COMPREHENSIVE MEASUREMENTS AND ANALYSIS OF SHIP WAVES IN THE ELBE ESTUARY, GERMANY

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INTRODUCTION

Hamburg has one of the biggest harbors in Europe and is a destination of the world's largest container vessels. However, the harbor approach extends for more than 100 km through the tidal Elbe estuary leading to a channel like confinement of the waterway, which is known to enhance primary ship wave processes and thus hydrodynamic forces on the river bed and banks. The ships speed is another major predictor for the ship wave intensity and an area of tension between environmental, nautical and economic interests. To determine the current state of the ship-induced loads on the banks and bed of the Elbe estuary, an ongoing in-situ measurement campaign along the estuary is set up to collect hydrodynamic data at different locations over a period of multiple years.
An important aspect of the analysis is to establish the relationship between the vessel properties, the waterway geometry and the resulting ship wave. Typically, this relation is solely determined for a specific cross-section geometry (Almström & Larsson, 2020). For the first time, the large number of measurements taken in different locations within varying cross-sections makes it possible to illuminate this aspect and thus include it as a predictor. Furthermore, the influence of large ship encounters shall be investigated, as up to 104m added ship widths are allowed to pass each other in a narrow area just before Hamburg. A permanent measuring station there was set up to investigate detrimental superposition of these waves, which is also a new and unprecedented investigation in this research field.

MEASUREMENTS

The measurements are conducted using bottom mounted ADCPs. With this instrument, multiple aspects of the hydrodynamic loads can be gauged simultaneously at one location. The vertical beam is utilized, using Acoustic Surface Tracking, to measure the water surface excursion due to tides, ship and wind waves in 8 Hz. Parallel to this, the flow velocity is profiled over the water column, determining the tidal and the ship-induced currents in 1 Hz. Those different signals are split into individual frequency components, to process them separately. The ship wave events are isolated using AIS (Automatic Identification System) data allowing dynamic (e.g. ship speed, passing distance) and static (e.g. dimensions, draught) ship properties to be assigned to the waves.
To this date 590 continuous days at four different locations along the estuary with about 25.000 ship passages are captured. The permanent measuring station is currently in continuous operation for over 14 months. The other stations were deployed for ten to twelve weeks each. This quantity makes the data set exceptional unique, as similar investigations rely on way less data points (e.g. Almström & Larsson (2020) with 466 ship wave events, Muscalus & Haas (2022) with 343 ship passages). The measurements are ongoing and will be expanded to further locations in the next two years.

Figure 1 - Bottom mounted ADCP before deployment

PRELIMINARY RESULTS

In the analysis of the preliminary dataset, the drawdown zA is used as a proxy for the ship-induced loads. The data shows, that container ships are the primary source of the loads as 97 of the 100 highest primary wave events are associated with those vessels, in particular the ULCS (Ultra Large Container Vessels). Applying regression analysis to the data, shows strong correlation between drawdown and a combination of ship and cross-section parameters (e.g. blockage factor n, depth-based Froude number Fr, passing distance m_A as seen Figure 2).

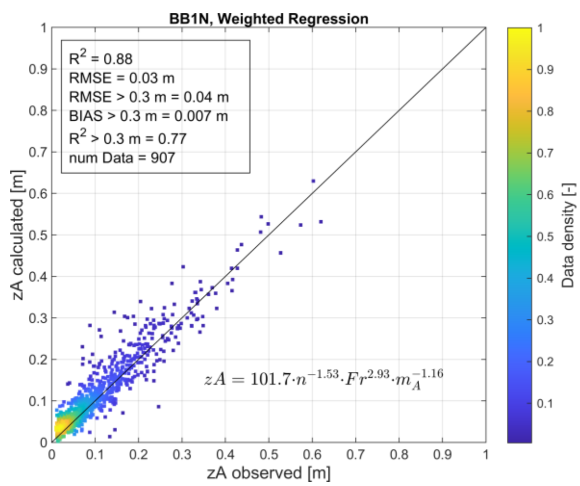

Figure 2 - Results of a weighted nonlinear regression analysis on data from a location at Schulau, near Hamburg

This model derived from in-situ data can be can be verified by comparison with scaled physical model experiments from a ship wave basin (Figure 3). At medium speeds ($8\ to\ 11\ knots$) there is a good match of the drawdown heights. At higher speeds ($> 11\ knots$), which is an extrapolation of the measured data, it shows an underestimation. However, it also shows that the extrapolation points in the right direction, which subsequently indicates a possible generalization of the regression model.

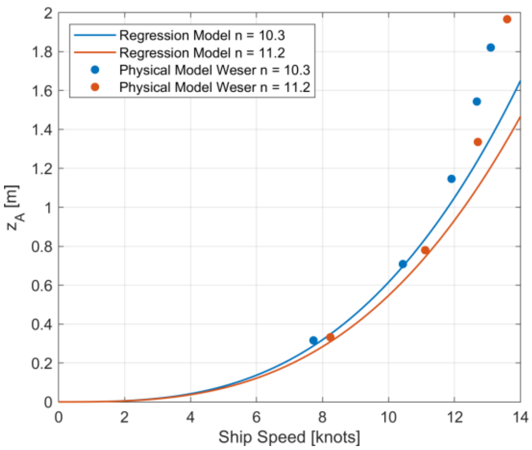

Figure 3 - Results of the regression model and scaled physical model experiments for blockage factor n=10.3 and n=11.2.

The model can be used to determine the temporal course of the ship wave distribution by applying historical AIS and bathymetric cross-section data to the equation.
This allows, for example, to investigate the efficacy of the ship speed regulation, which was introduced in the Elbe in 2018. For a location at Schulau, near Hamburg it can be shown, that median and peak loads, due to the faster travelling vessels are both significantly reduced due to this measure (Figure4).

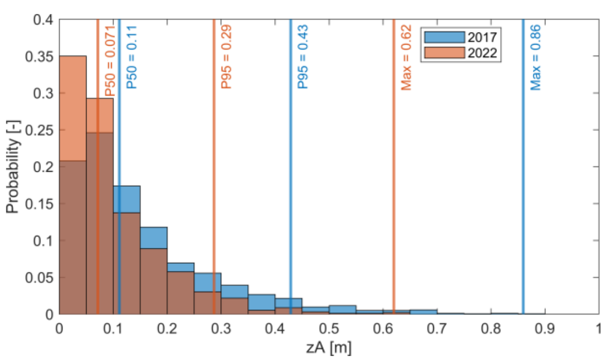

Figure 4 - Comparison of measured (2022) and calculated (2017) drawdown heights before and after the introduction of the speed regulation

The preliminary analysis of ship encounters indicates a superposition of the waves when two large vessels encounter each other. However, in these situations, the ships tend to sail slower, whereby only moderate drawdown events occurred to date in these situations. However, the location of the encounter varies heavily along the river section, which results in a small probability to measure the wave at a fixed location. Therefore, the deployment time of the permanent measuring station must be increased in order to allow for a more detailed analysis.

OUTLOOK

The measurements will be continued at different locations along the Elbe estuary. An important aspect of the further analysis will be the investigation of the influence of the cross-sectional channel geometry on the wave generation as well as the wave transformation to the bank. Based on this, the spatial distribution of ship waves along the Elbe estuary will be investigated. Subsequently, the relation of ship-, wind- and tidal wave loads along the river will be compared.

REFERENCES

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