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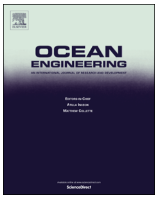

Dynamic design optimization of an equivalent truncated mooring system

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ABSTRACT

An important part in the development and hydrodynamic verification of new floating production systems involves carrying out testing on ocean basin laboratories. However, there is no ocean laboratory able to perform the testing of ultra-deepwater floating structure at reasonable model scale. Several methods have been proposed and developed to solve this problem. The hybrid passive method is organized in steps, where the first step is responsible for setting the truncated design. If this step is not performed satisfactorily, it may hamper the success of the testing. Thus, in order to minimize this issue, we propose in this paper the use of design optimization techniques to find the ideal truncated full-scale design considering the dynamic effects. We apply a calibration method to adjust design variables to optimally fit truncated mooring system to full-depth mooring system, in order to minimize the differences in motion and tension responses from the two systems. Furthermore, we check the truncated optimal design for many wave conditions using dynamic simulations. Due to the large computational cost involved in this check, we use high-performance computing to quicken this process. We will present and discuss two cases. In both cases, the results show that the truncated design found is equivalent to the full-depth design.

1. Introduction

The early 2000s was marked by world records in water depth of floating production facilities, that exceeded 5000 ft (1523.9 m). This number has been growing and currently exceeds 8000 ft (2438.3 m) of water depth. In 2016, there is an expectation to reach the mark of 9500 ft (2895.5 m), at the Stones field in the Gulf of Mexico (Offshore Magazine, 2005). Hence, the operating environment of the platforms and floaters production became hostile and challenging for the oil and gas offshore industry, especially because it requires new materials and innovative systems to resist the environmental loads. Thus, as well put by Ji and Xu (2014), the prediction of the dynamic responses of the floating facilities and its mooring lines is very important. Without this, it is not easy to overcome the still existing challenges to put in operation floating production systems.

Model testing (Buchner, 1999) is an essential part in the development and hydrodynamic verification of new floating production systems. Whenever possible, model testing should preferably be carried out in ocean basin laboratories which can accommodate the full depth of risers and moorings lines (Stansberg et al., 2002). Nonetheless, Stansberg et al. (2002) claim that there is no ocean laboratory to perform the testing of floating structures at depth greater than 1500 m for reasonable limits of model scale. Even today this claim is true, even after entering into operation the LabOceano (http://www.laboceano.coppe.ufrj.br) in 2003, with a 15 m depth and a central pit with additional 10 m depth.

Several methods have been proposed and developed to overcome this challenge in ultra-deepwaters testing. Most methods involves some kind of model test that combined with computer simulations allow us to reduce the water depth, known as hybrid methods. According to Stansberg et al. (2002), the hybrid model testing methods are seen as the most realistic alternative to perform model testing of ultra-deepwater floating structure. Nowadays, these methods continue to be widely used in verification of ultra-deepwater floating structures, like the recent works of Ji and Xu (2014), Fan et al. (2014b) and Molins et al. (2015).

Among the hybrid model testing methods, the hybrid passive

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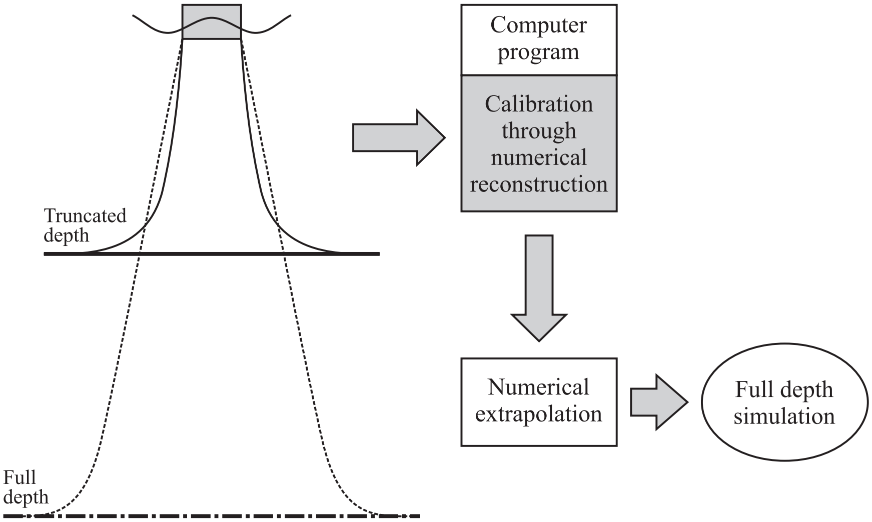

Fig. 1. Illustration of hybrid verification procedure at full-scale (adapted from Stansberg et al., 2002).

system is the most widely used and feasible method and it reflects the current practice (ITTC, 2005, 2008). The hybrid passive system involves model tests with truncated system (equivalent mooring system) and subsequent extrapolation to full depth by means of numerical simulations, combining numerical model and physical test.

The procedure for hybrid verification was described by Stansberg et al. (2000, 2002) and is present in the ITTC procedures (ITTC, 2008). The verification procedure can be illustrated in Fig. 1 and summarized as follows:

1. Design truncated set-up.
2. Select and run a proper test program with representative tests for the actual problem.
3. Numerical reconstruction of the truncated model tests to verify and calibrate numerical tool.
4. Numerical extrapolation to the full-depth mooring system.

This strategy has been widely used in several works, such as Stansberg et al. (2004), Baarholm and Palazzo (2004), Baarholm et al. (2006), Baarholm et al. (2007), Fylling and Stansberg (2005), Zhang et al. (2009, 2012, 2014), Fan et al. (2012, 2014a,b), Ji and Xu (2014), and Molins et al. (2015). Zhang et al. (2009) worked on static adjustment, and claimed that the step 1 of the previously described procedure is an important step to design the equivalent mooring system on truncated water depth according to the characteristics of the full-depth system, based on the static force-offset relationship. Often, the searching for equivalent systems involves using the trial-and-error approach based on the background knowledge of the analyst. Research on truncated systems and optimization methods has been carried out in recent years, such as Fylling and Stansberg (2005), Zhang et al. (2009, 2012, 2014), Fan et al. (2012, 2014b), Molins et al. (2015) and Felix-Gonzalez and Mercier (2016). In all these papers are used non-gradient optimization techniques, except the paper of the Fylling and Stansberg (2005).

Fylling and Stansberg (2005) define an objective function as a weighted difference of restoring forces, between the truncated and full-depth, in order to find an equivalent system in terms of the hydrodynamic characteristics of the vessel. The truncated design employed in the aforementioned study is complex, with addition of buoys, clumps and springs, needing experience to define the components of the truncated line. In a general way, the works of Zhang et al. (2009, 2012, 2014) and Molins et al. (2015) express the objective function as the weighted sum of the similarity of the restoring force and the mooring lines tension aiming to maintain the static characteristics between the truncated and full-depth. Nevertheless, in the work of Felix-Gonzalez and Mercier (2016), the objective function is the weighted sum of the Root Mean Square Error (RMSE) between the full-depth and truncated system for each of the six static response characteristics for the floater: horizontal restoring force in surge; displacements in sway and heave; and rotations in roll, pitch and yaw. Moreover, in all of them, the optimization process involves only the adjusting of the static response of the truncated system to full-depth system.

Unlike those works, Fan et al. (2012, 2014a,b) add a term in the objective function for consider damping characteristics, which in turn reflects in the dynamic characteristics between truncated and full-depth mooring system. For this, it was used a quasi-static method (Bauduin and Naciri, 2000) to calculate the damping induced by the mooring system. So, the inertial forces in the mooring line are neglected, since it did not used a finite element dynamics analyzes program.

In the context, Chen et al. (2000) claim that: “a mooring system not only provides the static restoring forces to the moored structure, but also interacts with the moored structure dynamically, especially in deep water”.

It should be mentioned that usually for horizontal plane modes, i.e. surge, sway and yaw, slowly varying motions are dominant, while for vertical plane modes, i.e. heave, roll and pitch, wave frequency motions are more important (Tahar and Kim, 2003; Kim et al., 2005). The wave frequency motions are caused by the first order wave forces, while that the slowly varying motions are caused by the second order wave drift forces (Wichers and Huijsmans, 1990). Typically, slowly varying wave drift force has fewer intensities with respect to the other wave components, but depending of the mooring system used this force may have an important effect. It can cause slowly varying motions of large amplitude, due to the possibilities of exciting resonance frequencies of the system (Løken, 1979), resulting in high peak tension in the mooring system.

In addition, as said by Waals and van Dijk (2004), usually the dynamics of mooring lines are underestimated by the use of truncated mooring system, which possibly will lead to differences in the floating motion responses. Thus, with the aim of minimize the dynamic differences between the truncated and full-depth systems, it becomes necessary to carry out an adjustment between the dynamic response of those systems (Ji and Xu, 2014).