Forecasting the development of the sea coastal area based on analysis of the clif-beach dynamic system

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Abstract. The paper is devoted to the study of the dynamics and stability of the coast. The seaside territories are an active geodynamic system, which, being at the junction of the land and sea systems, has a high rate of change (transformation) processes. Relevance of the topic due to the economic value of the shores and a huge in-crease in anthropogenic load on them. A dynamic simulation model is presented to calculate the optimal amount of beach-forming material to be maintained on the beach. The studies carried out made it possible to significantly clarify the ideas about the hydro- and lithodynamic processes occurring in the coastal zone of the beach. The influence of the parameters of waves and sediments that make up the beaches on such morphometric characteristics of the surf zone, which are important for the practice of marine coastal protection, such as the length and height of the wave run-up, the depth at the point of their collapse, is shown.

1 Introduction

The seaside territories are an active geodynamic system, which, being at the junction of the land and sea systems, has a high rate of change (transformation) processes. At the same time, in the conditions of urbanization, these transformations significantly affect the changes in natural complexes, and the living conditions of society and the characteristics of the economy.

With the development of geological, geographical and hydrophysical sciences, the most important regularities of water movement in the zone of transformation and destruction of waves, structural features, dynamics and development of sea coasts and shores were established. At the beginning of the 20th century, major works of foreign scientists appeared: R.A. Delhi - on the influence of tectonic movements and changes in the sea level on the formation of coasts, G.K. Gilbert - on the composition and origin along the coastal sediments of the coast of the Great Lakes, NM Fennemann - about the transformation of the bottom equilibrium profile under the influence of the energy of sea waves; E.R. Matthews - about

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the dynamics of the coastal territories of Great Britain, in which for a limited number of areas the numerical characteristics of the abrasion rates are established and methods of protecting the coast from destruction are proposed. D.U. Johnson summarized the scattered factual mate-rial, on the basis of which he proposed a concept for the development of the sea coast and published the world's first special monograph devoted to coastal processes and coastal relief [1-18].

Almost simultaneously in the Russian Empire, the works of N. Ya. Danilevsky and N.A. Sokolov along the delta of the river. Kuban laid the foundation for geological and geographical studies of the coastal zone. In the works of M.N. Gersevanov, for the first time, the characteristics of offshore hydraulic structures are given, which contributed to the rapid development of the hydrotechnical scientific direction at the beginning of the 20th century. A more detailed study of the hydrodynamic processes of near-sea territories was associated with the need to build ports in the White, Black and Barents Seas. In the study of the onshore part of the coastal territories, the geo-logical – geographical direction resulted in the geological – morphological one. The most important in this area are the works of L.S. Berg, who studied the morphological aspects of the coastal zones of the Aral Sea. These works are characterized by a component approach to the study of coastal areas. Principles for the general morpho-logical classification of seacoasts were also developed by Cotton, Valentin, Riftgo-fen, Shepard, O.K. Leontiev, V.P. Zenkovich, Johnson, Martoni, Shluteri, and many others. The coastal classification developed by S.A. Lukyanova, etc. 19-24].

2 Main part

Considering natural factors, it should be noted that specific landforms are created mainly under the influence of waves. Waves consume energy to change the coastal underwater and surface slopes, to create accumulative coastal forms and to move sediments. Under the influence of sea waves on a pebble or sandy beach, there is a movement of particles that make up the surface and underwater coastal slopes. When waves are directed at a certain angle to the beach, longitudinal sediment movement appears. Sediments consist of rock particles that are carried away by rivers, as well as particles that have formed as a result of abrasion of coastal areas. When exposed to waves at an angle of 90 degrees, particles move down the slope. This process causes a continuous process of abrasion of large particles of beach material and the entrainment of smaller particles to a depth.

Experts believe that a beach of sufficient width is the best protection of the coast from erosion by the sea surf: the energy of the waves rolling out onto the strip of the surf stream is extinguished and is spent on the gradual abrasion of rock particles. With a lack of alongshore sediment volumes, the width of the beach is gradually decreasing. The destruction of the beach almost always leads to the development of irreversible processes of disrupting the stability of coastal massifs (erosion of the main slopes of the coast, the formation of landslides that disrupt the stability of huge earth masses, the destruction of buildings and structures erected in the coastal zone), as a result of which the environmentally safe state of the beaches is disturbed. To ensure an ecologically safe state and proper protection from abrasion processes, as well as preserve the beach, various methods of protecting and strengthening the banks have been developed over the years.

The overall growth of man-made impacts has increased the negative development of coastal processes. Rising sea levels have also significantly accelerated the rate of coastal destruction. All this has led to a general degradation of the coasts, especially the beaches, which are the main recreational resource.

This topic was one of the main topics in coastal studies. Fundamental results were obtained that showed that the tasks of coastal research are very time-consuming and completely unsolved. In recent decades, a significant number of publications related to this topic have appeared again.

A distinctive feature of the cape breakwater is that the design process necessarily provides for the formation of a tombolo behind it. It can be formed naturally due to the formation of a wave shadow zone behind the breakwater with the appropriate characteristics of the coast, or it can be artificial, that is, bulk. The tombolo blocks the natural alongshore sediment movement behind the structure. Daily tidal changes in sea level can show a tombolo at low tide, and a peninsula at high tide.

Coastal breakwaters stand out from common parallel structures that reduce the amount of wave energy reaching the protected area. They are similar to natural ob-stacles, reefs and offshore islands that dissipate wave energy. A decrease in wave energy slows down the coastal current, leads to sedimentation and coastline bulge, or the formation of a significant sediment accumulation area in the protected area be-hind the breakwater. Some of the alongshore sediment flow may persist along the coast after the coastal breakwaters.

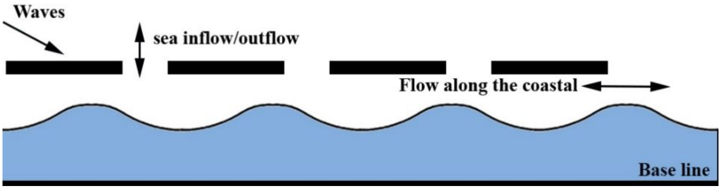

Fig. 1. Coastal breakwaters.

In the works of Esin N. V., Moskovkin V. M., Okun A.V., Trofimov A.M., Mendygulov Yu. D., a mathematical model of the dynamic cliff-beach system was formulated. This model has the form [38-44].

$$\begin{cases} \dfrac{dW}{dt} = \dfrac{ab}{W}H - KW \\ \dfrac{dH}{dt} = tg\alpha_0 \dfrac{b}{W} \end{cases} \quad (1)$$

Where W is the volume of debris per unit length of the beach, a is the content of beach-forming material in the cliff, K is the coefficient of sediment abrasion, b is the coefficient of deceleration of the cliff retreat rate, α_0 the angle of inclination of the coastal slope, H is the height of the cliff. In this paper, we want to consider a more universal mathematical model of the dynamic cliff-beach system, in which the rate of retreat of the cliff is approximated by a logistic curve, the height of the cliff H is the control parameter of this dynamic system, and an artificial control parameter U(t) is introduced – the rate of filling of the beach-forming material.

The model has the form:

$$\begin{cases} \dfrac{dW}{dt} = a\left(bw - cw^2\right)H\left(x\right) - KW + U\left(t\right) \\ \dfrac{dx}{dt} = \left(bw - cw^2\right) \end{cases} \tag{2}$$

where K is the coefficient of attrition of sediments, U (t) is the rate of filling of the beach – forming material, H(x) is the height of the cliff, x is the value of the cliff retreat, b is the coefficient of growth of the cliff retreat rate with an increase in the volume of detrital material W (at small W), C is the coefficient of deceleration of the cliff retreat rate (at large volumes W). The trivial solution of system (2) exists only for $(t) \equiv 0$:

$W \equiv 0$, $X \equiv X_0$=const

We find a nontrivial stationary solution of system (2). From the lower equation (2) we find:

$$W = \frac{b}{c}$$

The first equation of system (2) then gives:

$$\frac{dW}{dt} = 0 = -K\frac{b}{c} + U$$

$$U = \frac{Kb}{c}$$

That is, for the existence of a beach with a constant amount of beach-forming material $W=\frac{b}{c}$ constant filling is required $\frac{Kb}{c}$ beach-forming material per unit of time.

Let us now consider the case of the cliff-beach system when:

$$H(x) \approx const = H_0$$

Then the first of the equations (1) is closed and reduces to the logistic equation:

$$\frac{dW}{dt} = \left(abH_0 - K\right)W - acH_0W^2 \tag{3}$$

It can be seen that H_0 – is a control parameter of the system (a, b and K also, but in the case of a particular cliff-beach system they are practically they practically do not change in contrast to H_0). If H_0 satisfies the condition $H_0 < \frac{K}{ab}$ decision (3) $W \equiv 0$ the randomly generated material will also be stable δW will wear out in this case, there will be no beach. If H_0 will become more than $\frac{K}{ab} : H_0 > \frac{K}{ab}$, then, from equation (3) it can be seen that the initial fluctuation of the beach-forming material $0 < \delta W \ll 1$ will grow exponentially by law

$$H_0W \approx lxp\{\left(abH_0 - K\right)t\}\delta W \tag{4}$$

Until it reaches a stationary value that satisfies the equation:

$$\left(abH_0 - K\right)W - acH_0W^2 = 0 \tag{5}$$

Or

$$W = \frac{abH_0 - K}{acH_0} = \frac{b}{c} - \frac{K}{acH_0} \tag{6}$$

We linearize equation (3) in the vicinity of stationary solution (6) and obtain:

$$\begin{gathered} W(t) = W + Alxp\{-(abH_0 - K)t\} = \\ = W + (W(0) - W)lxp\{-(abH_0 - K)t\} \end{gathered} \tag{7}$$

Thus W(t)=W, and therefore the solution (6) is stable.

That is, for such a beach (H ≈ const) the optimal amount of beach-forming material that needs to be maintained on the beach is W from formula (6).

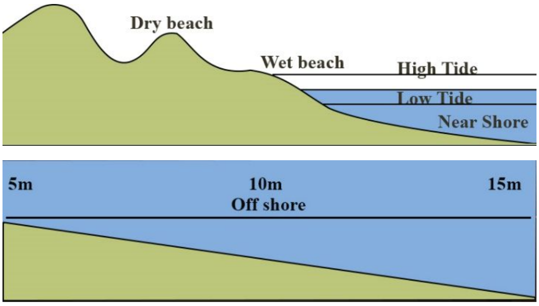

Fig. 2. Visualization of the modified mathematical model of the pebble beach dynamics.

3 Conclusions

The studies carried out made it possible to significantly clarify the ideas about the hydro- and lithodynamic processes occurring in the coastal zone of the beach. The influence of the parameters of waves and sediments that make up the beaches on such morphometric characteristics of the surf zone, which are important for the prac-tice of marine coastal protection, such as the length and height of the wave run-up, the depth at the point of their collapse, is shown.

The dependence is obtained for determining the alongshore discharges of pebble deposits, taking into account the parameters of the waves and the material that composes the beach. A detailed analysis of the distribution of the size and shape of the part made it possible to clarify the scheme of differentiation of the beach materi-al on the profile and in the thickness. The interrelation of the processes of formation of the active stratum of the beach with the value of the flow rate of the alongshore flow of pebble sediments is shown. An assessment of the impact of wave walls on alongshore discharges of pebble sediments and on the formed storm profile of the beach is given. The dynamics of a pebble beach protected by sea groins has been traced.

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