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Numerical and experimental analysis on motion performance of new sandglass-type floating body in waves

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A B S T R A C T

In order to solve the performance limitations of traditional ship-type and cylindrical FPSO, this paper presents a new concept of sandglass-type FPSO. For the new sandglass-type floating model, firstly by using classic boundary element method based on wave potential theory, the effects of shape parameters on motion performance of sandglass-type model are studied. Then the wave frequency versus minimum heave motion RAO is selected as the critical design parameter to control heave motion of new floating model, and its convenient engineering estimation expression is theoretically and mathematically deduced. Furthermore, on this basis the design guideline for sandglass shape is analyzed and proposed. Next according to the information of a cylindrical FPSO, a sandglass-type floating model with the same basic function has been designed. Finally, by analyzing the numerical solution and experimental data, the numerical boundary element method and design guideline in this paper can be validated to be effective and accurate. Furthermore, it can be found that the sandglass-type design can obviously improve the hydrodynamic performance of FPSO. Thus this paper can provide an innovative engineering platform and a design proposal for the development of ocean oil and gas exploitation.

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1. Introduction

As ocean oil and gas exploration expands towards the deep sea in harsh environments, FPSO (floating production, storage and offloading unit) has played an important part in the development mode, due to its large capacity of oil storage, multifunction, strong adaptability and convenience for maintenance and repair. In the future, FPSO will have wide and good application prospects [2,4,14].

Traditional ship-type and cylindrical FPSOs exhibit some performance shortcomings [17,19]. Firstly, the traditional ship-type floating body is extremely sensitive to the wave direction. Secondly, with the complicated environment and single point mooring system, FPSO would be usually in the oblique (beam) sea, which may result in poor heave and roll performance. Next, because the longitudinal scale is extremely large, the phenomenon of wave impact and green water is common and would damage the deck structure. Furthermore, the vane effect will cause frequent yaw motion, which results in the serious wear and tear of turret structure. As a result, regular maintenance and repair would significantly increase production costs. With a greater longitudinal scale, the relatively large bending moment of hogging and sagging will bring about the severe deformation and fatigue failure. Finally, the natural period of heave motion for the cylindrical floating body is still in the centralized area of wave energy and thus the heave motion response is very large.

Therefore recently some new concepts of ocean engineering structures are proposed. On one hand, based on the cylindrical FPSO, the auxiliary structures (such as skirts, heave plates and moon-pool, etc.) are used to improve heave motion performance. Therein the MPSO (mono-column production, storage and offloading system) is one of typical concepts [16,5–7]. On the other hand, a new concept of floating body with an innovative sandglass-type shape was presented by Huang et al. [9,10,11] Yao et al. [20] and Wang et al. [18], to solve the performance limitations of traditional ship-type and cylindrical FPSOs.

In this paper, firstly the new concept of sandglass-type FPSO is introduced. Next, by using classic boundary element method (BEM) based on potential flow theory, the effects of shape parameters on motion performance of sandglass-type model are studied. Furthermore, in order to provide guideline and scheme for the shape design of new floating body, the engineering estimation expressions of wave frequency versus minimum heave motion RAO for the new floating model are theoretically and mathematically deduced. On this basis, the basic functions of cylindrical FPSO "Sevan Piranema" (i.e., the design values of load capacity, displacement, storage space, topside area, etc.) are incorporated into the design for new sandglass-type FPSO vessels. Finally, the new sandglass-type floating body is compared with cylindrical model by numerical method and experimental analysis to verify the accuracy of the numerical method in this paper and show the advantages of hydrodynamic performance for the new sandglass-type FPSO.

2. Description of new sandglass-type FPSO

The new sandglass-type FPSO has an innovative floating body with sandglass-type shape, which has not only larger spaces of oil storage than traditional ocean platforms but also better hydrodynamic performance and adaptability to extreme sea environment than traditional ship-type and cylindrical FPSO [18]. On this basis, various modules (such as production, processing, storage, offloading, heating, living functions, etc.) are equipped on the upper deck, respectively, as shown in Fig. 1. Thus, the sandglass-type FPSO can be widely applied in various sea conditions and be better for multifunctional integration with more economic benefits.

For the new concept of sandglass-type FPSO, in order to maintain constant floating state, good stability and hydrodynamic performance for various working conditions (full load, ballast, etc.), an innovative method is presented by Huang et al. [12] to control performance of sandglass-type FPSO during offloading and loading operations, which includes a new loading and offloading technique and subdivision scheme with equal proportional volume. Then, a central cabin is settled in the middle of the main floating body, in which all kinds of pipelines can be configured for transport of oil and gas.