An Eulerian Scheme with Lagrangian Particles for Evaluation of Seakeeping Performance of a Ship in Nonlinear Wave

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ABSTRACT

The present paper deals with design tool using CFD and criteria for ship structures under impact pressure loads due to sloshing, slamming and green water. This study focuses on the development of numerical techniques for computing fluid-structure interaction and for evaluation of seakeeping performance of a ship in nonlinear wave with breaking. This paper also presents a prediction of a local highly impact pressure caused by a strongly nonlinear wave. The developed numerical model was applied to ship-wave interaction for evaluation of seakeeping performance of a ship in waves. The heave, pitch motion and added wave resistance were compared with experimental results and strip theory, and the results were in quite good agreement with them. It can be seen that the proposed model can capture accurately a nonlinear free surface with wave breaking generated by a ship motion in wave and calm water.

KEY WORDS: Seakeeping; CFD; Slamming; Green water; Nonlinear wave; Grid based method; Particle based method; Wave breaking.

INTRODUCTION

Ship resistance increases due to encountered by waves in sea, and it significantly affects the ship operation and fuel consumption. Anticipating this condition, ship performance can be improved toward propulsion efficiency by reducing hull resistance which is an extremely importance way. Therefore, this purpose can be attained by optimized design of a ship hull form.

The ship design has been done by applying various theoretical approach for calculating the response of the ship hull in wave, such as Slender-body theory, Unified theory, Enhanced unified theory, 3D Panel method and Rankin panel method. These methods have been developed and are routinely used as operational design tool. Although these methods are sufficiently accurate for evaluating seakeeping performance in calm water, it is difficult to apply motion of a ship in severe sea condition with wave breaking. It is indicated as strongly nonlinear behavior, e.g. slamming, green water, violent sloshing with impact load which are still attempted to compute in a recent numerical work for developing accurately computational fluid dynamics (CFD) tools.

Over the past several years, according to rapid advances in both hardware and several computational techniques, several kinds of capturing technique for multiphase flow have been developed. One is particle based method, e.g. MPS method (Koshizuka et al, 1996, Shibata et al, 2007 and 2009), SPH method (Gingold and Monaghan, 1977). The other is grid based method, e.g., Level set method (Sussman et al, 1997), Particle LSM (Enright et al., 2002), VOF method (Hirt and Nichols, 1981), CIP method (Yabe et al., 2001). Based on these existing computational techniques in naval architect and ocean engineering field, numerical researchers have developed several CFD tools, e.g. Hino, 1997, Miyata et al., 1985, Hu et al., 2005, Zhu et al., 1993, Kodama et al., 1985, Hirata et al., 1999, Oger et al., 2006 and 2007, Le Touzé et al., 2008 and Xnavis and so on. However, computation of ship motion in nonlinear wave with breaking and splashing is still insufficiently accurate to estimate a load including impact pressure due to wave breaking. The solution has still qualitative assessment in both reproducibility and validation in nonlinear wave with breaking phenomena.

In recent years, application for ship hydrodynamics, prediction of wave resistance and ship motion in nonlinear wave, has widely demanded to be devoted toward highly accurate estimation and has been enhanced to compute impact pressures induced by non-linear wave motions. Under this background, we have developed a coupled Eulerian scheme with Lagrangian particles (Mutsuda et al., 2007, 2008 and 2009), and have applied to evaluate a ship motion in nonlinear wave. The objective of development and application is to verify usefulness of the present method in design process. The model has two kinds of Lagrangian particles, i.e. SPH and free surface particle, on Eulerian grids to correct interface tracking error. The two types of Lagrange particles are collocated and attracted with highly accurate captured free surface under resolved region with Eulerian grids. The model is applied to numerical and experimental works to validate interaction of water waves and elastic structures such as wave breaking in shallow-water, impact pressure, violent sloshing, flip-through phenomena. Then, their usefulness has been confirmed in our previous numerical research (Mutsuda et al., 2007, 2008, 2009 and 2010).

In this study, the model is applied to ship-wave interaction for evaluation of seakeeping performance of a ship in wave. The heave, pitch motion and added wave resistance are compared with both experimental and theoretical results. We investigate that the present model is a powerful tool to compute a strongly nonlinear interaction between wave and a ship.