Simulations of Incompressible Fluid Flow-Elastic Structure Interactions by a Coupled Fully Lagrangian Solver

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ABSTRACT

This paper presents the simulations of a set of FSI (Fluid-Structure Interaction) problems encountered in ocean engineering by a novel fully-Lagrangian solver corresponding to incompressible fluid flows and elastic structures (Hwang et al., 2014). The fluid and structure models are founded on enhanced versions of Moving Particle Simulation (MPS) method (Koshizuka et al., 1996) and elastic structure (Kondo et al., 2007) model. A distinctive feature of this study is that the simulation method does not include any artificial stabilizing term either in the structure model or the fluid one (Hwang et al., 2014). The fluid-structure coupling is performed in a mathematically- and physically-consistent manner by careful attention to the mathematical concept of projection-based particle methods (i.e. Helmholtz-Hodge decomposition). The accuracy and effectiveness of this novel coupling algorithm is verified by qualitatively and quantitatively evaluating the volume conservation at fluid-structure boundaries. The coupled fluid-structure model is applied to numerical simulations of FSI such as sloshing flow with bottom clamped elastic baffle (Idelsohn et al., 2008) and the impact of an aluminum beam on undisturbed water.

KEY WORDS: Fluid-Structure Interaction; Moving Particle Simulation; Fluid impact loads; Lagrangian Method; Wet-drop simulation

INTRODUCTION

As a gradual increase in the world trading volume and the regulation of carbon emissions that came into force on International Maritime Organization from 2013, called the Energy Efficiency Design Index, the size of commercial ships has increased dramatically. Through explorations for ocean resources and construction techniques for offshore structures, the target of area for ocean energy development has been directed towards deep sea reservoir. And the offshore structures have become larger and are exposed to adverse environmental conditions. In particular, both offshore plants and ships are vulnerable to structural instability due to fluid impact loads in violent sea states. Consequently, a wide range of fluid-structure interaction (FSI) problems due to the fluid impact loads acting on the structures, such as sloshing, slamming, green-water, etc., have emerged in ocean engineering fields.

Many studies have examined FSI problems on marine hydrodynamic fields. The applications of FSI analysis to marine hydrodynamics have been expanded dramatically in recent years by the development of the construction ability and the enlarged trends of ships and offshore structures. In the past, most studies of the fluid-structure interactions focused on the hydroelasticity or flexible fluid-structure interaction. The springing and whipping problems on marine structures were considered as conventionally typical problems caused by hydroelasticity. Regarding the experimental studies, Watanabe et al. (1989) conducted experimental model tests on the vertical bending moment and relative motion in both regular and irregular waves with two kinds of bow flare forms. O’Dea et al. (1992), Ramos et al. (2000), Remy and Molin (2002), and MOERI/KORDI (2010) performed experimental tests with multi-segment model ships connected with a deformable bar for ship motions and structural loads.

In the numerical studies, strip theory had been used conventionally for hydroelasticity problems. Fonseca and Guedes Soares (2002) performed numerical analysis using a time-domain strip theory. The numerical methods showed similar results to the experimental data except in the high wave-amplitude because the strip method has limitations due to a linear assumption. Paik et al. (2009) used the computational fluid dynamic analysis method based on unsteady Reynolds averaged Navier-Stokes equation and finite element method to analyze hydroelasticity problems. Kim and Kim (2014) performed numerical analysis using a three-dimensional Rankine panel method and multi-combined structure analysis method.

Slamming and sloshing are also classified as FSI problems in this field. Sames et al. (1999) simulated bow flare slamming loads on a containership using Finite Volume Method (FVM). Two phase analysis was performed to express the overturned free-surface motion. The water entry velocity of the bow was estimated using a linear panel method but the structure was assumed to be rigid body. Yamada et al. (2012) performed an actual FSI analysis for the slamming problems.