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Impact of harbour moles and access channels on the South-East Baltic shore zone

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The paper deals with the impact of harbour engineering in the open South-East Baltic Sea shores on sandy seashores and bottom relief. Based on cartographic, literature and field investigation material, shore segments situated in harbours of Latvia, Lithuania, Russia, Poland and Germany are analysed. Shore zone evolution is discussed from the time when there were no harbour moles in the study area.

Key words: mole, access channel, bar, morphodynamics, harbour deepening, dumping

INTRODUCTION

The general features of the impact produced by outer hydro-engineering on the shore zone are rather well investigated. There is rich experience gained in construction of certain harbours and their operation, since people who worked in the ports did their best in order that the harbour environment and the processes occurring there were explored properly. Regularities of environmental impact are similar in harbours situated at sandy shores but not the same, since each harbour has its own specific engineering and plan structures as well as a unique position in the shore zone. Some of them are situated in the straits connecting the sea with internal fresh-water basins; others are in the river lower reaches or mouths, while some lie at an open seashore. Harbours differ greatly in their water area and the depth of the access channel, the length of outer hydro-engineering structures, i. e. moles and channels, etc. Some shores with harbours are notable for a well-developed nearshore drift, while others have no longshore transport of sediments. There are differences in natural conditions as well.

The purpose of the present paper is to analyse the impact on shore zone topography taking place in harbours situated under similar hydrometeorological conditions and sediments but differing in plan structure, development history and geographical situation.

METHODS

The paper deals with the impact on the shore zone relief by the SE and E Baltic (Latvian, Lithuanian, Russian Kaliningrad, Polish and German) harbours situated at the sandy shores, where hydro-engineering structures are directly affected by the open sea waves.

The impact on shore zone relief changes is analysed taking into account the harbour construction plans and maps grouped according to their type. The oldest ones reflect the state of the shores before harbour construction, others show construction stages or the period shortly after the construction, the third ones image effects and state of harbour reconstructions, and the forth ones (the latest) portray the situation of the 1990s or the start of the 21st century. Literature sources and personal experience in seashore investigations have been used as well in wiring the paper.

Impact on the shores in some SE Baltic states. Latvia has a long shoreline and several ports (Fig. 1). We shall deal, however, with only those harbours that are located on a more or less open sea shores, not in the bays, lagoons or rivers. From this point of view, a c. 235 km-long shore between the Lithuanian / Latvian border and the Kolkas Rags cape seems to be the most interesting. There are three ports operated in this section: Ventspils, Liepaja and Pavilosta. The first one is close to the zone where sediments drifting along the shore are accumulating, whereas Liepaja and Pavilosta are in the active transit zone of sediment

Fig. 1. Situation of ports at the SE Baltic shores
1 pav. Uostų išsidėstymas Pietryčių Baltijos krante

flow (Кнапс, 1966; Ulsts, 1998; Eberhards, 2003). According to Latvian experts, the port of Ventspils affects the shore length of 19 km (+5 km and −14 km, where accumulation is marked by "+" and erosion by "−"), Liepaja – 24 km (+10 and −14 km) and Pavilosta – 4.5 km (+1.5 and −3 km) (Eberhards, 2003). Hence, overall, these Latvian ports make an impact on 20.2% of its shores or a 47.5 km shore length.

Only 90.6 km of the shore belongs to Lithuania, with its main part (51 km) being on the Kuršių Nerija (Curonian) sand spit which is declared the National Park and entered into the UNESCO list of protected areas. Its sea coast has no hydro-engineering constructions. North of the Kuršių Nerija there is the port of Klaipėda and, farther, an olden system of the Šventoji harbour, now unserviceable. The sea coast at Palanga was also changing under the impact of the olden quay that later turned into a promenade pier – a sand drift-tight system. Later the pier was reconstructed into a more openwork system which, nevertheless, continues affecting the shore (Žaromskis, 2005). The port of Klaipėda affects approximately 25 km (+9 and −16 km) of the seashore. The broken-down southern pier of the Šventoji harbour affects an approx. 6.5 km shore-length (+4 and −2.5 km). The Palanga pier and a nearby groyne affect directly a 1.5 km shore-length (+0.5 and −1 km). Thus, the engineering constructions affect, directly or indirectly, a 33 km shore-length, or 36.4% of the total.

About 150 km of SE Baltic shore belong to Russia and contain two harbours: Baltiysk and Pionersky. Located near the convergence zone of the nearshore drift, the Baltiysk (former Pillau) harbour affects a rather short length of the shore (+3 and −2 km). Pionerskiy (Naujieji Kuršiai, Neu Kuhren) is in the zone feeding the nearshore drift. Its western pier goes even 560 m seaward, but due to its direction parallel to the shoreline it makes no great impact on the shore processes (+1 and −2 km) (Žaromskis, 2001). Hence, the harbours of Russian Kaliningrad region affect approx. 12% of the shoreline.

Open shore of the Baltic Sea in Poland is extended for about 400 km with four large ports on it: Szczecin, Swinoujscie, Gdynia and Gdansk. All of them are situated in favourable geographical conditions and undergo a rather weak impact of the marine processes. Gdynia and Gdansk are partly sheltered from the open sea by the Hel sand spit; Szczecin is situated in the Odra River delta, and only Swinoujscie harbour piers are reached by the N and NE wind-caused waves. As the shoreline here is exposed to the prevailing winds, the Swinoujscie region is in the zone where rather weak nearshore drift streams converge. On the contrary, Gdynia and Gdansk are located in the divergence zone of weak drift streams within the Gdansk–Puck bay (Subotowicz, 1995). Due to such location specificity, Polish ports impact directly only an approx. 14 km shore-length, including 12 km in Swinoujscie (Cieslak, 1995).

A significantly longer shore-length is formed by summing up segments affected by middle- and small-size ports and adding the zones affected by moles stabilising the mouths. The fifth Polish harbour, Kolobrzeg, makes the highest impact on the shore. At Kolobrzeg, the eastward nearshore drift stream prevails. Accumulation of sediments takes place here on a westward 3-km long segment, while erosion affects even a 13-km long segment east of the harbour. The moles of the Kolobrzeg harbour are not long: the western one extends only as far as about 200 m, while the eastern pier is nearly 300 m long – both reaching the 5-m isobath. Their role for the shore formation is determined by nearshore drift speciality. Beside Kolobrzeg, there are several small ports on the open seashore (Dziwnow, Mrzerzino, Ustka, Darlowo and Wladyslawowo, etc.), as well as hydro-engineering constructions stabilising the Vistula River arms. The moles of small harbour of Wladyslawowo reach only 5 m in depth, but being situated in the zone with a well-expressed nearshore drift they affect at least a 3–4 km long shore segment (Foltanski, 1938; Szmytkiewicz, 2003). Small and large harbours, taken together, affect approx. 42.1 km or 10.5% of the open shoreline. In fact, it is even higher, because the smallest engineering sites ignored here and used by fishers also affect shore-formation processes.

Although Germany has a rather long shoreline of the Baltic Sea, its major part lies in the belts, bays or areas sheltered by islands from the open sea waves. Therefore we shall discuss here only a small segment (approx. 60 km) of the shoreline east of Greifswald Boden. Moreover, these shores are considerably less affected by marine dynamical processes than those in Latvia or Lithuania.

There are no big ports on this coast, and small landing-places exert only a local impact on the shores, their total length being less than 4 km. Thus, only 2.4% of eastern German shores are affected by harbour engineering. It should be noted that nearly 80% of the Usedom Island shores, due to active erosion, are reinforced by breakwaters, groynes and erosion-proof slopes, and other hydro-engineering constructions (Generalplan…, 1994). This fact is a serious setback for determining the impact of small harbours on the shores.

Harbour dredging impact on shore processes. The majority of East Baltic ports built or renovated their outer hydro-engineering systems during the period from 1834 to the end of the 19^{th} c. Swinoujscie, Klaipėda and Gdansk should be noted here. The pole or crib type moles reached the depth of 7.5–8 m (Hagen, 1863) and met the harbour standards of that time nearly as long as by WWII. Such moles exerted a slight impact on shore formation in limited local segments. On the contrary, the harbour moles built on the turn of the 19^{th} and 20^{th} centuries (Gdynia, Ventspils and Liepaja) already ensured the access channel depth of 9–10 m. It should be reminded that by the mid-20^{th} c. dredgers were not very powerful. The harbour depth was, as a rule, ensured not by dredging but by extending moles to reach the surf zone or even beyond it. Under the conditions of a well-expressed nearshore drift, such constructions caused a significant direct impact on the shore zone, changing the state of the shore segments and the drift balance.

On the second half of the 20^{th} c. and in the 2000s, construction of considerably larger ships required deeper harbours, therefore highly efficient dredgers appeared. Many ports (Ventspils, Riga, Swinoujscie) deepened their harbour access channels to 12–14 m without changing the mole length. Only some ports, including Klaipėda, in order to improve navigation conditions, extended the moles, while other ports arranged their deep terminals offshore, as did Gdansk, or buoy terminals as in Būtingė. The dredging of access channels affected the morphodynamical processes both on the shore and on the underwater slope. So, the Klaipėda harbour impact zone, having reached the Olando Kepurė (Dutch Cap) point by the mid-20th c., now extended to Nemirseta or even farther north. The Ventspils harbour impact zone, which had reached about 8 km before, now shows a nearly double extension (Ulsts, 1998; Eberhads, 2003).

Dredging of harbours and their access channels not only makes longshore sediment migration difficult but also changes the volume of sediments on the shore zone. Maintaining the harbours deeper and deeper, the dredging and dumping volumes also increase. Deepening and cleaning of harbours from silt had been performed since olden times by using human and animal power, or steam power from the 19th century; now, modern machinery is used. So, in 1884 the output of bottom dredging in Pillau Harbour made 79.660 m^3 (Hagen, 1885). In 1853, the Klaipėda port board acquired a wooden 40 hp steam dredger capable to dug to a 7-m depth and a similar iron dredger in 1876 (Hagen, 1885). In the mid-20th c., the dredging volumes in the Baltic harbours reached hundred thousands m^3 per year (Žaromskis, Gulbinskas, 2003).

At the turn of the 21st c., the volumes of dredging in all Baltic harbours often reached millions of m^3 per year. So, according to HELCOM 2003 data, the volume of ground dug out made 3.7 mill. m^3 in all German harbours as well as respectively 0.7 mill., 4.07 mill. and 8.34 mmill. m^3 in Polish, Lithuanian and Latvian harbours (Fig. 2). It should be stressed that the bulk of this ground had been brought to the dumping sites. Especially high amounts were dug out and buried in the sea from Klaipėda and Ventspils harbours. In 1995, the Klaipėda port removed and buried in the sea a record volume of ground – nearly 2.4 mill. m^3. About a third of it was sand and coarse aleurite. An exception was only the period 2001–2002, when an experiment was carried out, and about 0.5 mill. m^3 of sand was brought to a depth of 3.5–7 m north of the port (Žilinskas, Jarmalavičius, Pupienis, 2003), and the rest was transported to the traditional dumping site at a depth of 40–45 m from which the sand does not come back to the shore zone lithodynamic exchange system.

The port of Ventspils is unrivalled in the Baltic Sea region by its harbour dredging and cleaning volumes. In 1996–1999, to reach the 17.5 m depth in the harbour and access channel, 8.025 mill. m^3 of ground was dug out (0.24 mill. m^3 per year) (Eberhards, 2003). The impact of the Ventspils harbour on the shore is weaker because of the location of the dumping site north of the harbour where the dumped ground is added to the northward longshore drift.

Thus, at the turn of the 21st c. many ports of the East Baltic provided the shore zone with sediment matter in higher volumes than the rivers did (Fig. 2). Unfortunately, the shore zone material accumulated in the harbours in a long run was buried in the open sea. Its impact on the shore zone is great and often exceeds the scale of natural shore-forming processes.

Changes in bottom morphology at the harbour moles. Dredging of harbours and their fairways causes not only accumulation or erosion in the shore segments having moles, but also significant morphological changes at the sea gate, most often due to the hydrodynamic situation changed by the mole. Analysis of SE Baltic harbours and development of their environment showed that, depending on harbour position (river mouth, open sea, strait), the impact on the environment is different, especially on the sea bottom areas beside the moles.

The harbours of Klaipėda, Baltiysk and Swinoujscie (the Swina mouth resembles a strait) can be examples of how their history is reflected in the cartographic material (Fig. 3).

In 1745, the depths in the Swina mouth ranged within 7.2–10.2 m, and there was a bar 2–3 m deep across its gate. By 1780, the Swina shores were reinforced and two parallel moles were built (Musset, 1920). Due to the shore reinforcement, the flow capacity to

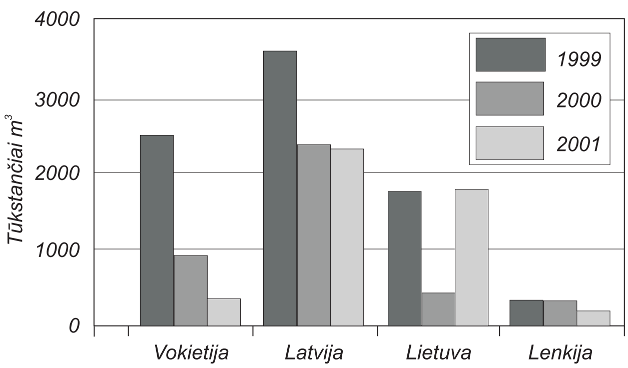


Fig. 2. Volumes of ground dredged and buried at the turn of the 21st century in the harbours of the Baltic Sea (HELCOM 2003 data)

2 pav. XX ir XXI a. sandūroje Baltijos valstybių uostuose iškasto ir jūroje palaidoto grunto kiekiai (HELCOM 2003 m. duomenys)

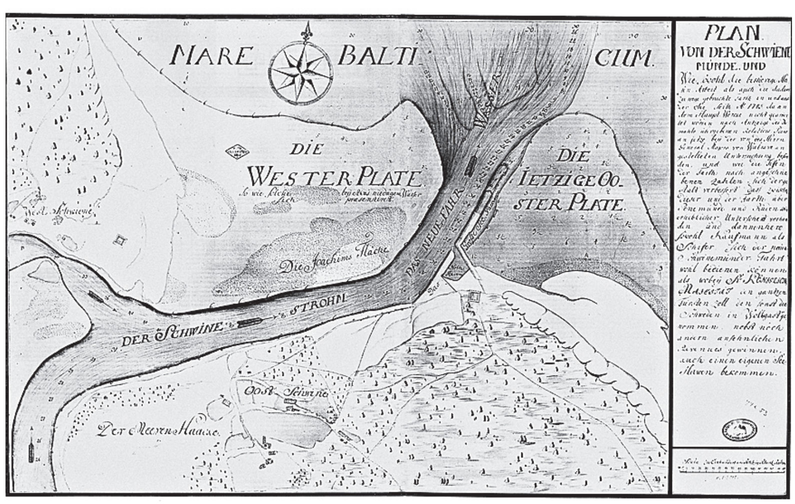
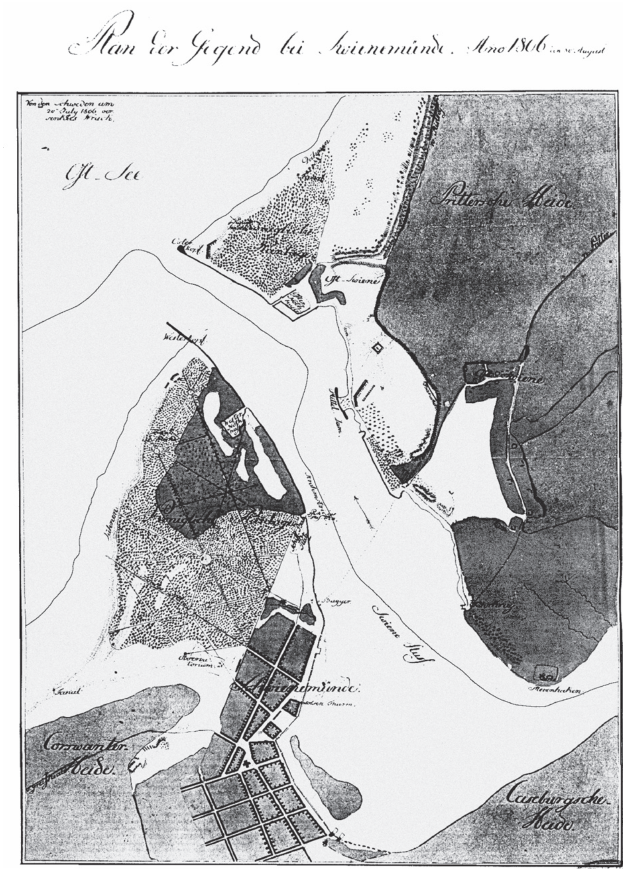


Fig. 3. Swina mouth plan compiled in 1745 under the leadership of major-general Walrawe. Scale in Rhine rods (1 Rute = 3.766 m), depths in English feet (0.3048 m). The original is in the German State Berlin (East) Library

3 pav. 1745 m. Svinos upės žiočių planas, sudarytas vadovaujant generolui majorui Valravei (Walrave). Mastelis – Reino rūtėmis (3,766 m), gyliai – anglų pėdomis (0,3048 m). Originalas saugomas Vokietijos valstybinėje Berlyno (Rytų) bibliotekoje



4 pav. 1806 m. švedų kartografų sudarytas uosto planas su Svinos krantų įrenginiais, miestu, jūros krantu bei įplaukos farvateriais. Mastelis – žingsniais (0,80 m). Originalas saugomas Vokietijos valstybinėje Berlyno (Rytų) bibliotekoje

Fig. 4. Harbour plan compiled by Swedish cartographers in 1806 with rather realistic portraying of Swina shore engineering units, town, seashore and access fairways. Scale in steps (0.80 m). The original is in the German State Berlin (East) Library

erode the bottom increased, and the depths between the shore and the moles reached even 18 m, whereas the shore at the eastern mole progressed seaward by 260 m. By 1800, east of the harbour, the shore augmented by about 100 m. At the same time, under the impact of moles west of the harbour, the shore changes were more difficult to be determined because of wide-scale amelioration works between 1780 and 1800. Judging from the map of an unknown author, detected in Berlin Library by E. Červinskas, the shoreline during the period from 1777 to 1800 moved seaward by 660 m. Such augmentation of land was formed here due to the drainage of the old river channel, regulation of river arms and afforestation of the coast. Such tendencies in shore evolution are confirmed by Harten's map compiled in 1797; however, it contains no additional information about the shore state. We can see here three small harbour basins designed newly and named by the author Noth Haffen (Disaster Haven). These basins at the harbour gate were designed for ships as a shelter during storms, when they did not intend to reach the significantly larger harbour of Szczecin.

Quite a few information about harbour environment changes caused by mole construction is obtained from a plan dated from 10 July 1806 and compiled by Swedish cartographers (Fig. 4). It differs from the previous plans since the Swedish plan contains the already existing engineering constructions and the regulated sea coast area. It should be stressed that the plan shows a fairway going along the eastern mole and turning westward beyond the gate along the shoreline. The direct course of ships is obstructed by a bar (Deecke, 1905) which is not shown in the plan. We know that, when the construction of the moles in the present-day Baltiysk harbour started, the situation was similar also in front of the Pilawa (Pillau) strait.

The evolution of the Swinoujscie harbour and the nearby shore in the 19th c. is well-reflected in a 1834 plan compiled by an unknown author and identical to the map with a detailed description given in the 1834 sailing directions. These documents show that the harbour moles reached a depth of 25–28 feet (7.5–8 m). Hence, the moles were built with a reserve, since ships with a 3–4 m draught were used at that time. The configuration of moles shows that they were built in order to reduce the sanding from the east. According to the 1998 chart, it should be accepted that from 1834 the main harbour embankments and moles have changed insignificantly. From 1934 the shoreline shifted seaward from the mole by only 17 m, while at the western mole the shore shifted by nearly 200 m. Only about 6 km westwards (on the German side), shore erosion takes place. During 100 years the shore retreated here by c. 30 m (Generalplan…, 1994). Now, the depth of 14 m is naturally rather stable at the harbour gate and the internal navigation channel, while the external channel is regularly dredged.

East of the harbour, the shore is notable for accumulative segments: sand dunes and 2–3 underwater longshore bars. Thus, Swinoujscie is in a zone of sediment drift going on in two directions: the westward drift is assessed to make 0.5 mill. m^3 per year and the eastward one about 0.4 mill. m^3 per year (Musielak, 1995; Ostrowski, Skaja, Szmytkiewicz, 2000). The access channel divides the old outwash fan into two unequal parts. A conclusion can be made that the harbour engineering affected mainly the formation of the shore next to the harbour. At the same time, the state of the deeper part of the nearshore and the remote shore was determined by the prevailing processes of interaction between the Odra River outwash and the sea waves.

It should be noted that there are no absolute analogues of environment changes in the Baltic Sea during the development of the Swinoujscie port. Some features resemble those in the Daugava River mouth due to construction of the Riga sea gate and its access channel (Рогов, Ромашин, Стейнбах, 1964).

The situation and conditions of the Baltiysk (Pillau before WWII) were similar to those of Klaipėda. The harbour, in the same way as Klaipėda, is sheltered by a sand spit, and a flow from the Aistmarės Lagoon is prevailing in the strait. The width of the strait and the configuration of harbour moles are similar as well. The basic difference is that the Pilawa (Pillau) Strait is only 2 km long; moreover, the seaward water flow is weaker than in the Kuršių Marios lagoon or Szczecin Boden.

A detailed description of the evolution of the Baltiysk harbour till the construction of modern type moles is given by L. Hagen (Hagen, 1885) whose father Gotthilf Hagen was the construction manager for this harbour from 1825. Therefore, L. Hagen had an opportunity to publish many maps of old Prussian ports. So the 1625-year plan with the first quarters of the Baltiysk town and natural shores of the strait showed that the depth was 7–9 m in the strait (isobath feet converted into

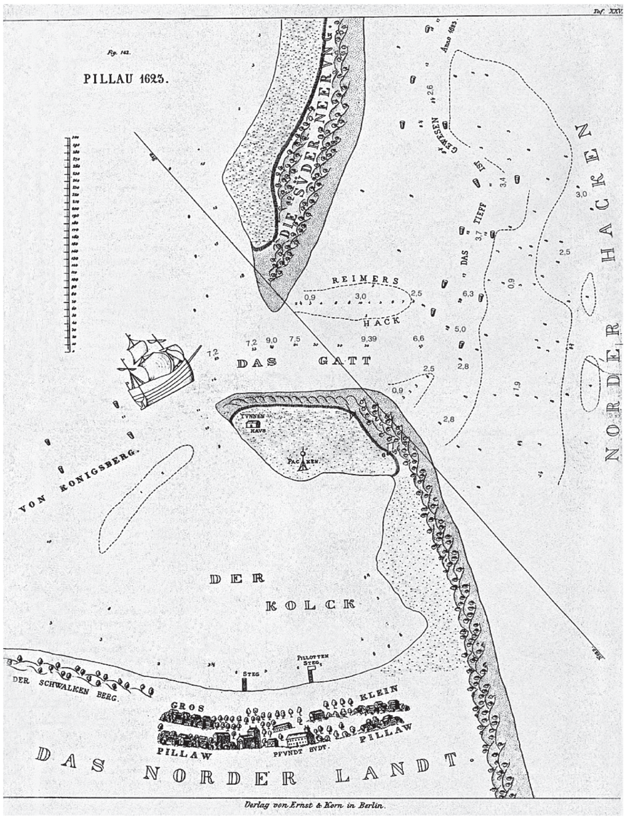


Fig. 5. A plan of Pilawa (Pillau) Strait in 1625. There was no town and port, and the strait was deep. In front of the strait there was a bar (Hagen, 1885)

5 pav. 1625 m. Pilavos sąsiaurio planas. Miesto ir įrengto uosto dar nebuvo, bet sąsiauris, prieš kurį plytėjo barinės seklumos buvo gilus (Hagen, 1885)

metres) (Fig. 5). To reach such depths of the bottom, the flow had to be very strong. Instead of a traverse bar in the sea in front of the mouth, two bars extended in the current direction were formed, the depth above them varying from 0.9 to 2.5 m. Only away from the shore there was a transverse bar with the depths above it ranging within 3–6 German feet (0.9–1.9 m).

The plan drawn in 1828 shows that the northern shore is reinforced by an embankment and that the construction of the southern mole is launched. The strait, if compared to that of 1623, is deeper and the side bars on the either side of the fairway are better expressed. From 1828 to 1854–1855, the shore augmented seaward by 100 m at the northern mole, but remained unchanged at the southern mole (Hagen, 1884). The depths in the strait reached 9.4 m (Fig. 5).

The map of 1884 shows the strait and the harbour having more present-day features: the mole construction is finished at a depth of 9 m as today. The shoreline at the southern mole remained stable and at the northern mole retreated landward about 50 m. In front of the gate, a trough 9.6–10.7 m deep is formed by sea and strait currents, and a transverse bar (depth 6.3 m) is formed at a distance of 350 m from the gate (Fig. 6).

The environment of the Pilawa (Pillau) Strait was under the impact of harbour engineering only until WWI. This is well reflected by the 1914 chart issued in Germany, It contains new information about the relief of the strait and the shore zone. The depths of 8–9 m prevailed again, but they were maintained by dredging a bit away from the sea gate. The depths in the bar channel, however, reached even 12–13 m. Moreover, the shore south of the harbour was actively eroding. The map indicates the efforts of people to make the shore stable by building groynes in a 0.5-km long segment. One more detail is interesting – if in 1884 the bottom ravine was 10.7 m deep, the chart shows already 13.8 m in this place (Fig. 7). Hence, the ravine deepened by a metre approximately each 10 m.

It should be noted that the shore zone at Baltiysk was affected not only by harbour engineering. In 1916, the Nogat arm of the Vistula River at Biala Góra was dyked, and the overland runoff into the Aistmarės decreased significantly (Winlel, 1939). At the same time, the role of erosion-causing currents from the lagoon weakened. Moreover, from 1912 to 1922, the development of an amber placer in Palmininkai began, and about 250–300 thousand m^3 of waste rock was dumped into the nearshore. Part of this material was transported by sea currents and waves towards the Baltiysk harbour (Pratje, 1932). During the hundred-year development of this placer, about 60–65 mill. m^3 of ground was dumped into the sea. About 40% of this material entered the lithodynamic exchange system of the shore zone (Aibulatov, Bass, 1983). Human activities changed substantially

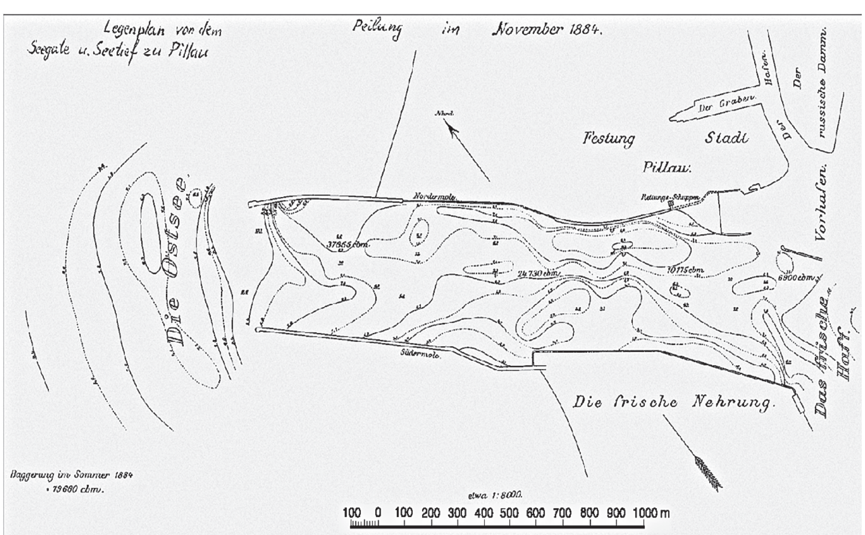


Fig. 6. A plan of Pilawa (Pillau) Strait and Baltiysk harbour in 1884 portraying the situation of hydro-engineering elements resembling the today picture. Volumes of ground dug out during cleaning of the fairway are given in m^3 (Hagen, 1885)

6 pav. 1884 m. Pilavos sąsiaurio ir Baltijsko uosto planas. Hidrotechninių įrenginių lokalizacija panaši į dabartinę. Plane parodyti ir valymo metu farvateryje iškasto grunto tūriai (m^3) (Hagen, 1885)

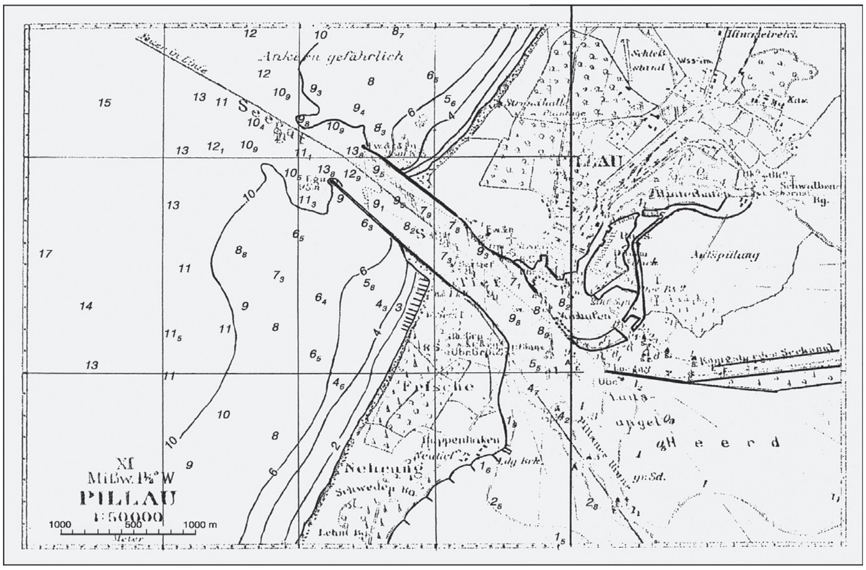


Fig. 7. A cutting from the 1914 chart of Pillau (1:50 000) with a nearly 14-m deep ravine washed by the currents at the mole tips, it was only 10.7-m deep in the 1884 map

7 pav. 1914 m. jūrlapio „Pillau" (M 1:50 000) iškarpa. Ties molų galais srovių išplautas beveik 14 m pagilėjimas, kuris 1884 m. žemėlapyje buvo tik 10,7 m

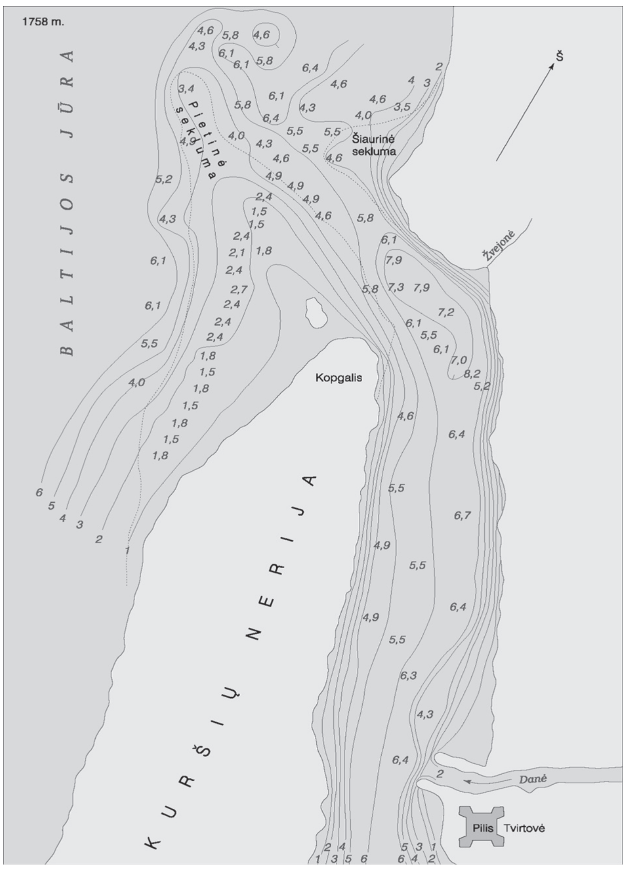


Fig. 8. State of the shoreline and depths at the access to the Klaipėda Strait before the mole construction. A cutting from the 1758 F. Pleshcheyev's map (Karta Zaliva Kurskiy) prepared for publication by E. Červinskas

8 pav. Kranto linijų padėtis bei gyliai ties įplauka į Klaipėdos sąsiaurį iki molų statybos. Iškarpa iš F. Pleščejevo „Karta zaliva Kurskij" (1758); žemėlapį spaudai parengė E. Červinskas

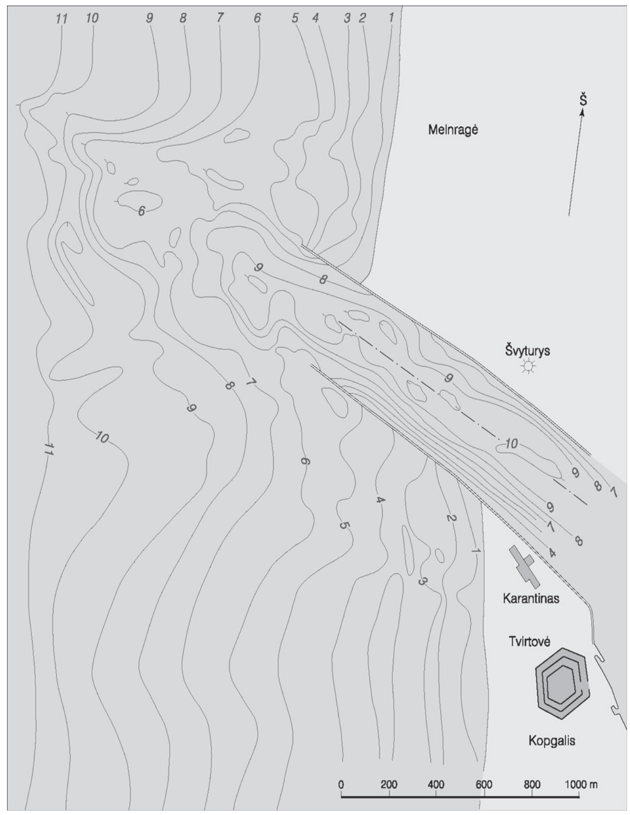


Fig. 9. The bathymetry plan of Klaipėda Harbour in 1924. It reveals the impact of the outflow current on the isobath character (compiled by E. Červinskas)

9 pav. 1924 m. Klaipėdos uosto batimetrinis planas. Jame išryškėja pro uosto vartus ištekančios srovės poveikis izobatų tįsai (parengta E. Červinsko)

the initial lithodynamic and morphodynamic processes at the Baltiysk Port and highlighted the prevailing dependence of the shore state not on the port, but on Yantarniy amber-pit exploitation. The tendencies of processes remained the same, mainly due to moles. After the groynes and other engineering systems eroded on the leeward southern part of the harbour, the shore is now eroding at about 3-km segment (Басс, Жиндарев, 2004). The depth of the ravine formed at the mole tips, according to the 1994 chart, reached 28.4 m.

The evolution of the Baltiysk harbour and its environs reveals an enormous impact on the shore caused by changing the natural drift balance, regulating the river runoff, replenishing the sore zone by sediments, constructing engineering units and maintaining them.

The harbour in Klaipėda, in a similar way as in Baltiysk, lies in a strait. Differently from its southern neighbour, the Klaipėda Strait is by c. 10 km longer than the Pilawa (Pillau) Strait and considerably shallower. Before the moles were built in the strait, 6–8 m depths prevailed in it and water depth above the bar used to be 4–5 m. The state of the Klaipėda Strait and the shores before the harbour mole construction is reflected best in the 1758 F. Pleshcheyev's map prepared for publication by E. Červinskas (Fig. 8).

We can see an embryo of a sand spit tip with a dune (Kopgalis) and a bar extending north-westwards for 1.5 km. The depths above it ranged from 1.5 to 3.4 m. At the same time, the northern bar is weaker expressed and lying deeper (3.5–4.6 m). Currents had washed an about 250 m wide fairway between the bars. The position of the shoreline and the depth distribution indicate an obvious northward transport of sediments and the tendency of the strait mouth to turn right. The deepest point in the strait was at the Žvejonė River mouth and reached 8.2 m, although the prevailing depths were 6.3–6.7 m. The Klaipėda harbour mole construction (1834–1878) and tendencies in bottom and shoreline changes had been discussed before (Кнапс, 1965; Žilinskas, 1998); we shall not elaborate on this theme, but shall discuss the morphological traits of the harbour mole environment seen in the plan drawn from the measurements made in May 1924 (Weber, 1924). This plan (Fig. 9) reflects the situation after 46 years from the construction of the harbour moles. Moreover, the plan portrays the situation reflecting depths formed almost naturally, since during WWI the harbour in Klaipėda was neither dredged nor cleaned.

If compared to the F. Pleshcheyev's map given above, the shoreline changed significantly after the moles were constructed. Together with formation of Kopgalis in a segment of about 1.5 km, the shoreline that before mole construction had been NNE-oriented (17° azimuth) turned to NNW (350°). The shoreline north of the harbour shifted seaward, but is direction changed insignificantly. Moreover, the southern mole affected severely the bottom relief – the southern bar is considerably less pronounced. The general position of the isobaths indicates that a major part of material being brought from the south to the north tries to go round the southern mole, but it is forced to move farther seaward by the outflow current. The impact of this current reaches the 11-m isobath. But its influence on massive sand transport is limited 700–800 m from the sea gate where due to slowing of the current a shallow 6 m deep is formed. At the same time the northern bar is better expressed.

It can be assumed that the changes of shoreline due to mole construction changed the shoreline exposition with regard to the prevailing winds. Therefore, the resultant of the northward sediment migration changed the direction and the northern bar began to develop more intensively. In other words, the shore attained development tendencies of today, as the northern bar is better expressed than the southern one. It is the change in shoreline exposition that explains why the variations at the Klaipėda harbour gate excite such a great shore reaction being observed now from the end of the 1990s. The shoreline exposition changes would be even more manifested if measuring the angle with regard to the prevailing winds we would include the length and the angle of the moles into the shoreline, this procedure is not being done, as a rule.

The measurement data accumulated in a long time show perfectly the peculiarities in the near-mouth bar. In 1924 the bar was formed at a site being 800 from the gate. The 1997–1999 investigation data showed that the influence of the current flowing from the harbour on sand drift was detectable at a distance of 800–1500 m from the harbour gate (Leppik, 1927; Žaromskis, 1999). If supposed that the outflow currents remained the same as they were at the start and the end of 20th c., it could be forecasted that the maximum accumulation of sand in the access channel should take place at a distance of about 1 km from the gate. Now this site is notable for 14–15 m background depths (instead of previous 10–11 m), thus such a probability is very low.

It is interesting also to compare impact of several moles on the bottom relief directly at the gate. Deep bottom ravines can be formed at the gate, as in Baltiysk, can be formed only by strong currents. They can appear due to a sudden change in water level in the sea, the lagoon or the Boden, as in the case of Swinoujscie. Length and capacity of the strait connecting a lagoon with the sea seems also to be important. The highest water carrying capacity is observed in a short strait of Pilawa (Pillau). Strong currents appear each time with the turn of wind from that inducing the surge to that causing lowering of water level (Musset, 1920, 1922). Moreover, seawards the span between the moles goes narrower, thus, increasing the speed of current flowing out.

In the case of Klaipėda and Swinoujscie such big difference in water levels between the sea and the lagoon (Kuršių Marios in Klaipėda and Boden in Szczecin) is not formed. However, now, as the Klaipėda harbour is significantly deepened and the gate is narrowed, the phenomenon of the Baltiysk harbour started to be expressed at the gate of Klaipėda harbour. After 2002, due to deepening erosion, the gate is deeper by 0.5 m. Such a tendency seems to persist in the nearest years.

CONCLUSIONS

The strongest impact on shore-forming processes in the South East Baltic region is undergone by the Lithuanian shores. In a short segment, there are three harbour-type engineering units affecting about 36% of the total Lithuanian seashore. The lowest impact on the shoreline (5.3% of the total) is observed from the Russian Kaliningrad ports.

Influence of harbour moles on the environment depends not only on mole length and configuration, but also on the geographical position of a harbour. The highest impact is undergone by shores with well-developed sediment longshore transport flows and by those which have moles stretching in the sea beyond the surf zone.

Majority of the SE Baltic harbours built and operated in 19th c. and the start of the 20th c. maintained their gate depth by extending the moles. Otherwise, in the second half of the 20th c., when highly productive dredgers appeared, the necessary depths were maintained by dredging and cleaning the access channels and harbour water areas. Such practice increased significantly the impact of harbours on the shore zone drift.

When the harbour moles are extended beyond the surf zone or the access channel is deepened, the former bars in front of the gate disappear. Under the conditions of short straits and those having high channel capacity for water, the deepening erosion takes place (Baltiysk). It can appear also during the gradual deepening (dredging) of the strait or changing the vertical section area at the harbour gate (Klaipėda).

At the turnover of the centuries (1999–2001) four Baltic states – Germany, Poland, Lithuania and Latvia – have brought to the dumping sites 16.8 mill. m3 of ground dug in the harbours. About a third of this material could be used for regeneration of the beaches.

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Rimas Žaromskis

UOSTŲ MOLŲ IR ĮPLAUKOS KANALŲ POVEIKIS PIETRYTINĖS BALTIJOS KRANTO ZONAI

Santrauka

Straipsnyje nagrinėjamas atviruose Pietryčių Baltijos krantuose įsikūrusių uostų įrenginių poveikis smėlingiems jūros krantams bei dugno reljefui. Remiantis kartografine, literatūrine bei natūrinių tyrimų medžiaga analizuojama Latvijos, Lietuvos, Rusijos Kaliningrado srities, Lenkijos ir iš dalies Vokietijos krantų atkarpos. Nustatyta, kad daugelis uostų (Gdanskas, Klaipėda, Svineujscė ir kt.), kurie kūrėsi iki XIX a. 8-ojo dešimtmečių, turėjo uostų molus, užtikrinančius 6–8 m gylį. Molai neišeidavo už bangų gožos zonos ribų, todėl neturėjo didelio poveikio kranto zonos reljefui ir nesukeldavo didelės ardos.

XIX a. pabaigoje ir XX a. pradžioje pastatyti uostų molai (Gdynė, Ventspilis, Liepoja) įplaukoje jau užtikrino 9–10 m gylį. Šie molai buvo pastatyti jau iki išorinio bangų gožos zonos krašto arba net už jos ribų. Jie galėjo sąlygoti jau didelius kranto pokyčius: nešmenų akumuliaciją priešvėjinėje molų pusėje ir išplovimą užuovėjinėje. Daroma išvada, kad uostų molų poveikis aplinkai priklauso ne tik nuo jų ilgio ir konfigūracijos, bet ir nuo paties uosto geografinės padėties. Didžiausią poveikį patiria

krantai, prie kurių būna intensyvūs priekrantiniai nešmenų srautai ir prie kurių pastatytų uostų molų galai yra už bangų gožos zonos ribų.

XX a. II pusėje atsiradus didelio našumo dugno gilinimo įrenginiams uostų įplaukos kanaluose vis didėjantis gylis dažniausiai palaikomi nebeilginant molų, o efektyviai valant farvaterius, pvz., Ventspilyje, Klaipėdoje, Svineujscėje. Šie darbai radikaliai keičia nešmenų balansą užuovėjinėje uostų molų pusėje, tai ypač ryšku Klaipėdoje. Be to, uostuose ir įplaukos kanaluose iškastas gruntas neretai išvežamas į sąvartos rajonus jūroje, esančius už kranto zonos ribų: 1999–2001 m. keturios Baltijos valstybės – Vokietija, Lenkija, Lietuva ir Latvija – į sąvartos rajonus jūroje išvežė 16,8 mln. m^3 uostuose iškasto grunto. Iš Vokietijos uostų buvo iškasta 3,7 mln. m^3, Lietuvos – 4,07 mln. m^3, Latvijos – 8,34 mln. m^3. Maždaug trečdalį šios medžiagos buvo galima panaudoti atkuriant nykstančius paplūdimius.

Uostų molus statant gylyje, kuris yra už bangų gožos zonos ribų, arba ženkliai pagilinus įplaukos kanalus, dažniausiai išnyksta prieš uostų vartus anksčiau buvusios barinės seklumos. Trumpų ir gerą pratakumą turinčių sąsiaurių sąlygomis ties uostų vartais vyksta gilinamoji erozija (Baltijskas). Ji gali prasidėti ir palaipsniui gilinant sąsiauryje esančią akvatoriją arba pakeičiant pratakos pjūvio plotą uostų vartuose (Klaipėda).

Tarp Pietryčių Baltijos regiono valstybių uostų įrenginiai labiausiai paveikia Lietuvos krantų krantodarą. Neilgoje kranto atkarpoje čia buvo net trys uosto tipo hidrotechniniai įrenginiai, kurių poveikis apima maždaug 36% visos kranto linijos. Mažiausią uostų poveikį (5,3%) patiria Rusijos Kaliningrado srities krantai. Atvirame Lietuvos krante esantys uostai daro poveikį 20,2%, Latvijos – 10,5% atviros jūros kranto linijos ilgio. Tarp nagrinėtų uostų didžiausias poveikio atkarpas sudaro Liepojos ir Klaipėdos uostai, ties kuriais vyrauja labai intensyvūs priekrantiniai nešmenų srautai.