Conference Paper, Published Version

**Uliczka, Klemens; Kondziella, Bernhard**

# Dynamic response of very large container ships in extremely shallow water

Verfügbar unter/Available at: https://hdl.handle.net/20.500.11970/100750

Vorgeschlagene Zitierweise/Suggested citation:
Uliczka, Klemens; Kondziella, Bernhard (2006): Dynamic response of very large container ships in extremely shallow water. In: 31st PIANC CONGRESS, Estoril, Portugal, 14. bis 18. Mai 2006. Estoril, Portugal: PIANC. S. 1-11.

# Dynamic Response of very large Container Ships in extremely Shallow Water

Dr.-Ing. KLEMENS ULICZKA and Dipl.-Ing. BERNHARD KONDZIELLA
Bundesanstalt für Wasserbau (BAW) – Dienststelle Hamburg
(German Federal Waterways Engineering and Research Institute – Hamburg Office)
Wedeler Landstrasse 157, D-22559 Hamburg, Phone: +49 40 81 90 8 0
Klemens.Uliczka@baw.de / Bernhard.Kondziella@baw.de

## Motivation

Within recent years, rapid developments in container ships have by far exceeded forecasts regarding the development of ship size. Very large POST-PANMAX container vessels with capacities of up to about 8,500 TEU already call at the ports of Hamburg or Bremerhaven. Container vessels with capacities of 9,700 TEU should be available in 2008. For this kind of vessel (length about l = 340 m, beam about b = 46 m and draught up to about t = 14.5 m), the dynamic response during channel navigation must be known – on the one hand in order to check if the calculation approaches used for further fairway adaptations of the lower and outer River Elbe and outer River Weser are also valid for such large vessels, on the other hand in order to enable optimum use of the waterways regarding economic aspects.

Initial fundamental studies of the dynamic response of such large container ships in hydraulic models (scale 1:40) have shown tendencies of a reduced squat (ULICZKA / FLÜGGE, 2001; FLÜGGE / ULICZKA, 2001), completed by additional model tests in extremely shallow water which is laterally bounded and unbounded (ULICZKA et al., 2004). Within the framework of a research and development project of the BAW, the response of these ship models in laterally unbounded and extremely shallow water was reproduced for the first time by numerical means using RANSE simulations (AZCUETA, 2003); however, e.g. regarding fairway dimensioning, this method still has to be considered as only having research status.

To complete the systematic fundamental studies, large-scale measurements of the dynamic response of large container vessels during channel navigation on the lower and outer River Elbe were undertaken with the support of HAMBURGER HAFEN- UND LAGERHAUS AG (HHLA), HAPAG LLOYD Container Line GmbH (HLCL) and YANG MING Marine Transport Corporation (YM). As expected, a first comparison with the system tests of the hydraulic model provided a good coincidence of the velocity-dependant squat (ULICZKA et al., 2004). Furthermore, in connection with hydrodynamic-numerical Hindcast modelling of the respective hydrological boundary conditions of the River Elbe, is was possible to compare and assess squat and trim measurements not only at singular cross-sections but along the entire length from Hamburg Harbour into the outer River Elbe over about 120 km almost without gaps, using selected calculation approaches.

Recent findings from additional studies with low under keel clearance (UKC) underline the necessity of continuous monitoring of vessel developments and their response in extremely shallow water as given during channel navigation on German sea-waterways (ULICZKA / WEZEL, 2005).

In the following, the term “Dynamic response” shall be reduced to the vertical vessel movements (squat and trim) in interaction with, amongst others, the vessel’s size, form and speed, fairway boundaries and bed structures. “Squat” shall be the lowering of the moving vessel with the primary wave system produced by itself while underway. “Trim” shall be the vessel’s torsion around its lateral axis, influenced amongst others by certain ship parameters and the vessel speed.

## System tests in a hydraulic model

The system tests in a hydraulic model were undertaken in order to provide the German Federal Waterways and Shipping Administration (Wasser- und Schifffahrtsverwaltung des Bundes, WSV) with the squat and trim parameters for future development planning; squat and trim depend on speed, water level and draught and are useful for the fairway depth determination. The model tests have been split into three sub-projects:

1. Recording squat and trim as well as ship-induced pressure and wave systems while underway over a firm and flat bed in laterally unbounded shallow water.

2. Recording squat and trim as well as ship-induced pressure and wave systems while underway over a firm bed with dunes in laterally unbounded shallow water.

3. Systematic studies for recording squat and trim as well as ship-induced pressure and wave systems while underway in a laterally bounded fairway in shallow water.

Selected results of the sub-projects 2 and 3 are presented below.

The dynamic behaviour of very large POST-PANMAX container ships interacting with beds with various dune configurations as well as laterally bounded fairways was investigated in the BAW-DH shallow water basin (length about 100 m, width about 35 m, max. water depth 0.7 m) at a model scale of 1:40. Selected ship parameters are summarized in Table 1:

| **Designation** | **Length** | **Beam** | **Draught** | **$UKC_R$*** | **$c_B$**** | **$SG^+$** | **Trim** | **$KG^{++}$** |
|---|---|---|---|---|---|---|---|---|
| - | m | m | m | m | - | - | - | m |
| JUMBO | 320 | 40 | 14.5 | 1-2 | 0.740 | 6.29 | hard | 11.8 |
| MEGA-JUMBO | 360 | 55 | 15.5 | 1-1.5 -2 | 0.677 | 6.10 | hard | 10.2 |

*$UKC_R$: under keel clearance ** $c_B$: block coefficient $^+$ SG: slenderness ratio $^{++}$ KG: centre of gravity above keel

Table 1: Ship parameters from investigations in a hydraulic model (scale 1:40)

The investigation's prediction capability was guaranteed by adhering to the geometric and dynamic conditions dictated by dimensional analysis. Using a laser target measuring system installed on the model ships, it was possible to record the vertical dynamic behaviour of the self-propelled, cable-guided models over a distance of approximately 90 m, from the acceleration to the braking phase. The internal velocity-independent forecast precision of the system was $\Delta S < 1$ mm (model; corresponds to < 4 cm in nature). Using the point, laser-geometrical measurement method, predicted values could also be obtained as a function of ship speed ($v_S < 18$ kn) with an accuracy of $\Delta S < 1$ mm (model).

**Ship underway over firm bed with dunes in laterally unbounded shallow water**

The following photo shows the dune section in the hydraulic model used for simulating the influence of bed structures on ship dynamics in extremely shallow water (example: dune length $\lambda_{FIELD} = 50$ m).

Figure 1: Dune section in laterally unbounded fairway in a model scale of 1:40 (here: dune length $\lambda_{FIELD} = 50$ m)

The following graph in Figure 2 shows a continuous recording of the vertical movement of the bow and stern of a JUMBO vessel moving over a flat bed as well as over dunes of 50 m and 100 m length and over a combined bed structure. A comparison of the graphs shows the container vessel’s dynamic response as a function of dune length.

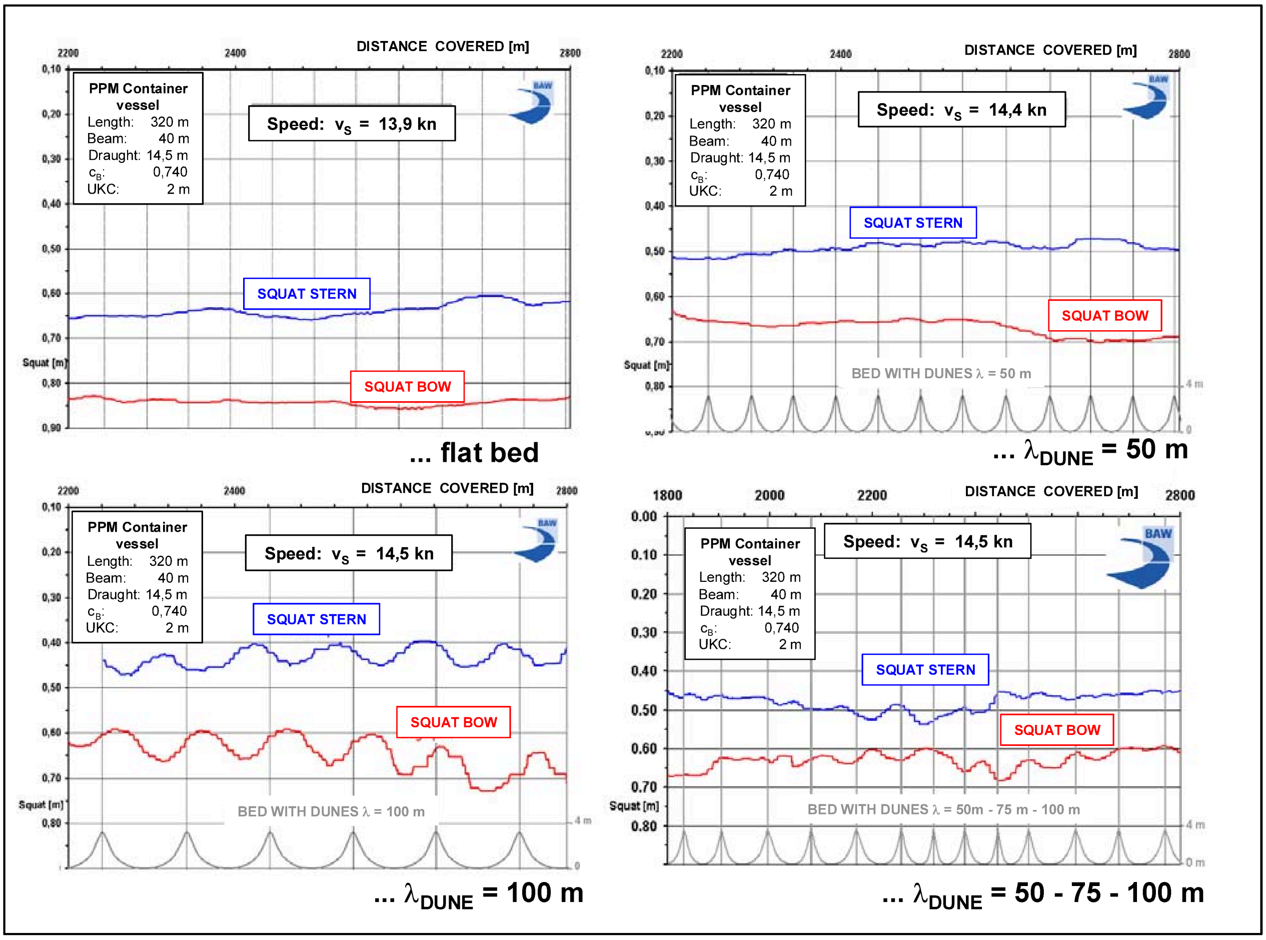

Figure 2: Dynamic behaviour of a large container vessel (JUMBO, bow and stern) moving over a flat bed, over dunes of different lengths, and of a combined bed structure (λ = 50 m, 75 m, and 100 m)

While underway over the dune section with λ = 50 m, the ship showed a slightly disturbed movement in relation to the flat bed. For λ = 100 m, a ratio of dune λ to ship length l of about λ/l = l / 3 was chosen, so that pitching of the large PPM container ship with the period of the dunes could be triggered. Triggering results from the locally higher bow squat with a smaller UKC over the crest of the dune and from the simultaneous lower stern squat with a locally higher water depth in the trough of the dune. The ship velocity-dependent amplitudes achieve maximum values of ΔS = 0.16 m ($v_S$ = 15.3 kn).

The systematic investigations using an array of dune sections of equal length were augmented by ship movement experiments over a bed with dunes of irregular length of λ = 50 m - 75 m - 100 m. Light pitching of the order of ΔS = 0.07 m ($v_S$ = 16.8 kn) was recorded for the JUMBO passing over the irregular dunes. The absolute squat value was reduced similarly to the tests with a constant dune length.

Figure 3 shows the functional correlation of the speed-dependant squat for the JUMBO moving over various bed forms (no dunes, λ = 50 m, λ = 100 m, λ = 50 m – 75 m – 100 m). The results of the point-wise measurements show a definite reduction of squat when moving over a dune section. This is particularly obvious for an under keel clearance $UKC_R$ = 2 m with a resulting squat in the order of up to ΔS = 0.3 m ($v_S$ = 15 kn).

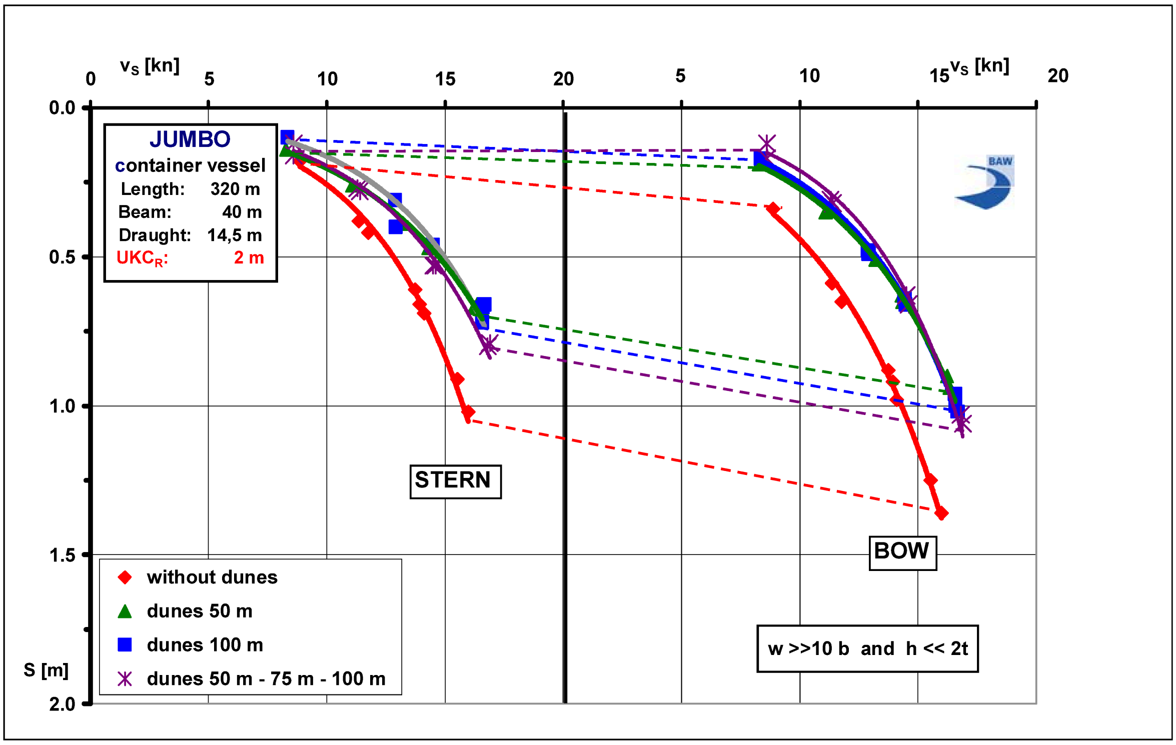

Figure 3: Impact of the bed form on the squat and trim of large PPM container vessel (here: JUMBO) with $UKC_R$ = 2 m

As is the case with the JUMBO, a reduced velocity-dependent squat is also evident for the MEGA-JUMBO over bed forms with dunes ($UKC_R$ = 1.5 m). Different from the JUMBO, the stern squat dominates the bow squat for the MEGA-JUMBO in extremely shallow water, resulting in a negative trim angle. This dynamic behaviour is due to the ship having a large beam (b = 55 m) and a single propeller drive and moving in extremely shallow water (marked pressure minimum from the propeller wake at the stern).

The following hydromechanical processes are important for discussing and explaining the very low squat values measured:

- Squat is the depression of the ship moving with the evolving primary wave system, and is at the same time a characteristic parameter of the ship's drag; by changes in the beam, length and flow-optimized hull forms of modern ships, the geometric conditions for the formation of the primary wave system have changed, and water level depression and thus the squat – with reference to ship size – have decreased.

- The influence of bed structures (dunes) on the dynamic behaviour of very large container ships in extremely shallow water had not been researched to date. For reasons of nautical safety, the maintained depth was based on the crests of the dunes. A higher form roughness of the system, and thus higher energy dissipation for the ship-generated back current, was assumed. This resulted in a stronger primary wave system which in turn increased the squat.

- The systematic model investigations show, however, that in comparison to a flat bed, an increased back current cross-section with accordingly reduced energy dissipation appears for a bed with dunes of very small slope (H = 4 m; $\lambda$ = 50 - 100 m), which in turn leads to weakening of the primary wave system and thus to a decrease in the squat.

- The supplementary investigations on the influence of irregular dunes on dynamic ship behaviour show that "pitching" – though lower than for regular dunes – was also detected here for all ship model types investigated, and that the absolute squat can decrease in a manner similar to the previous bed forms.

### Vessel moving in a laterally bounded fairway in shallow water

System tests for recording squat and trim while underway in a laterally bounded fairway were executed in the BAW-DH shallow water basin; for this purpose underwater structures were schematically simulated by aluminium systems that could be applied flexibly. Vessels moving in trapezoidal profiles (moving in the centre and off-centre) and in combined profiles of slopes and shallow water were investigated. Figure 4 provides a schematic representation of some of the extremely narrow cross-sections out of the test series “Slope / Shallow water” with cross-section ratios for MEGA-JUMBO vessels between n = 17.5 and n = 7.5 and partial cross-section ratios between $n_T = 25/10$ and $n_T = 10/5$.

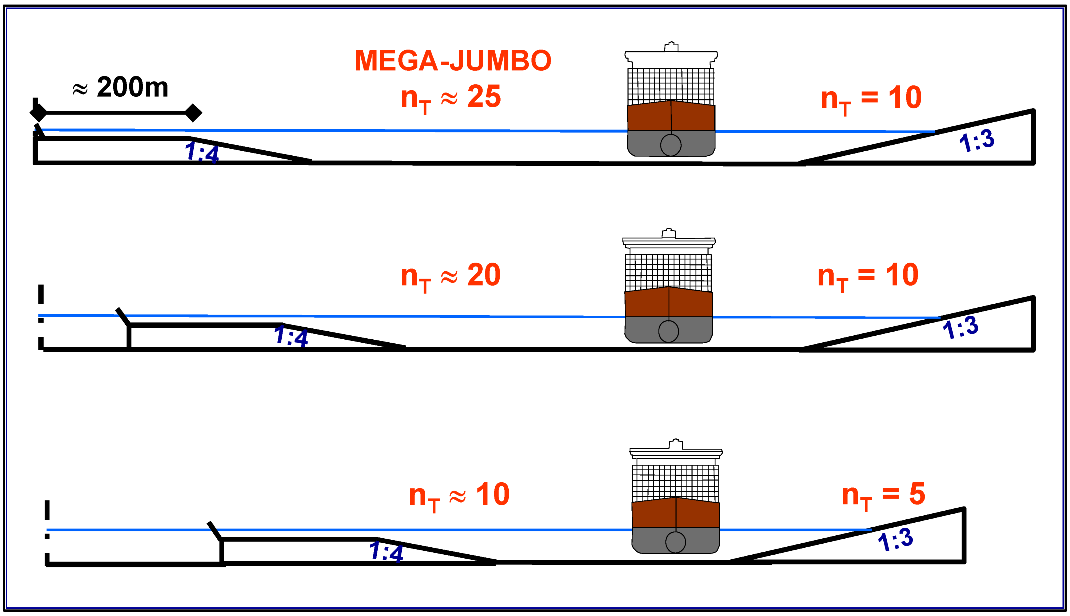

Figure 4: Schematic representation of some of the tested cross-sections out of the test series “Slope / Shallow water”

In order to show the proportions at the BAW testing site, Figure 5 is a photo of a MEGA-JUMBO vessel moving through a profile of the test series “Slope / Shallow water”.

Figure 5: System test for a MEGA-JUMBO vessel underway in laterally bounded shallow water at about $v_{S,MODEL} = 1.0$ m/s ($v_{S,FIELD} = 12.5$ kn; trapezoidal profile n = 15; $n_T = 10 / 20$)

One of the results selected here regards the speed-dependent squat of a MEGA-JUMBO vessel moving in the centre with e.g. n = 15 compared to moving off-centre with $n_T = 10 / 20$ (n = 15); this comparison revealed that, contrary to previous assumptions, the passing distance from the bank and therefore the partial cross-section ratio have an almost insignificant impact on the squat although the one-sided primary wave system, i.e. bank loads caused by swell and receding of the water level as well as back current, strongly increase with lower passing distances. The waterways resistance higher on one side while moving off-centre only impacts the somewhat lower ship velocity at identical propeller revolutions, which becomes clear above all by the possible maximum speed ($\Delta v_{S,MAX} \approx 0.5$ kn).

In Figure 6, comparative graphs of the velocity-dependent squat for the MEGA JUMBO vessel show to what extent lateral fairway boundings, such as shallow water sections, impact the squat within a fairway with a depth ratio of $h_{FAIRWAY} / h_{SIDE} = 3$.

Compared to the laterally unbounded fairway (in red)

- when moving in a trapezoidal profile with n = 25 (green), the squat only increases above $v_S \approx 13$ kn (at $v_S \approx 15$ kn, $\Delta S_{STERN} < 1$ dm increases)
- squat increases by about $\Delta S_{STERN} \approx 2$ dm at $v_S \approx 13$ kn ($\Delta S_{STERN} \approx 3$ dm at $v_S \approx 15$ kn) when narrowing the fairway by lateral shallow water sections (dark-blue)
- the hydraulic effect of the shallow water section (dark-blue) adjacent to the fairway on the squat and the trapezoidal profile (green) is about 20 %.

Changing the cross-section from a continuous slope of 1:4 (light-blue) into a fairway in a laterally quasi unbounded shallow water section (dark-blue) causes a notable squat reduction by approx. $\Delta S_{STERN} \approx 4$ dm at $v_S \approx 13$ kn.

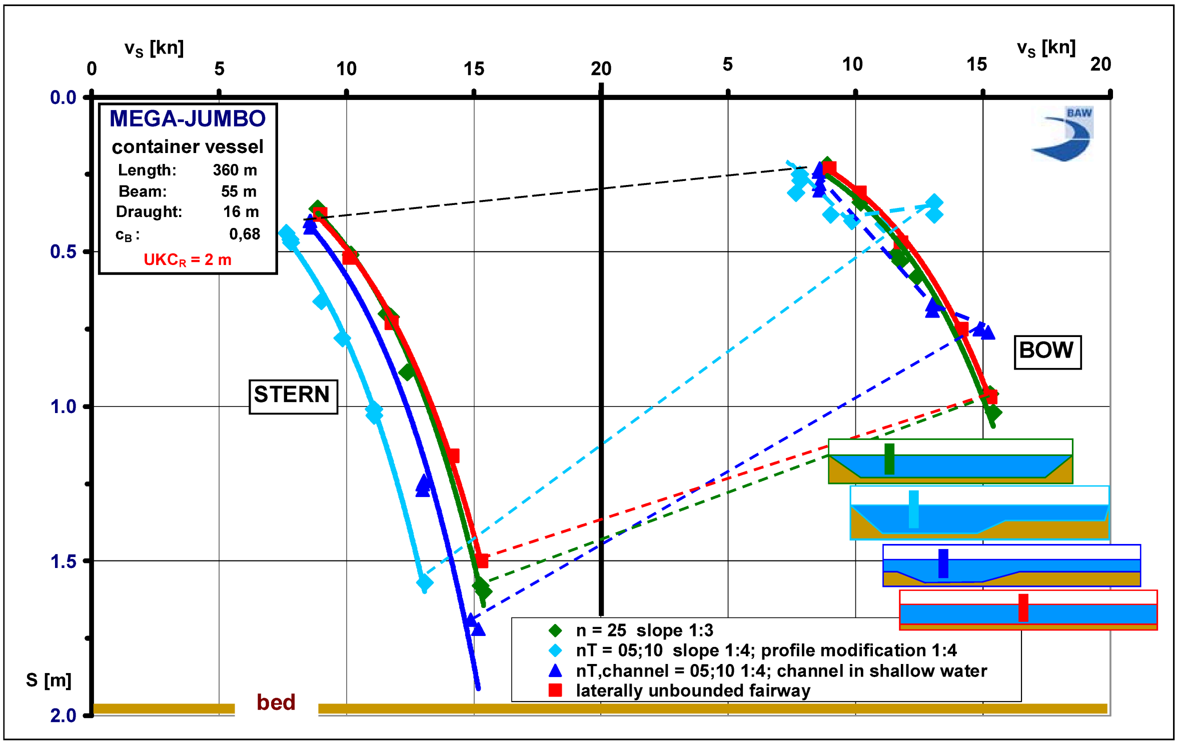

Figure 6: Impact of lateral shallow water sections ($h_{FAIRWAY} / h_{SIDE} = 3$) on squat and trim of a MEGA JUMBO vessel while moving off-centre at n = 7.5 ($n_T = 5 / 10$), and comparison with laterally unbounded fairway

For the German Federal Waterways and Shipping Administration (WSV), the examples of the above fundamental studies are of special importance as they enabled closer consideration of individual system parameters for fairway depth dimensioning regarding their effect on squat and trim.

## Additional measurements in field

Between April 2003 and June 2004, POST-PANMAX container vessels were accompanied for measurement purposes on 12 journeys under very calm as well as stormy meteorological conditions (up to about Beaufort Wind Scale 9). The shipping company HAPAG LLOYD (HLCL) supported 8 journeys of Hamburg Express Class ships (7,506 TEU), whereas 4 journeys for measurement purposes were undertaken on ships of the 5,500 TEU Class owned by the shipping company YANG MING (YM) with TOLLERORT CONTAINER TERMINALS (TCT) acting as the intermediary.

Table 2 presents selected characteristics of the vessel types as well as the range of mean draught and of the characteristic, draught-dependent block coefficient $c_B$ during the journeys.

| | Total length lpp [m] | Beam b [m] | Mean draught $t_m$ [m] | Block coefficient $c_B$ [-] | Capacity TEU |
|---|---|---|---|---|---|
| HAMBURG EXPRESS Class | 320.4 | 42.8 | 10.8 – 12.6 | 0.62 – 0.65 | 7,506 |
| 5,500 TEU YM Class | 274.7 | 40 | 11.4 – 13.2 | 0.56 – 0.59 | 5,500 |

Table 2: Selected characteristics of the investigated Post Panmax container vessels

In Hamburg Harbour, the container vessels were equipped with 4 autonomous global positioning systems on the bow and the bridge and one data collection system on the bridge (Figure 7). Vessel dynamics data were collected from Container Terminal Altenwerder (CTA) or from TCT until about north of Scharhörn (about 120 km ≈ 65 sm). Furthermore, at 6 cross-sections of the lower River Elbe, just before the respective vessel passing, current, temperature, and conductivity were measured from a small, very fast measurement vessel. During channel navigation, head-on and passing situations as well as extraordinary manoeuvres (amongst others change of pilot) were recorded and documented.

Figure 7 shows the positions of geodetic PDGPS antennae on the container vessel CMS BERLIN EXPRESS of HAPAG LLOYD. Manoeuvre data were collected from the respective navigation system.

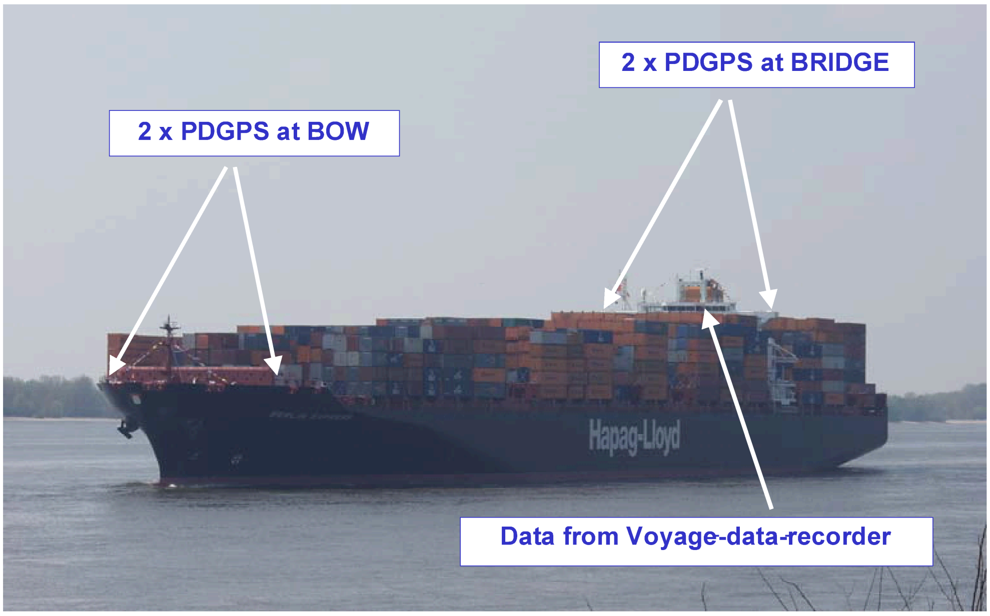

Figure 7: Positions of geodetic PDGPS antennae with example of CMS BERLIN EXPRESS container vessel of HAPAG LLOYD (HLCL) *Photo: BAW-DH*

Below, the satellite-based measurement method is only treated briefly; for details, please refer to the publication MAUSHAKE / JOSWIG (2004). Vessel movement, nautical manoeuvres, local squat, trim, and heel as well as net manoeuvring lane were analysed by means of special water gauge evaluations, highly precise PDGPS measurements and calculations of virtual reference situations – in combination with the vessel data (propeller speed, rudder position and others).

Checking the gauge interpolation procedure gave maximum differences between water level interpolation and additional PDGPS zero measurements of less than one centimetre. Water level extrapolation from St. Pauli gauging station into the basin of TCT, berth of the YANG MING vessels, was completed by PDGPS measurements from the accompanying boat (MAUSHAKE / JOSWIG, 2004).

Squat determination quality was estimated to be $\Delta S = \pm 0.05$ m; for under keel clearance (UKC) determination, given the quality of the digital terrain model from area and actual traffic safeguarding soundings, a precision of more than $\Delta UKC < \pm 0.2$ m can be presumed. For ship velocity (over ground) and heel, precisions of $\Delta v_S = \pm 0.08$ Kn and $\Delta\Phi = \pm 0.07$ ° respectively have been deduced (MAUSHAKE / JOSWIG, 2004).

Analysing the accompanying hydrological cross-section measurements permitted the flow and density conditions during the entire channel navigation to be taken into account – it was therefore possible to outline the squat vs. moving direction in water (Figure 8).

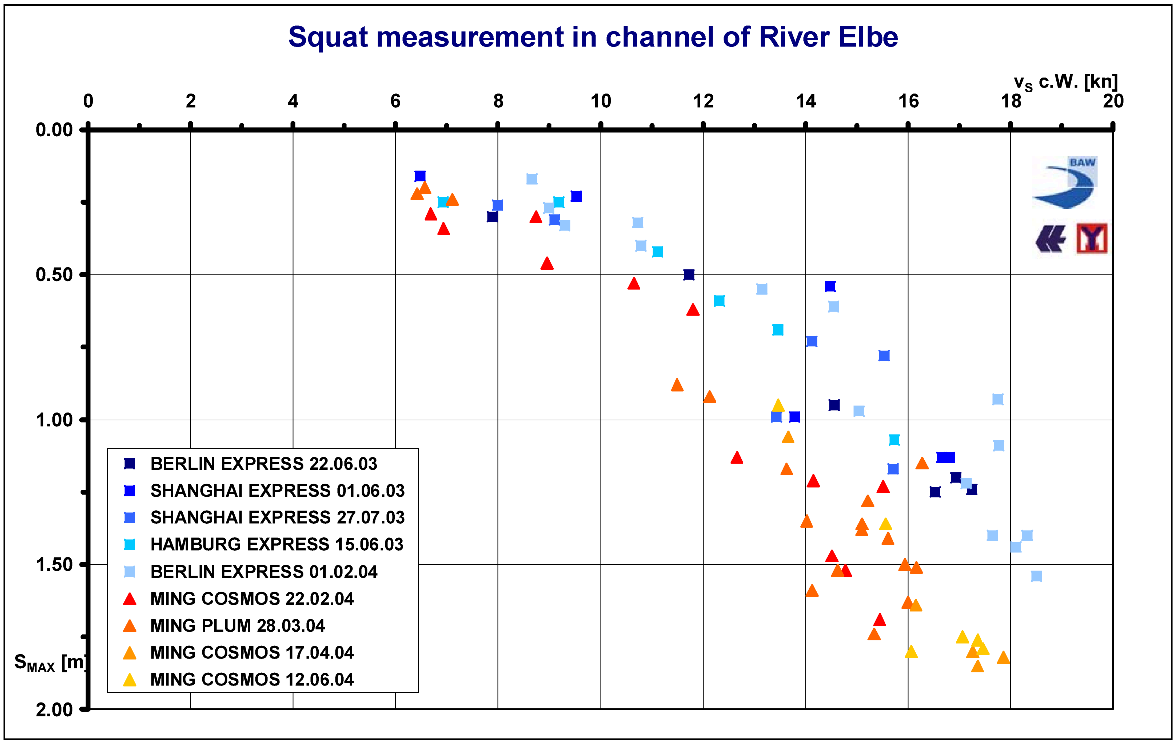

Figure 8: Velocity-dependent squat at the bow of container vessels of HLCL (squares) and YM (triangles) in the channel of the lower and outer River Elbe

In Figure 8, velocity-dependent squat values (bow; HLCL = squares; YM = triangles) spread on the one hand because of different vessel types, on the other hand as a consequence of the different waterway profiles in association with different UKC.

The higher bow squat of YM container ships results from the very strong, velocity-dependent bow trim starting at a vessel speed of about 11 kn; this results from the vessel design: above a draught of 12 m, the transom stern immerses, the immersed stern causing a buoyancy and thereby trimming the slim fore body into the receding water level. Body plans of this vessel type show that a notable buoyancy increase at the fore body only occurs starting from immersion depths at the bow of 16 m. Accordingly, the low blocking factor of the YM container vessels results above all from the fore body area.

HLCL container ships exhibited a much weaker trim, as the transom stern does not immerse even with larger draughts, and thus an approximately equally distributed buoyancy is present. This underlines the fact that in extremely shallow water, the trim behaviour and thereby the deepest point of a vessel, here the bow squat, clearly depend on the overall design of the underwater hull and especially on the buoyancy distribution in the longitudinal direction. Although significant with regard to the hydrodynamic form of the underwater hull related to a cuboid, the above results indicate that the block coefficient $c_B$ cannot be used as a general parameter to describe the dynamic behaviour of a vessel with the purpose of predicting vessel dynamics in shallow water.

Figure 9 shows CMS MING PLUM while moving on the lower River Elbe seen from astern where the immersed transom stern causes the additional stern buoyancy. The photo also shows the very slim fore body compared to the also bearing stern area.

Figure 9: CMS MING COSMOS while moving on the lower River Elbe with immersed transom stern and very slim underwater hull in the bow area, *Photo: BAW-DH*

**This marked bow trimming behaviour of large container vessels in shallow water with low $c_B$ values of less than 0.6, unknown so far, has been recorded by these in-situ measurements for the first time.**

On board the investigated container ships, the simplified empirical BARRASS formula (2004 and others) is used to determine squat in bounded fairways. In this empirical formula $S = c_B\, v_S^2 / 50$ (for bounded fairways), only the $c_B$ value, the ship velocity and an empirical factor enter the calculation ($S$ = Squat [m]; $c_B$ = Block coefficient; $v_S$ = Ship velocity [kn]); for large container vessels therefore, a clear excess of squat values is calculated and additionally a strong trimming of certain vessel types in the bow area is described in a contradictory way due to the linear approach of the $c_B$ value.

For operating their ships, shipping companies were provided with the squat analyses of the measurement journeys on the lower and outer River Elbe in the form of graphs together with the existing calculation approaches according to BARRASS (2004); on the basis of the differences measured, economical use of sea waterways was enabled.

## Testing selected dimensioning approaches

In order to check if the calculation approaches used for the dimensioning of the fairways of the River Elbe and River Weser are valid for large Post Panmax container ships, hydrological boundary conditions calculated and completed according to the Hindcast procedure were entered into the following formulas:

- ICORELS (PIANC/IAPH, 1997) $S = 2.0\, c_B\, (b\, t / l)\, (Fr_h^2 / (1-Fr_h^2)^{0.5})$

- TUCK/SCHMIECHEN (SCHMIECHEN, 1997) $S = t / 3 (Fr_h)^3$

where: $Fr_h = v_S /(g\ h)^{0.5}$ FROUDE depth number [-]
$v_S$ Ship velocity [m/s]

For comparison with the measured squat values, simplified presumptions regarding the soil topography (ship length average and two ship beams) had to be made, amongst others. Figure 10 shows, on the superimposed graphs for the CMS BERLIN EXPRESS journey on February 1st, 2004, an extract from the BAW's interpretation tool with River Elbe kilometre marking on the horizontal axis and measured squat, calculated squat, as well as differences from the maximum squat for the above approaches. The ICORELS approach with the pre-factor 2.0, used for the fairway dimensioning, describes the dynamic behaviour of HLCL HAMBURG EXPRESS Class during channel navigation sufficiently well. The SCHMIECHEN approach, approximated on the basis of in-situ measurements, and in line with its limitations, provides conformity with the measured values for HLCL vessels only from higher FROUDE numbers of $Fr_h > 0.7$ upwards (Figure 10). The extreme bow trimming of YM container ships starting at ship velocities of about 11 kn is covered neither by the ICORELS approach (F = 2.0) nor by the SCHMIECHEN approach (no graphic representation).

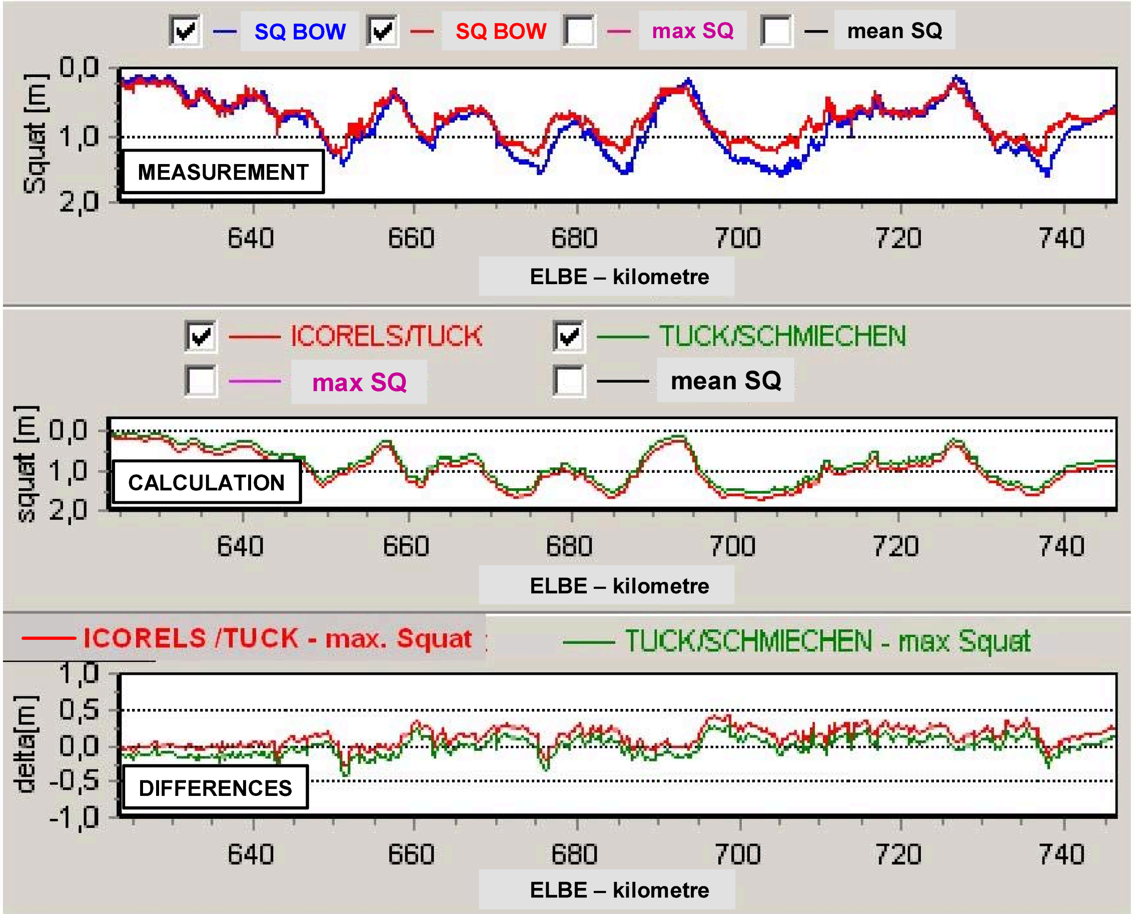

Figure 10: Extract from the BAW's interpretation tool with measured and calculated squat as well as differences from the maximum squat for the CMS BERLIN EXPRESS journey on February 1st, 2004

## Summary and conclusions

Knowledge of the dynamic behaviour of large container ships is necessary for fairway dimensioning and for optimum economic use of sea waterways. Accompanying container ships of the shipping companies HLCL and YM on the lower and outer River Elbe for measurement purposes supplemented former system tests in hydraulic models and confirmed their results.

The analyses of the system tests and of the in-situ measurements have been made known to the German Federal Waterways and Shipping Administration (WSV) in different publications and presentations; the results regarding the velocity, water level and draught-dependent parameters of squat and trim are now available for determining fairway depths in future development planning.

The shipping companies participating in the in-situ measurements were provided with the ship-specific squat graphs showing possible draught increases in the channel up to about 1 m.

The recent studies have revealed that, due to the versatility especially of large container vessel designs nowadays, the dimensioning approaches used for squat forecasts cannot be used to describe the construction-specific response of certain vessel types at higher velocities (e.g. with increased bow trimming).

It is recommended that the recording of large container ships dynamics during channel navigation be anchored as a permanent task within the Waterways and Shipping Administration; this will help to take into account the versatile designs and the response of the container vessels travelling today and in the future on the sea waterways regarding safety and ease of navigation.

### Acknowledgements

Without the generous support of HAPAG LLOYD Container Line GmbH and YANG MING Marine Transport Corporation, the particular interest of their staff and the intermediation of the HAMBURGER HAFEN- UND LAGERHAUS-AG (HHLA) and their Terminals CTA and TCT, these time-consuming in-situ measurements would not have been possible. All participants would like to thank them for this fruitful cooperation.

## Literature

Azcueta, R.: On the dynamic response of very large container vessels in extremly shallow water by means of RANSE simulation, Hamburg 2003 (not published)

Barrass, C.B.: Thirty-two years of Research into Ship Squat, In: Tagungsband 2. Squat-Workshop 2004, Aspekte der Unterkielfreiheit in Analyse und Anwendung, Elsfleth / Oldenburg 2004

Flügge, G., Uliczka, K.: Dynamisches Fahrverhalten und Wechselwirkungen mit der Fahrrinnensohle von sehr großen Containerschiffen unter extremen Flachwasserbedingungen, Tagungsband HTG-Kongress 2001, Hamburg 2001

Maushake, Ch. Joswig, S.: Messung von Squat, Trimm und Krängung sehr großer Containerschiffe im Rahmen von Grundsatzuntersuchungen auf der Elbe, Hydrographische Nachrichten Nr. 072, Deutsche Hydrographische Gesellschaft, 2004

PIANC/IAPH: Seehafenzufahrten – Ein Leitfaden zur Bemessung (translation), PIANC/IAPH AG II-30, Bulletin Nr. 95, Bonn 1997

Schmiechen, M.: Squat-Formeln, Das Schiff in begrenzten Gewässern,
18. Duisburger Kolloquium Schiffstechnik / Meerestechnik, Duisburg 1997

Uliczka, K., Flügge, G.: Squat-Untersuchungen für sehr große POSTPANMAX-Containerschiffe,
HTG/STG-Sprechtag FA Seeschifffahrtsstraßen, Hafen und Schiff, Hamburg 2001

Uliczka, K. Kondziella, B. Flügge, G.: Dynamisches Fahrverhalten sehr großer Containerschiffe in seitlich begrenztem extremen Flachwasser, HANSA, 141. Jahrgang, Nr. 1, 2004

Uliczka, K., Wezel, M.: Dynamisches Fahrverhalten großer Containerschiffe bei Revierfahrt auf der Unter- und Außenelbe, Tagungsband HTG-Kongress 2005, Hamburg 2005