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Access Routes to Baltic Sea Ports

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Access Routes to Baltic Sea Ports

By ANNETTE ERNST, HERWIG NÖTHEL and HOLGER RAHLF

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1. Introduction

Due to the growing demands of maritime traffic, access channels to the German sea ports along the Baltic coast have been changing during the last centuries. A historic review particularly highlights the development of the 'Hanseatic League', a free federation of merchants dating back to the middle of the 12^{th} century. Members were cooperating according to self-imposed rules and privileges in foreign trade with the intention of improving safety during dangerous sea voyages using the protection convoys allowed.

Even today, natural water depths in the fjords and bays of Schleswig-Holstein are sufficient for ships calling on ports such as Kiel and to the entrance of the Kiel Canal. Access channels to Lübeck and other ports, located further east along the coasts of Mecklenburg-Vorpommern, had to be artificially deepened quite early. The existing water depths were not sufficient for modern harbour requirements. Due to the littoral drift – typical for coastlines in equilibrium – moles and breakwaters had to be constructed to protect harbour entrances and mouths of navigable rivers from the beginning, e.g. at Travemünde or Warnemünde.

Hydrodynamic processes in the access channels are governed by baroclinic processes and meteorologically induced water level variations of the Baltic Sea. Tidal influence is negligible. Thus, under normal weather conditions, water level variations along the coast are in the order of centimetres to a few decimetres. They can, however, cause compensatory currents in the access channels with a possible change of direction more than once a day. Storm surges, in the Baltic frequently called 'storm high water', are frequently connected with low water levels due to the 'seiches' (Eigenschwingungen) of the Baltic Sea.

Current velocities of more than 1 m/s in the access channels occur only with steep gradients of the water level whereas currents velocities of a few dm/s are more frequent.

Because of the low salinity of the water, a relatively small freshwater discharge and compensatory currents, no distinct brackish water zone can develop. During long calm weather periods, thermohaline stratification in the water body can persist over several days, sometimes even for weeks.

Sedimentation processes in the access channels are dominated by the littoral drift (e.g. at Warnemünde) and partly by fluvial deposits (e.g. Trave). However, as a rule of thumb, maintenance dredging does not have to be carried out every year. In comparison to access channels in estuaries at the North Sea coast, dredged volumes are lower by an order of magnitude.

Because of the continental climate in the East, access channels at the Vorpommern coast can ice up during cold winters.

2. Geomorphology

An area of 415,266 km² (including Kattegat), an average depth of approx. 52 m and a volume of ca. 22,000 km³ make the Baltic Sea a small intra-continental marginal sea of the Atlantic ocean (HUPFER, HARFF, STERR and STIGGE, 2003). It is connected with the North Sea by the waterways/straits of 'Öresund', 'Great Belt' and 'Little Belt' via 'Kattegat' and 'Skagerrak' as well as through the Kiel Canal.

The German coastline in the South-west of the Baltic Sea has a length of 2,582 km, 637 km of which are part of the federal state of Schleswig-Holstein while 1,945 km belong to Mecklenburg-Vorpommern. For 1,568 km, coastal lagoons line the inner shores.

The geological and geo-morphological development of the German Baltic Sea coast has been described by KLIEWE, LEMKE, JANKE and NIEDERMEYER in KATZUNG (2004). As the result of the multiple progression and recession of the Nordic inland ice during the cold epochs of the Pleistocene, this area of the German Baltic coast is entirely covered by quaternary sediments. Only on the island of Rügen, a furrow slice of Cretaceous chipped from the pre-quaternary substrate, surfaced. Eustatically rising mean sea levels during warm periods of the Pleistocene and post-glaciation as well as epirogenetic subsidence and isostatic uplift had an influence on the course of the coastlines.

The last glaciers during the late Weichsel glaciation left a structured landscape with basins and sills, formed by till and boulder clay. During the late and post-glacial period of the transgression, first of all, the deep depressions of this till surface, such as the Mecklenburg Bay and the Arkona Basin were filled. Only with the faster water level rise during the initial Litorina-Transgression (1st main phase from 7,900 to 7,200 a B.P.) a considerable abrasion in the flooded regions occurred. This led, in connection with an increased bio-production in the water body and continually evolving hydrographical peculiarities of a thermohaline stratified marginal sea of the moderate northern latitude, to an increased sedimentation of silt. Silt was not only deposited in the deeper parts of the Mecklenburg Bay and Arkona Basin but also in the coastal lagoons. In regions of strongly structured coastlines with bays, in former near shore channels, river mouths and inlets, a fairly consolidated silt-clayey, brown to black-coloured organogenic still water sediment, rich with molluscs, was deposited (Litorina-clay/ Litorina mud).

In the shallower near shore areas, i.e. along basin banks and on the sills between the deeper basins, the sediment regime is determined by transport and erosion processes until today. Consequently, one finds boulder clay or sand, washed out from it, in the sediment surface layer. While till 2,000 B.P., during the 2nd and 3$^{rd\ main}$ phase of the Litorina transgression and intermittent phases of stagnancy and regression, the mean sea level rise in the Baltic Sea slowed down the build-up of baymouth bars and spits accelerated.

During the last two thousand years after the Litorina transgression, the processes of coastline adaptation intensified. They resulted in a permanent recession of the outer coastline by the levelling of cliffs, an increasing closure of coastal lagoon inlets by bars and spits and a parallel development of coastal dune systems. The German Baltic Sea coast is characterized by this sometimes abrupt changeover between cliffs and beaches.

Due to the westerly winds prevailing in the northern hemisphere, transport processes in the south-western Baltic Sea are shaped by currents from West to East. However, coastal recession is more distinctly induced by short-term rare meteorological/hydrological events triggering storm surges with extreme water levels and wave energy input. With regard to these dynamic geo-morphological processes, the German Baltic coast can be classified into the following regions, viewed from West to East (Fig. 1):

- Coastal fjords (Fördenküste) from Eastern Jutland to Kiel,
- large bays (Großbuchtenküste) from 'Probstei' (Holstein) to the tip of 'Buk' east of Wismar (Mecklenburg),
- the Mecklenburg 'equilibrium coast' to the peninsula of 'Fischland-Darß' with the in-between coastal fjords near Rostock,
- the equilibrium coastlines of 'Vorpommern' with longer spits and coastal lagoons (Bodden/Haffs) reaching to the Oder mouth.

Fig. 1: Morphological units along the German Baltic Sea Coast
(after KLIEWE and SCHWARZER, 2002)

3. Hydrology

The eastern basins of the intra-continental marginal sea 'Baltic Sea' are connected to the Kattegat in the eastern part of the North Sea by a relatively shallow passage (e.g. the Belt Sea has maximum water depths of 25 m).

Because of compensating currents between North and Baltic Sea, the permanent freshwater discharge into the Baltic and the almost total lack of tidal motion, properties and condition of the water body show a high spatial and temporal variability. This is clearly reflected in salinity, temperature and oxygen contents.

Mainly during summer and fall, baroclinic processes induce an inflow of North Sea water with a high salinity. This leads to an increasing salinity, higher temperatures and a lower oxygen content along the flow path. As a consequence of meteorologically induced high water events in the North Sea, occurring mainly in winter and spring, larger water masses infiltrate the warmer Baltic Sea water with its lower salinity. The last recorded major event of this kind was in 2003 (FEISTEL, 2007).

Salinity decreases steadily with increasing distance from the Belt Sea. Whereas in the 'Wismar Bay' long-term average salinity values of 13–14 PSU have been recorded, the 'Bay of Pommern' shows only 6–7 PSU. The Darss Sill (Darsser Schwelle) between Mecklenburg Bay and the Arkona Basin with a water depth of only 18 m separates a water body of a higher surface salinity of more than 10 PSU from the brackish waters east of Rügen with less than 9 PSU. In the inner coastal waters with bays and coastal lagoons, the salinity gradient is even more pronounced: In 'Greifswalder Bodden' approx. 7 PSU, in 'Oderhaff' only 1–2 PSU (GEWÄSSERGÜTEBERICHT MECKLENBURG-VORPOMMERN, 2000/2001/2002). The shallow inner coastal waters are usually fully mixed by wind and currents; the outer waters, on the other hand, show a vertical temperature and salinity stratification which in the deeper parts of the Kiel and Mecklenburg Bay and the Arkona Basin can cause a thermohaline discontinuity during summer.

Even though the density compensation currents decisively shape the physical and chemical composition of the water body, they hardly influence water levels along the coastline. This is also true for the tidal waves penetrating from the North Sea through Skagerrak, Kattegat and Belt Sea. The amplitude of the semi-diurnal tide in the western Baltic Sea is 0.5–3 cm; for the diurnal tide it is 0.5–15 cm.

Major water level variations in the Baltic Sea can be attributed to the dynamics of the atmosphere. The transfer of momentum from wind to water causes wind and surf set-up at the coast. Due to the physical shape of the Baltic Sea, maximum water level variations occur in its western part, in the northern Gulf of Bothnia and in the inner Gulf of Finland.

Along the German coast of the Baltic Sea storm surges are mainly triggered by winds which originate from cyclones moving from either the North Atlantic or the Mediterranean towards the Baltic. In their rear, north-easterly winds with high speeds and sufficient duration on a long fetch occur in the central Baltic Sea. In addition to the generated set-up, meteorological influences let Eigen-oscillations of the water body contribute to high water levels. An additional water level rise of an average of 20–30 cm, with a maximum of 45–50 cm, can be due to a pre-filling of the Baltic Sea (DIE KÜSTE 66, 2003).

The highest water level ever at the German Baltic coast was recorded at Travemünde, the oldest gauge in Germany, to be 3.30 m above mean water level during the storm surge of Nov. 12/13, 1872.

External loading on the coast does not only result from the height and retention period of storm surge water levels but also from the simultaneously occurring strong waves. Based on wave measurements in at least 8 m of water depth (MSL) at the Baltic coast of Schleswig-Holstein, extreme-value statistics have produced significant wave heights Hs of up to 3.8 m and a return period of 100 years (KOHLHASE et al., 2000).

At the same time, wave-induced currents are instrumental in the swirling-up and transport of sediment. For example, these processes were responsible for the coastal recession at Rosenort (Rostocker Heide) and the aggradation of 0.85 m/a at Darsser Ort (GENERALPLAN KÜSTEN UND HOCHWASSERSCHUTZ M-V, 1994).

Ice conditions along the German Baltic coast must not be neglected. During normal winters, only the shallow bays of the inner coastal waters ice up completely. Because of their secluded location, there is no significant water exchange with the warmer open sea. Minor formation of ice in the outer waters can be found along the eastern coast of Rügen and off the island of Usedom. Only during extreme winters does the surface layer of Kiel and Mecklenburg Bay cool off sufficiently to allow for ice formation on open waters (BSH, 1996).

4. Important Harbour Access Channels

4.1 Lübeck (Trave)

The River Trave empties into the Lübeck Bay at Lübeck-Travemünde. In comparison with the natural water level variations of the Baltic Sea of around ± 0.50 m (occurring approx. 95 % of the year), the freshwater discharge of the Trave is so small (riverine area of Schlei/ Trave: MQ = 7.53 m^3/s), that it hardly affects the current regime in the Lower Trave. Depending on the season, salinity in the Lübeck Bay around Travemünde varies between 8.2 and 18.7 PSU (time series 1997–2006). Baroclinic processes let salinity be felt at Lübeck (Trave km 5.55 with a step in the bottom from 8 m to 3 m). It is only in a few reaches, that sediment deposits as a result of the freshwater discharge of the Trave and its tributaries are noteworthy. However, more substantial sediment depositions in the river mouth stemming from littoral transport play an important role for maintenance of the depth of the navigation channel. Extreme storm high waters have moved the location of the Trave mouth several times in the past (SPETHMANN, 1953). Thus, one attempted to fix the course of the Trave channel in its river bed. Starting in 1465, training walls were built to be replaced by various mole structures later on. The present stable 'Northern' and 'Northern Channel' moles (Norder- und Norderrinnenmole) have proven their worth and have firmly established the river mouth (Fig. 2).

In the past, the Lower Trave between Lübeck and Travemünde has been adapted to the continuously increasing requirements of commercial maritime traffic (VON LILIENFELD-TOAL, 1981). An admiralty chart (map with surveyed depths) of 1811 shows water depths of only 2.20 m over a sand bar outside of Lübeck. Vessels with a draft of 2 m were only able to reach Lübeck during elevated water levels. Up to the Lübeck city ports, water depths were only between 2.50 and 4.00 m below MSL. Around 1840, steam-powered dredgers succeeded in breaking through the bar off Travemünde and established a water depth of 4.7 m in the area.

The first correction of the Trave was carried out between 1840 and 1854 (VON LILIENFELD-TOAL, 1981). Together with a straightening of the fairway at 'Herrenfähre' (km 13.7) and 'Stülper Huk' (km 21.0), a continuous depth of 4 m was established. During the 2nd correction (1878–1883), the cutoffs at 'Teerhof' (km 8.7–9.5) and at 'Schlutup' (km 16–17) were completed. During the 3rd correction of the Trave, the fairway was deepened to 7.5 m between 'Stadthafen' (km 5.9) and the roadstead off Travemünde (km 28). Now, the bottom width of the fairway ranged between 40 and 90 m.

Both world wars and the economic crisis in between let a further improvement of the Trave (4^{th} correction) to a water depth of 8.5 m proceed only slowly (1908–1961). Due to the fast growth of vessels of the international commercial fleet, the 5^{th} correction was carried out between 1961 and 1982. It included a depth increase to 9.5 m and further improvements of fairway and bends. Now, the width of the navigation channel from the Lübeck city ports to 'Siems' (km 15.3–the former 'Flender' shipyard) is 60 m, in the adjacent stretch to 'Stülper Huk' (km 21) 90 m and to the open sea (ca. km 29) it is 100 m. Presently, in the reaches from

Fig. 2: Mouth of river Trave at the Baltic Sea coast (Travemünde)

'Siechenbucht' to Travemünde (km 26.9 – 'Süderrinnenmole') the fairway has a depth of 10.0 m. From here on to the open sea a water depth of 10.5 m is being maintained.

Fairway maintenance dredging of about 22,000 m³ of sandy sediments is carried out mainly in stretches from 'Siechenbucht' (km 24) to the Trave mouth (km 27) approx. every 6 to 8 years. In a second reach between km 6.9 to 21.0, approx. 10,000 m³ of prevailingly muddy depositions have to be removed. A trailing suction hopper dredger is normally used. Within the framework of environmental monitoring, physical parameters such as oxygen content, temperature and turbidity as well as current velocities and directions are usually being recorded.

Sediment depositions, which have accumulated after the last correction of the Trave, will be removed within a maintenance dredging campaign, planned for several longer stretches for the years to come. In many reaches of the Trave, contamination of the bottom sediment, due to sewage disposal by harbour and industrial operations, has been going on for decades. Therefore, the selection of suitable dumpsites is a major difficulty. In cooperation with the Federal Institute of Hydrology (Bundesanstalt für Gewässerkunde-BfG), conceptions for the treatment of contaminated bottom sediments are presently being developed.

In addition to the standard hydrological assignments, the Federal Waterways and Engineering Research Institute (BAW) has carried out investigations of ship-generated wave and current loads on embankments.

4.2 Wismar (Wismar Bay)

The Bay of Wismar is located in the southern part of Mecklenburg Bay and, being a deep indentation, extends to the Hanseatic City of Wismar. Even in medieval times, the harbour of Wismar was of major importance for trade in the Baltic region. In 1810, the territory of the present city harbour had a mean natural water depth of 2.50 m. During the following 100 years, the first dredging measures (1845, 1849–1857, 1863 and 1908) were carried out to finally result in a water depth of 6.0 m in the harbour and 5.2 m in the access area on a width of 35 m. In the years from 1947 to 1950, the access to the harbour was improved to a depth of 7.0 m with a width of 35 m. Deepening of the fairway to 9.5 m while maintaining the width followed. In 1961, the fairway has widened to 60 m at the bottom. In the 1980s, widening of the bends at 'Walfisch' and 'Hohen Wieschendorf' was executed. Within the framework of another fairway improvement in 1998, extension of both sides of the fairway by 30 m each at a depth of 6.0 m was carried out (Fig. 3). This measure established a possibility of two-way traffic for vessels with a lesser draft. Presently, planning for deepening the navigation channel towards Wismar to 11 m with a width of 100 m is underway. Supplementary measures will be the establishment of the same water depth in the harbour reaches, the turning circle and the access to the shipyard.

Because of a sufficient natural water depth, maintenance works are only necessary for parts of the navigation channel in the inner Wismar Bay. Hydrodynamic processes in the bay with only weak current velocities result in only marginal morphological changes. Maintenance dredging, therefore, is only necessary every 7–10 years with an annual volume of 12,000 m³/a. Dredged spoils in the harbour consist mainly of muddy material while sandy sediments have to be removed normally with hopper dredgers in the fairway.

Parallel to the maintenance dredging works, monitoring field programmes agreed on with the environmental agencies are carried out. The water body at the dredging and dumpsite is checked for oxygen contents, water temperature, turbidity as well as current velocity and direction.

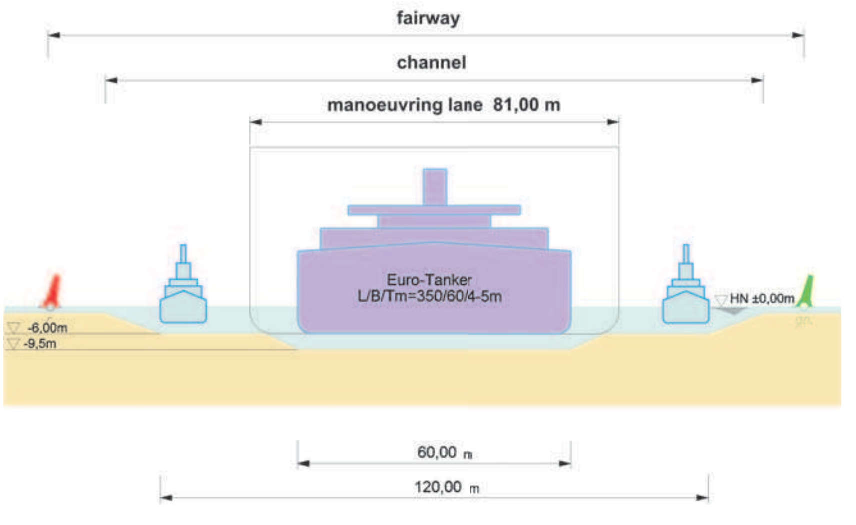

Fig. 3: Occupancy of the present cross-section of the fairway to Wismar during transfer of a new vessel

The contaminated dredged spoils are dumped on the containment area 'Fährort' on the island of Poel. In order to match its limited capacity, already dumped sediment is to be removed for an alternative utilization or recycling.

During the recent improvement measures, the entire system of the Wismar Bay, including the protected commodities according to the environmental compatibility code (UVPG), has been examined in detail. For the adaptation and improvement of the fairway, supplementary investigations are necessary. These include various field measurements, sample-taking and surveys as well as the preparation of a baroclinic hydro-numerical model for the simulation of advective salinity transport in the bay.

4.3 Rostock (Warnow)

Before the most recent improvement of the access to the sea port of Rostock at the end of the 1990s, a system of 4 separate moles protected the harbour entrance. The western mole (Westmole) dates back to the 16^{th} century. Together with the eastern mole (Ostmole = presently called 'Yachthafenmole'), it sheltered the real mouth of the Warnow, called 'Alter Strom' today. Between 1901 and 1903 and for the establishment of the railway ferry terminal for the link Warnemünde – Gedser, the new channel 'Neuer Strom' was initally dredged to a depth of 5 m and then protected by a mole on its eastern shore. At the same time, the 'Westmole' was extended by 200 m to the North by building a sand spit. This was to prevent further sediment influx into the channel. By 1955, a water depth of 8 m on a width of 35 m had been established.

Together with the construction of the new seaport (Überseehafen) of the German Democratic Republic (GDR), the access channel (Seekanal) with a water depth of 10.5 m and a length of 4.5 nm was built in 1958. Sediment volume to be dredged was 5.3 million m^3. The 'Ostmole' of the 'Neuer Strom' became the 'Mittelmole', and another mole was constructed at the eastern shore of the 'Seekanal'. The mole heads of 'West, Mittel and new Ostmole' were located on a straight line (SCHOCKEL, 1960). In 1963–1966 and 1972–1976, the depth of the 'Seekanal' was increased to 11.5 m and 13.0 m, respectively, with a width of 80 m.

Between 1996 and 1999, during the last upgrading of 'Seekanal', a water depth of 14.5 m with a width of 120 m was achieved in the inner part in order to enable two-way traffic. For this, the 'Westmole' had to be demolished. The 'Ostmole' became part of a new eastern mole, and the new 'Westmole' was fitted with a fork, arranged symmetrically to the new eastern mole, to reduce the energy of waves penetrating the 'Seekanal'. With an overall length of 7 nm, the 'Seekanal' widens to 220 m from the entrance to the offshore approach. Altogether, 4.5 million m^3 of sand and till were dredged and dumped offshore. All engineering structures were designed such as to match another deepening to 16 m.

When maintaining the depth of the 'Seekanal', one has to differentiate between sedimentation immediately in front of the 'Westmole', which is due to littoral drift, and silting-up of suspended matter with a high content of autochthonal organic substance in the inner 'Seekanal'.

To prevent sedimentation at the western edge of the channel between the moles, up to 34,000 m^3 of sand were removed in front of 'Westmole' in bi-annual precautionary dredging operations and dumped east of the channel. In 2001, a sand trap of 200 x 60 x 16 m dimensions was created and has to be cleared only every 7 years. The excavated sand will be dumped on a site 6 nm offshore.

After the last deepening of the 'Seekanal' was completed in 1999, the navigation channel in its inner reach has to be dredged for the first time in 2008. Dredged spoils are to go to the containment area ‘Markgrafenheide’. Offshore of the entrance, hopper dredgers are operating exclusively while in the inner ‘Seekanal’ mainly bucket dredgers, dipper dredges and cable dredgers are being deployed.

In the beginning of the 1990s, BAW issued a number of prognoses on the impact of the last upgrade. Because of the existence of baroclinic processes, the impact on the hydrodynamic conditons in the ‘Seekanal’ were investigated using a 3D-model with a high spatial and temporal resolution. Physical model investigations were carried out for the forecast of wind and ship-wave induced loads and became part of an extensive preservation-of-evidence programme (Fig. 4).

More recent model investigations were conducted in the context of construction measures in the Navy Arsenal, e.g. to predict the effect of a new ammunition pier on circulation processes in the ‚Breitling’ coastal lagoon.

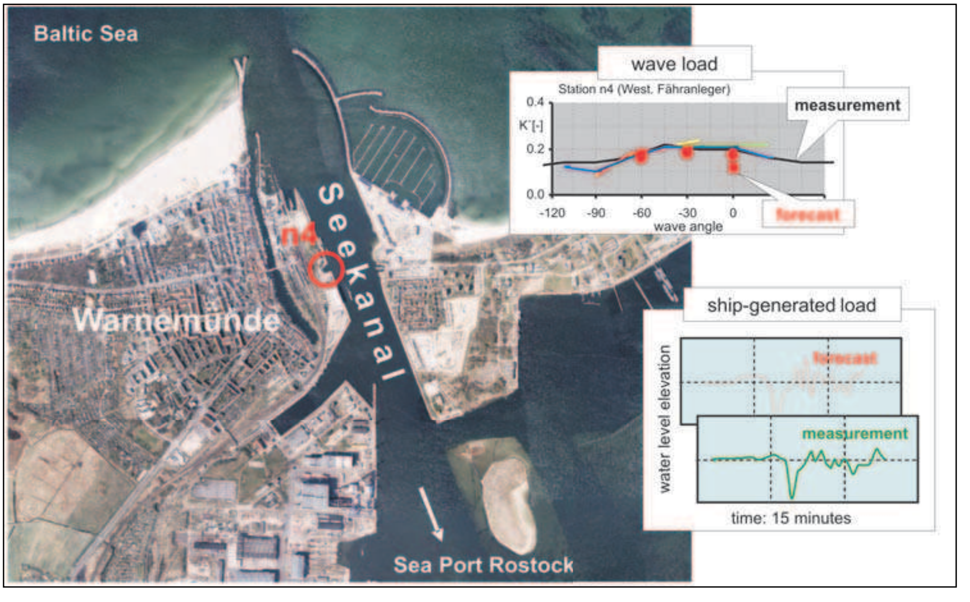

Fig. 4: System of moles at Warnemünde – predicted and measured wind and ship-generated wave loads at the ferry dock

4.4 Stralsund (Strelasund)

Stralsund, located on the ‘Strelasund’ has an access to the sea both from the North past the island of Hiddensee (Northern approach-‘Nordansteuerung’) and from the East via the coastal lagoon of ‘Greifswalder Bodden’ = eastern approach-‘Ostansteuerung’). The evolution of the waterways is described in KÖHLER (2005).

First mention of navigation problems due to insufficient water depths in the northern approach go back as early as the 17^{th} century, when water depths were probably around 2.50 to 3.0 m. Since the 18^{th} century, major efforts to improve channel depths were undertaken, initially by manual excavation. In 1890, the fairway was upgraded by deepening to 3.5 m and a breakthrough at 'Vierendehlgrund'. In the years 1910, 1938 and 1944, the upgrade was continued to depths of 4.0, 4.5 and 5.0 m, respectively, at a bottom width of 40 m. The deepened navigation channel acted as a sand trap accumulating the west-east oriented littoral drift. Sand deposits had to be removed continuously.

Dredged sand from deepening and maintenance had been pumped ashore to build up to an elevation above high water and crop the neighbouring 'Bock', a wind-influenced wadden area (Windwatt). Thus, the considerable constriction of the flow passage between the new island 'Bock' and the island of Hiddensee and resulting intensification of currents were expected to lead to an increased clearance of the navigation channel. This measure, however, was only partially successful since meandering tendencies of the channel necessitated a frequent adaptation of the light line marking the location of the channel. During those years, approx. 100,000 m^3/a had to be removed from the navigation channel annually. In 1985, the light lines were abandoned and the fairway, maintained to a depth of 4.5 m and marked by light buoys, has been following the morphological development of the natural channel. Consequently, dredged volumes dropped to 70,000 m^3/a. In 1986, dumping of material on 'Bock' was completely stopped. Ever since, spoils from the annual maintenance dredging works have been used for coastal protection measures (e.g. dike construction 'Ostzingst'), or the material has been dumped offshore north of 'Hiddensee'. Dredging is mainly done by hopper dredgers, seldom by bucket dredgers.

Since 1857, because of a considerably smaller maintenance effort in the eastern approach, the fairway has been upgraded in steps from 5.2 m (until 1943), via 6.0 m (1945–1954; 1961–1965) and 6.9 m (1997–2000) to 7.5 m (2006). Thereby, it has developed into the more important route to Stralsund. Construction measures mainly concentrated on a straight-line connection between two shallow water regions: the 'Ziegelgraben' close to Stralsund and the 'Palmer-Ort' channel where the 'Strelasund' merges into 'GreifswalderBodden'. Outside of this area, the fairway follows the naturally stable flow trench of the Strelasund. As a consequence of each upgrade, however, the reaches to be improved get longer: while during the 6.9 m-deepening approx. 1 million m^3 of Litorina-mud had to be dredged on a length of 15 km, establishing the 7.5 m depth along 23 km required dredging of 2 million m^3.

Maintenance of the eastern approach concentrates on the 'Palmer Ort' and 'Ziegelgraben' channels. In addition to the running of mud from the underwater slopes into the 4–5 m deep channels, sand, eroded along the northern shores of Strelasund and driven by the oblique current, deposits in the 'Palmer-Ort' channel.

Towards the end of the 1980s, dumping of dredged spoils had to be stopped because of environmental concerns. Thus, the material, rich in organic components, as well as dredged sediment from the last two upgrading measures (6.90 and 7.50 m depths) had to be dumped on the land-based containment area 'Drigge'.

For the maintenance of the eastern approach, an average of 65,000 m^3 has to be removed annually, varying between 20,000 and 100,000 m^3. For this, mainly bucket dredgers, dipper dredges or cable dredgers are deployed. They cut into the bed material with an optimum cutting depth and guarantee to produce an accurate transect of the channel with a minimum of sediment and almost no water removed.

In order to solve the continuous sedimentation problems in the northern approach, numerous investigations have been carried out by scientific institutes. During the 1950s, physical models have been run at 'Forschungsanstalt für Schiffahrt, Wasser- und Grundbau' (FAS) to look into the usefulness of river training methods for reducing sediment depositions. Extensive investigations with numerical simulation models on the morphodynamics of wind affected wadden areas (Windwatten) were carried out in the GCERC (KFKI) project MORWIN (BARTHEL and LEHFELDT, 2000).

Based on a literature search and data measured in the field, the effect of the last two upgrades of the channel on abiotic system parameters have been predicted using empirical methods. Results have been confirmed by runs of a 2D hydro-numerical model (Fig. 5).

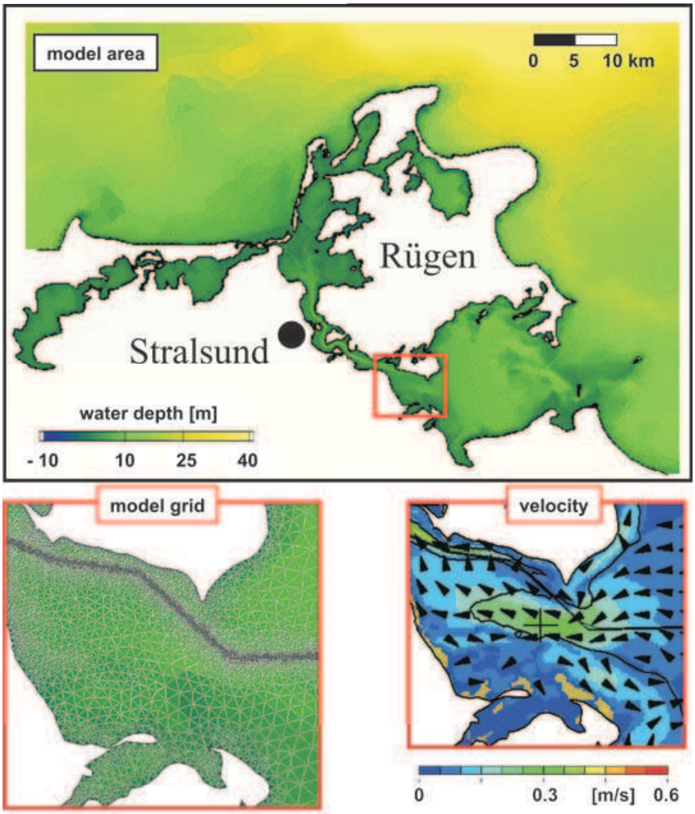

Fig. 5: Overview of 2D HN-model area, section of model grid and calculated velocity values

4.5 Wolgast (Northern Peenestrom)

Wolgast, located at the western shore of the 'Peenestrom' can be accessed from offshore via 'Osttief' or via 'Landtief' and 'Greifswalder Bodden'. The northern part of the 'Peenestrom' has been used as an approach to the Hanseatic City of Wolgast from time out of mind. At the beginning of the 20th century, one finds mention of the maintenance by dredging of the access channel with a width of 40 m and a minimum depth of 5.0 m (KRES, 1911). Only with the establishment of a naval base at Peenemünde towards the end of the 1950s, the fairway was improved in steps to a width of 70 m and a water depth of 6.0 m between Peenemünde and 'Osttief'. The stretch between Peenemünde and Wolgast received a water depth

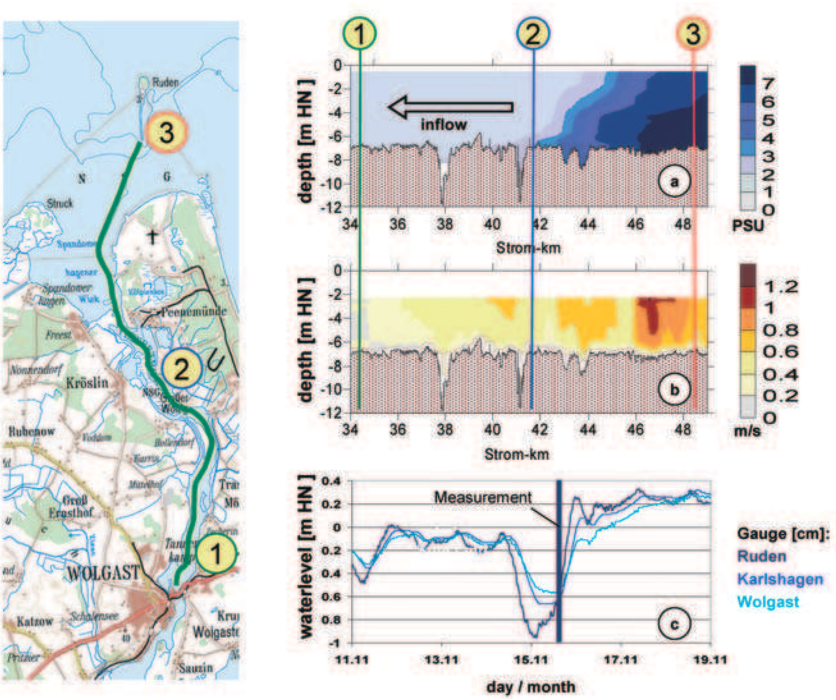

Fig. 6: Salinity values and current velocities during a period of water inflow, measured in the field on a longitudinal section in the northern 'Peenestrom' (WSA STRALSUND, 2007)

of 5.5 m in 1979/1980. In 1996/1997 it was deepened between Wolgast and 'Osttief-Ost' to be 6.5 m and the width was increased to 60 m from Peenemünde to Wolgast. The latest upgrade of the northern 'Peenestrom', with an adaptation of the bend as a reaction to increased length of vessels delivered by the shipyard, was carried out in 2007. In addition to dredging in 7 curves, a partial relocation of the fairway using naturally available water depths was done. In 2008/2009, the northern 'Peenestrom' will be deepened to 7.5 m till Wolgast.

Maintenance works on the navigation channel to Wolgast have to be carried out every 5 years on average. Approx. 150,000 m³ of dredged spoils are mainly dumped on sites off the island of Usedom. Smaller contingents are placed on a containment area at the 'Peenestrom'. Dredging works are done by hopper and bucket dredgers as well as dipper dredges.

In addition to dredging measures in the eastern approach to Stralsund and the access to Wolgast, some dredging is necessary in both connections of 'Greifswalder Bodden' to the Bay of Pomerania (Pommersche Bucht), namely the 'Osttief' and 'Landtief'. Dating back to documents of 1254, 'Osttief', cutting through the coastal lagoon sill between the islands of Ruden and Usedom, is mentioned to be a navigation channel which, at the beginning of the 19th century, was less than 4 m deep. During the course of the upgrade of the 'Peenestrom' its depth was increased from 6.0 to 6.5 m. 'Landtief', crossing the sill between Ruden and Usedom, was travelled after the removal of large boulders and the first dredging works at the end of the 18th century. The channel had a water depth of only 3.3 m in 1834 (DWARS, 1958). As an after-effect of WW II, the fairway, which in the meantime showed a depth of 4 m and a width of 60 m, had to be shut down for navigation in 1945. After cancellation of the

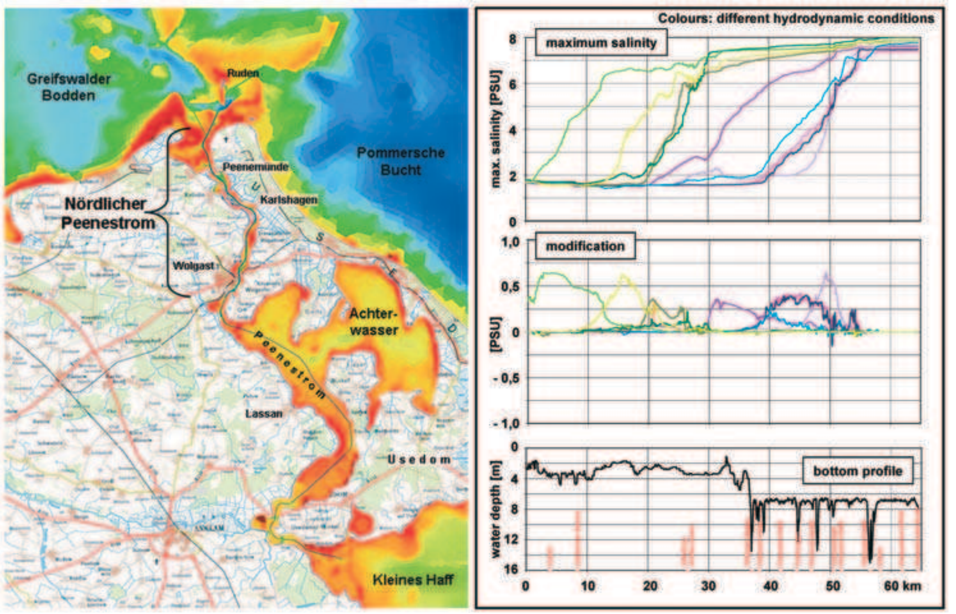

Fig. 7: Section of the model topography (left side) to give an overview of the northern 'Peenestrom'; modifications of maximum calculated salinity values due to construction measures (right side) (BAW, 2007)

blockade, the 'Landtief' was improved to have a water depth of 8.0 m with a width of 60 m in 1966/1967. Together with the upgrade of the eastern approach to Stralsund, it was widened to 90 m at a water depth of 7.5 m.

In the course of the environmental impact assessment for the two latest improvement plans, especially the baroclinic processes have been investigated in hydro-numerical simulation models. For the present planning process, a 3D-model of the southern Baltic Sea and coastal waters around Rügen was applied by BAW. Calibration of the model was based on extensive field investigations, documented in a technical report on the hydrodynamic conditions (WSA Stralsund, 2007) (Fig. 6). Model results concerning the baroclinic processes show that, with the realization of the presently planned construction measures, the maximum salinity in particular will increase due to an upstream shift of the mixing zone. The upgrade will boost the hydraulic capacity of the 'Peenestrom'. As a result, salinity-rich water volumes will be increasingly transported upstream (Fig. 7). Outside the mixing zone, no significant modification of salinity conditions will occur as a consequence of the construction.

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