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MEASUREMENT AND ANALYSIS OF SHIP'S SQUAT ON THE RIVER ELBE, GERMANY

by

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ABSTRACT

Among the many challenges in reference to the development of today's ports, the accurate prediction of ship's squat for current and future vessel types is of major significance in terms of operability and safety. Due to constantly increasing vessel dimensions, the under keel clearance has become a limiting factor for traffic on the waterway of the Elbe estuary in northern Germany in recent years. Thus, the approach to the port of Hamburg is tide dependent for many modern vessels and regulated according to a tidal transit-schedule managed by the German Federal Waterways and Shipping Administration. To ensure an optimized economical utilisation of the Elbe waterway, a reliable and estuary-specific assessment of the ship's dynamic response in restricted waters is crucial.

In order of the Waterways and Shipping Board Hamburg and in cooperation with the German Federal Waterways Engineering and Research Institute as well as the Hamburg University of Technology, Consulting Engineers von Lieberman implemented an extensive campaign to measure the ship's dynamic behaviour in various boundary conditions. Between 2013 and 2016, the estuary-specific correlations between the vessels' squat and hydrological, hydrodynamic, nautical and operational parameters (e.g. propeller revolutions) were investigated for container vessels with lengths up to 400 m and for capesize class bulker carriers. Measurements were carried out on board of the design vessel itself as well as on a research vessel, which escorted the design vessel along the pilotage area of the Elbe (approximately 65 nm). The survey comprised of 21 measurement runs on seven different vessel classes characterizing the current fleet on the Elbe. For most of these classes two outbound voyages and one inbound voyage were surveyed.

Aboard the design vessel, six high-precision differential GNSS receivers were installed to record the vessels' motions, positions, speed etc. with a frequency of 2 Hz. The devices were installed at the bow, on the wings and at the stern of the design vessel at portside and starboard side (figure 1). The convoying research vessel was used to measure the local salinity (using a CTD-probe) as well as the local current velocity and direction (using a Doppler Velocity Log DVL). AIS signals were recorded to collect data on encountering and overtaking vessels. Additional information about operational parameters of the design vessel was obtained from the VDR data. Mathematical models were applied for spatial and temporal interpolation of recorded water levels from existing gauges along the Elbe to the exact position of the design vessel. The bathymetry along the vessel's track was generated from official data sets and updated regularly with routine sounding data provided by the Federal Waterways and Shipping Administration and Hamburg Port Authority. Applying this holistic setup, an overall accuracy of the measured squat of ± 0.10 m or even better could be ensured.

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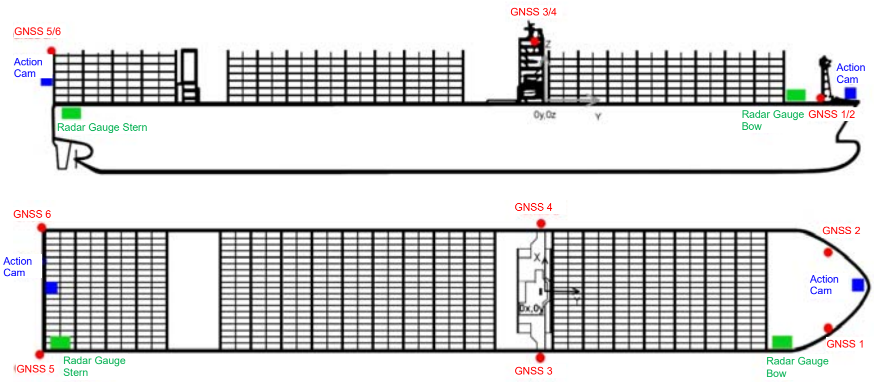

Figure 1: Position of the measuring equipment on the design vessel

The extent of the measurements, the number of considered parameters and the achieved accuracy form a unique squat data set. Based on its high resolution and its completeness it allows an unrivalled comparison between real sinkage and theoretical squat, for example calculated based on the ICORELS formula.

The theoretical squat according to the ICORELS formula is used in a slightly modified form within the framework of the Elbe tidal transit schedule. This approach differs by a pre-factor from the original formula published by PIANC in 1977. In the Elbe tidal transit schedule, a location-dependent ICORELS factor *Ic(x)* is used instead of the empirical coefficient of 2.4 for conventional ship forms. This factor takes into account not only the ship's form, but also waterbody-specific factors.

$$dts = Ic(x) * \frac{\mathrm{B} * TG_{SW}(x) * C_B}{L_{PP}} * \frac{{Fr_h}^2}{\sqrt{1 - {Fr_h}^2}}$$

$$Fr_h = \frac{v_w(x_s)}{\sqrt{g \cdot h(x_s, t)}}$$

The Froude's depth number Fr_h contains the speed of the vessel through water $v_w(x_S)$ that was derived from the current measuremnets on the conveying vessel and the local water depth h. The displacement volume of the design vessel is determined using the ship's width B, the location-dependent draught of the vessel $TG_{SW}(x)$, the length between perpendiculars L_{PP} and the block-coefficient of the vessel C_B. The C_B-value was selected for the mean draught and adjusted for the voyage based on the variation in water density (derived from the CTD data) and resulting change of draught.

The recorded and processed data were subsequently used to analyse the following parameters in detail:

- Comparison of measured squat to theoretical squat according to ICORELS
- Correlation of speed through water and squat
- Correlation of under keel clearance and squat
- Correlation of river width and squat
- Effect of ship-to-ship interaction on squat
- Correlation of drift and squat.
- Correlation of change of water density and change of trim
- Effect of heel on draught
- Effect of meteorological influences on the vessel's dynamics

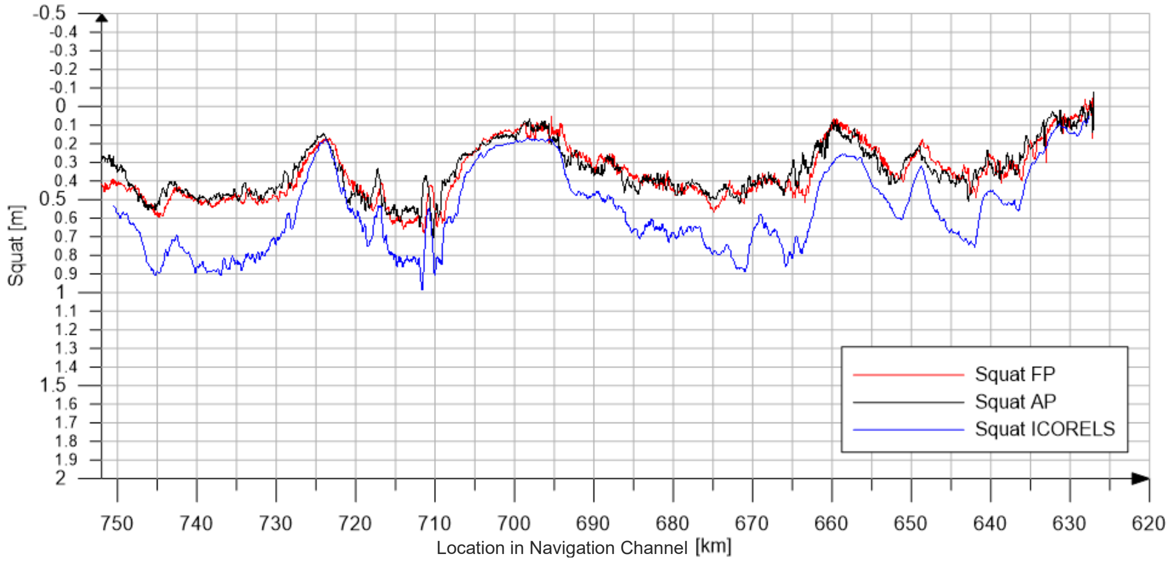

Figure 2: Comparison of measured squat at forward perpendicular FP and aft perpendicular AP and theoretcial squat according to ICORELS on vessel class C294

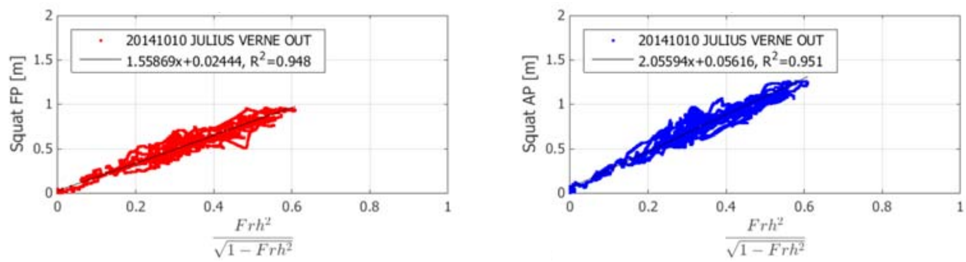

Figure 3: Correlation of squat at FP/AP and TUCK-parameter for vessel class C396

Based on the results of the survey the measured squat was compared to computed squat values using the ICORELS formula that is implemented in the tidal transit schedule for the Elbe (figure 2). The general applicability of this approach, which had been verified for the Elbe for smaller design vessels in an earlier field study, was confirmed to be adequate for the investigated larger vessels as well. Under certain conditions, the ICORELS formula underestimated the measured squat for container vessels with a length over all of 347 m and larger. Here, a dependency on the trim of the vessel could be observed. Additionally, new insights into locally increased squat due to encountering vessels and correlations with the bathymetry could be derived from the analysis (figure 3).