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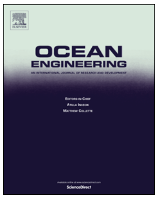

The influence of mooring system in rogue wave impact on an offshore platform

Murray Rudman[a,*], Paul W. Cleary[b]

[a] Department of Mechanical and Aerospace Engineering, Monash University, Victoria 3800, Australia
[b] CSIRO Digital Productivity Flagship Private, Bag 10, Clayton South 3169, Victoria, Australia

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ABSTRACT

The impact of a rogue wave on floating, moored offshore structures is a highly non-linear problem that has application to the design, operation and safety of offshore platforms. During such an impact, the platform's mooring system must maintain a safe platform attitude and withstand the forces from impact and the resulting platform motion. Here we apply Smoothed Particle Hydrodynamics to model rogue wave impact on a semi-submersible platform with a focus on the effect that different mooring systems have on platform motion and mooring tension. We show that mooring systems that are a hybrid of the Tension Leg Platform and Taut Spread Mooring systems could have advantages over non-hybrid systems. However, the mooring line material plays an important role in this assessment. In particular, the use of polyester rope in diagonal mooring lines offers advantages in the platform response. The effect of wave impact angle is to modify the maximum line tension and 45° impacts are seen to be the most important when designing for the worst case scenario. SPH is an excellent choice to model this complex non-linear fluid-structure interaction and make design choices based on predictions of platform motion during rogue wave impact.

1. Introduction

For the interaction of small amplitude waves with geometrically simple structures, good prediction of the wave-structure coupling can be obtained using mathematical approaches that approximate the interaction and dynamics, (Faltinsen 1990; Jain 1997). As the structures become more complex, the prediction becomes more difficult and numerical analysis using techniques such as boundary integral methods becomes necessary (e.g. Nielsen 2003). For irregular, and especially, non-linear large amplitude waves, good prediction becomes increasingly difficult. Wave-structure interaction in such cases involves many interacting physical phenomena, the most important being severe free surface deformation and large structural motions. When a structure has additional constraints such as mooring lines and chains, these must also be included in the analysis. Typically, wave tank testing is used to predict these kinds of interactions, however such testing is time consuming and expensive. Computational methods that can perform analyses in the early stages of design are desirable and can reduce the number of design alternatives that require wave tank testing. Fully three-dimensional Computational Fluid Dynamics (CFD) simulation of the interaction therefore becomes an attractive alternative for obtaining understanding of the essential mechanics of the interaction and consequently in assisting with design. These kinds of CFD simulations are starting to appear more frequently (e.g. Bunnick and Buchner 2004; Kleefsman et al., 2005; Gomez-Gesteira et al., 2005; Shao 2006; Cleary and Rudman 2009; Croaker et al., 2011; Groenenboom 2013) although they are not yet a commonly used design tool.

A highly non-linear problem that cannot be investigated with analytic or simplified numerical techniques is the impact of 'rogue' waves on offshore structures. In order to simulate rogue wave impact, the CFD technique must be capable of handling very high free surface deformation as well as significant motion of the structure in a simple and robust manner. In this paper we use the Smoothed Particle Hydrodynamics (SPH) technique (Monaghan 1994, Cleary et al. 2007) to consider rogue wave impact on a four-legged floating offshore platform. As discussed in Rudman and Cleary (2013), SPH has a number of natural advantages over the Volume-of-Fluid (VOF) technique often used for such cases (e.g. in the studies of Bunnick and Buchner (2004) and Kleefsman et al. (2005)).

The difference in platform response due to rogue wave impact on a Tension Leg Platform (TLP) and a Taut Spread Mooring (TSM) system was considered in Cleary and Rudman (2009) for 0° (normal) impacts where it was observed that the pitch response was

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[*] Corresponding author. Tel.: +61 3 9902 4627.
E-mail address: Murray.Rudman@monash.edu (M. Rudman).

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similar for both systems, the surge response of the TLP was significant whereas the heave response of the TSM brought the deck lowered the deck significantly. The effect of impact angle for rogue wave impact on a TLP was considered in Rudman and Cleary (2013). The primary effect of angle was related to the peak mooring line tension and duration of line "slackness" during wave impact. A 45° impact resulted in the maximum predicted tension on the leading line. The TLP's maximum heave, surge and pitch were predicted to vary only slightly with impact angle.

The aim of this paper is to understand how mooring system design modifies a platform response to rogue wave impact and how the mooring line tensions can be modified with choice of configuration and mooring line composition. Four different mooring systems are considered for wave impact angles from 0° (which is termed a normal impact) to 45°. The results show a clear distinction in platform behaviour between different mooring systems, suggesting the potential advantages of polyester rope in mooring lines. The results in this paper are based on simulations first presented in Rudman and Cleary (2009) however they include additional method details and figures and extend the analysis and discussion contained therein. These results further confirm the potential of SPH in the design of offshore platforms and mooring systems.

2. Simulation methodology

In SPH, the computational mesh is replaced by "particles" for which equations of motion are solved. Each particle carries mass, momentum and energy and is moved with a local estimate of the velocity. This approach uses a Lagrangian description of the equations of motion and the non-linear terms therefore do not appear. The simulation methodology used in this paper is described in previous papers, in particular in Cleary and Rudman (2009) and Rudman and Cleary (2013) and is also similar to that described in Croaker et al. (2011). Thus details of the equations, boundary conditions, platform description and mooring line representation will not be repeated here except when different. General, background to the SPH methodology used in this paper is well described in Monaghan (1994, 2005), Cleary (1998) and Cleary et al. (2007). Validation of the free surface predictions from the code has been undertaken in a number of detailed studies (Ha and Cleary, 2000; Cleary et al., 2006, 2014), estimates of forces resulting on boundaries have been validated in Cummins et al. (2012) and comparisons of wave interactions with tethered floating structures validated in Gunn et al. (2014).

2.1. Structure representation

The platform is discretised with a distinct set of boundary particles whose positions are fixed relative to each other. The boundary particles repel fluid particles that approach them with a normal force (Monaghan 1994). The platform's mass is set and its centre of mass and the moments of inertia about the three axes passing through the centre of mass are estimated from an assumed distribution of steelwork and pontoon ballast. Forces and torques on the platform are determined by integrating the pointwise local forces and torques applied by the fluid to each of the particles representing the structure. The structure is then moved each time-step by solving Newton's equations of motion for the structure. The coupling between the fluid and the platform motion automatically accounts for the lift, drag and added mass of the interaction and no special treatment is required to include these forces. The calculation of fluid impact forces on structures using SPH has been shown to be very accurate using comparison to lab-scale experiment (Cummins et al. 2012).

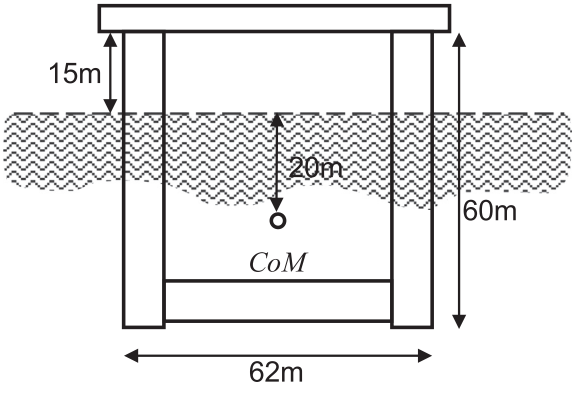

Fig. 1. Schematic of the semi-submersible platform.

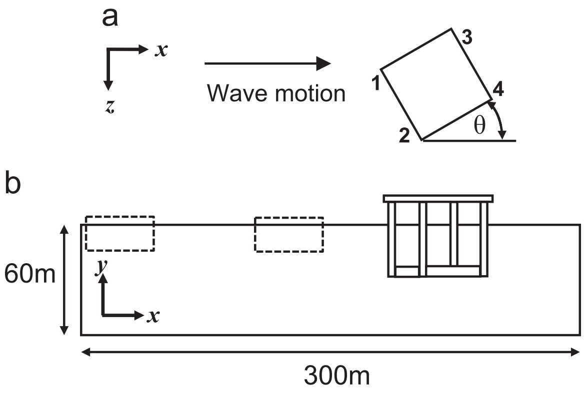

Fig. 2. Computational domain. (a) plan view (x–z plane) showing orientation with respect to the wave motion (θ) and 1–4 denote mooring cable ID. (b) elevation view (x–y plane). Domain size is x=300 m, y=60 m, z=150 m and the start and finishing location of the wave maker is shown as the two dashed boxes.

2.2. Computational domain and platform details

A schematic of the semi-submersible platform considered here is shown in Fig. 1. The semi-submersible platform consists of a deck and topsides attached to four vertical, hollow columns that in turn are attached to each other sub-surface by horizontal, hollow cross-members that together provide the platform buoyancy. The overall computational domain is shown schematically in Fig. 2 and the different mooring systems are shown in Fig. 3.

With reference to Fig. 2a, we simulate four wave impact angles of 0, 15, 30 and 45°. The computational domain is periodic in both horizontal (x and z) directions and is 300 m in the direction of wave motion and 150 m in the transverse direction. The depth of water subject to fluid motion is set to 60 m although the platform is assumed to sit in 500 m of water. The boundary condition on the bottom of the 60 m fluid layer is free-slip although the mooring lines are modelled as being attached to the ocean floor at a depth of 500 m. This approximation is necessary to limit the total number of SPH particles in the calculation to a manageable number. Around 1 million fluid particles with a spacing of 1.5 m are used to represent the water. This resolution was shown in Rudman and Cleary (2013) to be acceptably well converged for the current problem. The truncation of the domain at 60 m clearly represents an approximation that would significantly affect simulation of the transmission of a deep water ocean wave over long to moderate distances. However here, our focus is on the impact of a breaking wave over short distance and time scales, and the approximation has very little impact on the results. Results shown in Rudman and Cleary (2013) indicate that the water speed at depths below 40 m are less than 20% of those in the impacting