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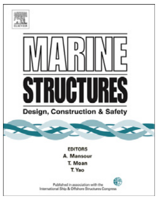

Bottom structural response prediction for ship-powered grounding over rock-type seabed obstructions

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ABSTRACT

This paper presents a simplified analytical method for predicting the resistance of ship bottom structures when a ship runs aground over rock-type seabed obstructions. During the powered grounding scenario, the structural damage caused by sharp seabed obstructions may lead to earlier penetration and serious consequences, such as compartment flooding, oil leakage and environmental pollution. Therefore, it is of great importance to rapidly and accurately analyse the response of a ship's bottom structure during powered grounding scenarios. A new simplified kinematically admissible analytical model is built to capture the dominant failure modes of the bottom transverse floor, which include plastic bending and membrane stretching, and the analytical expression of the resistance of the bottom floor is derived from a plastic mechanism analysis. The failure mechanisms of the bottom plating are also analyzed to provide insight into the main deformation mechanisms with reasonable predictive accuracy. The analytical prediction method is verified by numerical simulation using the code LS-DYNA. The simulation cases cover a wide range of indentations and semi-apex angles of the cone-shaped rocks. The results agree well, proving that the proposed analytical method can be used to predict the ship bottom structure crashworthiness during the structural design phase.

1. Introduction

As one of the most unavoidable types of accident, ship grounding over seabed obstacles will inevitably continue to occur despite the strict regulations and advanced navigation tools that have been introduced to enhance the safety of sailing ships. The damage caused by ship grounding may result in economic loss, severe environmental pollution, and, worst of all, the sinking of the vessel and the subsequent loss of numerous lives. The grounding accident of the Exxon Valdez, which released more than 11 million gallons of crude oil into the sea, is considered one of the most devastating environmental disasters. Such tragedies attract large amounts of public attention and show the importance of the reliable assessment of the grounding strength of ships.

Simonsen [1] proposed that the structural responses to grounding actions depend mainly on the scantlings, the nature of the loads, and the boundary conditions. Therefore, the shape and size of the seabed obstructions significantly affect the

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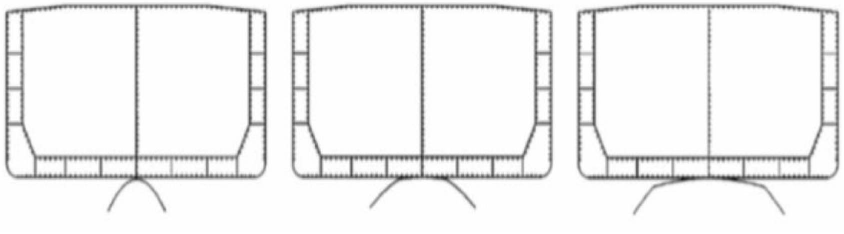
characteristics of bottom damage. Alsos and Amdahl [2] categorized seabed obstacles into three major types, “rocks”, “reefs” and “shoals”, as shown in Fig. 1. Sormunen et al. [34,35] studied the effect of rock shapes in structural damage modelling in grounding accident. The main point of this research is that the current simplistic rock models do not well correspond to actual measurements of the sea bottom, but there is no good parametric rock model exists currently. In order to resolve the feasibility of the analytical method, researchers often use a sharp wedge to represent rock-type seabed obstructions, but a cone-shaped rock was recognized as a more general representation for seabed obstructions by Rodd [3]. Nonetheless, in the future more realistic rock models should be proposed and investigated. Additionally, the damage mechanics of ship bottom structures are closely related to different grounding actions, such as vertical grounding action, referred to as “stranding” by Amdahl and Kavlie [4], and grounding action combined with forward movement, referred to as “powered grounding” by Simosen and Friis-Hansen [5]. In these different grounding situations, ship-powered grounding over a rock-type seabed obstruction is commonly referred to as “raking” by Wang et al. [6], as shown in Fig. 2, and may cause early penetration and very dangerous consequences, such as compartment flooding and oil leakage. Therefore, it is of crucial importance to predict the structural performance of a ship's bottom structure during the raking scenario in the preliminary structural design stage.

According to Hong [7], the current approaches to analysing ship groundings can be generally grouped into three categories: experimental methods, non-linear finite element methods (NLFEMs), and simplified analytical methods. In addition the statistical methods are also studied by many people, such as Eliopoulou Eleftheria et al. [8]. Among the four methods, experiments provide the most convincing results. However, experiments are often prohibitively expensive, and the results of small-scale experiments may not be extendable to real-scale conditions due to the intricate scaling effects involved. NLFEMs can provide significant details and satisfactory results as long as the modelling parameters are properly set and are thus considered “numerical experiments”. Moreover, NLFEMs have the advantages of low cost and repeatability. However, establishing an FE model is a lengthy process. Therefore, NLFEMs are usually used to verify simplified analytical methods. For example, Hu and Amdahl et al. [9] and Yu and Hu et al. [10] conducted numerical simulations to verify a simplified analytical method for shoal grounding. Compared with the abovementioned methods, the simplified analytical method has the advantages of providing reasonable accuracy, cost savings, time efficiency, and, most notably, insight into the governing physical processes. Based on these advantages, the simplified analytical method is used in this paper to study the response of a ship bottom structure during ship-powered grounding accidents.

During the ship-powered grounding scenario, the major participant structures include the bottom plating, the transverse bottom floors, the longitudinal girders and the stiffeners that are attached to the plates. The contact surface between the obstacle and the ship bottom is very limited when the seabed obstruction is sharp; in this situation, the contribution of the longitudinal girder is small and is thus neglected in the present study. It is assumed that the structural components behave independently, such that once the resistance of each component is evaluated, the total response of the ship bottom can be obtained by summing the individual resistances. Throughout the raking process, the bottom plating experiences two major deformation patterns: plate folding and plate tearing. The plate-folding model of plating was theoretically and experimentally



(a) rock **(b) reef** **(c) shoal**

Fig. 1. Seabed topology with reference to bottom size: (a) rock, (b) reef, (c) shoal (Alsos and Amdahl [2]).

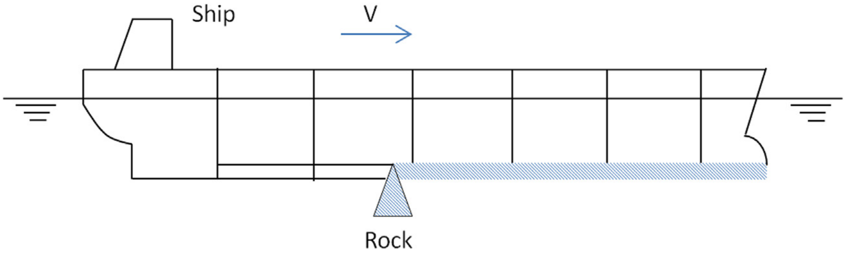


Fig. 2. Ship-powered grounding over rock-type seabed obstructions.