating body could solve this problem, and overcome some inconveniences in practical engineering applications especially in manufacturing and transportation of floating structures. Modularized floating platforms are preferred, where floating modules are coupled by connectors. Connectors are key components for combining the modules together as a whole floating platform so that the characteristic study of connectors is crucial. The strip method (Maeda et al., 1979) was used to

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study the response of one-dimensional modular floating system in regular wave, showing that rigid joints could induce huge shear forces. In order to reduce the hydro-elastic responses, hinged or semi-rigid connectors were also studied, proving that the stiffness of connectors is a critical parameter in determining the hydro-elastic response of the structure (Fu et al., 2007). Researchers also studied flexible connector which consists of two independent linear and torsion springs, and remarked that the incident wave period and connector stiffness are the two key parameters affecting the hydro-elastic response of the floating body (Xia et al., 2000). Owing to the structural complexity and huge scale of VLFS, the finite element analysis (FEA) is hardly to conduct. In the stimulus of this difficulty, the RMFC (Rigid Module Flexible Connector) model, which treats floating modules as rigid bodies connected by flexible connectors, is developed (Wang et al., 1991). From the work of Riggs et al. (2000), the response results predicted by the RMFC model correspond well to the FEA model's. The RMFC model is a simple method to assess the hydro-elastic response for the initial design of VLFS. By using the RMFC model, the flexible connectors are generally treated as non-dimensional springs that are assumed to only have independent linear stiffness in directions of intended degrees of freedom (Riggs et al., 1999). Paulling and Tyagi (1993) developed a procedure to predict hydro-elastic response of a floating structure for a wide variety of body geometries and joining mechanisms of connectors based on the RMFC model.

In recent years, a new modeling method (Xu et al., 2014a, 2014b; Zhang et al., 2015c), so called network modeling method, has been developed for the prediction of dynamic responses of multi-modular floating structures. This method treats individual floating modules as oscillators and connectors as couplings. The whole floating platform is viewed as a network system which is configured by the oscillators and couplings through a topological matrix. The superiority of the network modeling method is mainly summarized in following points. 1) It is a modularized modeling method that can quickly and flexibly build an arbitrary form of VLFS model by adding or dropping nodes and links (by assigning a topological matrix). 2) It deals with the connector model in strict accordance with the physical design of the connector rather than the linearization of connector stiffness widely adopted by the conventional methods. For instance, the inclination angle of elastic connector due to the deformation of the connectors and relative displacements of modules is taken into account to reflect the non-negligible geometric effect and material properties for flexible connectors. 3) The network modeling method is capable to analyze the synergetic effect among the elements of a network, complex dynamics and “amplitude death”. Amplitude death is a collective weak oscillation state, induced by nonlinearities, of which the mechanism can be used for the stability design of floating platforms. Xu and Zhang developed a 3D network modeling method (Zhang et al., 2015c) and applied the method to predict the nonlinear dynamics of a multi-modular floating airport in consideration of the material and geometric nonlinearities of the connectors (Xu et al., 2014b; Zhang et al., 2015c). Abundant nonlinear dynamic phenomena were revealed, such as amplitude death, jumping incidence and synergistic effect of the network (Xu et al., 2014a, 2014b; Zhang et al., 2015a, 2015b). Especially the discovery of the mechanism of amplitude death phenomena (Xu et al., 2014b) of non-autonomous systems could be used for the stability design of floating structures, where the distribution charts of amplitude death state could assist designers to determine the key design parameters (stiffness and configuration) of connectors (Zhang et al., 2015d). The results of these studies indicated that the compound type connection may deliver better dynamic stability (Zhang et al., 2017). The relevant studies also extended to the stability control of the floating platform by controlling the connector stiffness based on the amplitude death mechanism (Xia et al., 2016). All these works on the network modeling method show a promising potential in handling nonlinear dynamic analysis of VLFS, but there has been a lack of experimental verification.

In this paper, the network modeling method is validated by an experimental test. A wave basin experiment is therefore setup where a scaled three-modular floating platform model is deployed in shallow water for the test. In the validation study, both the linear model and nonlinear model of the network modeling method are examined in the collation of the hydro-elastic method and experiment test. The responses of modules and loads of connectors are employed for the comparison studies, as usually done in laboratory tests (Dong et al., 2008; Loukogeorgaki et al., 2014; Ma et al., 2013). This is the first piece of work to assess the correctness of the network modeling method with experimental test although numerical verifications have been already conducted before. It is a crucial step to confirm the feasibility of the newly developed modeling method in real engineering. Through the comparison study, the network modeling method could be well accepted as a new tool for response analysis of VLFS, especially when nonlinearity is involved.

This paper is organized as follows. Firstly the network modeling method is briefly introduced, where the linear model can be derived from the original nonlinear dynamical model through linearization. The wave basin experiment is elaborated including the test basin, deployment of three-modular floating platform model, island, basin-bottom terrain and sensors arrangement. Then the comparison study is carried out among the linear and nonlinear models of the network modeling method, the hydro-elastic method and experimental data. Finally a conclusion is drawn for the network modeling method.

2. Network modeling method for VLFS

In this section, the network modeling method (Zhang et al., 2015c) will be elaborated in conjunction with a multi-modular floating platform. The multi-modular floating platform consists of a number of floating modules connected by flexible connectors. This kind of floating structure can be viewed as a network system with a number of nodes and links. In view of the network theory (Barabási and Albert, 1999; Watts and Strogatz, 1998), floating modules can be treated as nodes (oscillators), and connectors bonding modules together can be treated as links (couplings) of the system. The mooring system and wave excitations can be viewed as environmental constraints on the network system. A network model can be integrated from the models of oscillators, couplings and constraints by using a topology matrix that defines the configuration of connections in the network. The network modeling method is a modularized approach. It delivers the benefits of 1) flexibly reconstructing network models by adding or dropping nodes and links, 2) dealing with the connector model in strict accordance with the physical design of the connector rather than the linearization, and 3) a convenient tool for analyzing synergetic effects among the elements of a network.

Fig. 1 shows a chain-type floating platform formed by a number of connected semi-submersible modules. There is a global coordinate (x, y, z) where the x-y-axis plane is set on the undisturbed free-surface of water and the z-axis point upwards. The modules are numbered from *1* to *N*. A local coordinate (η_i, ζ_i, ξ_i) is set at the rotation center of each floating

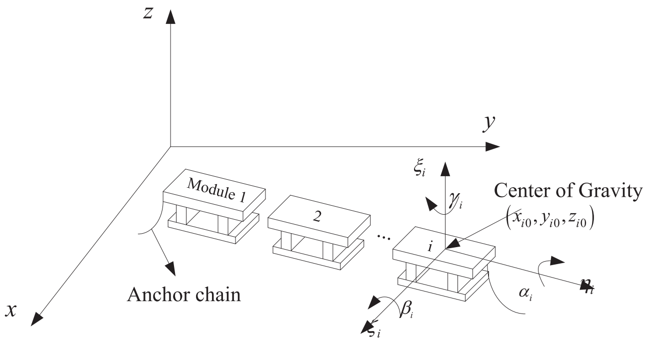

Fig. 1. Sketch of coordinate systems.