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A Coupled FE-SPH Approach for Simulation of Structural Response to Extreme Wave and Green Water Loading

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Abstract

This paper presents an analysis technique for predicting the interaction of large ocean waves with ships and offshore structures specifically with respect to extreme wave loads, green water and the level of structural damage caused. This is a complex problem involving the interaction of non-linear fluid and structural behavior. The coupled SPH - Finite Element approach is used, where the water is modeled with SPH and the structure with shell or continuum finite elements. The explicit finite element method is the established method for simulating the crash and impact response of structures.

Existing work has developed and demonstrated the approach for aerospace applications including crash of helicopters on water. The developments required to the more complex fluid behavior required for offshore applications are described. A set of simulation results is shown to demonstrate method can correctly represent the behavior of a floating structure and the structural response to water impact. The final test model is an offshore mooring buoy to extreme waves, with model tank results available for comparison.

Introduction

Green water loading and wave impact are major sources of damage in the marine industry. Design for such eventualities is based on empirical considerations and on model test data in the absence of reliable theoretical models for predicting the relevant loads. The objective of this research is to develop and demonstrate an analysis tool capable of predicting the response of structures to extreme wave loading. To achieve this objective the tool must be capable of representing the following important features of this problem:

- The behavior of extreme waves, including breaking,
- The response of a floating structure to waves,
- The interaction of the water with a structure,
- The response of the structure to the fluid loading including large deformations and non-linear material behavior (including plasticity, damage and failure).

Together these features form a time dependent and highly non-linear problem.

Smooth Particle Hydrodynamics (SPH) is a numerical technique for the approximate integration of the governing partial differential equations of continuum mechanics. It is a meshless Lagrangian method that uses a pseudo-particle interpolation method to compute smooth field variables. Each SPH particle has a mass, Lagrangian position, Lagrangian velocity, and internal energy; other quantities are derived by interpolation or from constitutive relations. The SPH approach was initially developed for the simulation of astrophysics problems [1,2], with the critical development being a method for the calculation of derivatives without a computational mesh. Review papers by Benz[3] and Monaghan[4] cover the fundamentals of SPH. Libersky and Petschek [5] extended SPH to work with the full stress tensor, developing a 2D formulation. This addition allowed SPH to be used in problems where material strength is important and lead to the coupling of SPH with existing finite element codes [6,7].

The application of SPH to water waves and related free-surface hydrodynamics problems was begun by Monaghan [8], who performed two-dimensional simulations of a dam break problem and wave propagation onto a shallow beach. More recently SPH simulations have been further compared with published experimental results, an example being Scott Russell's wave generator [9], with the SPH method in agreement with the experimental results. In these simulations use an artificial equation of state to produce a quasi-incompressible fluid, the approach used in this work. SPH has also been used for wave mechanics with exact enforcement of incompressibility [10]. This uses an implicit pressure update that allows a larger time