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Grounding Bottom Damage and Ship Motion over a Rock

Bo Cerup Simonsen
Department of Naval Architecture and Offshore Engineering, Technical University of Denmark
Lyngby, Denmark

Tomasz Wierzbicki
Department of Ocean Engineering, Massachusetts Institute of Technology, Cambridge, MA, USA

ABSTRACT

A model for prediction of damage to tankers during grounding is presented. The model takes into account the coupling between the external ship dynamics and the local damage process of the hull girder. The model for the local damage is based on a least upper bound solution with kinematic compatibility between all structural members. Friction is taken into account, and it is shown how friction contributes to the horizontal resistance force and the vertical reaction force. The resistance of the structural members is expressed in closed forms thus requiring very little modeling time. The model was validated by small-scale tests and a large-scale test. Application of the theory is illustrated by a study of the grounding damage of a single-hull VLCC.

INTRODUCTION

The urgent political, social and economic reaction to the grounding of the *Exxon Valdez* and the promulgation of OPA90 presented the opportune climate to mobilize and impel further research activities in the field of crashworthiness of ships.

In the automotive industry, the application of international crashworthiness performance criteria is an established practice, preceded by two decades of research and development by the industry and its regulatory agencies. The philosophy of setting performance criteria derived from fundamental principles of mechanics and the detailed knowledge of structural response during a crash has been a driving force for innovative design in this highly advanced and competitive market.

In the maritime industry, however, sufficiently detailed and accurate analytical methods for damage prediction due to grounding have not been developed. The existing methods such as those of Minorsky (1959) and Vaughan (1978) are often gross approximations, lacking detail and accuracy due to simplified assumptions, primitive parameters, and debatable failure criteria. Clearly, a crashworthiness engineering approach to ship design is a departure from traditional industry methods because it emphasizes a new technology which reverts to a more basic knowledge of the grounding damage process at the detail level.

The objective of the current paper is to present the basis of an analytical model for assessment of ship damage due to grounding on hard rock.

As for ship-ship collisions, it is convenient to separate the grounding problem into external dynamics and internal mechanics. External dynamics is concerned with the global ship motion, and internal mechanics describes the structural response to the penetrating rock. The present model takes into account the coupling between external and internal mechanics.

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EXTERNAL DYNAMICS

This section is concerned with the external dynamics of a ship grounding process and it describes how the global ship motion is calculated in the present analysis. For grounding on a sandbar of a sloping beach, it is a common practice to consider only motion in the vertical plane due to the two-dimensional nature of the beach. (See for example Simonsen and Pedersen, 1995.) For grounding on a relatively narrow object like a rock, however, such an assumption is too restrictive and a more general case of motion in all six degrees of freedom must be considered.

The section is organized in the following manner: First we consider horizontal plane ship motion in order to find the effect of hull rotation around a vertical axis (sway, yaw). It is here assumed that the vertical component of the rock reaction is zero. Due to a nonlinear character of the equations of motion, the problem must be solved by a numerical time simulation procedure. The analysis shows that we can assume the damage path to be linear and neglect the sway and yaw motion. Then, in a separate analysis the motion in the remaining degrees of freedom (surge, heave, pitch, and roll) is considered and two relationships between ship motion and ground reaction are developed based on a static equilibrium and a balance of energy.

Ship Motion in Horizontal Plane — Damage Path

When a ship runs aground on a rock which is not in the symmetry plane, the ship will begin to rotate around a vertical axis at the rock. It would be convenient to neglect this sway and yaw motion but to justify such a simplification, three questions have to be answered:

- Can the damage path be assumed to be linear?
- Will the damage path stay within the ship or leave it?
- Does a substantial part of the initial kinetic energy go into the sway and yaw motion?

In order to answer these questions accurately it is necessary to solve the equations of motion for the ship numerically. If it is found necessary, closed form expressions for the above-mentioned effects can be developed subsequently. It should be empha-