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An analytical method for predicting the ship side structure response in raked bow collisions

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ABSTRACT

As an increasing number of ships continue to sail in heavy traffic lanes, the possibility of collision between ships has become progressively higher. Therefore, it is of great importance to rapidly and accurately analyse the response and consequences of a ship's side structure subjected to large impact loads, such as collisions from supply vessels or merchant vessels. As the raked bow is a common design that has a high possibility of impacting a ship side structure, this study proposes an analytical method based on plastic mechanism equations for the rapid prediction of the response of a ship's side structure subjected to raked bow collisions. The new method includes deformation mechanisms of the side shell plating and the stiffeners attached. The deformation mechanisms of deck plating, longitudinal girders and transverse frames are also analysed. The resistance and energy dissipation of the side structure are obtained from individual components and then integrated to assess the complete crashworthiness of the side structure of the struck ship. The analytical prediction method is verified by numerical simulation. Three typical collision scenarios are defined in the numerical simulation using the code LS_DYNA, and the results obtained by the proposed analytical method and those of the numerical simulation are compared. The results correspond well, suggesting that the proposed analytical method can improve ship crashworthiness during the design phase.

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1. Introduction

As continuous streams of ships sail in the heavy traffic lanes, collisions still inevitably occur, although many efforts, such as advanced navigational tools, have been introduced to enhance the safety level of sailing ships. The structural responses of ships in collision accidents are of great concern in the maritime industry due to the potential consequences to safety, environment pollution, and economic investment losses.

The raked bow is a common design. Many ships, including supply vessels, merchant vessels, oil ships, and warships, have a raked stem, even if they are equipped with a bulbous bow below. Most ship collision studies concentrate on the damage caused by the bulbous bow. For example, Hong et al. [1] proposed a direct design procedure for a FPSO side structure that might be subjected to large impact loads caused by a bulbous bow; Haris and Amdahl [2] proposed an analytical model to investigate the crashworthiness of a ship's side structure struck by rigid bows of two different shapes. Gao and Hu [3] proposed a simplified analytical method for rapid predicting a FPSO side structure's crashworthiness to withstand a collision by a rigid bulbous bow. Although the bulbous bow is generally stronger than the raked stem, the response of ship side structure to a raked bow collision should not be neglected. For example, Loïc Buldgen et al. [4,5] proposed a simplified analytical method to analyse the oblique collision between two ships.

In the preliminary design stage, it is of great importance to predict the structural performance of a ship's side structure to various potential accident scenarios. Additionally, in the risk evaluation after accidents occur, it is essential to assess the consequences related to corresponding scenarios rapidly. For these situations, a rational design procedure and calculation tools with high efficiency are required. According to Hong [6], the current approaches to analyse ship collisions can be generally grouped into three categories: experimental methods, non-linear finite element methods (NLFEMs), and simplified analytical methods. Among the three methods, full-scale or large-scale collision and grounding experiments are seldom executed because they are too expensive and risky; thus, small-scale experiments are typically used to verify analytical methods; however, the costs are still high, and the experimental results are difficult to interpret at real-scale conditions due to the intricate scaling effects involved. Because of the explosive development of computer technology, the model test methods are being gradually replaced by NLFEMs, which are considered “numerical experiments”, and can provide significant details and satisfactory results on the deformation process of structures subjected to collision accidents as long as the modelling parameters are properly set. Moreover, NLFEMs have the advantage of low cost and repeatable analyses compared with the experimental method. Therefore, NLFEMs are extensively used. For example, Haris and Amdahl [7] used the software LS_DYNA to produce virtual experimental data for several ship collision scenarios. Yu et al. [8] conducted numerical simulations to verify a simplified analytical method for shoal grounding. Kitamura [9], Endo et al. [10], and Yamada and Endo [11] analysed a series of buffer-bow designs with numerical simulations. Alsos and Amdahl [12] investigated the failure criterions with respect to fracture by numerical analyses. However, establishing the FE model and calculating different accident scenarios is a lengthy process.

Compared with the above mentioned methods, the simplified analytical method has a comparative advantage given its reasonable accuracy, cost savings, time efficiency, and, most notably, its superiority in providing insight into the governing physical processes. Based on these advantages, researchers have developed theoretical models of nearly all ship structural components involved in ship collision and grounding.

To analyse the crashworthiness of a struck ship, its side structure is typically divided into three basic elements: the web girders, such as decks, transverse frames and longitudinal girders; the side panels, such as outer and inner shell plating; and the stiffeners that are attached to the shell plating. Once the resistance of each basic element is evaluated, the total response of the entire structure can be obtained by summing the individual resistances. The crushing resistance of web girders was theoretically and experimentally studied by Wierzbicki and Culbertson–Driscoll [13], Wang and Ohtsubo [14], Simonsen [15], Zhang [16] and Hong and Amdahl [17]. Gao and Hu [18] summarised and compared these various approaches and proposed a new theoretical model. Plate tearing typically occurs after a crushing indentation of the web girder reaches a certain distance. Wierzbicki and Thomas [19], Ohtsubo and Wang [20] and Zhang [21] proposed plate tearing models that can be used to calculate the tearing force