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Engineering

New Approach of Hydraulic Engineering Measures to Protect the Black Sea Poti Coastline from Erosion

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(Presented by Academy Member Archil Prangishvili)

The paper presents an engineering solution for the protecting and substantiality of the shoreline from the erosion of the Rioni River "City Canal". During the investigations, the six km long coastline is divided into two parts: The 1 km long coastline adjacent, where the longshore currents are strong; the rest of the coastline, where the influence is weaker. The need to clean the bed of the canal is substantiated and an optimal cleaning scheme is suggested. The need the clean the bed of the canal is substantiated and an optimal cleaning scheme is proposed. The solid material removed during cleaning should be dumped in a one km strip adjacent, which will be further processed and distributed by the waves. In order to protect the remaining shore from erosion, underwater barriers parallel to the shore are used in the sea. Sand-filled geotextile tubes are used as underwater barriers, which are both economically and environmentally adjusted. Graphical and analytical criteria are used to determine the parameters of underwater barriers and the nature of the morphological change of the shore (erosive, cumulative). On the basis of the analysis of the results obtained in the paper, a justified scheme for the protection of the coastline south of the "City Canal" from erosion has been developed. *© 2023 Bull. Georg. Natl. Acad. Sci.*

wave, current, shore, geotube

The erosion processes in the city of Poti and its maritime region are mainly caused by sedimentation of the Rioni River bed "City Canal" with solid sediment. Due to this, the cross-section of the bed has decreased by about 30-35% and instead of 500 m^3/s of water, it carries 200-250 m^3/s. As a result, the volume of solid sediment brought into the sea by the river decreased and the deficit amounted to 200,000-250,000 m^3 per year [1,2]. The sea has catastrophically washed away the coastline of Poti and pushed it back by hundreds of meters. At the same time, a delta was created at the confluence of the "Nabada Channel" with the sea, which is growing over time. The average speed of shore washing in a multi-year cut is 6-8 m/year. The volume of beach-forming sediment deposited in the riverbed is approximately 1,000,000 m^3 [2].

The situation is particularly alarming in the 6 km coastal strip south of the confluence of the Rioni River "City Canal". Despite many attempts, the problem is currently unsolved and its solution is an urgent issue.

In order to fill the deficit of sediment in the coastal zone, it is necessary to clean the bed of the “City Canal” and dump the sediment in the coastal zone. Afterward, the Canal will cover the design flow rate and the amount of solid sediment introduced into the sea will increase. This measure will partially solve the problem. Further action is required to fully resolve the issue and will be discussed below.

The transport of sediment in the coastal zone adjacent to the “City Canal” is strongly influenced by the riparian currents generated when the Rioni River flows into the sea. Therefore, we will divide its 6-kilometer section of the coastline south of the into two parts: 1) The 1-km-long coastal strip adjacent, where the riparian currents arising from the flow of the Rioni River into the sea are strong; 2) The rest of the coastline, where the Rioni River influence is weak.

1 km long coastal strip adjacent to the "City Canal". In the 1 km strip adjacent to the estuary, when the Rioni flows in, a southward-directed coastal flow is generated, which carries solid sediment from this area. In addition, during southwesterly storms, the northward along shore currents bring solid sediment into the mouth of the "City Canal", which then flows into the open sea, and this sediment is lost to the area. To prevent loss of sediment, geotubes filled with sand about 100 meters long should be arranged on this section of the bank.

In order for the bank protection scheme developed by us to work successfully, it is necessary to partially fill the sediment deficit and add additional sediment to the 1 km strip adjacent to the "City Canal". For this, it is necessary to clean the canal bed". The extracted material will be dumped in a 1 km strip adjacent, which will be further processed and distributed by the waves.

We have developed an optimal scheme for cleaning the "City Canal", the essence of which is as follows: the cleaning of the canal should be carried out gradually over a period of 5 years through a suction device. 200,000 m^3 of material removed annually will be dumped on the bank through a pipeline along the river bank (Fig.4).

The coastline is 5 km long. In order to protect this part of the shore from erosion, we will use the method of placing submerged breakwaters (SBW) parallel to the shore. Geotextile pipes (geotubes) will be used for this reason filled with sand as SBW. The use of submerged geotubes is justified both economically and ecologically [3].

The main geometric parameters of submerged geotube placement are: length of the geotube – L_b, width $-w_b$, height $-d$, its distance from the shore $-x_b$, distance between geotubes – L_g, and depth of geotube crest under water – a. For Poti coastline, it is convenient to place geotubes $x_b = 100;\ 180\text{m}$, from the shore, where the water depth is $h_b = 2;\ 3\text{m}$. Below are conducted the following studies for these parameters. The geotube placement parameters has been taken: $a = 0.5;\ 0.7\text{m}$. $L_b = 120;\ 180\text{m}$, $L_g = 60;\ 120;\ 180;\ 240\text{m}$.

The morphological equilibrium profile of the shore is calculated by the formula [4]:

$$h(x) = A \cdot x^{2/3},\ A = 0.21 D_{50}^{0.48}\ \left(D_{50} = 0.2\,\text{mm}\right). \tag{1}$$

In numerical calculations, we take the wave height in deep water $H_i = 1.3;\ 1.8\text{m}$ and the period $T_p = 9\,\text{s}$. The wave height in the coastline is proportional to the water depth $H = \gamma h.$ in the coastline of Poti $\gamma = 0.73$ [1].

Graphical criterion for the shoreline response to multiple SBW. The contribution of the variation of the lateral confinement ratio $m = \frac{L_g}{L_b}$ can be analyzed using the cumulative sediment displacement values in the lee of the SBW. The different degree in wave sheltering is shown to be dependent on the relative wave height $\left(\frac{h_b}{H_i}\right)$ with h_b being the depth at the location of the breakwater). Based on these relations the following equation can be derived for the location of data point on the x - axis [5,6]:

$$x = \left(\frac{a}{h_b}\right)^{\frac{3}{2}} \left(\frac{L_b}{h_b}\right)^2 \left(\frac{A^3}{h_b}\right)^{\frac{1}{2}} \left[1,22\left(\frac{L_g}{L_b}\right)^2 - 3,67\left(\frac{L_g}{L_b}\right) + 3,22i\left(\frac{h_g}{H_i}\right)^2\right], \quad y = \frac{h_b}{H_i} \qquad (2)$$

where $i = 0.36$, H_i is the wave height at SBW, $\frac{h_b}{H_i} \geq 1.25$ and $0.25 \leq \frac{L_g}{L_b} \leq 2.5$.

The functional dependence determining the shore reaction between the system parameters is expressed by the formula [5]:

$$y = 2\log_{10} x + 0.65. \qquad (3)$$

The graph of function (2) in semi-logarithmic scale is a line. If the points calculated for the values of the system parameters are placed on the graph to the left of the line, then the reaction of the bank is accumulative, and on the right - erosive [5]. The results of the numerical experiments conducted in Fig. 1.

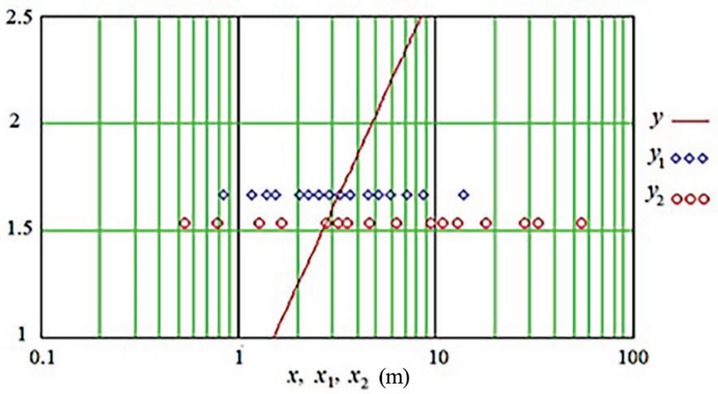

Fig. 1. Determination of the morphological change of the shore graphical criteria.

In Fig. 1 Calculations are performed for two values of x_1 : $x_b = 180$ m, $h_b = 3$ m, x_2 : $x_b = 100$ m, $h_b = 2$ m, 16 points are calculated for each parameter.

Analytical criterion shoreline response to multiple SBW. In works [6,7] it was proposed the following criterion to make a rapid first assessment of the potential shoreline response:

$$r = \frac{\eta + \eta_b}{\eta_g} \qquad (4)$$

In equation (4) η is the rise of the water level after the transfer of water to the through a geotube; η_b – the rise of the water level during the breaking of a new wave at the shore; η_g – There is a rise in the water level after the undisturbed passage of the waves between the breakwaters and breaking on the shore. The rise of the water level during the breaking of waves near the shore η_b and η_g is calculated by the following formulas [8]

$$\eta_{b,g} = \frac{3\gamma_{b,g}^2}{8+3\gamma_{b,g}^2}\cdot h_{b,g}, \quad (\gamma_g = 0.63;\ \gamma_b = 0.68). \tag{5}$$

It is known that $r>1$ after waves pass over the geotube, 2-cell circulations of currents occur and the shore is eroded. When $r<1$ waves pass over the geotube, 4-cell circulations of currents occur and the shore is accumulative [6,7].

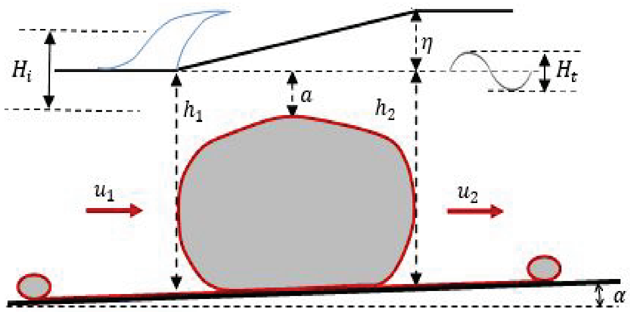

Fig. 2. Cross section of submerged geotube.

$$\frac{q_1^2}{g(h_2+\eta)} - \frac{q_1^2}{h_1\cdot g} + \mu B\frac{q_1}{g} + \eta a + \frac{\eta^2}{2} + C = 0 \tag{6}$$

$$q_1 = u_1 h_1 = C_1\sqrt{2g\eta}\cdot h_g\cdot\frac{L_g}{L_b}, \tag{7}$$

where $\mu = f_w\frac{\gamma\sqrt{g}}{\pi}$, $\gamma = \frac{H_i}{h_b}$ $B = \int_0^{w_b}\frac{dx}{\sqrt{h(x)}}$, $f_w \approx 0.16$ $C_1 = 0.54$, $\beta = \frac{1}{8}\left(\frac{1}{2}+\frac{2kh}{\sin 2kh}\right)+\frac{0.9kh}{2\pi}$, $C = \beta_2 H_t^2 - \beta_1 H_0^2$, $k = \frac{2\pi}{L}$ – wave number, L – wave length ; $H_t = K_t\cdot H_t$, where K_t is the wave transmission coefficient, which is determined by the formula [9,10]:

$$K_t = 0.4\frac{a}{H_t} + 0.8\cdot\left(\frac{w_b}{H_i}\right)^{-0.31}\cdot\left(1-e^{-0.5\zeta}\right),\ \zeta = \frac{\alpha}{\sqrt{\frac{H_i}{L}}},\ L = \frac{gT_p^2}{2\pi},\ \alpha \approx 0.017. \tag{8}$$

The results of the obtained numerical solution of the system of equations (6)-(7) are given in Fig. 3.

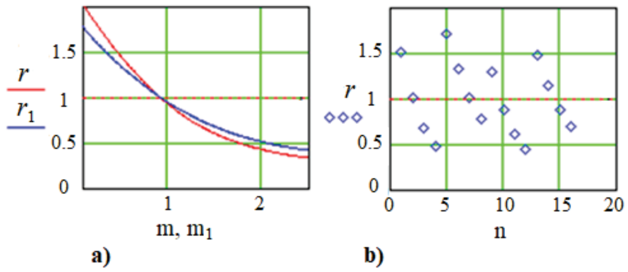

Fig. 3. Dependence between the parameters of the shoreline response of the coast with the analytical criterion.

In Fig. 3. a) The relationship between the lateral confinements ratio m, m_1 and the shoreline response parameter r is shown. The system parameters for r are: $x_b = 180\,\text{m}$, $h_b = 3\,\text{m}$, $H_i = 1{,}8\,\text{m}$. For r_1: $x_b = 100\,\text{m}$, $h_b = 2\,\text{m}$, $H_i = 1{,}3\,\text{m}$. On Fig. 3. b) shows the values of the shoreline response parameter r when ($n = 16$ is the number of points) $x_b = 180\,\text{m}$, $h_b = 3\,\text{m}$, $H_i = 1{,}8\,\text{m}$.

The results obtained for underwater geotubes are in complete agreement with the results obtained by the numerical model Delft3D for a similar coastline [6].

In order to protect the remaining 5 km of the shore from erosion, we will use submerged geotube (geotubes filled with sand) located parallel to the shore. Based on the calculations for the Poti coast, we choose the following values for the geotube placement parameters:

$$x_b = 180\,\text{m},\ \ a = 0.5\,\text{m},\ \ w_b = 5.1\,\text{m},\ \ L_b = 120\,\text{m},\ \ L_g = 180\,\text{m}.$$

For such values of the submerged geotube placement parameters, the 5 km long bank located to the south of the "city channel" will be cumulative.

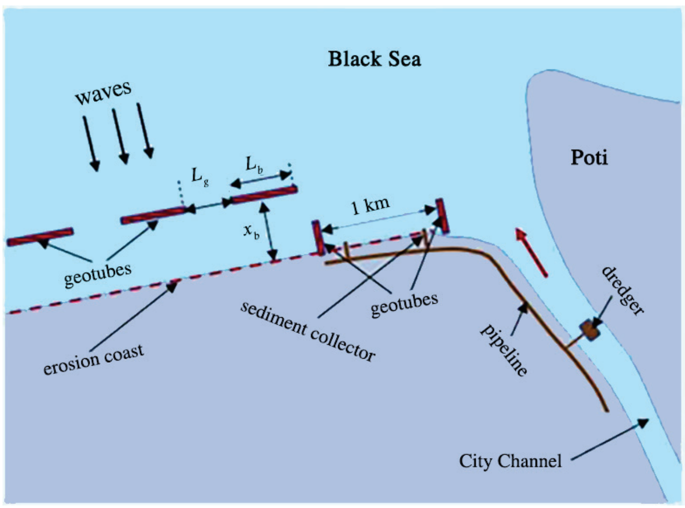

Fig. 4. Erosion protection scheme of the coastline south of the "City Canal".

Based on the analysis of the obtained results, a scheme for the protection of the coastline south of the "City Canal" has been developed, which is shown in Fig. 4.

Conclusions

Thus, during the 5 years of cleaning the "City Canal", an additional 200,000 m^3 of solid sediment will be deposited annually on the 1 km section of the adjacent bank, which will be distributed throughout the entire coastline through waves and coastal currents. As a result, erosion processes on the coast will decrease, and the shore will increase in a 1 km strip. After the cleaning of the river bed of the “City Canal”, the channel will cover the design rate and accordingly, the volume of introduced solid sediment will increase, which will have a positive effect on the morphological change of the bank.

5 years after the implementation of the proposed hydraulic measure, an 8 km long pulp pipeline with its intermediate pumps will be laid along the seashore and the Rioni “City Canal”. Then, if necessary, the pulp line can be extended by 1 km and the sediment removed in the main channel of the Rioni River in the lower basin of the watershed. In this part of the river, a large amount of beach-forming sediment is obtained, and if necessary, to protect the bank, this sediment can be moved to the shoreline with the existing system. In addition, if the “City Canal” becomes silted over time, the existing system can be used to clean it again.

The geometric parameters of the underwater geotubes located in the 5 km long coastline are selected in such a way that after the waves pass over the geotubes, 4-cell circulations of currents occur between them and the shore. In this case, the morphological reaction of the coast is accumulative. In addition, due to the deposition of sediment, the coastline will receive additional nutrition and will be protected from erosion (Fig. 4).

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ინჟინერია

ქალაქ ფოთის შავი ზღვის სანაპირო ზოლის ეროზიისაგან დაცვის ჰიდროტექნიკურ ღონისძიებათა ახალი სქემის შემუშავება

ი. საღინაძე*, მ. კოდუა**, მ. ფხაკაძე*

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(წარმოდგენილია აკადემიის წევრის ა. ფრანგიშვილის მიერ)

ნაშრომში შემუშავებულია მდინარე რიონის „საქალაქო არხის“ სამხრეთით მდებარე სანაპირო ზოლის ეროზიისაგან დაცვის საინჟინრო ღონისძიებები. გამოკვლევებისას 6კმ-იანი სანაპირო ზოლი დაყოფილია ორ ნაწილად: 1. „საქალაქო არხის“ მიმდებარე 1 კმ სიგრძის სანაპირო ზოლი, სადაც ძლიერია ნაპირგასწვრივი დინებები; 2. დანარჩენი სანაპირო ზოლი, სადაც მდინარე რიონის გავლენა სუსტია. დასაბუთებულია „საქალაქო არხის“ კალაპოტის გაწმენდის აუცილებლობა და შემოთავაზებულია გაწმენდის ოპტიმალური სქემა. გაწმენდისას ამოღებული მყარი მასალა უნდა დაიყაროს „საქალაქო არხის“ მიმდებარე 1კმ-იან ზოლში, რომელსაც შემდგომში ტალღები გადაამუშავებს და გადაანაწილებს. ნაპირის დარჩენილი ნაწილის ეროზიისაგან დაცვისათვის გამოყენებულია ზღვაში ნაპირის პარალელური წყალქვეშა ბარიერები, ქვიშით ავსებული გეოტექსტილის მილების (გეოტუბები) სახით, რაც გამართლებულია როგორც ეკონომიკურად, ასევე ეკოლოგიურად. წყალქვეშა ბარიერების პარამეტრებისა და ნაპირის მორფოლოგიური ცვლილების ხასიათის (ეროზიული, აკუმულაციური) განსაზღვრისათვის გამოყენებულია გრაფიკული და ანალიზური კრიტერიუმები. ნაშრომში მიღებული შედეგების ანალიზის საფუძველზე შემუშავებულია მდინარე რიონის „საქალაქო არხის“ სამხრეთით მდებარე სანაპირო ზოლის ეროზიისაგან დაცვის დასაბუთებული სქემა.

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