SHIP-GENERATED WAVES OVER A COMPLEX BATHYMETRY

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INTRODUCTION

Problems related to shipping have increased worldwide during the last decades as a result of more traffic travelling at higher speeds and using larger vessels. When ships move in a restricted fairway they generate primary (drawdown) and secondary (transverse and divergent) waves (Bertram 2000) that often cause adverse impact to adjacent shores.

An example of this is the Furusund fairway in Sweden, which since the 1980's has experienced increased traffic and larger ships. This has resulted in a loss of natural fine sediment habitats along the shores as well as structural damages to piers and jetties (Granath 2015). Furusund is an important fairway into Stockholm, the capital of Sweden, and is located about 25 km north of the city within the Stockholm archipelago. It is mainly trafficked by large ferries (length/width/draft: 200x30x7m). The wind-wave regime in the fairway can be described as a low-energy environment, due to the short fetches and no swell. Hence, ship waves have a significant impact on the shores in terms of bed and bank erosion.

This study aims at determining the primary ship wave characteristics and their relationship to ship properties and bathymetric conditions in the Furusund fairway. Measured water levels were collected for this purpose during three months at three locations. Existing empirical formulas for drawdown are evaluated based on the measurements and compared with a new formula derived for the specific fairway. The results are used for designing nature-based protection against ship-generated waves along the shores and to validate analytical and numerical models that can be employed for ship wave generation and propagation.

METHODOLOGY

A field campaign was carried out between June and August in 2014 with the purpose of measuring water levels at three locations within the Furusund fairway, one month per location; however, only two locations are used in the present analysis. Measurements were made with a capacitance gage, sampling the water level at a frequency of 4 Hz. Information about ship passages in the fairway during the measurement campaign was collected from AIS data (Automatic Identification System) provided by the Swedish Maritime Administration. AIS includes information about ship position, speed, course, heading, draught, name, and identification number. From the identification number, information about ship properties such as length and width could be obtained. The field campaign included about 2,100 ship passages.

For each ship passage, a 15-min long sequence of measured water levels was extracted. Each sequence was filtered with a low-pass filter in order to extract the primary waves using a zero-down crossing method. Primary waves were defined as waves with a period longer than 20 sec and an amplitude exceeding 5 cm. The low-pass filter eliminated the signals from the wind-generated waves and the secondary waves.

Eight empirical formulas derived for estimating drawdown (Bhowmik et al. 1981; CIRIA et al. 2007; Dand and White 1978; Gelencser 1977; Hochstein 1967; Kriebel et al. 2003; Maynord 1996; Schijf 1949) and five empirical formulas developed for calculating ship squat (Barrass 1979; Eryuzlu et al. 1994; Huuska 1976; Römisch 1989; Yoshimura 1986) recommended by (Briggs et al. 2010) were applied and evaluated against 530 measured drawdown waves. Squat formulas are included to investigate if this type of formulas also can be applied for predicting drawdown heights in fairways with complex bathymetry.

Then, new empirical formulas were derived for drawdown height and wave period based on measurements and regression analysis with dimensionless groups associated with the physics of ship wave generation.

RESULTS

Figure 1 displays measured water levels during a ship passage where the primary wave can be seen as a depression, followed by a package of secondary waves.

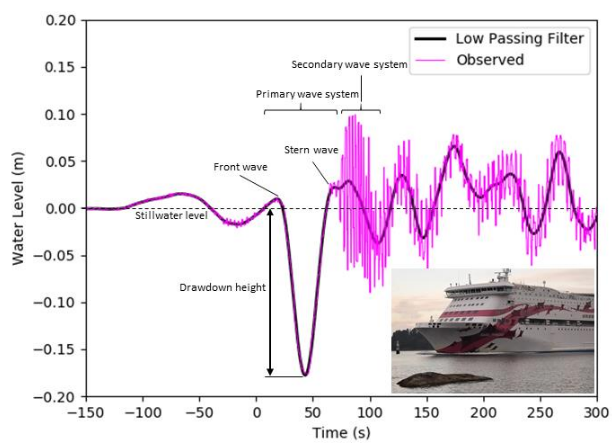

Figure 1 - Measured water level during the passage of Baltic Princess (shown in right corner). Time corresponds to when the ship passes the measuring station.

The height of primary waves reaches up to 0.32 m and the period up to 119 sec. The distributions of heights and period vary depending on whether ships are inbound or outbound in the fairway. Data shows considerable scatter and none of the nine included parameters has a correlation higher than $r = 0.51$. The highest correlation is obtained for distance from ship to shoreline. The importance of this parameter explains why Bhowmik et al. (1981) and Maynord (1996) are the only evaluated formulas having a R^2 higher than zero, since they include this parameter. However, the two formulas are not able resolve the scatter in data and they underestimate the drawdown heights for larger waves (see Figure 2).

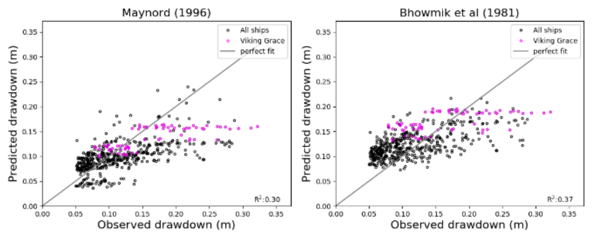

Figure 2 - Predicted drawdown for the two best performing formulas. Black markers shows all data, pink markers show drawdown for one specific ship, "Viking Grace", and the grey line shows a perfect fit between observed and predicted.

Based on the dataset in this study, two new formulas for drawdown height and for wave period were developed, using regression analysis for selected dimensionless variables. The formula for drawdown height performed better than the evaluated formulas, with an R^2 = 0.50, whereas the formula for wave period only had an R^2 = 0.22 (see Figure 3).

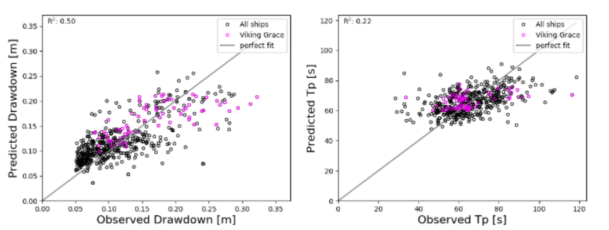

Figure 3 - Predicted drawdown height (left figure) and period (right figure) using the newly derived empirical formulas. Black markers shows all ships, pink markers indicate one single ship, "Viking Grace", and the grey line shows the perfect fit.

DISCUSSSION AND CONCLUSION

Few studies have investigated ship wave generation in fairways with a complex bathymetry. However, the ability to predict drawdown heights in such locations are important in fairways where protection against ship waves are needed.

From the measurements included in this study, it is apparent that the shape of ship wave system is in agreement with ship waves in fairways with less complex bathymetry. Nevertheless, this study indicates that the generation of primary waves is affected by the bathymetry and/or by dynamic processes as ships maneuver in the fairway. This explains why none of the empirical formulas, included in this study, are able to satisfactory predict drawdown. This is further illustrated by the difference in distribution between drawdown for inbound and outbound ships. The formula for drawdown, derived in this study performs better than the existing formulas, but the former still contain significant scatter.

This study shows that in fairways with complex bathymetry empirical formulas for primary waves should be used with caution; however, they are useful for conceptual studies not requiring great detail.

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