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Estimating sea bottom shapes for grounding damage calculations

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ABSTRACT

Groundings are among the most common and serious maritime accidents. The shape of the sea bottom is one of the important factors that determine the extent of grounding damage on ships, including loss of watertightness. This paper presents a four-step methodology for mathematically analyzing sea bottom shapes, where individual peaks are identified and isolated from larger datasets. To these individual peaks mathematical models are fitted and the goodness of the fit is evaluated.

The aim is to develop mathematical rock models that can be used in grounding damage analysis. The method is applied to bottom topography data from the two busiest tanker harbors in Finland. As potential mathematical rock models common assumptions found in literature as well as new suggestions are used.

It was observed that rocks vary in shape and size locally as well as between different geographical areas. This highlights the need to have rock models that are flexible enough to model a wide range of sizes and shapes so that the local conditions can be taken into account. This includes modeling asymmetrical shapes, which is not taken into account in the current models. The analysis results suggest using a binormal function to describe the bottom shape: This model gives overall better goodness-of-fit test results than the cone and polynomial models. In the data the binormal model can model well the also the bottom shapes where the polynomial and conical models had a good fit in statistical terms. Although the paper discusses data

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from the Gulf of Finland, the framework for analyzing bottom shapes is expected to be applicable to other sea areas as well.

1. Introduction

Groundings are among most common and serious maritime accidents. As grounding happens, significant parameters affecting the resulting damage are e.g. ship kinetic energy, loading condition and structural solutions (e.g. double bottom, compartments), the angle of attack to the ground and tides, and the properties of ground itself (e.g. shoal, rock). The relation between kinetic energy, structural solutions, the resulting damage and the residual strength of hull girder has been investigated by several authors using idealized bottom shapes such as cones and parabolas [1–4,8–10,14–18,21–23,33–37,39,40].

However, as stated by several authors (e.g. Refs. [1,11,24,34]) bottom shapes have central role in ship grounding event and therefore need further investigation. As an example of this [1] presented a comparative study on a single ship grounding on rock, reef and shoal. While sharp shape cuts the plating easily, the damage might be limited. As the size of indenter increases, the damage naturally spreads out for larger area in double bottom. Even if there is no hull fracture, the overall damage may harm the global strength of the hull girder [1,5,35]. From a risk analysis perspective this has significant implications; e.g. on oil tankers a widespread damage might result in no oil spill if it is absorbed by the outer hull whereas a narrow but deep cut that penetrates the inner hull might result in a significant oil spill.

Another important issue is the grounding depth. Currently it is assumed to be either triangularly [13,30] or uniformly distributed [13]. In a triangular distribution the theoretical grounding depth range is between sea level ($z = 0$ m) and vessel draft. The most likely grounding depth is so that the sea bottom barely scrapes the ship bottom and the least likely grounding depth is at 0 m depth. [13] created the distributions based on expert opinions, not on empirical data. Grounding reports usually do not specify the actual grounding depth, thus there is a need for further research. Tikka et al. [30] state that "Distributions for speeds, obstruction depths, and tides were based on the data from charts, NOAA[1], USCG[2] offices, and pilots," but the exact data or methodology behind arriving at triangular distribution for the grounding depth is not specified.

This paper describes a systematic approach to identify individual peaks from the sea bottom data pool and how the individual peaks can be modeled mathematically for grounding damage calculations. The paper also aims at testing the assumptions regarding grounding depth and the current conical rock shape assumption using bottom topographical data from selected Finnish harbors. Having correct assumptions regarding these factors is important for the damage estimation in the existing grounding models.

1.1. Current rock shape assumptions in literature

Currently the bottom shape during grounding is assumed to be a symmetrical cone-like object with varying diameter and slope. Most commonly the rock is assumed to be a blunted cone, see e.g. Refs. [15,21,26]. There is some variations in how the cone tip looks like, i.e. whether it is simply cut-off or rounded, see Fig. 1. Another rock model found in literature is the polynomial rock used by Ref. [9]; who use a 2nd order polynomial equation to describe the rock, see Fig. 1. The equation is

[1] National Oceanic and Atmospheric Administration.
[2] United States Coast Guard.