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Full six degrees of freedom coupled dynamic simulation of ship collision and grounding accidents

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ABSTRACT

By taking advantage of the user-defined load subroutine (*loadud*) and the user common subroutine (*usercomm*) in LS-DYNA, the authors proposed a new coupled approach for simultaneously calculating structural damage and the planar 3DOF ship motions in ship collisions. The coupled procedure aimed at predicting the detailed structural damage together with reasonable global ship motions. This paper extends the method to consider the full 6DOF ship motions; thus, ship collision as well as grounding accidents can be properly handled. This method is particularly useful for design purposes because the detailed ship hull profile is not needed.

A traditional ship maneuvering model is used for the in-plane surge, sway and yaw degrees of freedom with a series of nondimensional coefficients determined from experiments. It is assumed that the out-of-plane degrees of freedom are not coupled with the in-plane ship motions, and there is no coupling among roll, pitch and heave motions. The implementation is verified through free decay tests, and the obtained natural periods show good agreement with theoretical results.

Several collision and grounding cases are simulated in which a supply vessel crashes into rigid plates with different orientations. The effects of the roll motion, the heave and pitch motions and the full 6DOF motions are studied. The results are compared with those from a 6DOF decoupled method. Ship motions through the proposed method compare reasonably well with SIMO results. It is found that several consecutive impacts may occur in the simulation of one collision case due to the periodic motions. This is not taken into account in the decoupled method, which makes this method unconservative.

1. Introduction

Ship collisions and groundings are highly nonlinear, coupled dynamic processes involving large structural deformations and fluid structure interactions. To simulate the collision process accurately, it is necessary to couple the fluid and structure domains efficiently. However, this coupling is still challenging to implement. The major obstacle is that in most numerical

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codes used for structural analysis, the effect of surrounding water cannot be included efficiently. Various methods are proposed to simplify the problem.

In the past decades, the most widely used method for ship collision analysis is that pioneered by Minorsky [1] in which the collision problem is decoupled into external dynamics and internal mechanics. Examples of theoretical models for external dynamics can be found in Pedersen and Zhang [2] for planar 3DOF ship motions and in Liu and Amdahl [3] for 6DOF ship motions. Liu and Amdahl's model allowed the geometric shape of vertical contact and objects with 3D eccentricities such as icebergs to be considered. The energy determined in the external dynamics analysis is dissipated as strain energy in the assessment of the internal mechanics, where the ship is typically supposed to move in a displacement-controlled manner. The decoupled method is simple to apply and provides reasonable accuracy of the energy prediction in most cases. However, ship paths are not well predicted, and the error of the final penetration into the struck ship can be as large as 80% according to Tabri [4]. In addition, the effects of the fluid are considered to be constant added masses that may lead to further inaccuracies.

For a more accurate prediction of ship motions and structural responses, a few researchers have turned to the coupled solution. Petersen [5] suggested a coupled simulation procedure, taking into account the transient effects of hydrodynamic loads. The strip theory was used, and sectional added masses and damping were calculated through the use of an approximate method. Ship motions were restricted to the horizontal plane. Tabri et al. [6] extended the simulation technique to full 6DOF for models of both the striking and struck ships. Brown [7] developed a Simplified Collision (SIMCOL) model that was capable of coupling the internal and external mechanics of the planar motions. SIMCOL was especially useful in the preliminary design stage. Mitsubishi developed a program entitled MCOL (Mitsubishi Collision) to address rigid body dynamics. Le Sourne [8] coupled the MCOL code with the super element method [9] to tackle the internal and external mechanics simultaneously. The MCOL code has also been used by Tørnqvist [10] for symmetric collisions and by Biehl et al. [11] for collisions between a push barge and a rigid wall. The above methods are usually based on certain simplifications of the collision forces. For example, Petersen [5] simplified the collision forces with four nonlinear springs. Tabri et al. [6] assumed the homogeneity of ship stiffness and represented the collision forces by integrating the normal and tangential tractions over the contact surface between the colliding bodies. The super element method uses the collision resistances of the simplified analytical solutions [8,9].

An alternative approach to coupling local deformations and global ship motions is the Arbitrary Lagrangian Eulerian (ALE) finite element method in which the model is divided into two domains: a fluid domain and a structure domain. Traditional Lagrangian meshes are used in the structure domain. In the fluid domain, Eulerian meshes are adopted to avoid possible large mesh distortions. Within each time step, the fluid and structure domains are simultaneously calculated, and forces and boundary conditions are transferred. The huge number of structural and fluid elements for a full ship simulation and the complex solvers in both domains require considerable computation capacity. Therefore, full-ship collision simulations through the ALE method are rarely reported in the literature. More often, the ALE method is carried out for studying the sloshing interaction between the fluid and structures, such as in Rudan et al. [12] and Zhang and Suzuki [13].

Yu et al. [14] presented useful tools, the user-defined load subroutine and the user common subroutine in LS-DYNA, with which the planar 3DOF ship motions and structural deformations are efficiently coupled. The effects of the fluid were calculated through the use of a traditional ship maneuvering model on the basis of experiments. The hydrodynamic forces were applied as a force vector to the rigid beam model. This paper further extends the method to consider the full 6DOF ship motions during ship collisions and groundings. Decay tests for roll, pitch and heave are carried out to verify the implementation of the user load and to ensure that the correct natural periods are obtained. Several collision and grounding cases, in which a supply vessel crashes into rigid plates with different orientations, are simulated through the 6DOF coupled method. The effects of the roll motion, the heave and pitch motions and the full 6DOF motions are studied. The results are compared with those from a 6DOF decoupled approach and are discussed in some detail. It is interesting to observe that several consecutive contacts do occur in the simulation of one collision case, and the secondary impacts will make the 6DOF decoupled method very unconservative in some cases. Ship motions through the proposed 6DOF coupled method compared reasonably well with the results using SIMO. SIMO [15] is a computer program for the simulation of the motion and behavior of floating vessels. The added masses and damping forces, which are calculated with potential hydrodynamic theory, can be directly imported. Ship collision forces can be applied as an external force vector.

The proposed coupled method is shown to be capable of efficiently coupling structural deformation and the 6DOF ship motions. Unlike most previous coupled models, the internal mechanics are calculated through the use of LS-DYNA; thus, the collision forces and damage extents of structures can be predicted with high accuracy, while the global motions are predicted reasonably well. In addition, the method can be widely used because no external routines are needed. Therefore, this method constitutes a promising tool for coupled ship collision and grounding analysis.

2. The coupling algorithm using LS-DYNA

2.1. LS-DYNA for structural analysis

LS-DYNA is a general purpose finite element code for analyzing the large deformation static and dynamic response of structures. It is widely used in the automotive and offshore industries for crash and impact analysis. LS-DYNA uses the explicit central difference scheme to integrate the equation of motions. For maintaining solution stability, the timestep size should