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Comparing rock shape models in grounding damage modelling

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ABSTRACT

Groundings are among the most common and destructive maritime accidents. Sea bottom shape influences greatly what kind of damage the ship structure suffers and whether this leads to loss of water tightness.

Sormunen et al. [21] presented and statistically compared rock models used in grounding damage analysis with detailed bottom shape data from two Finnish harbour fairways. The results were promising in terms of statistical fit especially for the binormal rock model, which also showed a wide range of flexibility in representing different types of sea bottom shapes. However, this measure does not explicitly tell if the model rock in grounding damage analysis results in similar damage size as real rocks cause. To test this, this paper develops a framework for studying, testing and evaluating rock models in terms of resulting grounding damage. FEM is used to analyse and compare grounding damage of rock models to the actual rock using otherwise identical grounding scenarios. Analysis is performed for four different real rocks with each rock being modelled with four different analytical rock models as well.

The results show that rock models with good statistical fit did not necessarily result in similar grounding energy compared to results using the real rock. Differences in energy are caused especially by the rougher surface of the real rocks. For the similarity in rock area and the damaged ship structure element volume the results are much better, especially for the binormal model. As such another criteria for evaluating rock models for grounding damage analysis is needed. The results show that the damaged material volume is strongly linearly dependent on the rock area- and volume metrics. A similar linear dependency exists between the damaged volume and the energy dissipated in grounding. Knowledge of these relationships can be used towards estimating grounding damage of ships in future investigations, but rock surface unevenness should be evaluated as well.

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1. Introduction and aim

Groundings are among the most common and destructive maritime accidents that can lead to loss of ship, cargo, life as well as potentially long-term environmental damage if noxious liquid cargo is spilled. To model grounding risk several studies have been conducted, see e.g. Refs. [15,17] and [5] for an overview. Understanding the risk is the first step towards mitigating it.

There are different approaches and tools for predicting grounding damage on ships ranging from simplified analytical methods to detailed non-linear finite element analysis [2,22]. In general, these tools require a number of inputs related to the ship (mass, velocity, structural scantlings, etc.) as well as inputs related to the sea bottom shape and ship draft during grounding. The sea bottom shape is one of the important factors that determine whether a grounding leads to loss of watertightness and consequently to a spill [1]. Currently the sea bottom during grounding is most often assumed to be a symmetrical conical object, see e.g. Refs. [16] and [20,6]. and [7] use a polynomial rock while in Ref. [21] a binormal rock model was proposed. A discussion of the sea bottom shape models can be found in Ref. [21]. To which extent these rock models represent real sea bottom shapes is unknown. Therefore [21] tested four different analytical rock models and their goodness-of-fit to real data in terms of coefficient of determination (R^2), This gives a quantitative metric to how closely the rock model shape matches the data. The analysis was carried out using real bottom shape data from Finnish Transport Agency covering the two busiest Finnish tanker harbour fairways. The tested model rocks included proposals from the literature as well as novel models proposed in that paper: two different polynomial equations, a cone and a binormal function. The results show that the binormal function gives overall the best results and for most cases a good statistical fit in terms of coefficient of determination (R^2). However, this mathematical fit does not necessarily mean that the rock model would result in similar grounding damage as the real rock in identical grounding scenarios.

Therefore, the main aim of this paper is to develop a framework for systematically studying, testing and evaluating rock models in terms of resulting grounding damage. This includes quantifying the most important parameters and comparing whether a rock model with a good statistical fit results in similar grounding damage as the real rock. The insight gained by comparison of structural damages and absorbed energies is vital for assessing the overall performance of analytical rocks and thus sets a stage for improvements in damage stability rules and regulations.

2. Framework

The authors propose a four-step framework for comparing grounding damage differences using rock models and actual rock data:

- Step 1: Selection of real bottom data and bottom shape models for analysis.

Current rock shape assumptions in literature are cone- or polynomial shaped models, which show a relatively poor statistical fit to real data. Furthermore, there is a large variation in size and shape of real bottom shapes, which needs to be reflected in the rocks and rock models that are used for studying grounding damage [21]. Therefore, four different rocks representing various sea bottom shapes and four rock models are selected for analysis, see Eqs. (1)–(4).

- Step 2: Grounding damage estimation with selected rock models and real rocks.

Knowing the exact shapes of the rocks, non-linear FEM is used to calculate the grounding damage for each case. In these comparative simulations, the same ship is used and the only changing input variable is the sea bottom shape, i.e. rock.

- Step 3: Comparison of obtained grounding damage.

Knowing the results from step 2, the grounding damage due to different rock models is then compared with the results obtained using the real rocks. Furthermore, the main parameters affecting the differences in damage results are determined and analysed. This has currently not been studied systematically in the literature.

- Step 4: Acceptance or revision of bottom shape models.

Based on the findings in step 3, the goodness of the bottom shape models is evaluated and the degree to which they can be used to replicate real rocks is assessed. In this paper this is done by using a similar grounding scenario for the real rock and for each of the rock models, for which the differences in damage are compared. The differences in damage results are evaluated and compared to the degree of geometrical similarity between the rock model and the real rock. This is measured in terms of coefficient of determination (R^2), which has an upper limit of 1 for a perfect fit of the model to the data. The assumption is that as R^2 goes towards 1 the grounding damage difference goes to 0 between the model and the real rock. If the results show a poor fit in terms of grounding damage, recommendations for improving the accuracy of the rock models are given.

This framework is applied on case study bottom data from selected Finnish fareways, which is described as follows.