Ocean Engineering 92 (2014) 245–254

Contents lists available at ScienceDirect

Ocean Engineering

journal homepage: www.elsevier.com/locate/oceaneng

Verification of a hybrid model test method for a deep water floating system with large truncation factor

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ARTICLE INFO

Article history:
Received 28 August 2013
Accepted 28 September 2014
Available online 7 November 2014

Keywords:
Hybrid model tests
Truncation
Deepwater semisubmersible
Coupled dynamic analysis

ABSTRACT

The hybrid model test method has been regarded as the most reliable method to investigate the dynamics of deepwater floating systems when the wave basin is not large enough to conduct the full water depth model tests at reasonable model scales. In order to get the reliable experimental results, the truncation factor should be less than 5. However, as the offshore oil and gas industry moves towards deeper waters, the model tests of floating structures carried out at the wave basin with reasonable model scales need to be revamped. The objective of the present study is to investigate the feasibility of largely truncated hybrid model test for the deep water floating systems. The hybrid model test techniques and the dynamic behaviors of the truncated mooring lines are also studied. In order to achieve the static and dynamic similarities easily in the largely-truncated model tests, an optimization design method of the truncated mooring system is proposed, and the similarities of platform motion responses as well as the mooring lines dynamics are investigated in the largely-truncated model tests. To verify the present method, a deepwater semisubmersible system operated in 1500 m and 1000 m water depth is truncated to 200 m water depth based on the static equivalent principle (the truncation factors are 7.5 and 5 respectively), and the dynamically similar design is implemented to the model tests which are carried out at China Ship Scientific Research Center wave basin. The motion responses of the platform and the mooring line dynamics are obtained. These experimental results are used to compare with the numerical simulation, which is based on the full time domain coupled dynamic analysis method. The comparisons show that the numerical results are in good agreement with the model measurements.

1. Introduction

As the offshore oil and gas industry moves towards deeper waters, the operating environment of the floating system became hostile. Therefore, the system must be designed reliable enough to resist the environmental loads. The prediction of the dynamic responses of the platform and its mooring lines is extremely important.

A model test verification has become an important step in the development and hydrodynamic analysis of floating offshore platform systems (Stansberg et al., 2004). However, with the floating structures pushing their activities to deep and ultra-deep water, the model tests carried out at wave basin at reasonable model scales present new challenges (Stansberg et al., 2002, 2004). Ultra small scale test seems to be a feasible approach to this problem (Moxnes and Larsen (1998); Stansberg et al., 2000a, 2000b). However, it needs much more accuracies to execute model test, and sometimes, the experiment results are unreliable, since a little error in the experiment could result in large discrepancy. In order to conquer the problem, a hybrid verification was proposed, and has been regarded as the most reliable method (ITTC, 2002, 2005).

Researchers all around the world have studied hybrid model tests for many years. Also, some significant results were achieved. Ormberg, et al., (1999) selected a semisubmersible operated in 335 m water depth as the research object, the model tests were carried out both at 335 m full water depth and 116.5 m truncated water depth at MARINTEK. The model test results of truncated water depth were then extrapolated to 335 m full water depth. It was found that the numerical extrapolation results were in good agreement with full water depth model test results which could prove that the hybrid model tests were reliable. The applicability of hybrid model test was further verified by Stansberg et al. (2000a, 2000b). Stansberg et al. (2000a, 2000b) carried out the model test for a semisubmersible operated in 1100 m water depth in 1:150 scale, the 550 m truncated water model test was conducted at the

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http://dx.doi.org/10.1016/j.oceaneng.2014.09.047
0029-8018/

same time, it was found that the truncated model test results were in good accordance with full water depth system. However, some different conclusions were drawn by other researchers. In the 1:60-scale OTRC experiment, a FPSO system for Gulf of Mexico operated in 8700 ft water depth was truncated to2580 ft water depth, the model results shown that the full depth mooring line dynamics were underestimated by truncated mooring lines (Kim et al., 2005). The same discoveries can also be found in Chen et al.(2000) and Waals and Van Dijk (2004). This difference was due to the truncation. It is then concluded that a great attention should be paid to design truncated mooring system, since it affects the hybrid model test results directly. For this reason, several researchers have developed the design method to water depth truncated mooring system. Zhang et al. (2009,2012) presented optimization methods to design the equivalent water depth truncated mooring system. Waals and Van Dijk (2004) discussed an empirical formula method to optimize truncated mooring system considering both static loads and dynamic loads.

However, studies about hybrid model tests with large water depth truncation factor are limited. It is inevitable that the truncation factor is becoming larger with the hydrocarbon exploration activities moving to deeper water area, and it should also be noticed that the horizontal truncation comes along with water depth truncation which promote horizontal restoring force growth rapidly with horizontal offset. However, studies about the hybrid model tests with water truncation factor greater than 5 have not yet been carried out yet. In order to study the feasibility of the hybrid model tests with large truncation factor, the hybrid model tests with truncation factors of 5 and 7.5 are carried out. Meanwhile, the comparisons of the experimental measurements with the numerical simulation are presented.

2. Objectives and experiment description

2.1. The deep water floating system

The floating structure used in this study is a semisubmersible, which was designed to operate in South China Sea. Two different operation water depths of 1500 m and 1000 m are discussed here. The semisubmersible model is shown in Fig. 1.

The main parameters of the semisubmersible are shown in Table 1.

Two different catenary mooring systems are used to corresponding operation water depths. Both of the mooring systems have 12 mooring lines, and the arrangement of mooring lines can be found in Fig. 2. Fig. 3 shows the model of semisubmersible and its mooring system.

The parameters of mooring lines applied in 1000 m water depth are shown in Table 2, and it should be noted that the first segment begins at the fairlead. The mooring lines in 1500 m water depth have the same properties as those in 1000 m except for the length of each segment, the details are shown as Chain R4S, 450 m, Wire, 2000 m and Chain K4, 1500 m.The pretensions of the mooring lines at 1000 m and 1500 m water depth are 2500 KN and 3471 KN respectively.

Fig. 1. The semisubmersible model.

Table 1
Main parameters of semisubmersible.

Description	Unit	Quantities
Length	m	114.07
Breadth	m	78.68
Deck height	m	8.6
Draft	m	16
Displacement	t	48196.6
Center of gravity(Z_g)	m	25.98
Center of gravity(X_g)	m	57
Roll radius of gyration	m	29.79
Pitch radius of gyration	m	31
Yaw radius of gyration	m	36.58

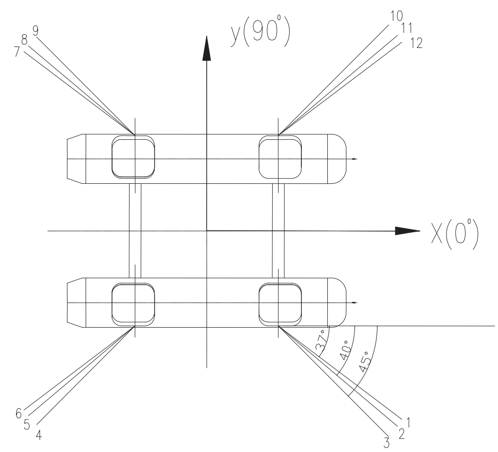

Fig. 2. Arrangement of mooring lines.

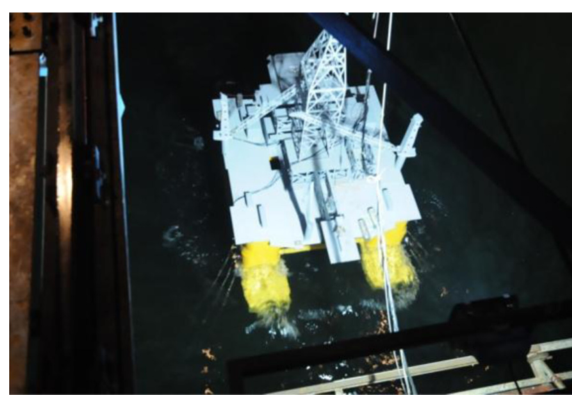

Fig. 3. The semisubmersible and its mooring system model.

Table 2
Parameters of 1000 m water depth mooring lines.

Designation	Diameter (m)	Length (m)	Axial stiffness (MN)	Weight of unit length in water(N/m)
Chain R4S	0.084	450	620.340	1215.2
Wire	0.16	1500	235.242	40
Chain K4	0.09	1000	711.480	1391.6