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Comparison of slamming and whipping loads by fully coupled hydroelastic analysis and experimental measurement

Jung-Hyun Kim [a,1], Yonghwan Kim [a,*], Rae-Hyoung Yuck [b,2], Dong-Yeon Lee [b,3]

[a] *Department of Naval Architecture and Ocean Engineering, Seoul National University, Seoul 151-744, Republic of Korea*
[b] *Samsung Ship Model Basin, Samsung Heavy Industry, Daejeon 305-380, Republic of Korea*

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ABSTRACT

This paper proposes a numerical method for analyzing whipping using a fully coupled hydroelastic model. The numerical analysis method utilizes a 3-D Rankine panel method, 1-D/3-D finite element methods, and a 2-D generalized Wagner model, which are strongly coupled in the time domain. The computational results were compared with those of a model test of an 18 000-TEU containership. The slamming pressures and whipping responses to regular waves for bow flare and stern slamming were compared. Furthermore, the slamming pressure was decomposed into its dynamic and static components. The numerical and experimental models produced similar results. In addition, the effects of the discretization and geometric approximation of the 2-D slamming sections were investigated.

1. Introduction

High-speed commercial vessels easily experience whipping. A broad bow flare and a flat stern are more susceptible to severe slamming. Severe slamming induces significant hull girder vibration, which is referred to as whipping. It is well known that whipping tends to increase the extreme load. For example, MSC Napoli experienced structural failure near its engine room owing to extreme load induced by whipping (Marine Accident Investigation Branch, 2008). Full-scale measurements taken during recent studies have revealed that whipping significantly affects the fatigue strength and ultimate strength (Drummen et al., 2008; Hirdaris et al., 2009; Storhaug et al., 2010, 2011). In addition, a whipping identification method applied to full-scale measurement data can assist a deeper understanding the effect of whipping (Kim et al., 2013).

To take the effect of whipping into consideration in the structural design of ships, a numerical or experimental test is necessary. Although an experimental test is more reliable than a numerical one, the latter is preferable for testing various ships and wave conditions. For a numerical test to be reliable, the method should have been validated against the results of an experimental test. Recently, systematic model tests of ship springing and whipping were conducted as part of the Wave-Induced Loads on Ships Joint Industry Project (WILS JIP) in Korea (MOERI, 2010, 2013). The test results are expected to greatly assist the validation of a numerical method that can be applied to real ships.

* Corresponding author. Tel.: +82 2 880 1543; fax: +82 2 876 9226.
E-mail addresses: wowplusme@snu.ac.kr (J.-H. Kim), yhwankim@snu.ac.kr (Y. Kim), rh.yuck@samsung.ac.kr (R.-H. Yuck), dy.lee@samsung.ac.kr (D.-Y. Lee).
[1] Tel.: +82 2 880 7143; fax: +82 2 876 9226.
[2] Tel.: +82 42 865 4374; fax: +82 55 630 7671.
[3] Tel.: +82 42 865 4368; fax: +82 55 630 7671.

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Numerical simulation of whipping can be found in many recent papers (Drummen and Holtmann, 2014; Kim and Kim, 2014; Oberhagemann and Moctar, 2012; Tuitman, 2010; Hirdaris and Temarel, 2009). A numerical method roughly consists of three parts, namely, a fluid solver for the seakeeping problem, a structural solver for the rigid-body and flexible motions, and a slamming solver for calculating slamming loads. There are various methods utilized by fluid solvers, including the 2-D strip theory method, 3-D panel method, and 3-D CFD method. The 3-D panel method is presently considered to be the most practical for time-domain simulation; the 3-D CFD method is still too heavy for extended simulation. Regarding the structural part, either a 1-D beam model or a 3-D FE model can be used depending on the purpose. When considering structural discontinuity, a 1-D beam model exhibits almost the same structural behavior as a 3-D FE model, including in the torsional response (Kim and Kim, 2014; Senjanović et al., 2009). The slamming load acting on the bow flare, bottom, or stern should also be considered when the linear potential theory is used for the seakeeping problem; it is automatically included in the 3-D CFD method (Oberhagemann and Moctar, 2012). The 2-D generalized Wagner model (GWM) is commonly used because it reliably calculates the slamming load and its computational speed is suitable for time-domain simulations (Khabakhpasheva et al., 2014; Mei et al., 1999; Zhao and Faltinsen, 1993). Although a 3-D slamming model is desirable because a ship slamming is basically a 3-D problem (Kim and Hong, 2008; Korobkin and Scolan, 2006), the theoretical study on the slamming of 3D for arbitrary body shape is not available at this moment, Although CFD can be a candidate for this purpose, its practicality and accuracy are very limited.

In the present study, a fully coupled hydroelastic model was used for the numerical simulation of whipping. The numerical model consists of a 3-D Rankine panel method in conjunction with a weakly nonlinear approach, 1-D/3-D FE model and 2-D GWM, which are coupled with each other. The results of wedge drop and whipping tests were used to validate the numerical model. For the validation, the experimentally and numerically determined sectional force and slamming pressure were compared. The pressure was decomposed into three components, which are proportional to acceleration, velocity square, and displacement, respectively. In addition, the discretization error in the slamming sections and the effect of coupling the motion and slamming loads were investigated.

2. Theoretical background

2.1. Fully coupled approach

A fully coupled approach is effective for hydroelastic analysis of whipping because the interaction between the fluid and the structure plays a role in the natural vibration of the ship. The fluid flow around the ship is solved by the 3-D Rankine panel method. The rigid-body and flexible motions of the structure are determined by the 1-D/3-D FEM. In addition, the slamming loads are calculated by the 2-D GWM or by wedge approximation. The three methods are coupled together in the time domain.

2.2. 3D Rankine panel method

The 3-D Rankine panel method for the seakeeping problem is based on the works of Kim and Kim (2008), Kring (1994), and Nakos (1990). The coordinate system moves with the advancing ship and its forward speed along the x-axis as shown in Fig. 1. The origin is located at the projection of the center of mass to the water plane. The set of the boundary value problem is expressed as follows:

$$\nabla^2\phi = 0 \quad \text{in } \Omega_F, \tag{1}$$

$$\frac{\partial\phi}{\partial n} = \vec{\mathbf{U}}\cdot\vec{\mathbf{n}} + \frac{\partial\vec{\mathbf{u}}}{\partial t}\cdot\vec{\mathbf{n}} \quad \text{on } S_B, \tag{2}$$

$$\left[\frac{d}{dt} + \nabla\phi\cdot\nabla\right][z-\zeta(x,y,t)] = 0 \quad \text{on } z=\zeta(x,y,t), \tag{3}$$

$$\frac{d\phi}{dt} = -g\zeta - \frac{1}{2}\nabla\phi\cdot\nabla\phi \quad \text{on } z=\zeta(x,y,t), \tag{4}$$

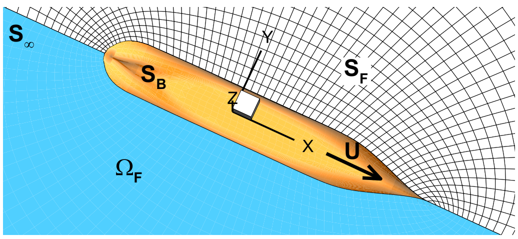

Fig. 1. Coordinate system of 3-D Rankine panel method.