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CHOOSING THE TYPE OF SHORE PROTECTION STRUCTURES IN RESERVOIRS (USING THE EXAMPLE OF THE NOVOSIBIRSK RESERVOIR)

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Abstract: An increasingly urgent issue is the safety of the population, including the safety of living in the coastal zone of large bodies of water and in areas adjacent to hydraulic structures. The presence of such infrastructure facilities obligates the state to ensure their safe use for the population of the country: erecting and safely operating hydraulic structures, preventing the occurrence of emergency situations related to flooding and floodplain flooding, etc. However, adverse conditions and negative developments are increasingly occurring: dam collapses, accidents at waterworks, flooding and threats of urban areas flooding. All this directly relates to the condition of hydraulic structures (GS) and their service life; reconstruction is needed, as well as the construction of new ones. Protection of coastal areas of reservoirs is particularly important in today's world, as climate change and human impact have a negative effect on this area. One of the effective ways to protect is the use of coastal protective hydraulic structures (CPHS). The subject of study is an important part of the regional infrastructure - the Novosibirsk Reservoir, located in the Novosibirsk region and the Altai territory. The reservoir has multiple purposes (water supply, recreational and navigation). However, the coastline of the reservoir is constantly affected by various negative impacts, such as erosion, landslides, and flooding. Determining the optimal type of hydrological engineering structure for protecting the shoreline of the Novosibirsk reservoir based on analysis of existing CPHS types, their characteristics, and usage conditions is an urgent task for regions like the Novosibirsk area and Altai.

Keywords: hydraulic engineering structure, safe operation, emergency situation, shoreline, reservoir, shore-protecting hydraulic engineering structure

ВЫБОР ТИПА БЕРЕГОУКРЕПИТЕЛЬНЫХ СООРУЖЕНИЙ НА ВОДОХРАНИЛИЩАХ (НА ПРИМЕРЕ НОВОСИБИРСКОГО ВОДОХРАНИЛИЩА)

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Аннотация: Все более актуальным вопросом является безопасность населения, в том числе безопасность проживания в прибрежной зоне крупных водных объектов и на территориях, примыкающих к гидротехническим сооружениям. Наличие таких объектов инфраструктуры обязывает государство обеспечивать население страны их безопасным использованием: возводить и безопасно эксплуатировать гидротехнические сооружения, не допускать возникновение чрезвычайных ситуаций (ЧС), связанных с подтоплением, затоплением пойменных территорий и пр. Однако, все чаще развиваются неблагоприятные условия и негативные события: происходят прорывы дамб, аварии на гидроузлах, наводнения и угрозы затопления урбанизированных территорий. Все это связано напрямую с состоянием гидротехнических сооружений (ГТС), сроком их службы, необходимостью реконструкции, потребностью в возведении новых ГТС. Защита береговой полосы водоемов приобретает особое значение в условиях современного мира, так как изменение климата и антропогенное воздействие

оказывают негативное влияние на эту территорию. Одним из эффективных способов защиты является использование берегозащитных гидротехнических сооружений (БГТС). Объектом исследования является важный элемент инфраструктуры региона - Новосибирское водохранилище, расположенное на территории Новосибирской области и Алтайского края. Водоем имеет многоцелевое назначение (водоснабжение, рекреация и судоходство). Однако, береговая полоса водохранилища постоянно подвергается различным негативным воздействиям, таким как эрозия, оползни и подтопление. Определение оптимального типа гидротехнического сооружения для защиты береговой полосы Новосибирского водохранилища на основе анализа существующих типов БГТС, их характеристик и условий применения, является актуальной задачей для таких регионов России как Новосибирская область и Алтайский край.

Ключевые слова: гидротехническое сооружение, безопасная эксплуатация, чрезвычайная ситуация, береговая линия, водохранилище, берегоукрепительное гидротехническое сооружение

INTRODUCTION

Since the formation of the Novosibirsk Reservoir (more than 50 years ago), significant changes have taken place in the lives of the region, including those related to the development of coastal zones of this water body, a significant increase in population and infrastructure necessary for high-quality habitation on its shores. In addition, anthropogenic impact and climate change have undoubtedly had a significant impact on this area. It should be noted that Novosibirsk, created as a result of damming the Ob River to build the Novosibirsk Hydroelectric Power Station, was supposed to be located in a chain of reservoirs beginning with the Katun River in the Altai Republic, which merges with Biya in Biysk, Altai Krai, forming one of the world's largest lowland rivers, the Ob.. However, due to various compelling reasons, this project has not been implemented. Although in recent years, the question of its relevance has been raised again, it is reasonable to say, in connection with a number of the above-mentioned facts that the combination of these conditions significantly affected and continues to affect the state of the coastal zone of the Novosibirsk Reservoir. It is essential, first and foremost, to ensure the safety and stability of this area in the face of climate change and human impact.

METHODS

Various methods are used to calculate coastal protection hydraulic structures (CPHS) at reservoirs, which take into account the natural conditions and features of the shoreline. The results of these calculations are refined based on field studies, laboratory tests, and experiments. The Novosibirsk valley reservoir regulates seasonal flow. According to its morphological features, it is divided into three sections: the upper section (130 km away from the dam), the middle section (60-130 km), and the lower section (up to 60 km). Nineteen small rivers flow into the reservoir, with the largest being the Berd River.

When designing a CPHS at a reservoir, the following factors must be considered:

Natural conditions of the coastal zone. In order to determine the dynamics of the collapse of the banks of the Novosibirsk reservoir, monitoring has been conducted since 2016.

Reference points were installed along shores of Novosibirsk Reservoir in 2017 to monitor dynamics of coastal collapse. 56 total rappers were installed: 31 on right bank and 25 on left bank. Coordinates of established reference points summarized in special table. Every year, specialists conduct on-site surveys in first decade of June and third decade of September. Surveys conducted by both road and water. Data on dynamics of coastal collapses generated in tabular format (Table 1)

In addition to monitoring the natural conditions of the coastal zone of the Novosibirsk reservoir, we used data from hydrometeorological surveys and the results of engineering and geological surveys ordered from third-party specialized organizations with necessary SRO permits to make constructive and design decisions for the

construction of CPHS. The data obtained was analyzed and applied to justify a particular type of construction that takes into account the type of soil, its properties and condition.

The topography of the bottom and shore of the reservoir was carried out by a team of specialists who were part of the group of authors for this work, independently using specialized calibrated instruments including an echo sounder, flow meter, and hydrometric turntable. Furthermore, in IndorCAD Rivier and IndorCad Drow programs we performed in-house processing of the results obtained. A sample map is shown in Figure 2.

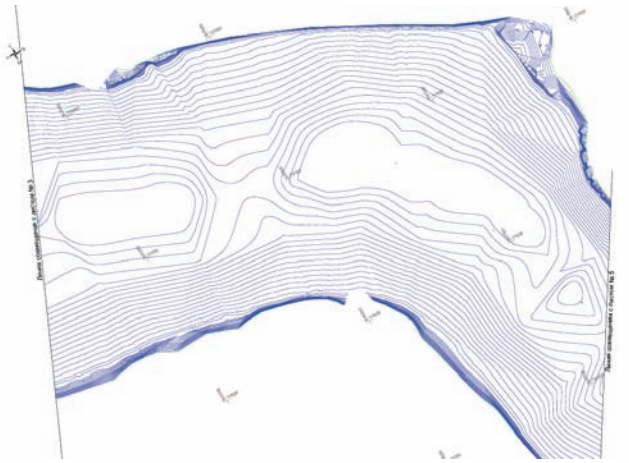


Figure 2. An example of creating a hydrographic map

An important aspect of the design of the CPHS is the analysis of *hydrological regimes*. Several hydraulic stations are in operation at the Novosibirsk reservoir, including the villages of Verkhny Beif and Spirino etc. Based on the available data, the amplitudes and the frequency of fluctuations in water levels are determined, which allow for making constructive decisions. The level regime of the reservoir is determined by periodic changes in volume due to water intake and use, as well as fluctuations caused by wind. Filling up in spring, the reservoir is triggered during the autumn-winter period, with an average operating amplitude of 4.76 m.

The basin of the reservoir is located in the territory of Novosibirsk Oblast and Altai Krai. The area of water surface is 1,070 square kilometers; the total volume is 8.8 cubic kilometers. The maximum width is 22 kilometers, the length is 185 kilometers, and the maximum depth is 29 meters. The average depth is 9 meters and 50 percent of the area is less than 5 meter deep. Sanatoria, boarding houses, recreation centers, children's health camps, and other facilities are located on the shore. Coastal erosion processes at the Novosibirsk Reservoir began during its filling and were intense. These processes continue today. The main cause of erosion is wind waves, which are associated with a lack of loose material in the coastal area. The consequences of coastal erosion lead to an aggravation of environmental problems, such as the reduction of fish resources, coastal destruction and bottom siltation. This leads to a deterioration in water quality. The total length of the coastal strip of the Novosibirsk reservoir is 550 kilometers, of which 332 kilometers are subject to treatment. When justifying a particular CPHS, we calculated current speeds, wave heights, ice conditions, and other parameters using existing calculation methods such as wave and ice loads described in the joint venture. The geological structure of the coast, consisting mainly of fine sands and loams, is the main factor in processing. During operation, the rate of coastal retreat has decreased somewhat, but only engineering protection can prevent further loss of land. Therefore, one of the most urgent problems is to protect the coast from the effects of wind and waves. Forecasts of dangerous engineering and geological processes (for example, landslides, earthquakes, etc.) are made based on the collected long-term data.

But the processes of coastal erosion lead not only to the loss of fertile land, but also to sedimentation of the river. During the operation period, the area of the reservoir at NPU = 113.5 m increased from 1070 km to 1082, and the volume increased from 8.8 to 8.02 km due to dead volumes. The useful capacity remained practically unchanged. According to observations, approximately 40,000 m3 of sediment settles annually in the bed of the reservoir, which causes the shallowing of the

water body and deterioration of its ecological condition as a whole. Because of the continuous impact of water on coastal areas, it is necessary to organize systematic and continuous monitoring of coastal areas, forecast related natural hazards, develop and implement effective methods to prevent or minimize their consequences.. The changes in the position of the coastline and the formation of islands in the area of predominantly fluvial morpholithogenesis of the Novosibirsk reservoir between 1960 and 2024 are shown in Figure 3. Based on the results of monitoring, if it is necessary to strengthen the coastline, specialists choose hydraulic structures based on feasibility studies.

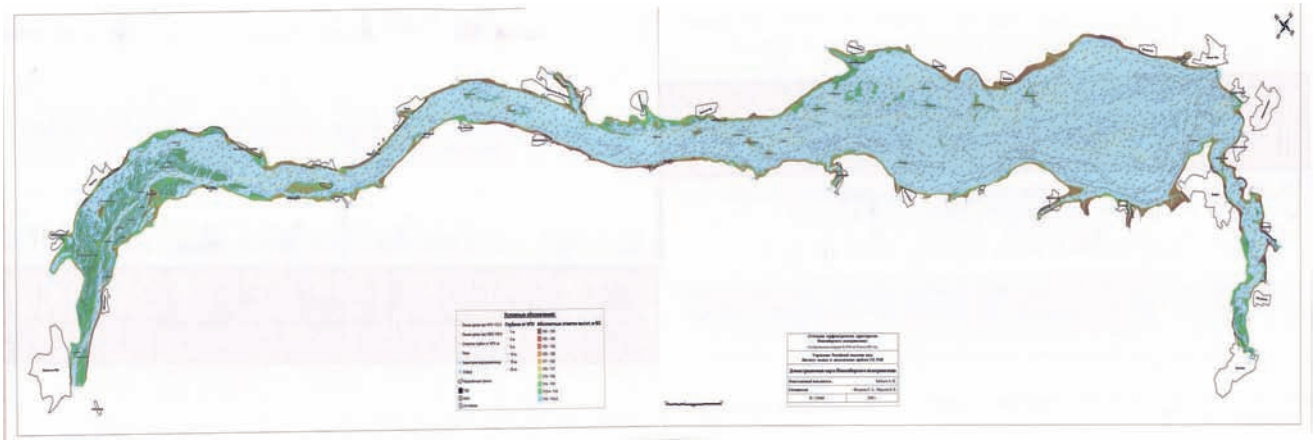


Figure 1. A diagram of the Novosibirsk reservoir

Table 1. Table of the dynamics of changes in the distance from the reference point to the shore (in meters)

№ Rp	location	2016	06.2017	09.2017	06.2018	09.2018	06.2019	09.2019	06.2020	09.2020	06.2021	09.2021	06.2022	09.2022	06.2023	09.2023	06.2024	09.2024	06.2025
1	Berdsk	21,8	21,5	21,5	21,3	21,3	21,0	21,0	20,90	20,85	20,60	20,60	20,50	20,50	20,45	20,45	20,30	20,30	20.10
2	Sosnovka	59.9	47,1	43,3	43,0	42,8	42,5	42,4	42,2	42,1	42,0	39,5	39,3	39,2	38,9	38,7	38,5	38,3	37,9

Hydraulic structures designed to protect the shores and bottoms of reservoirs from the negative effects of water are classified as shore-protecting hydraulic structures, and provide engineering protection against the negative effects of the water.

The choice of the HS type depends on specific terrain conditions, such as topography, geological structure, hydrological regime, etc. It is important to consider not only the purpose of protecting the coastline when choosing a structure but also factors such as the type of reservoir, economics, environmental impact, durability, maintenance and safety. Only after a comprehensive analysis of these factors can specialists select the correct type of structure and design it.

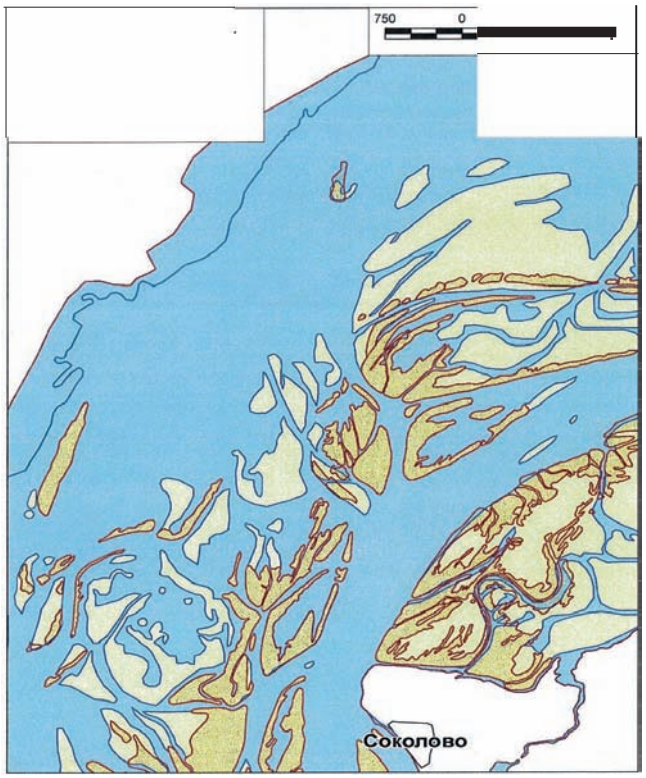


Figure 3. Changes in the position of the coastline and the formation of islands in the area of predominantly fluvial morpholithogenesis of the Novosibirsk reservoir from 1960 to 2024

In accordance with a number of regulatory and legal documents in force on the territory of the Russian Federation, coastal protection hydraulic structures belong to Class III. However, the class of coastal protection structure can be increased to Class II if destruction of coastal protection structures could lead to an emergency situation. To solve the problem of neutralizing negative effects of water on the Novosibirsk reservoir, we will consider the following options used in practice of coastal protection:

- rejuvenation of the coastal slope;
- biological protection applications;
- increasing the cross-section of the watercourse;
- filling with stone;
- applications of gabion structures;
- using geosoft;
- applications of monolithic (concrete, asphalt and other) coatings;
- applications of precast reinforced concrete structures;
- applications of sheet pile structures;
- applications of flexible concrete coverings.

All of these protection methods may be applicable to the specific case under consideration. However, some of them have been rejected due to their lack of compliance with the criteria for "safety" and "reliability". Other measures simply cannot be implemented because of the impossibility to do so, based on natural conditions in the area of the Novosibirsk Reservoir and its coastal zone. For example, when creating a "coastal slope rejuvenation", it is important to ensure that the angle of the slope is between 5.71 or 1 to 10 (the so-called "beach slope"). With this angle, the stability of adjacent concrete structures, as well as the stability of soil used as a base for those structures, is ensured. Thus, by flattening the coastline to a point less than 5.71 degrees, the coast is protected from destruction by breakwaters. Due to multi-storey buildings (e.g., Berdsk's right-bank section of the reservoir and the left-bank section fully developed by population), such methods as rejuvenating the banks cannot be used in our case to strengthen them.

The next method of coastal protection being considered is to increase the cross-section of a watercourse. However, the effectiveness of this method has not been confirmed by our calculations. With an increase in either depth or width in the water course, the flow rate slows down. It would not be constructive to increase the Novosibirsk reservoir's cross-section by increasing its width. Instead, an increase in depth would cause soil carried by currents to deposit in areas with slower currents. Over time, under natural processes, the cross-sectional area of the reservoir will return to its original size. This type of protection is only effective when combined with other types of defenses.

Protection of the coast by filling it with stones is one of the oldest methods to prevent erosion. Our hydraulic calculations show that the velocities of water flow in the Novosibirsk

Reservoir fully correspond to those calculated velocities at which there is no movement of stones from coastal protection structures along the shoreline. This movement begins at flow velocities between 0.8 and 1.3 meters per second. However, natural conditions in Siberia have their own limitations. In winter, stones of coastal defenses freeze into ice. When water levels rise in the river (during winter or spring floods), ice rises, tearing off layers of frozen stones from the surface. Currents can tear ice floes with frozen rocks away from the shore and carry them downstream. The filling of stones collapses. Also, as long-term experience shows, a stone deposit can be destroyed by a wind wave of over 1.7 meters high. According to hydraulic calculations carried out in the absence of winter floods on the Novosibirsk Reservoir, the ice thickness is at least 1 meter, so it is impractical to use stone filling due to significant destruction as an individual unit. However, in combination with other hydraulic structures, this type of shore protection is quite effective.

Gabion structures are another way to protect the coastal slope. They began to be widely used in hydraulic engineering construction in the late 1990s, i.e., more than 25 years ago. Practical experience with the use of gabions has revealed their unreliability, so the use of this type of structure entails high operational costs. As a result, gabion structures have lost their attractiveness, and their use is declining rapidly.

The gabion structures have been replaced by geogrids. Coastal protection structures using geogrid are very similar to gabion designs. At the same time, the strength of a "stone container" geogrid is far greater than that of a gabion grid. Unlike gabions, however, geogrid does not have a bottom, which can lead to accidents.

Monolithic coatings in relation to conditions of use, and importantly from the point of view of reliability of coastal protection structures, the manufacturing technology for this type of monolithic (concrete, asphalt, or other) coating on an open construction site often fails to meet the requirements for frost and water resistance, which leads to rapid destruction of the coating. In addition, constructing monolithic coatings requires precise alignment of the slope of the protected surface and subsequent compaction, which is difficult to achieve in practice. If the ground subsides during use, cracks will form on the coating, causing accidents and potentially leading to emergencies if not repaired promptly.

As for the experience of using precast reinforced concrete structures as shore protection structures in the conditions of water bodies, such as the Novosibirsk reservoir, they are inferior to other alternatives, even though they have a more complex construction process. This is because precast structures always have a lower support, on which the plates rest.

When it comes to protecting the shoreline of a reservoir, tongue-and-groove systems can be fragile and unreliable, based on years of experience. Based on 50 years of observation, the thickness of sheet piles is reduced from 10±1 mm to 2±1 mm, leading to complete destruction.

Let's consider the option of coastal protection in its relatively new form - using flexible concrete coverings. Flexible concrete slabs are placed on top of geotextiles, which act as an anti-diffusion barrier. In essence, the geotextile protects the object from negative effects of water. The main purpose of a flexible concrete slab is to prevent the destruction of the geotexiles. This type of coastal protection has been used recently. Facilities where pilot projects using flexible coverings have been implemented, including large reservoirs, are under our supervision. These projects were completed only five years ago and still meet requirements for operation and reliability.

RESULTS AND DISCUSSION

Having considered all types of existing coastal protection structures and returned to the shoreline of the Novosibirsk reservoir, we can discuss the need to combine at least two types of hydraulic structures in design work. Only then will the purpose of this work be achieved. Engineering protection of reservoir shorelines

has gone through similar stages in its development to coastal protection history, but in a shorter time frame. Only 40 years ago, when selecting means to protect reservoir shores, priority was given to breakwater walls and various coastal coverings, such as stone-cast, reinforced concrete and asphalt concrete. It took less than ten years to realize all the disadvantages of passive structures and make significant adjustments to the strategy for coastal protection of artificial reservoirs. Coastal protection structures installed at the Novosibirsk Reservoir have truly prevented further erosion on the protected shorelines.. However, in the adjacent coastal areas, abrasive processes have noticeably intensified, on the contrary. Moreover, after several years, breakwater walls and coastal coverings have often begun to collapse quickly due to erosion of the bottom directly in front of them and violation of the integrity of their base.

Therefore, a different integrated approach to the design and construction of coastal protection structures is currently proposed. As an example, we should consider the section of the shoreline of Novosibirsk Reservoir near the village of Krasny Yar in Ordynsky District of Novosibirsk Region, which is undergoing active erosion (Fig. 4). A coastal protection structure with a length of 3,175 meters is required in this area. The construction of the facility was selected based on a comparison of similar projects located at the Novosibirsk reservoir and the estimated costs of implementing measures. After analyzing the initial data for the selected section of coastline, two integrated versions of coastal protection structures are proposed: a sheet pile wall made from composite material and a banquet made from rock mass, as well as an artificial division of coast into bays. The site was divided into segments for settlement. Wave effects were calculated for each site separately (see Fig. 5).

To prevent the abrasion of the coastal slope by wave load, it is planned to fill in the building profile of a sandy beach along the coast and install a beach-holding structure in the form of an intermittent breakwater.



Figure 4. Estimated segments of the site being considered

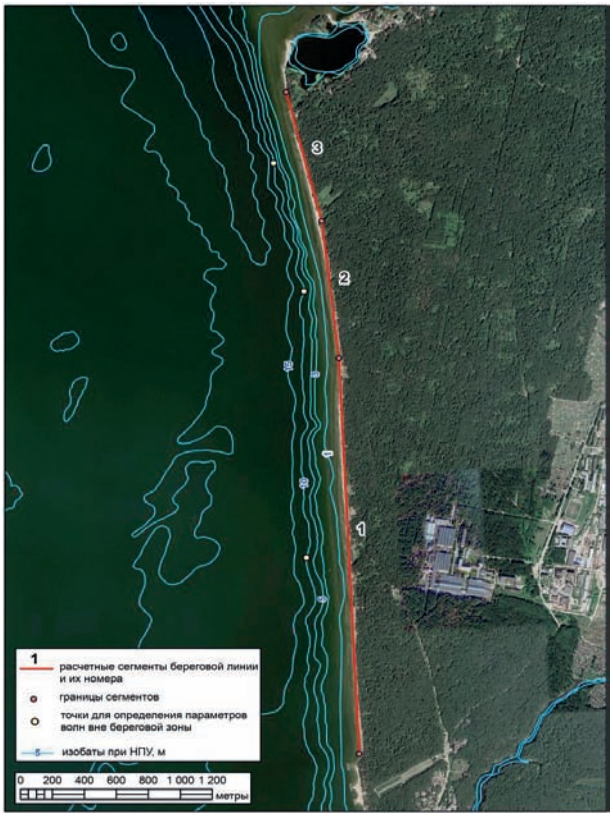


Figure 5. Points for determining the parameters of waves in the coastal zone

The first part of the complex structure is a rock banquet. After reshaping it by the excitement of water area of Novosibirsk reservoir, the banquet will take the form of natural stone beaches. Rock banquets have proven themselves as reliable structures that effectively perform their coastal protection function at Novosibirsk Reservoir. The disadvantage of rock banquets is the impossibility of using them for recreational purposes due to safety concerns. Calculations have been made for all segments and summarized in tables, based on which wave acceleration lines have been built in the most dangerous areas, an example of which is shown in Figure 6 for selected wave points along active wind directions.

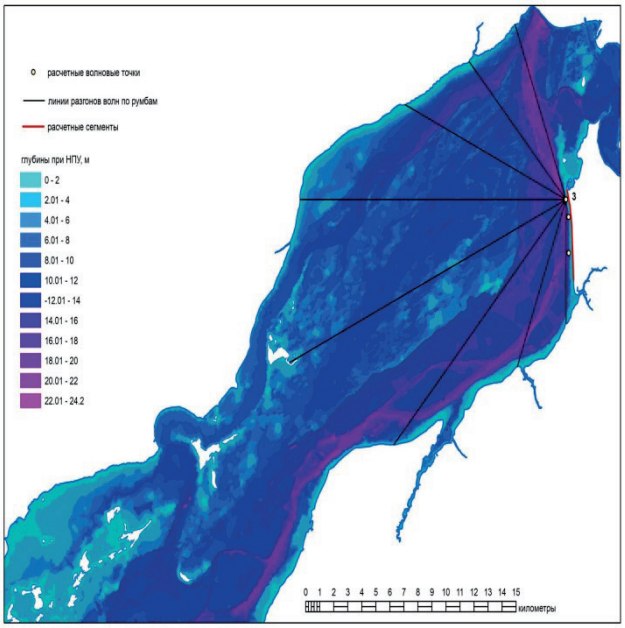


Figure 6. lines of wave acceleration along active wind directions for point No. 3, segment No. 2 (Point No.3)

The calculations of the wave elements were performed taking into account division into depth zones, which are clearly expressed in the approach to the projected section of the coast. The deep-sea area - has a depth $d > 0.5\bar{\lambda}_d$ (where the average $\bar{\lambda}_d$ wavelength is in the deep sea zone), and the bottom does not affect the main characteristics of waves.

Shallow - with a depth of $0.5\bar{\lambda}_d \geq d > d_{cr}$, where the bottom affects the development of waves and their main characteristics. (The critical depth of water is d_{cr} at which the first wave collapses occurs).

Surf - with a depth of d_{cr} to $d_{cu,r}$, within which wave destruction begins and ends.

Near-shore - with a depth of less than $d_{cu,r}$, within which the flow from destroyed waves periodically rolls onto the shore. The calculation of the deep-water zone is performed at the depth at the edge of the zone. The average height and average period of waves in the deep-sea zone are calculated according to formulas (P 31.3.07-01):

$$\frac{g\bar{h}}{V^2} = 0{,}16\left\{1-\left[1+6{,}0\cdot 10^{-3}\left(\frac{gL}{V^2}\right)^{1/2}\right]^{-2}\right\}\times \text{th}\left\{\frac{0{,}625\left(\frac{gd}{V^2}\right)^{0{,}8}}{1-\left[1+6{,}0\cdot 10^{-3}\left(\frac{gL}{V^2}\right)^{-2}\right]}\right\},$$

$$\frac{g\bar{T}}{V} = 19{,}47\left(\frac{g\bar{h}}{V^2}\right)^{0{,}625}$$

The average wavelength in the deep-sea zone is determined by the known value of the average period, according to the formula: $\bar{\lambda} = \frac{g\bar{T}^2}{2\pi}$.

The average wave height in shallow waters, $\bar{h}_s$, m, with bottom slopes less than 0.002, must be determined using the formula:

$$\bar{h}_s = \bar{h}_d \cdot \text{th}\left[\frac{0{,}1\left(\frac{gd}{V^2}\right)^{0{,}8}}{\frac{g\bar{h}_d}{V_w^2}}\right],$$

Where d is the depth of the water at the calculated point

The height of the waves in the i% zone must be determined by the formula, with decreasing depths and bottom slopes of i ≥ 0.02:

$$h_i = k_t \cdot k_r \cdot k_i \cdot \bar{h}_d,$$

where: k_t – is the transformation coefficient;
k_r – is the refractive index; k_i – s the coefficient of transition to wave height; i % security; $\bar{h}_d$ – the initial average wave height in deep water.
The coefficients k_t, k_r and k_i, cshould be determined according to regulatory documents.
The transformation coefficient k_t, must be calculated using the formula:

$$k_t = \left\{ \frac{C_N \left(1 + \frac{4\pi}{C_n} \cdot \frac{d}{\bar{\lambda}_d} \right)}{\operatorname{sh}\left(\frac{4\pi}{C_N} \cdot \frac{d}{\bar{\lambda}_d} \right)} \right\}^{\frac{1}{2}}$$

Where

$$C_N = th^{0,5}\left(\frac{2\pi d}{\bar{\lambda}_d} \right)$$

d is the depth of water at the calculated point.
The refractive index for the bottom sections with rectilinear isobaths (with $0<a_d<60$, degrees) should be calculated using the formula

$$k_r = \left[\frac{1 - C_N^2 \sin^2 \alpha_d}{\cos^2 \lambda_d} \right]$$

Where: α_d - The angle between the direction of the waves and the normal to the isobaths at a calculated point;
C_N is a parameter defined by the formula.
The refractive index k_r дfor bottom sections with curved isobaths can be determined in accordance with the recommendations.

The wavelength, $\bar{\lambda}$, m, moving from the deep-sea water area to the transformation zone, must be determined using the formula.

$$\bar{\lambda} = \bar{\lambda}_d th^{0,5}\left(\frac{2\pi d}{\bar{\lambda}_d} \right)$$

The depth of the first wave's collapse, d_{cr}, in the surf zone with a constant bottom slope, must be determined using the formula.

$$d_{cr} = a_i \left[arcth\left(\frac{5,9 \cdot 2\pi (h_d)_{1\%}}{g\bar{T}^2} \right) \right] \cdot \frac{g\bar{T}^2}{2\pi}$$

where $\begin{cases} a_1 = 4,3 \\ a_2 = 5,4 \\ a_3 = 6,3 \end{cases}$ at $\begin{cases} 0,001 < i \le 0,033; \\ 0,033 < i < 0,049; \\ 0,05 \le i \le 0,2. \end{cases}$

The depth of the last wave, $d_{cr,u}$, m, from which the waves roll onto the shore is allowed to be calculated using a constant slope of the bottom, i: $d_{cr,u} = k_n^{n-1} d_{cr,}$
Where $d_{cr,u}$ – is the depth of the first wave collapse.
The wave height in the surf zone is 1% $h_{sur,1\%}$ at $d_{cr} \le d \le d_{cr,u}$ It must be determined using the formula.

$$h_{sur,1\%} = 0,18 \left[th\left(a_i \frac{2\pi d}{g\bar{T}^2} \right) \right] \cdot \frac{g\bar{T}^2}{2\pi}$$

Where is the coefficient ai, it should be taken in accordance with the requirements of clause 2.17 these guidelines. where $\begin{cases} a_1 = 4,3 \\ a_2 = 5,4 \\ a_3 = 6,3 \end{cases}$ at $\begin{cases} 0,001 < i \le 0,033; \\ 0,033 < i < 0,049; \\ 0,05 \le i \le 0,2. \end{cases}$ The wavelength in the surf zone, $\bar{\lambda}_{sur}$, m, should be calculated using the formula.

$$\bar{\lambda}_{sur} = th^{0,5}\left(9,2 \frac{2\pi d}{g\bar{T}^2} \right) \cdot \frac{g\bar{T}^2}{2\pi}$$

A wave surge is formed when waves collide and its

magnitude depends on the estimated height of the wave along the line of first collision (h_{sur}) and its average period. The calculation of the wave surge is performed according to the formula given in: $\Delta h = \frac{13,7}{g}\left(\frac{h_{sur}}{\overline{T}}\right)$. For Class III structures, in accordance with SP 38.13330.2012, p.5.9, the maximum calculated water level is assumed to be 5% secure. This is 113.70 mBS, in accordance with "Basic Provisions of the Rules for use of water resources in the Novosibirsk reservoir on the Ob river". The most dangerous wind directions are SSW, SW and WSW (highlighted in red).

To ensure the possibility of recreational use of the coast of the Novosibirsk reservoir, a beach 300 meters long is inserted into the considered variant. A system of enclosing boulders and breakwaters is envisioned to protect the sandy beach from significant losses of beach-forming sand. This will help reduce the loss of beach sand due to longshore sand transfer and the bay dissection of the beach inserts. The bay shape of this beach is most resistant to the effects of various storm directions due to its accumulating capacity for beach-holding structures. During the initial period of banquet formation, deepening and processing of the shoal will occur before the banquet. Processed products will be involved in long-range sediment flow. In order to accumulate the largest fraction from recycled soils of the shoals, we provide for installation of spurs that simultaneously act as technological platforms for machines and mechanisms. Beach-retaining structures will also play this role. The presence of accumulation zones reduces recycling of structures and extends their service life.

The outline of the banquet in the plan is close to the position of a cliff's brow. It should be noted that the jagged or broken position of the banquette in the plan has a greater resistance to the effects of excitement than a rectilinear position. This is because when exposed to wave fragments, waves change direction, leading to formation of oncoming currents. All this contributes to formation of sedimentation zones and accumulation zones, which ultimately leads to dissipation of excitation energy. The improvement of offshore areas and construction of anti-erosion structures allows the complex of coastal protection structures to be brought to parameters that ensure normal recreational use and enhance aesthetic appeal of coastal structures. Next, long-range sediment transport calculations were performed.. For sand deposits with a grain size range of $0.1 \leq d50 \leq 1$ mm, we used the widely used CERC formula. At the same time, it should be noted that the calculation formula uses the height of the significant wave (H_s) and the peak period of the wave spectrum (Tp), both of which are related to average wave parameters (H and T). An example of calculation results for a similar segment is shown in Figure 7.

The second part of the coastal protection structure is the artificial division of the coast into bays using various structures and elements made mostly of unsorted stone, such as bunks, breakwaters, blocking elements, and artificial capes. Bays can be filled (immediately or after formation by natural waves of a given size) with beach-forming material to form bay-shaped beaches, or they may not be filled with any imported soil in some cases.

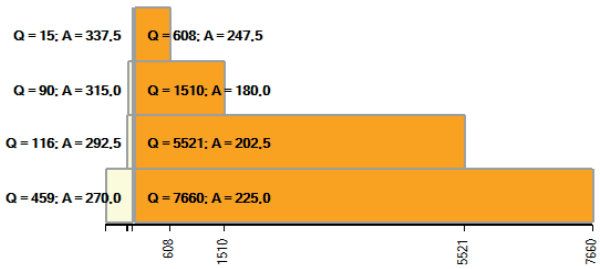


Figure 7. The contribution of waves (wind) of various directions to the resulting sediment flow in the calculated segments: A is the direction of wind (waves) in degrees; Q is the total volume of sediment flow from waves in this direction (m³/year)

Positive values of flow are shifted to the right, and negative values are shifted left. The direction and capacity of the resulting annual coastal sediment flow, caused by wind waves, for the area under onsideration are shown in Figure 8.

Table 2. Calculation of wave elements in the deep-water zone for three segments

Naming of indicators	UOM	Designation	The value of the current points				
Active points	-	-	S	SSW	SW	WSW	W
Wave acceleration length	m	L	6198	9056	17363	21328	18954
Wind speed 4% probability of Ob GMO	m/sec	V	21	24	23	18	16
Average wave parameters							
- height	m	$\overline{h_d}$	0,83	1,02	1,13	0,98	0,87
- period	sec	$\overline{T}$	3,43	3,79	4,07	3,96	3,80
- length	m	$\overline{\lambda_d}$	18,38	22,44	25,88	24,50	22,56
Estimated wave height in storm mode with a 4% probability							
-1% P in the wave system	m	$h_{1\%}$	1,72	2,13	2,36	2,10	1,85
-2% P in the wave system	m	$h_{2\%}$	1,57	1,94	2,19	1,91	1,70
-5% P P in the wave system	m	$h_{5\%}$	1,44	1,79	1,99	1,75	1,55
Depth at the boundary of the zone $0.5\bar{\lambda}_d$	m		9,2	11,2	12,9	12,2	11,3

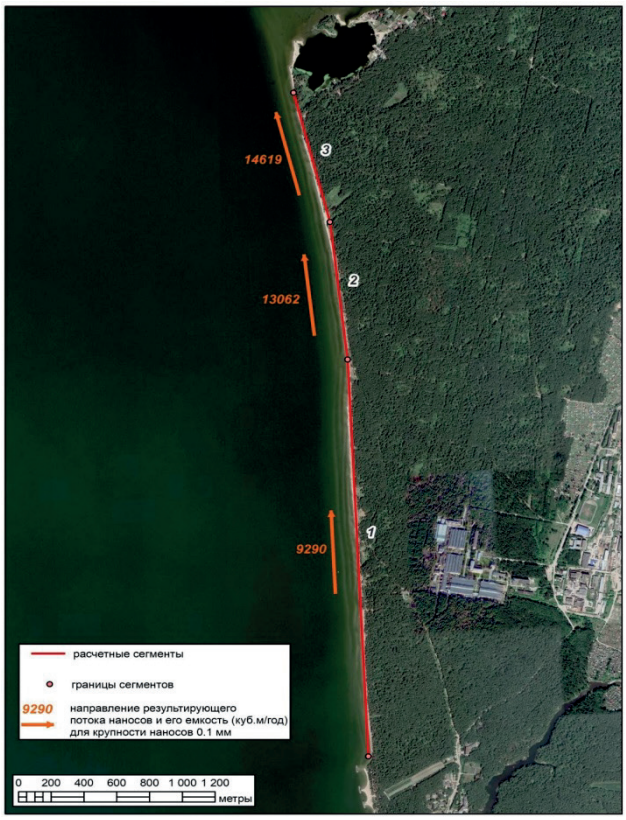


Figure 8. The direction and capacity of the annual coastal sediment flow in the coastal zone of the site under consideration

In the considered variant, beach-retaining structures are provided, which are intermittent breakwaters. In the shadow of these structures, the rudiments of overflows form, blocking the through movement of sediments along the coast and contributing to the dissection of the bay by an artificially created sand prism. With the division of the coast into bays, the beaches formed within them are the most stable. To ensure the formation of a wave shadow in the armhole of the breakwater, it is necessary that the length of this structure be 1.5 times greater than the distance between the shore and the breakwater. The calculated profile of the beach should also not extend beyond the line of breakwaters, while the beaches are most stable in bays with an approximately circular outline. At the same time, the length of a breakwater should be at least equal to the width of an underwater beach.. These conditions correspond to breakwaters, with an average

length of 90 m, and gaps between them averaging 90 meters, removed no more than 60 meters from the filled-out sand prism, which is the capital class of these shore protection structures. The construction of coastal protection structures as provided in the design documentation aims to prevent further damage to the coast from dangerous natural processes, such as coastal slope abrasion from waves during stormy periods.

The durability of the adopted design solution and its reliability during the service life (at least 50 years) is justified by several factors. The design solution is a proven system, and the applied polymer composite sheet pile profile SHK-150UM is produced using injection pultrusion with a polyurethane binder. This ensures high stability of properties and resistance to aggressive environmental influences, as confirmed by test reports. The resistance to temperature fluctuations and UV radiation, as well as low water absorption, are also confirmed. The anchor system's durability is further justified by its anti-corrosion protection, while the length of the tongue-and-groove wall measures 5260 meters. The calculation of the bearing capacity of the tongue-and-groove wall and anchor pile was performed using Midas GTS NX software in a two-dimensional formulation. Structural elements of the structure include: vertical element - sheet pile profile SHK-150UM, with a length of 5 meters and maximum depth of 3.8 meters; distribution belt of paired channels 12P GOST 8240-97 at levels 114.20 and 113.70; interconnected and attached to the sheetpile through a bolted connection M12; anchors made of A400 reinforcing bars with a diameter of 28 cm, GOST 5781-82, with a 4 meter length in increments of 0.4 meters, fastened to the tongue and groove wall through the distribution belt at 11.4. Anchors are mounted through steel plates GOST 19903 -74 measuring 0.2 x 0.02 m through bolted connections M18; anchor piles are channel 14 P GOST buried in ground with 3 meter lengths in 0.6 m steps, 4 meters apart from tongue-and groove walls.. The anchor rods are mounted to the anchor pile through a steel plate measuring 200 x 200 mm 15, through a bolted connection M18. Fastening metal parts with M12 and M18 bolts and nuts. The anchor system is protected with anti-corrosion coating that meets the requirements of SP 287.1325800.2016 and SP 2.13330.0201. The anchor must be painted with epoxy-based enamel to protect it. It is also recommended to fill attachment points and connections of anchor rods with bitumen-rubber paint / mastic to protect them. A drainage prism is used to relieve filtration pressure. This prism consists of small fractions of crushed stone separated by Geospan TS-110 geotextiles. The formed sinuses are filled with crushed stones. Filtration holes with a diameter of 20 mm are arranged in sinuses with a spacing of 11.37 mm at a step of 0.96 ft. An upper polyurethane composite belt PKSH-160 painted in bright color is installed on top of the walls for overall stability. Main angles of rotation are provided by angular polyurethane connectors USK-150.. Temperature-sedimentary seams with a pitch of no more than 25 meters are arranged in the upper belt and the distribution belt in the sheet pile joint. Backfilling is performed with soil (fine, homogenous, water-saturated, medium density sand) extracted using a hydro-mechanical method. The filling mark is 114.70, and the soil compaction coefficient is accepted according to SP 22.13330.2016 (clause 9.14), with k_{com} =0.95. Fine and powdery sand is located at the base of the sheet-pile wall. To prevent erosion of the foundation, a stone berm has been arranged on the front side, with a width of 4800 m and a slope of 1: 1.5. The diameter of the stones used for fastening was estimated to be 0.45 m, and after reshaping the profile, stone fastening would provide a non-erosive foundation for the tongue-and-groove wall. Load-bearing capacity calculations for both the tongue and groove wall and anchor piles were performed. The mass of each element in the stone fastener was also calculated, as well as the parameters of stone fasteners.

CONCLUSION

In conclusion, I would like to note that the authors of the work focus on the relevance of the problem of coastal protection of the Novosibirsk reservoir, primarily for the local population and the ecosystem as a whole. They demonstrate the need to develop and implement effective and efficient measures taking into account financing features and difficulties arising from natural changes. The CPHS construction considered in this paper is aimed at preventing further destruction of the coast by dangerous natural processes such as abrasion of the coastal slope by waves during storm periods. The durability of the adopted design solution and its reliability during the service life of the design (at least 50 years) is justified by the following factors:

- the constructive solution is a proven bolverk system (Abramov, D. S., Shielded bulwarks: A historical review, research, design competition and calculation methodology features. Hydraulic Engineering 1(30)/2013; Kostyukov, V.D., Reliability of marine berths and their reconstruction, Moscow: Transport, 1987). Many structures of this type built in the 1960s and 1970s are still operational and have exceeded their designed service lives (Reconstruction of bolverk berths by changing the structure from a spacer to a gravity-based one, Nikolaevsky, M.Yu., Gorgutsa, R.Yu. and Sokolov, A.V., HYDRAULICS AND HYDROTECHNICS OF THE XXI CENTURY, No.1 (17), 2014).
- the applied polymer composite sheet pile profile SHK-150UM is manufactured using injection pultrusion with a polyurethane binder, which ensures high stability of properties and high resistance to aggressive environmental influences. The resistance to temperature fluctuations, UV radiation, and low water absorption is confirmed by test reports.
- the durability of the anchor system is justified by the anti-corrosion protection applied that meets the requirements of SP 287.1325800.2016 and SP 28.13330.2012. To prevent the adverse effects of human activity on the coastal environment, a coastal protection zone has been established, where safe economic activity is regulated.

To prevent the adverse effects of man-made activities on the CPHS, a coastal protection zone is provided where safe economic activities are regulated.

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Having analyzed the proposed options for existing coastal protection structures, the authors of the article propose a way to assemble several types of coastal protection hydraulic structures. These structures can serve as a model for other regions facing similar problems. An experiment is currently being conducted on the basis of a laboratory. The aim of this experiment is to obtain confirmed data on the stability of these hydraulic structures to the effects of waves, currents, and ice.

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