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Experimental investigation of oil leakage from damaged ships due to collision and grounding

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A B S T R A C T

The objective of the present paper is to study the oil flows from damaged ships with different tank designs during collision and grounding incidents. For this purpose, analytic models of instantaneous oil spills are proposed, and CFD simulations with FLUENT software were carried out. Experimental tests were also designed and performed. These experimental tests are intended to verify the performance of the proposed model and CFD simulations and to investigate the fluid dynamics of accidental oil spills caused by grounding and collision. The results from the tests provide some quantitative information on the behavior of oil spills from damaged tanks with different tank designs that are either below or above the waterline. The model tests also show how the space between the inner and outer hull will capture the oil that is spilled from the main cargo tank. The effectiveness of these spaces in terms of retaining the oil is influenced by the tank designs and opening conditions. In general, the double-hull design has the best performance, while the double-side and the double-bottom design help to reduce the oil spill and increase the oil spill time.

1. Introduction

An important part of protecting the environment is to ensure that there are as few spills as possible. Accidental oil leakages sometimes occur and require a quick and adequate response in order to reduce the environmental consequences. Both the government and industry are working constantly to reduce the risk of oil spills by introducing strict new legislation and stringent operating codes (Fingas (2001)).

Most tankers are loaded such that the internal pressure at the tank is larger than the external sea pressure. Thus, if the tank is damaged, cargo flows out. If the tanker carries substantially less cargo such that the hydrostatic balance is established at—or several meters above—the tank bottom, water tends to enter the ship through the hole in the hull as long as the highest point of damage is below the hydrostatic balance level (National Research Council (1991)). The industry has invoked new operating and maintenance procedures to reduce the number of accidents that lead to spills. Based on historical statistics, grounding is the leading cause of oil spills from vessels (26%), followed by collisions at 22%. Some other accidental causes of oil spills are explosion/fire (9%), ramming (9%) and sinking (7%); human error (5%) and mechanical failure (2%) cause the least number of spills (Keisha, 2005). The complete analysis of ship grounding and collision is an extensive process and can be divided into several approaches. A systematic design procedure for grounding was presented by Amdahl et al. and is shown in Fig. 1 (Amdahl et al., 1995). The starting point is to characterize the ship dimensions, structural scantlings, forward speed and cargo arrangement. The sea floor conditions are very important and may vary from sharp rocks to hard shoals or soft clay/sand banks. Step two describes the external mechanics during grounding and collision, i.e., rigid body motions and the hull girder loads (Tavakoli et al., 2007). During this stage, the hydrodynamic loads interact with the grounding and collision loads. In collision and grounding, when the hull of a loaded tanker is ruptured, some of the oil flows into the sea. The damage to the hull girder is determined in step three. This step describes the internal mechanics and is closely related to step two in the sense that the evolution of the hull damage must be determined by taking into account rigid body motions that affect the degree of structural damage (Tavakoli et al., 2007; Alsos et al., 2007). The next step deals with the residual strength of the ship in its damaged condition. If the ship rests on the sea floor, further damage and additional hull girder loads may be caused by ebb tide and waves. After the hull damage is determined, the consequences of the grounding and collision incident may be estimated in terms of oil spill, water flooding and damage stability, which is done in step five. The present paper focuses on this step. Finally, in step six, the resulting damage/oil spill can be evaluated against some acceptance criteria. These criteria may be expressed as limits to oil.

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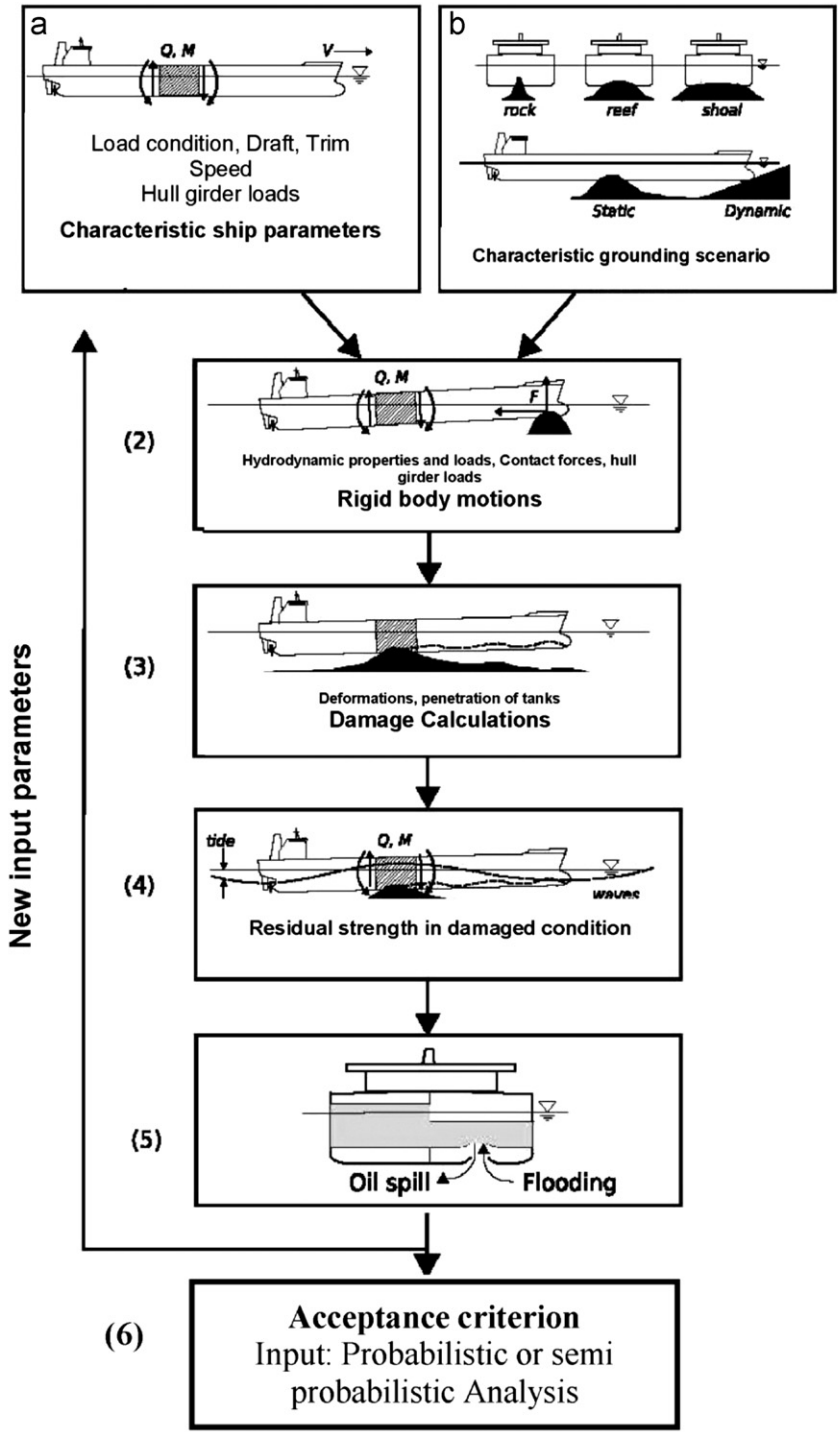

Fig. 1. The process of grounding analysis.

Generally, an oil spill involves the motion of two immiscible liquids in complex geometries and at a wide range of length scales. The oil loss includes both instantaneous loss and subsequent loss due to environmental effects such as tide, current and wave action. The instantaneous oil loss depends on the tank design, ship speed and the size of the hole at the damaged location. In the grounding scenario, if the internal hydrostatic pressure is higher above the opening, outflow occurs and produces a gravity current. The hydrostatic pressure is the key factor in analyzing the leak rate. The flow continues at an ever-decreasing rate until the inside and outside pressures are equalized. In order to calculate the theoretical outflow rate and spill volume, a model based on Bernoulli's principle is proposed (Tavakoli et al., 2008) and developed to cover the hydrostatic changes due to an oil spill (Tavakoli et al., 2009). Karafiath and Bell (1992a,b) performed the model tests of oil outflow for mid-deck and double-hull tanker configurations.

Analytical methods were applied for the analysis of oil–water flow for tanks with damage in the form of openings, and the total spill and loss rate were established. The effects of various configurations of hull designs were studied. The analytical model was also extended to cover collision Scenario and CFD simulation