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Study on Collision Between Two Ships Using Selected Parameters in Collision Simulation

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Abstract: In the present analysis, several parameters used in a numerical simulation are investigated in an integrated study to obtain their influence on the process and results of this simulation. The parameters studied are element formulation, friction coefficient, and material model. Numerical simulations using the non-linear finite element method are conducted to produce virtual experimental data for several collision scenarios. Pattern and size damages caused by collision in a real accident case are assumed as real experimental data, and these are used to validate the method. The element model study performed indicates that the Belytschko-Tsay element formulation should be recommended for use in virtual experiments. It is recommended that the real value of the friction coefficient for materials involved is applied in simulations. For the study of the material model, the application of materials with high yield strength is recommended for use in the side hull structure.

Keywords: ship collision, collision accident, non-linear finite element, collision parameter, hull structure

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1 Introduction

Ship transport is essential for transporting people and products between islands in the Indonesian archipelago. One of the busiest shipping routes is the Merak (Province of Banten) to Bakauheni (Province of Bengkulu) route through the Sunda Strait, where, in a section of the strait, traffic traveling from east to west (from Java to Sumatra) crosses traffic traversing from north to south (Batam, Singapore, to the Indian Ocean). Thus, accidents frequently occur in this area; two accidents have occurred in the past three years between 2012 and 2014, and the most recent of which was a collision between a roll-on–roll-off (ro–ro) passenger ship and general cargo ship in May 2014. In the marine and naval community, there is an increasing demand for the reduction in ocean pollution and vessel losses that occur in relation to such accidents. The tragic losses of numerous ro–ro passenger ships such as the European Gateway in 1982, the Herald of Free Enterprise in 1987, and particularly, the catastrophe of the Estonia in 1994 with the loss of more than 800 lives have led many countries to reassess passenger ship safety. In addition, collision and grounding significantly contribute to ship structural damage, and according to the statistics of Lloyd's Register on 1995, collision and grounding of ships are responsible for nearly half of all ship losses (Zhang, 1999a).

In recent years, there have been improvements and developments in simulations and analyses of ship collisions. Such work began with the use of the empirical formula of Minorsky for determining the energy absorbed by a ship structure during collision (Minorsky, 1959). This was followed by Zhang (1999b), who provided an illustration of coordinates involved in the external dynamics of ship collisions, and then Kitamura (2002), who applied the Finite Element (FE) approach in a collision and grounding simulation. The results of previous research indicate that the use of the FE approach for conducting collision simulation and analysis in a virtual experiment is adequate for calculating and producing results that agree with simplified analysis or real experiment results. However, several parameters are involved when the FE method is applied in virtual experiments, and these parameters affect the results.

This paper presents an integrated study of parameters involved in collision simulations with the aim of predicting the influence of such parameters on the results of a numerical simulation of ship collisions. The parameters investigated in the integrated study are limited to element formulation, friction coefficient, and material model.

2 Collision research review

FE analysis has previously been used in full-scale experiments and collision accident studies, and numerous

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studies on ship collisions have been performed by scientists and other authorities. For example, a comparative study was performed on the structural integrity of single and double side skin bulk carriers under collision damage, in addition to the numerical modeling of ship collision based on FE codes by Ozguc *et al*. (2005). Moreover, the FE method has been applied in the simulation of collision and grounding damages (Kitamura, 2005). Furthermore, a ship collision study by Pedersen and Zhang (2000) determined the effect of ship structure and size on grounding and collision damage distributions, and Wiśniewski and Kolakowski (2003) mentioned the effects of selected parameters such as ship velocity on ship collisions. The bending stress of a ship's hull during ship collision was determined by Pedersen and Li (2009), and numerous ship collision simulations based on collision types have been studied by Haris and Amdhal (2013). Research related to energy absorption by a ship structure during collision was performed by Lehmann and Pechmann (2002), and in this respect, a study of the internal mechanic modeling during ship collision was conducted by Paik and Pedersen (1996). Based on the work of Kitamura (2002), improvements have now been made in the accuracy and practicality of the FE method, particularly when data from real accidents, physical experiments, and/or the use FE analysis, i.e., numerical experiments, are employed.

3 Theory and methodology review

The most practical method currently employed for conducting analyses and simulations of collisions is the FE method using numerical simulations, which are divided into linear and non-linear simulations. Non-linear analysis is applied as a method to calculate stresses and deformations of products under the most general loading and material conditions, for example, with dynamic (time-dependent) loads; large component deformations; and non-linear materials such as rubber or metals, beyond their yield point. Non-linear analysis is a more complex approach but results in a more accurate solution than linear analysis when the basic assumptions of linear analysis are violated. The application of an algorithm in both linear and non-linear analysis can also be significant depending on the type of simulation. In the present study, Lagrange multiplier algorithm or augmented Lagrange is used in collision simulation. In the classical Lagrange multiplier method, contact forces are expressed by Lagrange multipliers, whereas the augmented Lagrange method involves the regularization of the classical Lagrange method by adding a penalty function from the penalty method (Simo and Laursen, 1992). This method, unlike the classical one, can be used for sticking friction, sliding friction, and frictionless contact conditions. An illustration of the concept of this algorithm is presented in Fig. 1. The representation of the contact problem, which involves the minimization of potential Π, is presented in Eqs. (1)–(3) as follows:

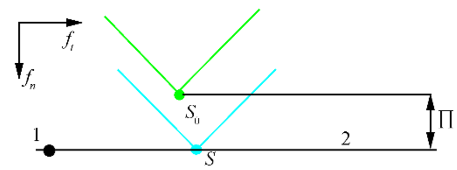

Fig. 1 Contact element in Lagrangian method

$$\prod(u,\boldsymbol{\Lambda})=\prod_b(u)+\boldsymbol{\Lambda}^{\mathrm{T}}g+\frac{1}{2}\boldsymbol{g}^{\mathrm{T}}k\boldsymbol{g} \tag{1}$$

$$\boldsymbol{\Lambda}^{\mathrm{T}}=\left[\begin{Bmatrix}\lambda_n^{1}\\ \lambda_t^{1}\end{Bmatrix},\begin{Bmatrix}\lambda_n^{2}\\ \lambda_t^{2}\end{Bmatrix},\ldots\begin{Bmatrix}\lambda_n^{k}\\ \lambda_t^{k}\end{Bmatrix}\right] \tag{2}$$

$$\boldsymbol{g}=\left[\begin{Bmatrix}g_n^{1}\\ g_t^{1}\end{Bmatrix},\begin{Bmatrix}g_n^{2}\\ g_t^{2}\end{Bmatrix},\ldots\begin{Bmatrix}g_n^{k}\\ g_t^{k}\end{Bmatrix}\right] \tag{3}$$

where λ_n is the Lagrange multiplier for the normal direction, λ_n is the Lagrange multiplier for the tangential direction, g_n is penetration along the normal direction, and g_t is penetration along the tangential direction.

The augmented Lagrange is basically the same as the penalty method, but the λ_i constant is added to the augmented Lagrange, which makes this algorithm extremely accurate [13]. The equations for these algorithms are as follows:

$$\delta\Psi=\int_V\sigma^{\mathrm{T}}\delta\varepsilon\mathrm{d}V+\int_\Gamma(\varepsilon_N g_N\delta g_N+\varepsilon_T\boldsymbol{g}_T\delta\boldsymbol{g}_T)\mathrm{d}A \tag{4}$$

$$\Delta F_{\text{cont.}}=K_{\text{cont.}}\,\Delta x_{\text{penetr}} \tag{5}$$

$$\delta\Psi=\int_\Gamma[(\lambda_N+\varepsilon_N g_N)\delta g_N+(\lambda_T+\varepsilon_T\boldsymbol{g}_T)\delta\boldsymbol{g}_T]\mathrm{d}A \tag{6}$$

$$\lambda_{i+1}=\lambda_i+K_{\text{cont.}}\Delta x_{\text{penetr.}} \tag{7}$$

where $F_{\text{cont.}}$ is the contact force, $K_{\text{cont.}}$ is the contact stiffness, $x_{\text{penetr.}}$ is the distance between two existing nodes on separate contact bodies, and λ_i is the Lagrange Multiplier.

Collision analysis has undergone many developments and improvements since its introduction and can be classified into four categories: empirical, simplified, experiment, and FE methods. Empirical methods were introduced and developed in past research. In the present study, Zhang's empirical formula method is considered. Proposed formula is using empirical formula from Zhang which the formula implementation is divided into crushing and folding as well as tearing damage mode. These formula for two deformation modes i.e. crushing and folding as well as tearing are presented on Eqs. (8) and (9) consecutively (Zhang, 1999c).

$$E=3.50\,(t/d)^{0.67}\sigma_0 R_T \tag{8}$$

$$E=3.21\,(t/l)^{0.6}\sigma_0 R_T \tag{9}$$

where E is the absorbed energy (MJ), σ_0 is the height of the rupture aperture in the side shell (m), t is the average thickness of the crushed plate (mm), d is the average width of plates in the crushed cross-section (mm), l is the critical tearing length (mm), and R_T is the destroyed volume of material (m^3).