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Near-shore evolution model for Palanga area: feasibility study of beach erosion management

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The problem of coastal erosion is becoming increasingly visible at the southeastern coast of the Baltic Sea. Its fine, sandy beaches were heavily affected by storms at the end of the 20th century, and recovery processes are hardly noticeable. Especially it is valid for the continental part of the Lithuanian coast where Palanga, the most important summer resort place of Lithuania, is located. The possibilities of Palanga beach erosion management are considered in this feasibility study. A near-shore evolution model for the Palanga area has been developed using the GENESIS modelling system. Various erosion management scenarios are analysed, erosion mitigation measures are proposed and recommendations for further studies are given. The most proper solution is construction of submerged breakwaters behind the Palanga bridge to mitigate erosion and increase beach width.

Key words: beach erosion management, near-shore evolution, sediment transport, modelling, GENESIS, the Baltic Sea coast

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1. INTRODUCTION

The problem of coastal erosion is becoming increasingly visible at the southeastern coast of the Baltic Sea. Its fine, sandy beaches were heavily affected by storms at the end of the 20th century (Žilinskas et al., 1994; 2000; Jarmalavičius et al., 2001). Despite relatively long calm periods between these events, the recovery processes are hardly noticeable; on the contrary, the costal erosion proceeds further (Minkevičius, 1999; Žilinskas et al., 1998, 2001).

The Palanga area (Fig. 1) is the most important recreation area in the continental part of the Lithuanian coast of the Baltic Sea. Large dunes and beaches were formed here after an impermeable pier (Old Palanga Bridge) was built there in 1892 (Žaromskis, 2005). How-ever, time, sea waves and wind devastated this construction. It became partially permeable in the second half of the 20th century. In 1997, a new bridge 470 meters long (Palanga Bridge) was constructed. The new Palanga Bridge is founded on piles and hence is completely permeable.

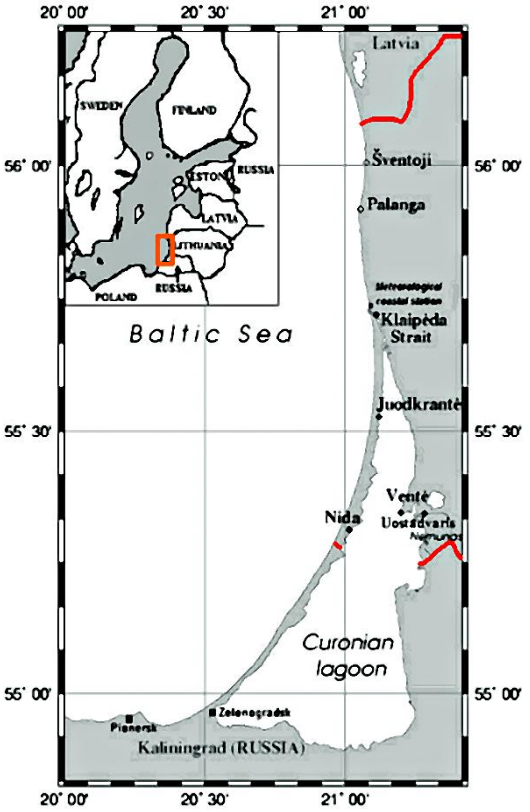

Fig. 1. Lithuanian coastal area of the Baltic Sea
1 pav. Lietuvos Baltijos pajūris

In the period 1995–1999, coastal erosion in the Palanga area reached a catastrophic scale: the coastline retreated about 115 m (23 m per year) (Žilinskas et al., 2004). The coastline retreat increased even more after the stones of the old pier were removed (1997–1998). The situation became even more complicated after the stormy winter of 2001–2002: the coastal strip south of the Palanga Bridge up to the Birutė hill (1600 m) was heavily eroded and the loss of sand reached 20 000 m^3 (12.5 m^3/m) (Žilinskas et al., 2004).

In order to protect the beach in Palanga from further erosion, an impermeable groin was built in the place of the old pier in summer 2005. In addition, a beach nourishment of 40.000m^3 sand was carried out in the Palanga area in the beginning of 2006. However, a systematic analysis of the situation with the prediction of the further development of the beach and the evaluation of the sufficiency of the applied measures is still highly desirable. This study is a first attempt to fill this gap. The chosen analysis methods depend on the limited availability of data. Therefore, the results of this study should be treated as primary results having the profoundness of a feasibility study.

2. MATERIALS AND METHODS

General remarks

The main factors to form a beach and to influence the morphological development of a coastal stretch are waves and currents and their interactions as a result of wind, and the local water levels. In order to assess changes of beach morphology and topography, detailed quantitative evaluations of sediment transport, both local and in neighbouring areas, are required. General and physically correct solutions for the calculation of sediment transport do not exist, but there are many more or less empirical formulae for the calculation of sediment transport capacities induced by waves, as well as many empirical formulations for sediment transport rates induced by currents.

Since the real near-shore current velocity field is very complex, most of the theoretical approaches need simplifying assumptions. For practical engineering purposes, the overall coastal sediment transport is subdivided in long-shore and cross-shore sediment transport. Hence, two more or less one-dimensional processes are the basis for morphological development assessment in coastal areas.

Considering the long-shore and the cross-shore sediment transport separately, it can be concluded that erosion and/or accretion of sediment and the development of a beach are mainly caused and influenced by the long-shore components of sediment transport and that the cross-shore sediment transport solely causes relocation and re-arrangement of sediments within the dynamic cross-shore profile.

All constructions used for coast protection influence the local waves and the local currents, thus causing local changes in sediment transport capacity and hence sediment accretion in areas where the sediment transport rate decreases. Besides the accretion of sediments, which is often the intended effect of a construction, all constructions influencing the local sediment transport will also form an erosion area leewards of the construction, the so called lee-erosion. Lee-erosion may extend up to several kilometres and completely re-arrange the morphological appearance of a coast.

Description of the models

The 1-D GENESIS modelling system (Hanson and Kraus, 1991; Gravens et al., 1991) which is part of the Beach Processes Module of the Coastal Engineering Design Package, CEDAS (Very-Tech Inc., 2005) was used in this study as a main tool. GENESIS is designed for special applications in coastal engineering projects intended for long-term shoreline change simulations. The name GENESIS is an acronym for Generalized Model for Simulating Shoreline Change. The modelling system and methodology of application have been matured due to numerous types of projects (e. g., Kohlhase et al., 1999).

The GENESIS simulates shoreline changes produced by spatial and temporal differences in the long-shore wave-induced sediment transport. Shoreline changes such as those produced by, e. g., beach fills and river sediment discharges can also be represented. The main application of the modelling system lies in simulating shoreline response to structures and constructions sited in the near-shore area. Shoreline changes produced by cross-shore sediment transport, which are mainly associated with storms and seasonal variations in wave climate, cannot be simulated. Hence, such cross-shore processes are assumed to be averaged out over a sufficiently long simulation interval or, in the case of a new project, to be dominated by rapid changes in shoreline position from a transition to an equilibrium configuration.

Depending on the stage of the project study, the amount and quality of the available data and the level of modelling effort required, GENESIS can be applied at two different levels – in the scoping mode and the design mode. The scoping mode uses minimal data input and might be employed in a reconnaissance study to better define the problem and to identify the potential project alternatives. The design mode enters feasibility or design studies for which a substantial modelling effort is required. While this study is the first attempt to model the shoreline dynamics in the Palanga area, the use of GENESIS in the scoping mode was chosen.

The minimal input data set needed for the GENESIS simulation in the scoping mode involves: a) offshore wave characteristics (height, period, direction, water depth where waves were measured); b) initial coastline position coordinates; c) lateral boundary conditions (the sand flux rates on the left and right ends of the coastline); d) structure positions and characteristics (permeability, transmission coefficients); e) effective grain size; f) near-shore and beach geometric parameters (berm height, depth of closure); g) model parameters: K_1 controlling the magnitude of long-shore sand transport rate, and K_2 controlling the distribution of sand within the calculation area.

The modeling system GENESIS is composed of two major sub-models. One sub-model calculates the long-shore sand transport rate and the resulting shoreline changes. The other sub-model is a wave model that calculates, under simplified conditions, breaking wave heights and the angle alongshore as determined from wave information given at a reference depth offshore. This sub-model is called the internal wave transformation model, as opposed to another, completely independent, external model, which can be optionally used to supply near-shore wave information to GENESIS. The availability and reliability of wave data as well as the complexity of the near-shore bathymetry are used to evaluate which wave model to apply. Two external wave models are presented by CEDAS: RCPWAVE and STWAVE package.

Input data and representation of the modelling area by the model

The main characteristics of data used in the study are given in Table 1. Some features of experimental material influencing the uncertainty of model predictions should be noticed here.

Table 1. **Data used in the study and their characteristics**
1 lentelė. **Naudoti duomenys ir jų charakteristikos**

Data	Spatial resolution	Spatial coverage	Time frequency	Time period or date	Author or source
Bathymetry	**1** Distance between profiles (along the coast) 1 km	Lithuanian Baltic coast, up to 15 m depth	N/A	2004	Baltijos jūros Lietuvos krantų geologinis atlasas, 2004
	2 Distance between measurement points 3–10 m	About 400 m south and north from the bridge. About 600 m seaward	N/A	2005	Hydrographical Office of the Lithuanian Maritime Safety Administration
Coastlines	**1** Distance between measurement points 10–50 m	Whole coast	N/A	2001	Baltijos jūros Lietuvos krantų geologinis atlasas, 2004
	2 Distance between measurement points 10–50 m	Pieces not covering whole coast	N/A	1999, 2005	Hydrography Center of Lithuania Safe Navigation Administration
	3 Distance between measurement points 2–5 m (4–50 for 2002)	2 km around the bridge	N/A	1999, 2002, 2005	Palanga municipality
Sand erosion/ accretion	1 km	Whole coast	N/A	1993–2003	Baltijos jūros Lietuvos krantų geologinis atlasas, 2004
Wind speed and direction station	One station	N/A	3h	2000–2005	Klaipėda hydrometeorological

Since no reliable wave information is available for the Palanga area, simplified prediction methods for the assessment of wave characteristics were applied. The wave heights and wave periods for a depth of 20 m were calculated from wind speed and wind fetch length using the CERC / SPM wave forecast / hind cast method (CERC, 1984).

A second uncertainty was the quality of bathymetry measurements. Though available maps and bathymetry data allowed us to conclude the study area to have a rather irregular bathymetry, a detailed analysis showed that the data resolution almost in the whole area was too rough to model the wave transformation by an external wave model. Therefore, only the internal GENESIS wave model was used in the model simulations. However, using the GENESIS internal wave model is recommended only when the bathymetry contours are more or less parallel to the coastline. Since the coastline shape and available bathymetry data analysis revealed some deviations from this requirement, decision was made to represent them by some structures in the model.

The most important bathymetry irregularity was found close to the Promenade Bridge. Analysis of the shape of the coastline has shown that a small spit is formed there (Fig. 2). According to historical data (Žaromskis, 2005), it is quite stable and was not eroded completely even when the stones of the old pier had been removed after the construction of the new bridge. Analysis of high resolution bathymetry data (Fig. 3) in the vicinity the bridge revealed a shoal around 500 m long and 300 m wide, located near the seaward end of the bridge. The water depth of this shoal varies within 1.7–2.5 m. The shoal works as a submerged breakwater protecting the area around the bridge from wave energy and thus supports the formation of the spit. In the model, this structure was represented by a permeable breakwater (Fig. 4) and its parameters were calibrated in order to achieve an agreement between the measured and the

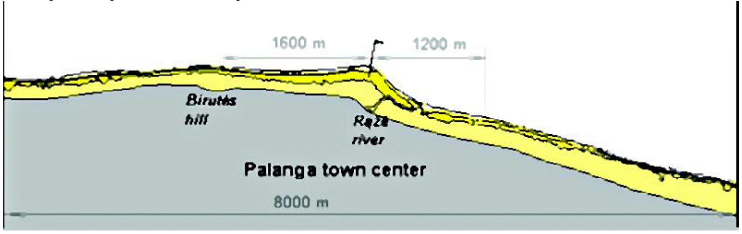

Fig. 2. Modelling area (full area: 8000 m long) and area of interest (1600 m long area south the bridge and 1200 m area north the bridge)

2 pav. Modeliuojama (ilgis 8000 m) ir tikslinė (1600 m piečiau tilto ir 12000 m šiauriau tilto) teritorijos

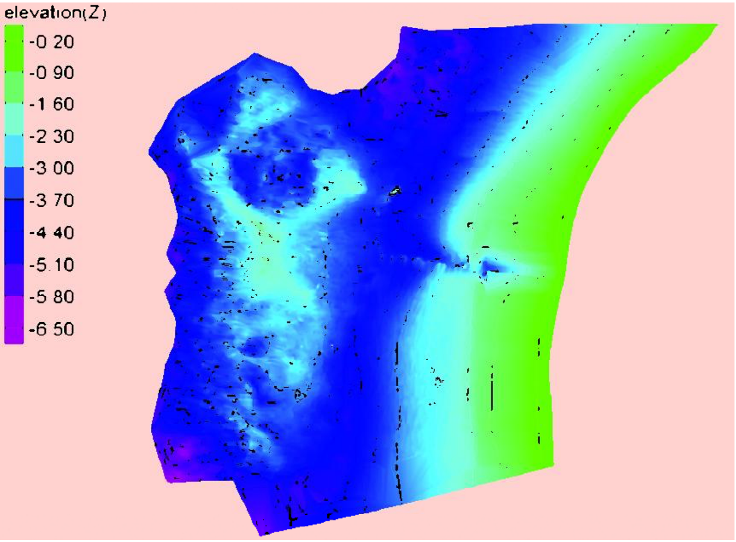

Fig. 3. Shoal near the Palanga Promenade Bridge (map based on measurements of the Hydrographical Office of the Lithuanian Maritime Safety Administration)

3 pav. Sekluma prie Palangos tilto (žemėlapis sudarytas remiantis Lietuvos saugios laivybos administracijos hidrogafinės tarnybos duomenimis)

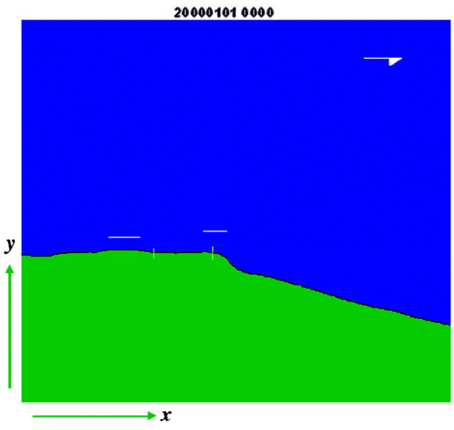

Fig. 4. Representation of modelling area by GENESIS. On the left – breakwater and non-diffracting groin near Birutė hill; on the right – Promenade Bridge groin and shoal near the bridge represented by breakwater

4 pav. Modeliuojamos teritorijos atvaizdavimas GENESIS modelyje. Kairėje pusėje – bangolaužis ir nedifrakcinė buna netoli Birutės kalno, dešinėje pusėje – buna prie Palangos tilto ir sekluma simulated coastlines. Another deviation was observed near the Birutė hill (Fig. 2). In this place, a small groin is formed from stones and ship remains. Some scarce bathymetry data and sediment maps show also that boulders are forming a breakwater seaward from this place. These two structures were presented in the model by a breakwater and a non-diffracting groin (Fig. 4). The position of the groin was treated also as a calibration parameter. These simplifications are satisfactory only for the initial study which aims at revealing the main trends and possible solutions. Applying the model in the design mode, the influence of these shoals should be taken into account using an external wave model which takes into account bathymetry irregularities.

One more artificial structure was found important in the modeling area. The stones that were removed during the construction of the new Palanga Bridge were moved back to the place of the old bridge in 2000, forming a partly permeable groin. Though no considerable impact of this groin was found when analyzing the coastline dynamics during the period 2000–2005, it was represented in the model as a non-diffracting groin (Fig. 4) with the permeability value 0.7, wich later changed to 0 for simulations of an impermeable groin which was constructed in the same place in summer 2005.

The area of interest was defined as a strip of the coast from the Birutė hill (1600 m south of the promenade bridge) to the point located 600 m north from the river Rąžė mouth as most intensively used as a summer resort place (Fig. 2). As there were no measurements for the sediment transport rates, to avoid the influence of boundary conditions on the model results a wider area (8 km long) was chosen as the modeling area (Fig. 2), with the boundary points in the areas where the coastline was found to be stable. Pinned lateral boundary conditions (coastline is stationary at the boundary) were used in the simulations.

Since measurements of the coastlines were available for 2000, 2002 and 2005, the period 2000–2005 was found to be the most favorable for the wave hind cast and calibration-verification of the GENESIS model. Also, this period intersects with the period 1993–2003 when erosion accretion was measured at the continental coast of Lithuania.

Analysis of coastlines from different sources showed that the most reliable coastlines for the area of interest are the coastlines measured by the Palanga municipality. These measurements cover only a 2-km-long modelling domain around the Palanga Promenade Bridge. Therefore, the lower resolution coastlines extracted from the Geological atlas of the Baltic Sea for the Lithuanian coast (Geological Atlas, 2004) and presented by the Hydrographic Center were used to cover the remaining domain of the modelling.

A value $d_{50} = 0.17$ mm was used for the median grain size of the sand. The berm height and the depth of closure (the depth where no significant sediment transport occurs) were equalled to 3 and 5 m, respectively. Since during the initial model runs these parameters were found to be not sensitive to the results, no more efforts were taken to make these values more accurate.

The GENESIS uses the Cartesian coordinate system where the x axis is directed alongshore from the left to the right and the y axis is directed offshore. The model state variable is the position of the coastline y as a function of time t and coordinate x. The governing equation for the shoreline position in the GENESIS is

$$\frac{\partial y}{\partial t} + \frac{1}{D_B + D_C}\frac{\partial Q}{\partial x} = 0,$$

where Q is the long-shore sand transport rate calculated as a function of wave height, the angle of breaking waves and other wave characteristics (Hanson, Kraus, 1991; Gravens et al., 1991); D_B and D_C are berm height and the depth of closure.

According to the requirements of the GENESIS model, the coordinate system LKS-94 was transformed by rotating anticlockwise by 90 degrees and shifting the origin to the point (317050, 6197300). After the transformation the x-axis was renamed to y and the y-axis to x. The view of the modelling area with the initial coastline in 2000 and all structures is shown in Fig. 4. The 15 m spatial discretization step for the x-coordinate and 0.5 h for the time were used in all simulations to guarantee the numerical stability and accuracy of the solution.

Calibration and verification of the model

The GENESIS model was calibrated and verified changing the model parameters in order to reproduce correctly the measured coastline for 2002 and 2005 and sand transport. The parameters that varied during the calibration and their values are listed in Table 2.

Only beach accretion-erosion rate data for the study area were available for the period 1993–2003, and they were used to calibrate the values K_1 and K_2. Unfortunately, erosion-accretion is not enough to calibrate both parameters. Accretion-erosion can be expressed as the difference of sand transport rate to the left and to the right (for the grid cell it is equal to a difference between the net rates to the left and to the right), and, therefore, the same accretion-erosion values can be obtained with different sand transport rates. Sand transport itself is also equal to the difference of two values (Hanson, Kraus, 1991; Gravens et al., 1991). The range of the first value is controlled by K_1 and of the second by K_2. Therefore, the value $K_1 = 0.7$ was fixed as the most recommend able value (Hanson, Kraus, 1991; Gravens et al., 1991) and K_2 was varied to obtain an agreement with measured accretion-erosion. The measured annual average of accretion-erosion for the period 1993–2003 was compared with the simulated annual average for the period 2000–2003.

Since GENESIS calculates the sand transport rate from the landward edge of the berm to the depth of closure, the ratio between erosion-accretion on the land with erosion-accretion on the full width of a transport area

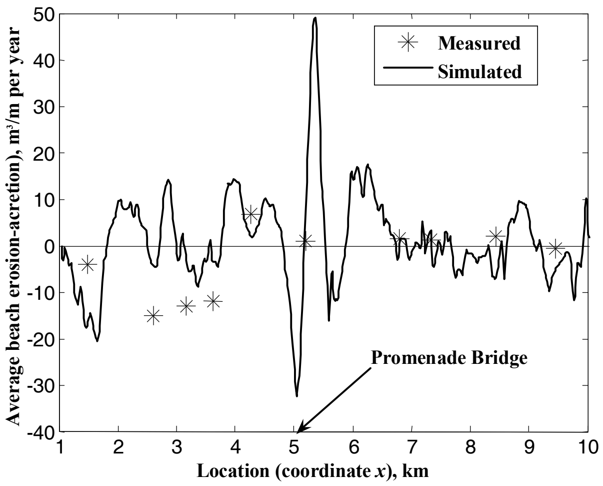

Fig. 5. Comparison of measured and simulated accretion–erosion

5 pav. Modeliuotos ir matuotos erozijos ir akumuliacijos palyginimas

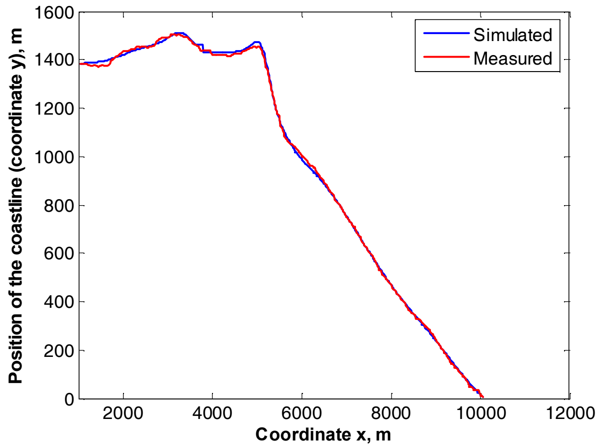

Fig. 7. Comparison of measured and simulated coastlines for the year 2002

7 pav. Modeliuotos ir išmatuotos 2002 m. kranto linijos palyginimas

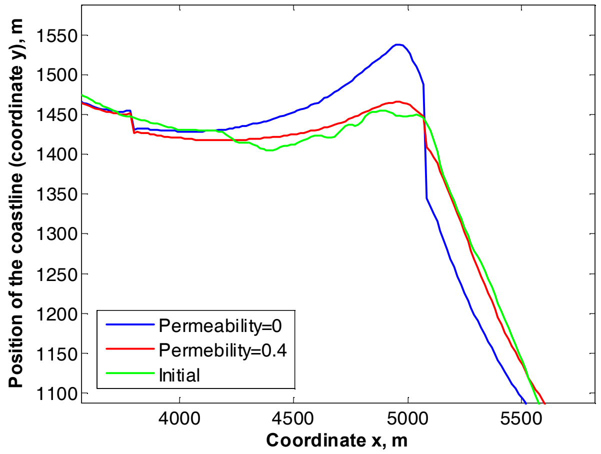

Fig. 9. Comparison of coastlines in 2005 with coastlines at the end 2017 with impermeable groin and with groin permeability 0.4

9 pav. 2005 m. ir 2017 m. kranto linijų, kurios susiformuotų esant nepralaidžiai bunai (pralaidumas 0,4), palyginimas

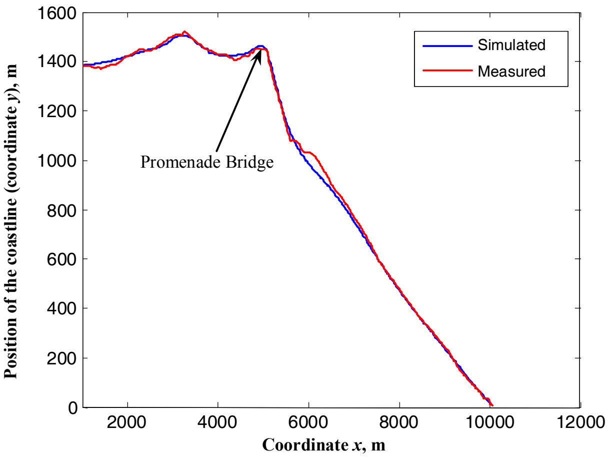

Fig. 6. Comparison of measured and simulated coastlines for the year 2005

6 pav. Modeliuotos ir išmatuotos 2005 m. kranto linijos palyginimas

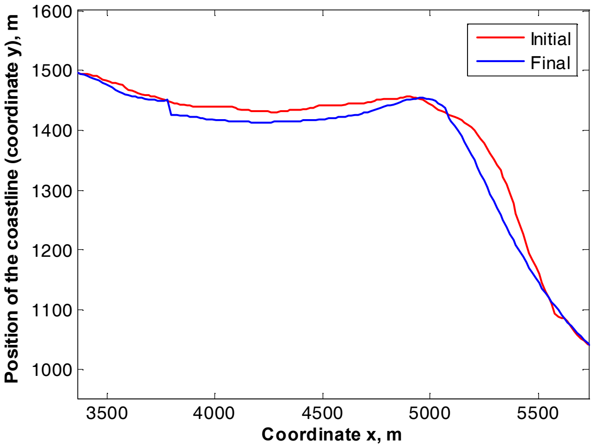

Fig. 8. Comparison of coastlines in 2005 and the end of 2017 with the structures existing before impermeable groin construction

8 pav. 2005 m. ir 2017 m. kranto linijų, kurios susiformuotų be nepralaidžios bunos, palyginimas

should be used. According to the assumptions made in the derivation of the governing equation (Hanson, Kraus, 1991; Gravens et al., 1991), this ratio should be greater but of the same order as the ratio $(D_B + D_C) / D_B$. The value of the ratio equal to 3 was used in the simulations.

Analyzed engineering alternatives and scenarios

Various scenarios were calculated and analyzed in order to reveal the possible trends and to find the most reasonable solution for Palanga beach protection. To reveal the possible trends, a 12-year simulation period (from 2005 to the end of 2017) was used. The waves obtained for the period 2000–2005 were repeated periodically and were used for the forecast.

No additional structures scenario. It is important to know the general trend of the coastline dynamics if no measures are applied. If the construction of an impermeable groin near the Promenade Bridge in summer 2005 should be treated as a significant effort, this scenario is thought to follow the conditions of 2000–2005, i. e. before the impermeable groin was constructed.

Impermeable groin scenario. The construction of the impermeable groin was the first significant measure to protect the beach from the erosion. It is important to know the influence of this structure in order to plan additional measures. Since the general coastal engineering practice shows that groins usually increase erosion on the lee side of the structure, a negative influence on the northern side of the bridge might be expected.

Nourishment scenario. The goal of this scenario is to forecast the possible effects of the beach fill on the southern side of the Promenade Bridge during the period February 1–April 1, 2006.

Additional measures scenarios. Taking into account the results of previous scenarios, additional measures to protect beach from erosion by these scenarios were considered. For the purpose of these investigations, mainly offshore breakwaters with different layouts were analyzed.

3. RESULTS AND DISCUSSION

Calibration and verification results

A comparison of the measured and the simulated accretion-erosion is presented in Fig. 5. It is obvious that no high agreement can be expected, because the averaged values come not from the same but from the intersecting periods. Therefore, to get the measured and calculated values of the same order of magnitude can already be treated as a satisfactory result.

A comparison of the measured and the simulated coastlines for the year 2005 is presented in Fig. 6 and for the year 2002 in Fig. 7. The difference between the measured and the simulated shorelines in the area in most cases does not exceed 20 m, except the right side of the bridge where the coastline during 5 years moved by more than 70 meters. Slightly higher differences were found observed near $x = 6000$. This area was already outside the area of interest. The differences in this place might be caused by the influence of some structures that are not represented in the model. To conclude, agreement between the measured and the simulated coastlines is satisfactory to use the GENESIS model in the scoping mode.

No additional structures scenario

Figure 8 shows that the situation which was representative for the area before the construction of the impermeable groin (erosion on both sides of the bridge) should be expected. The coastline retreats landward by 20 to 70 m versus the coastline of 2005. It means that if no measures are taken the situation would worsen during the next 12 years. As the modelling results show, a stable coastline would been reached in approximately 7 years.

Impermeable groin scenarios

The impermeable groin has a considerable but ambiguous influence on the both sides of the bridge (Fig. 9). In the area between the Birutė hill and the Palanga Bridge, the accretion reaches a maximum of up to 100 m near the bridge, and erosion on the northern side of the bridge is significant.

An important question is: can the results be better if the permeability of the groin would be higher? One additional scenario with a higher groin permeability equal to 0.4 was calculated. Figure 9 shows that the general trend is the same, though the maximum difference in coastlines between these two scenarios is considerable and equals to 80 m. As one can see in Fig. 9, though the coastline would be almost stabilized on the northern side, erosion would not be avoided completely. At the same time, the positive effect would be lost in the southern parts of the area of interest. Taking into account that the construction of a groin with a given permeability is very complicated, it can be concluded that the variation of permeability has no practical value for the further solutions.

Nourishment scenario

The results of simulations by beach fill in winter–spring 2006 (increment of the berm width by 15 m; start point 685 m south from the bridge and the end point 290 m

Table 2. **Parameters and their values after calibration**
2 lentelė. **Parametrai ir jų reikšmės po kalibravimo**

Parameter	Description	Value
K_1	Controls the magnitude of long shore sand transport rate	0.7
K_2	Controls the distribution of sand in calculation area	0.7
TBW1	Transmission coefficient for the breakwater near the Promenade bridge	0.8
X1BW1	Left tip × coordinate of the breakwater near the Promenade bridge	2855
X2BW1	Right tip × coordinate of the breakwater near the Promenade bridge	3543
YBW1	y coordinate of the breakwater near Promenade bridge	1745
TBW2	Transmission coefficient for the breakwater south from the Birutė hill	0.99
X1BW2	Left tip × coordinate of the breakwater south from the Birutė hill	4847
X2BW2	Right tip × coordinate of the breakwater south from the Birutė hill	5357
YBW2	y coordinate of the breakwater south from the Birutė hill	1860
PG1	Permeability of non-diffracting groin near the Birutė hill	0.2
XPG1	Coordinate × non-diffracting groin near the Birutė hill	3801

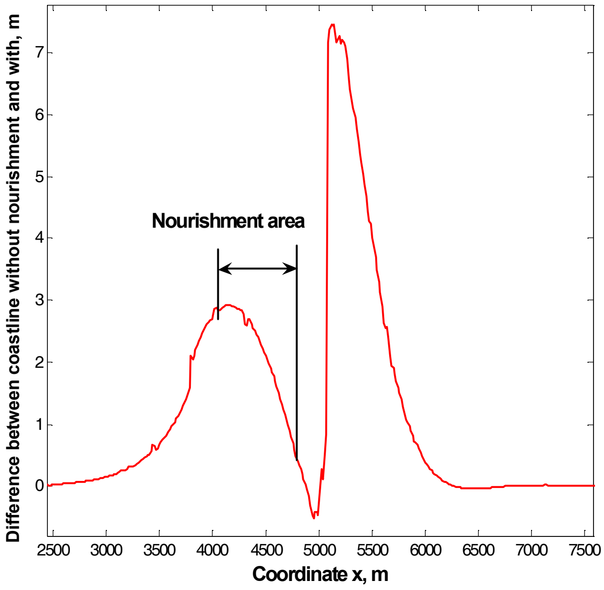

Fig. 10. Difference between coastlines in the end 2017 with nourishment done in 2006 and without nourishment

10 pav. Skirtumas tarp kranto linijų 2017 m., kai paplūdimys nepapildytas smėliu, taip pat įvertinus 2006 m. atliktą papildymą

south from the bridge) are presented in Fig. 10. The impact of this measure is positive, but sand is distributed all over the simulation area. Comparison of the beach increment area after the nourishment and in year 2017 leads to the conclusion that almost all nourished sand will remain not far from the nourishment place, increasing the sand reserves of the area. Independently of the residence time of the sediments in the project area, additional beach nourishment in this area and / or the adjacent coastal stretches will induce a better supply of sediments into the coastal system.

Additional measures scenarios

As can be seen from the scenarios analyzed above, the most problematic area in future will be the area north of the Palanga Promenade Bridge, where erosion will further increase due to the impact of the impermeable groin. Analysis of various scenarios and possible solutions has shown that the most suitable measure to mitigate this impact is construction of submerged breakwaters as a continuation of the naturally formed shoal of the bridge (Fig. 11). Other solutions do not seem good for this purpose. The erosion mitigation effect could be achieved by a system of groins, but these structures will change the view of the beach considerably and will limit the movement through the beach. Beach nourishment can give only temporary effects, because the sand will be distributed in a wider area. However, as stated above, beach nourishment will bring additional sediment into the system.

The simulations show that to mitigate erosion by additional breakwaters on the northern side of the bridge just behind the groin is also not easy. Some of the results indicate that it might be necessary to artificially reduce the transmission of the natural submerged breakwaters to reach this goal. In Fig. 12, the results of simulations with two offshore breakwaters (Fig. 11) with the transmission coefficient equal to 0.4 and 0.6, respectively, and with the transmission coefficient of natural breakwater decreased from 0.8 to 0.6 are shown. Though these additional structures reduce the erosion and even result in an accretion of the area of interest, this scenario has negative side effects, i. e. erosion considerably increases further to the north.

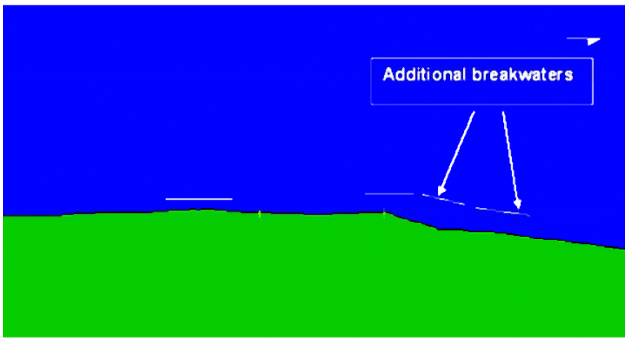

Fig. 11. Spatial configuration of two additional breakwaters as continuation of naturally formed shoal

11 pav. Papildomų bangolaužių kaip natūralaus bangolaužio tęsinio išsidėstymas

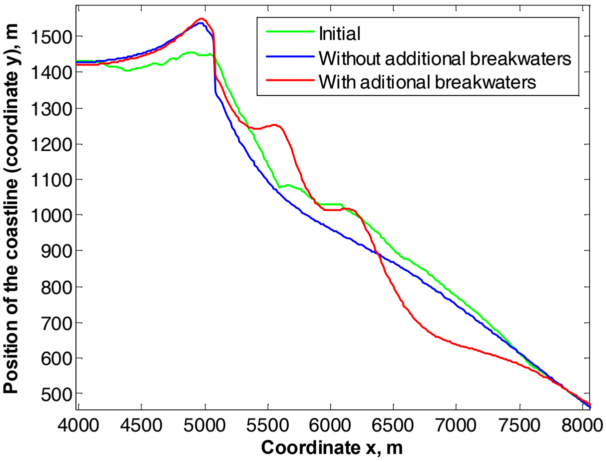

Fig. 12. Comparison of coastline with two submerged breakwaters north from the bridge with the coastline without breakwaters in the end of 2017. Green line is coastline in summer 2005

12 pav. Skirtumas tarp kranto linijų 2017 m., kurios susiformuotų esant dviem panardintiems bangolaužiams ir be jų. Žalia spalva pažymėta kranto linijos padėtis 2005 m. vasarą

4. FINAL REMARKS

An initial study of the possible technical and non-technical measures to protect the Palanga beaches is presented. The available data were analyzed and the GENESIS modelling system was applied to reveal the possible trends of the coastal line dynamics and to find possible and feasible solutions for the problem of coast protection.

The existing data are the main reason why in this initial study only general trends and a relative comparison of possible solutions are presented. A more detailed study with higher quality data is recommended to get more precise and reliable results which are urgently needed as the basis for the implementation of protection measures. The most problematic were the wave data. The eye evaluation of waves is not too reliable and some generalized data are not enough to perform high-quality predictions needed for the design of the constructions. The main recommendation for future studies is to install wave gauges near Palanga for the measurement of directional wave data in order to get long-term time series of offshore wave parameters.

A more detailed near-shore bathymetry and the use of the external wave model together with GENESIS is recommended in the future design process of the protection measures. For a detailed in-depth analysis of the problem, also additional simulations using 2D-sediment transport models (e. g., Mike 21 or Delft 2D/3D) may lead to a better understanding of the transport processes in the Palanga coastal area (especially sand exchange with deeper water) and hence to a better design of coastal protection measures.

The main trend of the coastline dynamics in the recent ten years was erosion on both sides of the Palanga Bridge. The results of the simulation with the GENESIS modelling system shows that this trend will persist during the next years if no measures are applied.

The application of several measures was considered, and prediction of their influence on the coastline dynamics is shown in this report. The influence of the impermeable groin constructed in summer 2005 is of interest, since public opinion about its possible impact differs. The results of the modelling clearly show a positive impact of this structure on the southern side of the Palanga Bridge in the sense of increasing sand accretion and stabilizing the coastline; however, on the northern side increased erosion should be expected. Also, it is not only a question of the permeability of the groin. The simulation with permeability equal to 0.4 shows the same general trend, though with a lower but still considerable accretion and erosion on the southern and the northern sides of the Palanga Beach, respectively.

It is also important to assess the impact of the beach nourishment in spring–winter 2006. Simulations show that the beach width the increment done by this fill will decline considerably in future, but the simulation results also indicate that the majority of sand will be distributed close to the nourishment place. Independently of the residence time of the sediments in the project area, additional beach nourishment in the project area and / or the adjacent coastal stretches will induce a better supply of sediments to the coastal system of Lithuania. Additionally, it should be stated that the absolute differences of simulated coastlines with and without beach nourishment are small compared to the recent uncertainty of the model, and more reliable conclusions may be drawn using more accurate data. The efforts to find a solution for mitigating the erosion on the northern side of the bridge do not give unambiguous results. The most proper solution is the construction of submerged breakwaters as a continuation of the shoal behind the bridge. This will slightly mitigate the erosion near the groin and even increase the beach width further to the north. However, in any case, north of the installed breakwaters, due to lee-effects of the breakwaters, additional erosion will occur and the width of the beach will decrease because of the retreat of the coastline.

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PALANGOS KRANTO ZONOS KAITOS MODELIS: PAPLŪDIMIO EROZIJOS VALDYMO GALIMYBIŲ ANALIZĖ

Santrauka

Krantų erozija tampa vis aktualesnė visai Pietrytinei Baltijai. Labai smarkiai smėlio paplūdimiai nukentėjo XX a. pabaigoje suintensyvėjus uraganiniams štormams, tuo tarpu natūralus paplūdimių atsistatymas vyksta lėtai. Ši problema ypač svarbi Palangos, svarbiausios Lietuvos rekreacinės zonos, paplūdimiams. Apsauginio kopagūbrio ir paplūdimio formavimasis ties Palanga priklausė nuo žmogaus veikos dar XIX a. pabaigoje, kada čia buvo pastatytas pirmasis promenadinis tiltas. Ilgą laiką jis veikė kaip pusiau pralaidi buna, tačiau 1997 m., pastačius naują polinės konstrukcijos tiltą ir pašalinus akmenis, suintensyvėjo nešmenų migracija išilgai kranto. Tuo metu šioje kranto atkarpoje jau pasireiškęs kranto ardymas dar labiau sustiprėjo. Nors šiam procesui sustabdyti pastaraisiais metais buvo imtasi kai kurių priemonių (bunos atstatymas senojo tilto vietoje, paplūdimio pamaitinimas smėliu ir kt.), tačiau sistemingesnės būklės analizės, paplūdimio kaitos prognozės ir taikomų priemonių efektyvumo vertinimo iki šiol labai trūko.

Šio tyrimo tikslas ir buvo spręsti minėtus uždavinius panaudojant kranto inžinerijos metodus ir visų pirma gerai pasiteisinusius kranto erozijos valdymo matematinius modelius. Darbe panaudotas GENESIS modelis, skirtas prognozuoti bangų ir inžinerinių įrenginių poveikį krantui. Tyrimo metu buvo išanalizuota esama faktinė medžiaga (dugno ir paplūdimio reljefas, geologinė sandara, kranto linijos dinamika, nuosėdų sudėtis, meteorologiniai ir hidrologiniai duomenys), reikalinga modelio darbui, ir atliktas modelio kalibravimas. Reikia pažymėti, kad šiuo metu turima faktinė medžiaga nėra pakankamai detali, kad būtų atlikti skaičiavimai, reikalingi inžinerinių įrenginių projektavimui. Ypač trūksta bangų ir nešmenų pernašos parametrų matavimų. Todėl darbe buvo naudojami supaprastinti modeliavimo metodai, leidžiantys įvertinti galimas tendencijas. Darbe išanalizuoti scenarijai leidžia nustatyti galimas kranto linijos kaitos tendencijas bei numatyti priemones, sušvelninančias neigiamus padarinius.

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МОДЕЛЬ РАЗВИТИЯ БЕРЕГОВОЙ ЗОНЫ ПАЛАНГИ: ВОЗМОЖНОСТИ УПРАВЛЕНИЯ ЭРОЗИЕЙ ПЛЯЖЕЙ

Резюме

Проблема береговой эрозии становится все более актуальной для всей юго-восточной Балтики. Песчаные пляжи сильно пострадали во время участившихся во второй половине XX в. ураганных штормов, а их естественное восстановление проявляется слабо. Это особенно актуально для пляжей г. Паланги – важнейшей рекреационной зоны Литвы. Положительное значение для развития авандюны и широких песчаных пляжей Паланги имел построенный еще в конце XIX в. променадный мост, который служил как полупропускная буна. Однако с 1997 г., когда был построен новый мост на свайных конструкциях, интенсифицировалась вдольбереговая миграция наносов и начался сильный размыв берега. В целях предотвращения эрозии в последние годы проводятся берегоохранные мероприятия (реконструкция буны на месте старого моста, подпитка пляжа песком и т. д.). Поэтому актуальными стали оценка эффективности проводимых мероприятий и прогноз дальнейшего развития пляжей Паланги. Цель настоящей работы – найти решение указанных задач с помощью математического моделирования. Использована модель GENESIS, предназначенная для прогноза влияния волновой деятельности и инженерных сооружений на состояние берега. Для составления и калибровки модели использованы и проанализированы имеющиеся фактические данные: рельеф и геологическое строение прибрежной зоны, топография пляжа, динамика положения береговой линии, состав осадков, гидрометеорологический и гидрологический режим. Следует отметить, что пока не хватает фактических данных, особенно по волновому режиму и перемещению наносов, поэтому возможно применить только упрощенные методы моделирования. Рассмотрены различные сценарии, которые позволяют наметить тенденции развития берега и принимать решения по целесообразности дальнейших берегоохранных мероприятий.