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Numerical Studies of Green Water Effect on a Moored FPSO

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ABSTRACT

A simple mooring cable model is coupled with an incompressible flow solver to study the green water effect on a FPSO with and without mooring cables. A Volume of Fluid (VOF) technique is used to capture the violent free surface motion. The incompressible Euler/Navier-Stokes equations, written in an arbitrary Lagrangian-Eulerian (ALE) frame, are solved using projection schemes and a finite element method on unstructured grids. The position of the body is obtained based upon the solution of the general equations of rigid body motion (6-DOF) and the hydrodynamic forces and the mooring cable tension forces acting on the body. Numerical studies of the motion responses of a freely-moving FPSO, a moored FPSO and a side-by-side moored FPSO/LNGC in extreme waves are carried out in this study. Highly nonlinear wave-body interactions and mooring effects have been modeled successfully.

KEY WORD: Finite element method; FPSO; volume-of-fluid method; green water on deck; ship motion; mooring.

INTRODUCTION

Floating production storage and offloading (FPSO) facilities are widely used in the offshore industry due to their economical efficiency, reliability and adaptability. Specifically, one point mooring system is used for the purpose of getting smaller mooring line force. But this also makes the bow of the FPSO to be exposed to the effect of waves. The risk of a FPSO suffering from green water can be very high. Severe green water can not only affect the working efficiency of the FPSO but also cause structure damages, and is of considerable concern to the stability and survivability of the FPSO (Buchner, 2002; Veldman, 2006). In addition, side-by-side offshore oil offloading nowadays becomes a routine method in oil and gas storage and transportation around the world. For instance, a Liquefied Natural Gas Carrier (LNGC) is often side-by-side moored at sea with a FPSO during the offloading operation. Therefore, there is a great need for developing numerical methods that can be used to study the green water effect on a moored FPSO or a side-by-side moored FPSO/LNGC.

It has always been a challenge to simulate the dynamics of FPSOs and the green water on deck, for the impact loads due to slamming and green water are associated with highly nonlinear free surface flows. The computation of highly nonlinear free surface flows is difficult because neither the shape nor the position of the interface between air and water is known a priori; on the contrary, it often involves unsteady fragmentation and merging process. There are basically two approaches to compute flows with free surface: interface-tracking and interface-capturing methods. The interface-tracking method computes the water flow only, using a numerical grid that adapts itself to the shape and position of the free surface. This method can not be used if the interface topology changes significantly (e.g., overturning or breaking waves).

On the other hand, the interface-capturing method considers both fluids as a single effective fluid with variable properties; the interface is captured as a region of sudden change in fluid properties. The interface-capturing methods based on the Eulerian approach require no geometry manipulations after the mesh is generated and can be applied to interfaces of a complex topology such as overturning or breaking waves.

As the objective of this study is to model the highly nonlinear free surface flows, one of the most promising interface-capturing methods – volume-of-fluid (VOF) method is adopted in this study. In the VOF method, only one value (the volume fraction of water) needs to be assigned to each mesh cell, and only a scalar convection equation for the volume fraction needs to be solved to propagate the volume fractions through the computational domain. The VOF method was first reported in Nichols and Hirt (1975), and more completely in Hirt and Nichols (1981). This method has been improved in several aspects in the recent years (e.g., Scardovelli and Zaleski, 1999) and used to simulate breaking waves