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JOURNAL OF ENVIRONMENTAL ENGINEERING AND LANDSCAPE MANAGEMENT
ISSN 1648–6897 print/ISSN 1822-4199 online
2012 Volume 20(3): 240–247
doi:10.3846/16486897.2012.660884

IMPACT OF KLAIPĖDA PORT JETTIES RECONSTRUCTION ON ADJACENT SEA COAST DYNAMICS

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Submitted 06 Apr. 2011; accepted 18 Oct. 2011

Abstract. During the reconstruction of 2001–2002, the Klaipėda port jetties were lengthened (the northern jetty by 205 m and the southern by 278 m). These works produced an impact on dynamic coastal processes in the neighbourhood of the port. The evaluation of the impact of jetties reconstruction was based on the data obtained in 1995–2010 during the monitoring of coastal dynamics in the port of Klaipėda. Study area includes 10 km coastal strip of mainland and 12 km coastal strip of Curonian Spit. The analysis of the data concerning the changes in the annual amount of coastal sediment served as a basis to evaluate the impact of Klaipėda port jetties on the trends in coastal dynamics prevailing before the reconstruction and their changes after it. It was found that in the mainland coastal stretch closest to the jetties, where in the last decade before jetties extension the seashore was relatively stable, the coastal erosion trends were dominant. Meanwhile, the closest to the jetties coastal stretch of the Curonion Spit, where erosion processes dominated in the last decade before jetties extension, stabilized right after the reconstruction and with a passage of time sediment accumulation trends have become prevailing.

Keywords: environmental monitoring, seaport of Klaipėda, jetties, coastal sediments, dredging.

1. Introduction

Multi-purpose hydrotechnical constructions are inevitable attendants of human economic activities. Depending on a size and a design, these constructions change the patterns of hydro-morphodynamic processes in the coastal zone (Komar 1983). The shallow sandy coastal zones (the whole Lithuanian coast belongs to this type) are especially sensitive to the changes of hydro-morphodynamic processes. These changes usually results in undesirable coastal erosion. To neutralize the erosion processes, various new coastal protection measures are implemented which often cause the same or even more serious problems in the adjacent coastal stretch for example, pier reconstruction in Palanga (Žilinskas *et al.* 2008, 2010). Though engineering constructions are projected after assessments of possible environmental impacts, the Lithuanian and global practice shows that these preliminary assessments are rarely accurate (Komar 1983; Carter 1988; Van de Graff *et al*. 1991; Haan 1992; Žaromskis 2008; Žilinskas 1998; Žilinskas *et al*. 2008, 2010; Lashchenkov 1987). The impact of any hydrotechnical construction can be accurately evaluated through monitoring of coastal dynamics: regular observation of coastal landscape elements focussing on the object features, the nature and intensity of their changes.

The monitoring may range from visual observations (Millington *et al*. 2009) to extensive complex investigations (Hemsley 1990; Morang *et al*. 1997a, 1997b; Larson *et al*. 1997; Gorman *et al*. 1998).

The jetties of Klaipėda and Šventoji ports and Palanga pier with the protective groyne have a significant impact on the condition of the Lithuanian coast. The jetties of the port of Klaipėda undoubtedly influence the most coastal processes. In order to determine their impact on the state of coasts, monitoring of Klaipėda port coastal dynamics was started in 1995 (Fig. 1). The data accumulated in the 15 years of monitoring can serve as a basis for some conclusions about the impact of these hydrotechnical constructions before and after the reconstruction in 2001–2002.

The main objective of this paper is to assess the impact of Klaipėda port jetties reconstruction on adjacent sea coast dynamics on the basis of coast dynamics monitoring data.

2. Investigated area and methods

More significant works related with the construction of the Klaipėda port jetties, deepening of the navigation channel and reinforcement of embankments were started in the Klaipėda Strait in 1834. Later, the jetties were several times extended until the northern jetty reached a length of about 2070 m in 1994 and the southern 1362 m. The depth of the entrance channel then reached 12–12.5 m.

The analysis of cartographic data of different time periods encompassing the XIX and XX centuries has revealed that after every jetties lengthening, dynamic processes within the coastal zone became more intense until, over time, coastal area had adapted to new conditions reaching profile equilibrium, and coast relatively stabilized. Since the last jetties extension (1957) after over 30 years the coastline had been adapted to the changed conditions and dynamic processes reached stability (Žilinskas 1998).

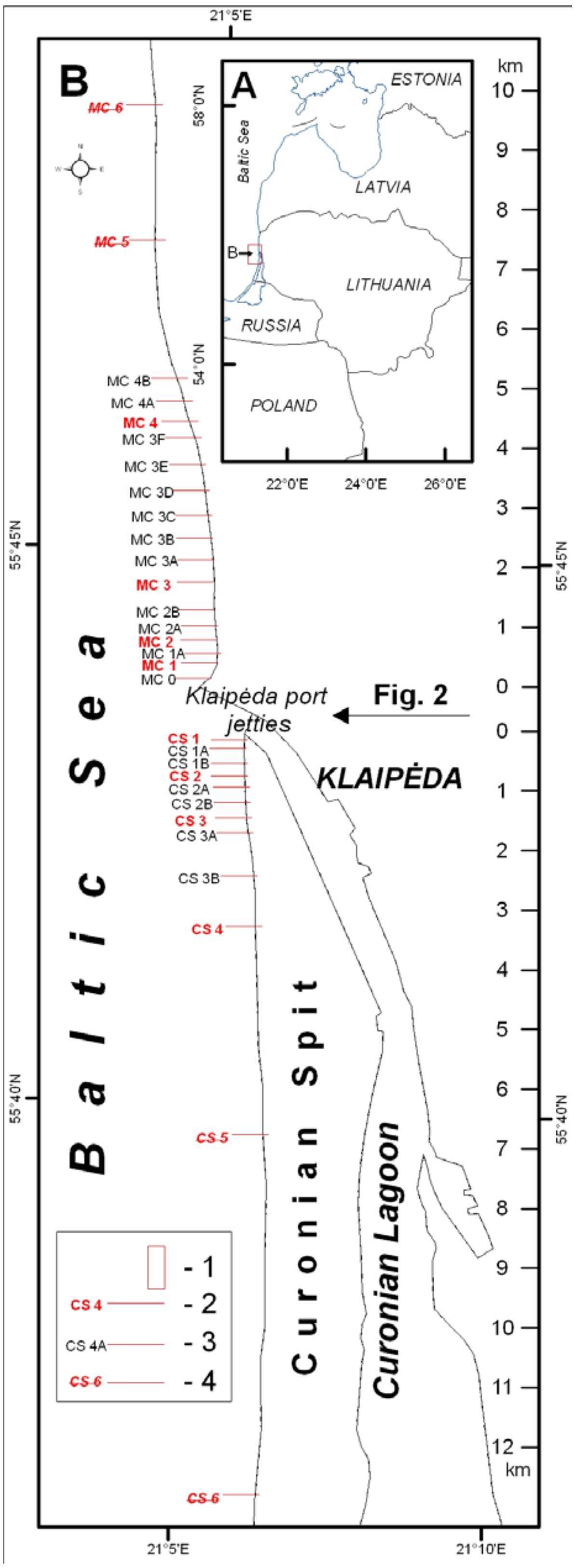

Fig. 1. Location of study sites: 1 – study area, 2 – measuring profiles set up in 1995, 3 – measuring profiles set up in 2001, 4 – measuring profiles eliminated in 2001. MC – mainland coast, CS – Curonian Spit. On the right site – distance (km) from the Klaipėda port jetties

Although in individual time periods coastal erosion within the sector of investigations was relatively intense (Žilinskas 1998), however, it did not raise a serious danger to houses and seaport as well as to their infrastructure. Therefore, no significant coast management works were carried out. Here so called "natural management" without intervention of human being took place.

Since the middle of the XX century, with the increasing flow of tourists, only optimizing works of recreational environment (recreational infrastructure development and dune supervision and management) were performed within study area.

Executing the Klaipėda port development project (the beginning of 2001–October, 2002), both jetties were extended and the entrance channel was deepened. By means of 101 400 m^3 of stones, the northern jetty was lengthened by 205 m and the southern (166 500 m^3 of stones) by 278 m (Bacevičius 2003). Besides, the northern jetty was turned in NE–SW direction (Fig. 2). The southern jetty was turned in the same direction but at a smaller angle. The entrance channel was deepened to 14.5 m. Jetties extension was carried out in order to protect the entrance channel from tides (waves) and deposits accumulation during storms, and thus ensure greater security for incoming vessels to the port.

Also, seaport fairways were dredged to enable vessels of larger draughts to enter the port. As Klaipėda port is rapidly developing, new reconstructions are inevitable in the future; and the impact of reconstruction will induce an adjacent sea coast dynamics response. For these reasons, since 1995 the coastal dynamics monitoring has been started within the affected port area. Data collected during this time will help to create a coast arrangement strategy within this coastal area.

In 1995, the observation stations were selected according to specific character of each coastal stretch (beach and dune morphometric characteristics, coast structure and geodynamic trends). As the jetties of Klaipėda port represent the main impact factor on the coast, the observation stations were arranged by the principle of rarefying network of points, i.e. the distances between monitoring stations increased moving away from the jetties. Thirteen monitoring stations were set up (6 in the mainland and 7 in the Curonian Spit coasts). Benchmarks were built and geodetically tied. Based on the analysis of the data collected during five years since the beginning of the observations, the network of observation points was optimized. In 2001, the farthermost points from the jetties, where the impact actually was not fixed, were excluded. The network of points closer to the jetties, where the greatest transformations took place, was thickened (Fig. 1).

The monitoring observations take place once a year in the first week of June when the weather is calm, the coast is relatively stable and water level is close to the average long-term. The cross-profiles of the coast were levelled (using electronic tachometer TOPCON 229) and surface sediments were sampled from the western slope and the foot of the dune ridge, middle of the beach and from the shoreline. Based on the measurement data, the changes of the shoreline, the crest and the foot of the dune ridge and the volume of sediments in the beach, in the dune ridge and in the coast in general (beach + dune ridge) were calculated. Sand samples were screened (using Fritch laboratory equipment) to determine the distribution of different sand fractions, average diameter of grains and sorting. Extra observations were carried out after extreme storms: in December, 1999, after hurricane "Anatoly", and in January, 2005, after hurricane "Ervin". Analysis of monitoring data showed that not all measured and calculated morphological rates of the coast equally reflected the coastal changes.

For example, sand sorting coefficient, spatial and temporal distribution patterns of sand grains varied within a narrow range or even were stable (Jarmalavičius 1998; Žilinskas *et al*. 2001) and did not reflect the coastal changes. For this reason, the present evaluation of coastal geodynamic trends is based on the best geoindicator: *the surface sediment budget (m^3/m) or the sum of the temporal and spatial changes of eroded and accumulated coast composing material (calculated till the line of the long-term average sea level).*

3. Results

Since the beginning of monitoring (1995), the coast has changed differently in different sectors. Analysis of the collected data showed that the mainland coast sector (about 600 m long) closest to the port has been eroded (Fig. 3 A). The maximal rates of erosion occurred in a 250 m length stretch situated 100–300 m away from the jetty. In this stretch the loss of sand during 15 years amounts to 42 m^3/m. Erosion processes are slowed down until approximately 600 m away from the jetty they are replaced by the processes of accumulation. The most intensive accumulation was recorded in the sector situated approximately 1000–2000 m away from the jetty. The sand supply in this sector has increased to 65 m^3/m. Further to the north, accumulation rates decrease until about 3000 m away from the jetty where the state of the coast can be regarded as relatively stable. Till the end of investigated stretch the sand supplies vary within a small interval without any dominant trend.

The most intensive erosion on the Curonian Spit coast was recorded in an approximately 200 m long coastal stretch closest to the jetty (Fig. 3 B). The amount of eroded sand reached 53 m^3/m. In an approximately 1000 m long sector situated at the south of the jetty (between 500 and 1500 m from the jetty), erosion processes were weaker. The loss of sand reaches about 10–20 m^3/m. Northwards (from approximately 2000 m), accumulation processes have been dominant: on average 60 m^3/m of sand has been accumulated. Generalizing the geodynamic trends, the investigated coastal zone may be divided into stretches characterised by different dynamics properties. In the mainland coast the following stretches were distinguished: a stretch of dominant erosion between 50 m and 500 m from the jetty, a stretch of dominant accumulation between 700 m and 3000 m from the jetty and a relatively stable stretch 3000 m away from the jetty northwards.

On the Curonian Spit the following stretches were distinguished: a stretch of the most intensive erosion including the zone till 200 m from the jetty, a relatively stable stretch between 300 m and 2000 m from the jetty, and a stretch of dominant accumulation 2000 m from the jetty southwards.

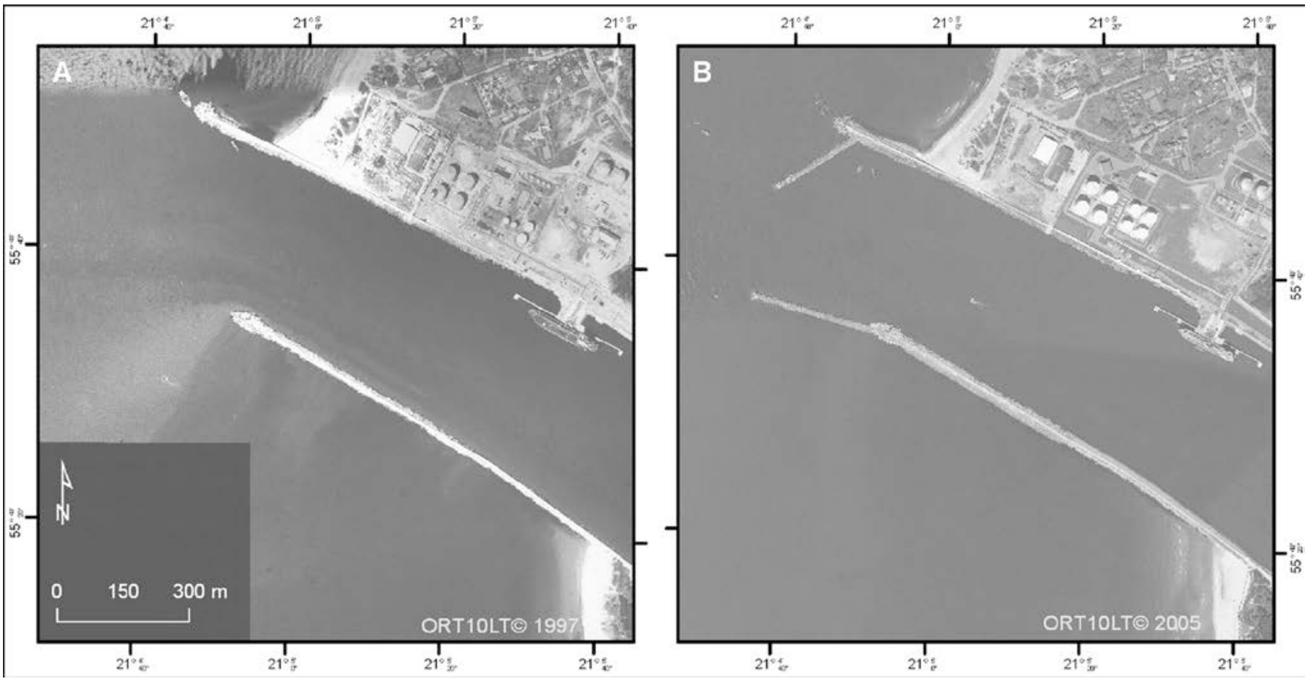

Fig. 2. Klaipėda sea port jetties before (A) and after (B) reconstruction

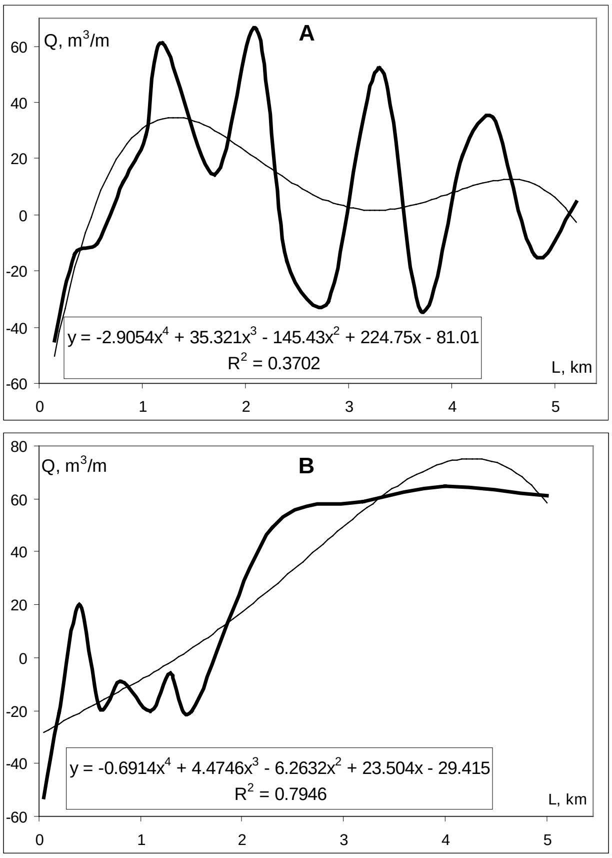

Fig. 3. Fluctuation of sand amount (Q) in 1995–2010 along the mainland coast (A) and Curonian Spit coast (B). "0" on abscissa axis – Klaipėda port jetty

To evaluate the impact of jetty reconstruction, a more detailed temporal analysis of coast stretches with different geodynamic trends was performed (Figs 4 and 5). It should be noted that the data from 1995 were taken as a reference point (zero value) for calculating the annual sediment dynamics. It means that all values of changes refer to the period after 1995. The sediment fluctuation patterns in the mainland coastal sectors of different dynamics (Fig. 4) show that the changes varied. This is especially true for the first two coastal stretches (Figs 4 A and 4 B).

Before the reconstruction, weak accumulation closer (MC profile 1) and erosion farther (MC profile 3) from the jetty were observed. After the reconstruction, approximately since about 2002–2003, the geodynamic trends in these stretches have changed. Closer to the jetty (MC profile 1), erosion processes have begun whereas farther from the jetty (MC profile 3) accumulation has started. In the farthest (Fig. 4 C) coastal stretch, the impact of jetty extension has not been reflected in the sediment amount changes. The accumulation processes that started in this coastal stretch before the jetty reconstruction (in about 2000) continue.

The analysis of the fluctuation of sediment amount in the coastal stretches of different dynamics (Fig. 5) of Curonian Spit shows that intensive erosion took place in the stretch closest to the jetty (CS 1). Sediment accumulation has begun in this stretch in 2003 as a result of the lengthening of the jetties (Fig. 5 A). In the southernmost coastal stretch (CS 3), the trends of sediment amount dynamics remain similar, but are less marked. Before the reconstruction, erosion processes also took place in this stretch. After the reconstruction, they were replaced by accumulation processes (Fig. 3 B). In the farthest coastal stretch (CS 4) constant sand accumulation was observed before and after the lengthening of jetties (Fig. 5 C).

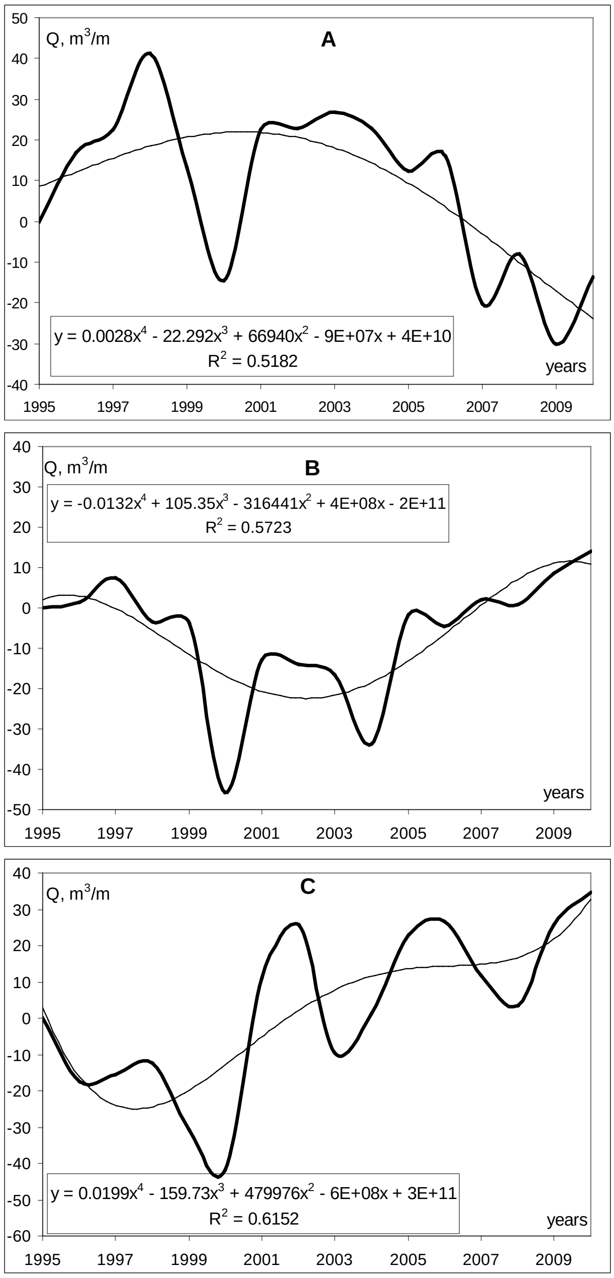

Fig. 4. Fluctuation of sand amount (Q) in 1995–2010 in MC 1 (A), MC 3 (B) and MC 4 (C) measuring profiles. For location of measuring profiles see Fig. 1

Together with the sediment amount fluctuation, the coastal cross-section has also changed. Due to the morphometric differences on different sides of the jetty, these changes were not the same.

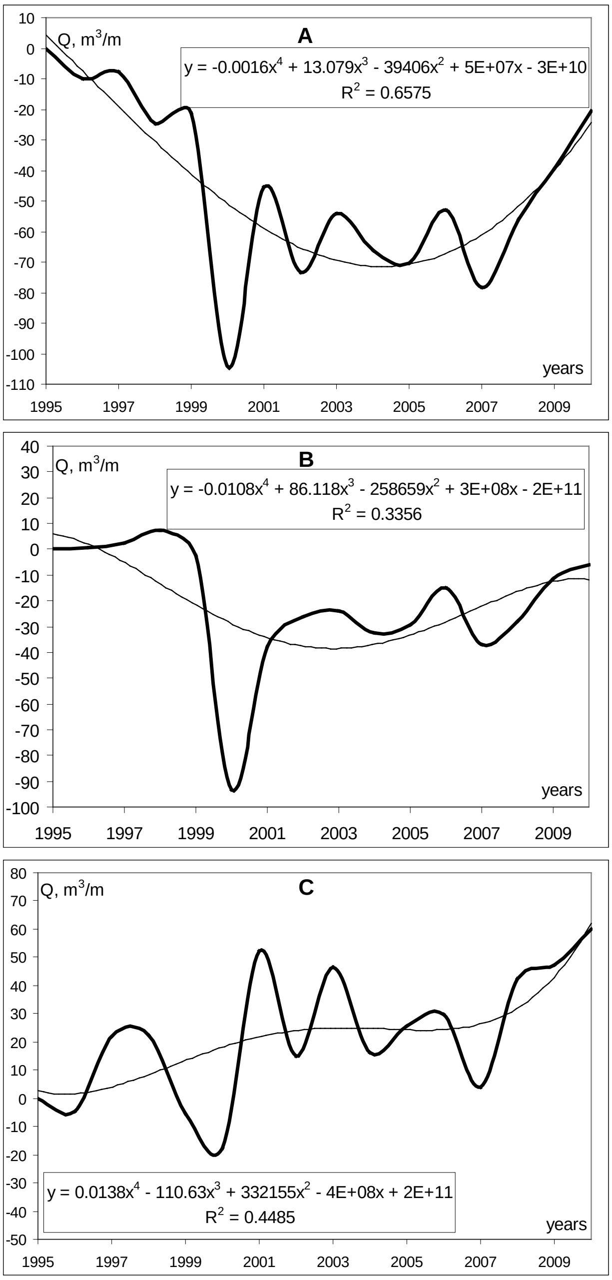

Fig. 5. Fluctuation of sand amount (Q) in 1995–2010 in CS 1 (A), CS 3 (B) and CS 4 (C) measuring profiles. For location of measuring profiles see Fig. 1

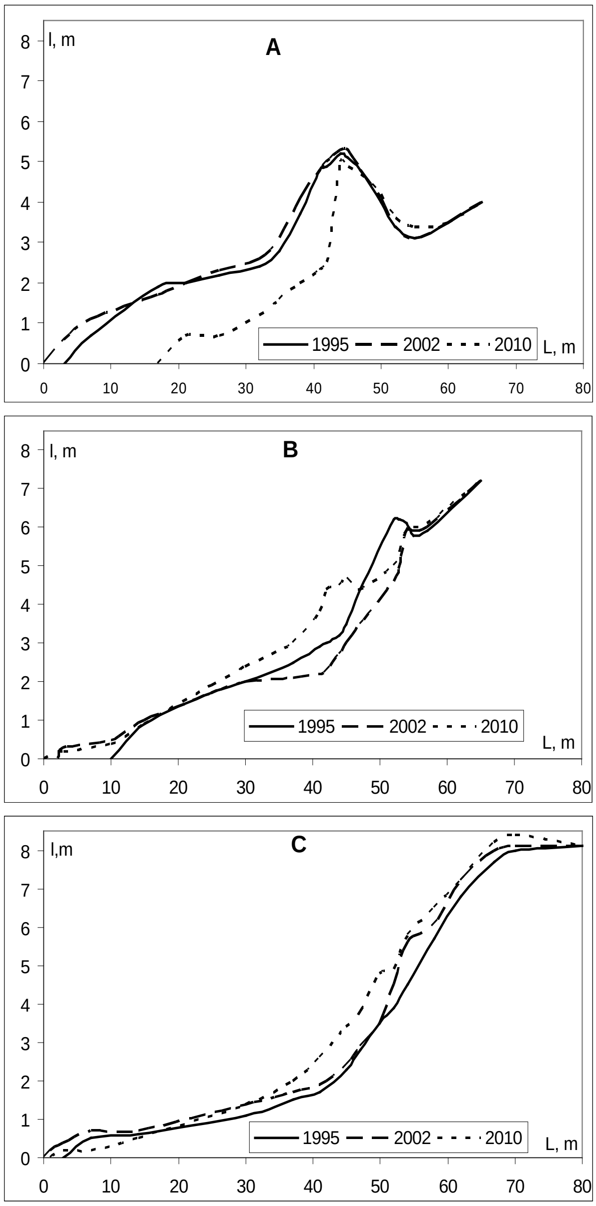

Fig. 6. Changes of cross-section profiles: MC0 (A), MC3 (B) and MC4 (C). For location of cross-section profiles see Fig. 1

On the mainland coast, where the beaches are characterised by a large height, before the jetty reconstruction the main changes near the jetty had taken place only on the beach; after the reconstruction, farther from the beach, the erosion processes has also started on the dune ridge. Here the dune ridge has retreated up to 7 m (Fig. 6 A).

On the Curonion Spit within the coastal stretch nearer to the jetties the largest erosion had occurred on the dune ridge before the jetties reconstruction. As the top of the dune has retrieved about 7 m, the dune has lost up to 40 m^3/m of sand. Meanwhile, the cross-section of the beach has remained almost unchanged (Fig. 7 A).

After the jetties reconstruction, characterised by the beginning of the accumulation processes, the sand has been again mostly accumulated on the foot of the dune ridge, having a slighter influence on the shape of beach cross-section. Within the coastal stretches farther from the jetties it was observed that although in the transverse coastal profile such large changes have not occurred, but on the mainland coast, where beaches are higher and to reach the dune ridge by waves is difficult, the key processes have taken place on the beach. Meanwhile, on the Curonion Spit, where the beaches are flat and waves can reach the dune ridge, the greatest changes have occurred on the foot and slope of the dune preserving the beach morphometric parameters from significant changes (Figs 6, 7).

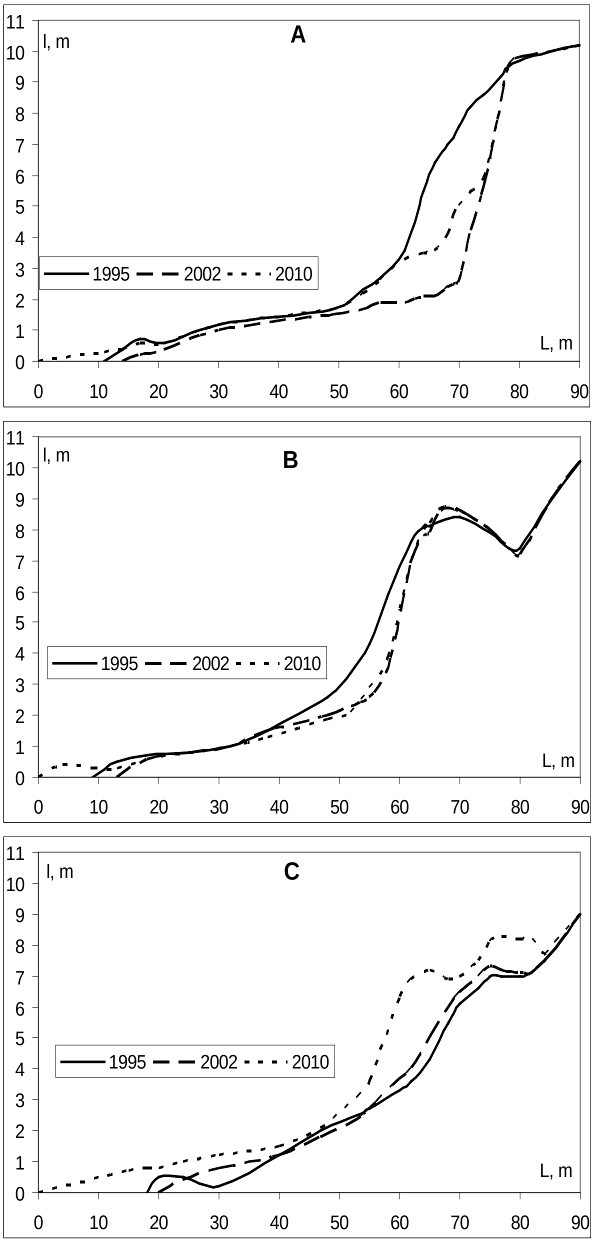

Fig. 7. Changes of cross-section profiles: CS1 (A), CS3 (B) and CS4 (C). For location of cross-section profiles see Fig. 1

Judging the annual and long-term sediment amount fluctuations along the investigated coastal zone, the port jetties not only affect the character of coastal dynamic trends but also the amplitudes of their fluctuations. Closer to the port where the coast have no possibility to develop "freely" due to the interface with the jetties, the annual sediment fluctuation amplitudes are smaller than in the "freely" developing stretches farther from the jetties. Yet the long-term sediment budget fluctuation is larger if closer to the jetties and smaller if farther away from them.

4. Discussion

Since the construction of the Klaipėda port jetties in 1835, they have been changing the water mass and sediment circulation. This in its turn has been changing the trends of coastal dynamics. Lengthening of the port jetties in 1845, 1875, 1878 and 1957 expanded their impact area: approximately 11 km on the southern (Curonian Spit) side and about 5 km on the northern (mainland coast) side (Žilinskas 1998). By the end of the 20th century, the geodynamic coastal trends had been established. Due to the fact that within Klaipėda port area affected by reconstructions more significant coast management works were not performed, it can be concluded that the main factor determining the analysed dynamics fluctuations of coast section are Klaipėda port jetties and their extension.

After the port reconstruction in 2002, the trends of coastal dynamics have changed. As the extension of the jetties was relatively small in comparison with the old ones and the time span after the reconstruction rather short, the changes occurred in a shorter coastal stretches: 3–3.5 km on both sides. However, even in this short stretch, geodynamic trends and their intensity vary. The most intensive changes occurred in the stretches closest to the jetties, which lengths are: 350 m in the mainland coast and 200 m in the Curonian Spit coast. Between 3000 m and 3500 m on both sides of the jetties, the changes are weakening. Farther, the geodynamic trends of the coast have reminded unchanged so far.

It can be said that coastal response to the lengthening of jetties in the sectors close to the Klaipėda port confirm the commonly recognized rule that when jetties cross the alongshore sediment migration flow in shallow sandy coastal zones sediments are accumulated on their windward side and are eroded on their lee side. On the windward side, the coast advances into the seawards and on the lee side it retreats. Processes of this kind have started in 2002 in the coastal stretches near the Klaipėda port after lengthening the jetties. However, it is believed that in the course of time the described geodynamic trends in the neighbourhood of Klaipėda port may change. The trend of coastal erosion on the lee side of the port (mainland coast) entailed by lengthening of jetties will continue with the only difference that the length of the sector of maximal erosion will increase. Meanwhile on the windward side (Curonian Spit coast), the geodynamic trends will change radically. In the course of time, the accumulation that started in 2003 will be replaced by coastal erosion. These changes will occur as a result of dredging of the entrance channel and storm tides (even higher due to longer jetties). Similar processes were observed during the previous reconstructions of the port jetties (Žilinskas 1998). As coastal response to the dredging takes about 10–15 years, it may be expected that after this time accumulation in this coastal sector will be completed and replaced by erosion.

Storm tides are another important factor strengthening coastal erosion on the windward side of jetties. As the Klaipėda port jetties are not perpendicular to the shoreline but obliquely angled (Fig. 2), the storm tides generated by dominant western winds at the junction of the shoreline and the southern jetty usually are considerably higher than in the adjacent coastal sectors. Higher waves flood the beach penetrating deeper into the land and intensively eroding the coast. The sand stirred by the waves is washed away into the sea by gravitation force and near-bottom currents. Previous investigations showed (Žilinskas *et al*. 2000, 2005) that during hurricane storms ("Anatoly", "Ervin", etc.), the water in the described area rises so high that it overflows the southern jetty into the Klaipėda Strait. The water carries the washed away sand.

5. Conclusions

1. Lengthening of Klaipėda port jetties in 2001–2002 affected coastal dynamics on their both sides. The strongest impact was located in the stretches closest to the jetties (350 m long in the mainland coast and 200 m long in the Curonian Spit coast). Moving away from these stretches, the impact of reconstruction gradually weakened and at a distance of 3–3.5 km from the jetties it was not fixed.

2. It was found that in the mainland coastal stretch closest to the jetties, where in the last decade before jetties extension the seashore was relatively stable, the coastal erosion trends were dominant. Meanwhile, the closest to the jetties coastal stretch of Curonion Spit, where erosion processes dominated in the last decade before jetties extension, stabilized right after the reconstruction and with a passage of time sediment accumulation trends have become prevailing.

3. It was found that port jetties affect not only the character of coastal dynamic trends but also the amplitudes of their fluctuations. Closer to the port where the coast have no possibility to develop "freely" due to the interface with the jetties, the annual sediment fluctuation amplitudes are smaller than in the "freely" developing stretches farther from the jetties. Yet the amplitudes of long-term sediment fluctuations are larger closer to the jetties and smaller farther from them.

4. In the future, due to the processes of washing away of sediments into the sea (strengthened by entrance channel dredging and very high storm tides caused by the jetties extension), accumulation processes in the sectors closest to the southern jetties may be replaced by erosion.

Acknowledgements

The authors wish to thank Ada Jurkonytė (Institute of Geology and Geography) and Anna Cichon-Pupienis (Lithuanian Geology Survey) for translating this manuscript into English.

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REKONSTRUOTŲJŲ KLAIPĖDOS UOSTO MOLŲ ĮTAKA GRETIMŲ JŪROS KRANTŲ DINAMIKAI

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S a n t r a u k a

2001–2002 m. vykdant Klaipėdos jūrų uosto rekonstrukcijos darbus buvo prailginti molai (šiaurinis 205 m, pietinis – 278 m). Vertinant molų rekonstrukcijos įtaką jūros krantų greta uosto dinamikai remtasi nuo 1995 m. atliekamos jos stebėsenos duomenimis. Tyrimų rajonas apėmė 10 km ilgio žemyno kranto juostą ir 12 km ilgio Kuršių nerijos kranto juostą. Matavimai buvo atliekami 18 profilių žemyno krante ir 12 profilių Kuršių nerijos krante. Analizuojant kasmetinės kranto sąnašų kiekio kaitos duomenis įvertinta Klaipėdos uosto molų įtaka gretimų krantų dinamikos tendencijoms, vyravusioms iki molų rekonstrukcijos, ir jų pokyčiams po molų rekonstrukcijos. Nustatyta, kad žemyne, arčiausiai molų esančioje kranto atkarpoje, kurioje pastarąjį dešimtmetį iki uosto molų prailginimo krantas buvo santykinai stabilus, po rekonstrukcijos įsivyravo kranto ardos tendencijos. Kuršių nerijos krante, kur pastarąjį dešimtmetį iki molų prailginimo arčiausioje nuo molo kranto atkarpoje vyravo intensyviõs ardos procesai, po molų rekonstrukcijos krantas iš pradžių stabilizavosi, o vėliau čia pradėjo vyrauti sąnašų akumuliacijos tendencijos.

Reikšminiai žodžiai: aplinkos stebėsena, Klaipėdos uostas, molai, kranto sąnašos, įplaukos kanalo pagilinimas.

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