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The Use of Natural Stone in Marine Hydraulic Engineering Construction

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Abstract

The paper substantiates the feasibility of using natural stone in offshore hydraulic engineering for the purposes of coast protection and construction of protective structures. A review of the Russian and world practice of using natural stone in the construction of offshore structures was made. Russian and foreign scientific, technical and regulatory framework concerning the use of natural stone in marine hydraulic engineering was analyzed. A feasibility study for the need to develop technical requirements for natural stone was completed. A brief assessment of the social, economic and environmental efficiency of the use of natural stone in offshore hydrotechnical construction was carried out, a methodology and criteria for monitoring the compliance of natural stone with the established requirements were developed. At the same time, the actual results of research and development work in the field of studying the properties of building materials and structures, determining the normalized parameters and improving design solutions that meet the safety requirements of structures were used. The accumulated domestic and foreign experience in the use of building materials and technologies, experience in the design, construction and operation of facilities, changes in the legal framework of the Russian Federation are taken into account. The role of natural stone as a building material for structures in marine areas is defined and its key advantages over other materials are identified: environmental friendliness, versatility and simplicity of construction technologies.

Keywords: breakwater, coast protection, environmental friendliness, groin, hydraulic engineering, natural stone, protecting structure

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Применение природного камня в морском гидротехническом строительстве

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Аннотация
Работа посвящена обоснованию целесообразности применения природного камня в морском гидротехническом строительстве для целей берегозащиты и возведения оградительных сооружений. Выполнен обзор российской и мировой практики применения природного камня в строительстве морских сооружений. Проведен анализ российской и зарубежной научно-технической и нормативной базы, затрагивающей вопрос использования природного камня в морском гидротехническом строительстве. Выполнено технико-экономическое обоснование необходимости разработки технических требований, предъявляемых к природному камню. Выполнена краткая оценка социально-экономической и экологической эффективности применения природного камня в морском гидротехническом строительстве, разработаны критерии контроля соответствия природного камня установленным требованиям. При этом использованы актуальные результаты научно-исследовательских и опытно-конструкторских работ в области изучения свойств строительных материалов и конструкций, определения нормируемых параметров и совершенствования конструктивных решений, отвечающих требованиям безопасности сооружений. Учтен накопленный отечественный и зарубежный опыт применения строительных материалов и технологий, опыт проектирования, строительства и эксплуатации сооружений, учтены изменения в законодательстве Российской Федерации. Определена роль природного камня в качестве строительного материала для сооружений в морских акваториях, обозначены его ключевые преимущества перед другими материалами, из которых особого внимания заслуживают экологичность, универсальность и простота технологий строительства.

Ключевые слова: берегоукрепление, буна, волнолом, гидротехническое строительство, оградительные сооружения, природный камень, экологичность

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Introduction

Despite the widespread use of natural stone in marine hydraulic engineering, as well as the reference of natural stone in a number of domestic and foreign regulatory documents, currently there are no formalized technical requirements for natural stone concerning construction in marine areas.

The purpose of the study is to substantiate the utility of the development of technical specifications for natural stone used in hydraulic engineering for the purposes of coastal protection and the construction of protecting structures, as well as checking procedure concerning the compliance of natural stone with established requirements.

To achieve the set goals, the following tasks were solved:

– to review the Russian and world practice of using natural stone in the construction of offshore structures in marine areas;

– to analyze the Russian and foreign scientific, technical and regulatory framework concerning the use of natural stone in marine hydraulic engineering, results of research and development work in the field of studying the properties of building materials and structures, determining the normalized parameters and improving design solutions that meet the safety requirements of structures;

– to substantiate the feasibility of the use of natural stone in marine hydraulic engineering for the purposes of coastal protection and construction of protective structures, determining its key advantages over other materials;

– to complete a feasibility study for the need to develop technical requirements for natural stone;

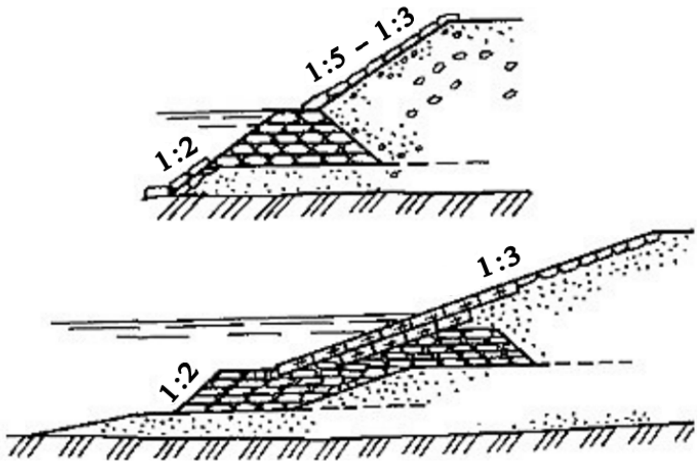
– to assess the social, economic and environmental efficiency of the use of natural stone in offshore hydrotechnical construction.

Analysis of the Russian and world practice of using natural stone in marine hydraulic engineering construction

As a rule, abroad (England, the Netherlands, France, Italy, Cyprus, the USA, Asian countries) rubble-mound coast protection structures are built in order to protect the coast. Rubble-mound beach-holding groins and breakwaters are widespread in the above stated regions. Moreover, rubble-mound berms are widely used to protect coasts in non-recreational areas. Rubble-mound structures, in comparison with concrete ones, are better combined with the natural coastal landscape and are preferable from the environmental point of view. It should be noted that monitoring of structures and coastal processes is carried out during the entire period of their operation. When performing lithodynamic studies for the purposes of marine coast protection and protecting structures design, it is recommended to consider not a local emergency section of the coast, but the entire lithodynamic system as a whole.

In foreign practice, massive seawalls are also quite often used, as they perceive loads from waves that break directly on the structure. In the USA, the stability of such walls in the event of erosion of foundation soils is usually provided by pile foundation and a steel sheet-pile shield, which is impervious to the soil underlying the wall. The base of the seawall is often reinforced with a beached bank made of large stone, less often with a protective wave-damping beach [1)]. In Asian countries (Japan, Taiwan), wave-damping covers (aprons) made of stone or profile solid monoliths are used to protect seawalls [1, 2].

Sloping revetments made of one or more layers of stone are used as a more efficient structure compared to seawalls with no destructive effect on the beach located in front of them (Fig. 1).



F i g . 1 . Design of sloping revetments using natural stone

During the construction of sloping revetments abroad (Holland, England, USA, Japan), the structures can be made of stone in the form of a dump or laying made from a quarry mass of heterogeneous size. In this case, the role of the return filter can be performed by geosynthetic materials. Sloping revetments made of natural stone allow significant subsidence without compromising their functional purpose.

Currently, breakwaters are also widely used in coast protecting construction abroad. They differ in their construction materials and in the cross section design. The materials used for the breakwater construction are natural stone and concrete [3, 4]. The examples of coastal protection with the help of sloping revetments and breakwaters are shown in Fig. 2.

[1)] U.S. Army Corps of Engineers, 2002. *Coastal Engineering Manual. Engineer Manual 1110-2-1100*. Washington, DC: U.S. Army Corps of Engineers (6 volumes).

F i g . 2 . Examples of coastal protection using natural stone: *a* – stone sloping revetments, Oregon (the USA); *b* – stone sloping revetments, Cyprus; *c* – breakwaters on the Italian Adriatic coast

Groins are most often used to keep beach-forming material (sand or pebbles) from moving along the coast and to accumulate material in the spaces between the groins. To construct groins, stone is usually used, and less often concrete. Wood and steel are not used on the banks with pebble deposits. In the USA, on rocky soils, preference is most often given to gravity-type groins made from a rock blanket or in the form of cells made of steel sheet-pile with stone or sand material and laying on top of a monolithic concrete plate or a natural stone protective covering.

If it is necessary to ensure their imperviousness (on the shores with sand deposits), rubble-mound groins are made with a core of a quarry mass containing a significant amount of fine fractions. In a number of European countries, rubble-mound groins are arranged most often (see Fig. 3).

F i g . 3 . Rubble-mound groins: *a* – seawalls protected by a beach with rubble-mound groins, Nice (France); *b* – rubble-mound groins Venice (Italy)

In the Russian practice of coast protecting hydraulic structures (HSs) construction, natural stone blanket is the simplest way, and at the same time quite reliable one, to protect the slope against erosion. Nowadays, this structure is used more and more often, since much attention is paid to the possibility of using the coast for recreational purposes and to the environmental component of the project (comfortable habitat for marine fauna) when designing coast protecting measures.

To protect sections of the seacoast that are not used for recreational purposes, the use of rubble-mound berms is most effective. This protecting method is very common due to low labor intensity, ease of repair and restoration. It is disadvantageous in water perviousness, which makes it necessary to protect the bulk soil against sloughing and suffusion, e.g., with the use of geotextiles. The examples of the use of rubble-mound coast protecting structures are shown in Fig. 4, *a*.

In the Russian hydraulic engineering, the practice of coast protecting against erosion with the help of artificial beaches under the protection of groins and breakwaters, including rubble-mound ones, is widespread. Foreign and domestic experience in the design and construction of marine coast protecting hydraulic structures shows that the beach is the best wave-damping structure to protect the coast against erosion. In turn, the protection of beaches with rubble-mound structures is considered to be the best way to protect the coast due to its environmental friendliness, possibility of combining coast protecting and recreational functions, as well as the possibility of preserving the natural landscape. If the requirements of the project are observed and the quality of the laying is good, structures look rather aesthetically pleasing.

It should be noted that there is no prohibition on the construction of natural stone structures in recreational areas. As a rule, signs are installed on such beaches with a warning about the danger of being on rubble-mound structures. An example of the use of coast protecting natural stone structures on the Black Sea coast of Russia is shown in Fig. 4, *b*. Reinforced concrete plates on top of the groins make it possible to increase the accessibility of facilities for vacationers, including disabled people.

Fig. 4, *c* also shows the examples of partly ruined rubble-mound groins at the Tuapse – Sochi section. The shore horizon runs along the deformed heads of such groins. Nevertheless, even partly ruined groins fulfill their function. They hold the beach.

Analysis of the Russian and foreign scientific, technical and regulatory framework concerning the use of natural stone in marine hydraulic engineering

The method used in Russia to calculate mound coast protection includes determining the required size of a homogeneous stone or deformation of a protecting structure when using non-uniform size materials of a given particle size distribution, as well as the required protection thickness.

F i g .   4 . Use of natural stone in Russian hydrotechnical construction: *a* – rubble-mound revetment at the right bank of the Nechespsukho River in the village of Novomikhailovsky (the Krasnodar Region); *b* – a rubble-mound groin with traverses in the village of Nebug (the Krasnodar Region); *c* – partly ruined rubble-mound groins at the Tuapse – Sochi section

The design of marine coast protection and protecting structures is based primarily on the correct consideration of natural geomorphological, lithodynamic and hydrological conditions. Such conditions are considered in the main document regulating the design of marine coast protecting HSs in the Russian Federation, namely, SP 277.1325800.2016 *Coastal Protection Constructions. Design Rules*. This document has been developed for tideless seas (as well as lakes and water-storage basins). It provides approximate areas and conditions concerning the use of groins (without specifying the material of structures), underwater breakwaters (without specifying the material of structures), wave-damping berms and blankets made of large stone. These conditions must be guided by the initial choice of the type of structures. Recommendations are given for choosing the type of beach-holding structures, depending on the type of coast, coastal configuration according to the plan, hydro- and lithodynamic regimes of the sea coastal zone, geological and geomorphological characteristics of the coastal slope, etc. Schemes for the formation of planned outlines and sections of artificial beaches in combination with beach-holding structures are given.

The document also contains requirements for the weight and size of stones in the slope coast protection blanket. The choice of groin design is not regulated by the document (the use of one or another groin design should be determined by a proper feasibility study).

The document recommends to give preference to spreading profile breakwaters of rubble-mound construction when constructing artificial beaches under the protection of underwater breakwaters on the coasts used as recreational areas. Moreover, the requirements for the estimated weight of the groin stones are given.

It is important to note that such Russian seas as the Black Sea, the Sea of Azov, the Caspian and Baltic Seas are tideless (with mild tides). The Arctic seas (the Barents, Kara, Laptev and East Siberian Seas), the Far Eastern seas (the Bering, Okhotsk and Japan Seas), as well as the White Sea are tidal. Ignoring tidal phenomena or insufficient scientific substantiation of design solutions in such areas can lead to a violation of the integrity or to the complete destruction of structures [5]. In this regard, in addition to SP 277.1325800.2016, the document SP 416.1325800.2018 *Engineering Protection of Tidal Sea Coasts. Design Rules* has been developed. According to this document, recommendations are given to pervious (e.g., rubble-mound) breakwaters when constructing artificial beaches under the protection of underwater breakwaters on the coasts used for recreational areas. According to the Russian Industry-Specific Construction Standard VSN 5-84/MMF *Use of Natural Stone in Marine Hydraulic Engineering Construction*, it is recommended to use natural stone for the construction of sloping revetments and wave-damping blankets. In SP 416.1325800.2018, a formula is given for determining the minimum mass of profile blocks (solid monoliths) or large armor blocks for the construction of the outer part of the laying or the mound of sloping revetments and wave-damping blankets exposed to the effects of waves breaking on them. Tidal phenomena can have a significant impact on the timing of the HSs construction, which once again emphasizes the need for careful consideration and proper accounting of all natural phenomena at the construction site. The same applies to HSs built in the Arctic seas, where, in addition to tidal phenomena, construction is complicated by such natural conditions as high ice forces, as well as a very short navigation period.

In SP 38.13330.2018 *Loads and Impacts on Hydraulic Structures (Wave, Ice and Ship-Produced)*, a requirement is given to take into account the roughness of the slope surface and the filtration properties of the slope material when determining the height of the slope surge. The requirements concerning the weight of the stone are given in Chapter 5. Currently, such requirements should be applied in accordance with the List of National Standards and Codes of Rules (Parts of such Standards and Codes of Rules), which provides obligatory compliance with the requirements of the Federal Law *Technical Regulations on the Safety of Buildings and Structures* approved by the Decree of the Government of the Russian Federation. Formulas are given in order to determine the calculated mass of an individual element when protecting a slope with the rubble stone. When calculating according to these formulas, only its density is taken into account from the characteristics of the stone itself.

In SP 277.1325800.2016 *Marine Coast Protecting Structures. Design Rules,* the conditions for the use of coast protecting structures, including groins, underwater breakwaters, wave-damping berms and blankets made of the large stone are given. The document provides recommendations for the construction of an underwater banquet or underwater breakwater from mound or other structure at the foot of the beach if the design profile of the relative dynamic equilibrium of the artificial beach under construction does not match the natural underwater slope due to the large steepness of the latter. According to this document, recommendations are given to pervious (e.g., rubble-mound) breakwaters when constructing artificial beaches under the protection of underwater breakwaters on the coasts used for recreational areas. As the most effective protective coating of the sea slopes of protective dams against destruction under the impact of waves, ice, currents and precipitation, a sloping-stone coating is given, which significantly dampens wave energy and reduces the surge height. In the document, stone mounds and beached banks also made from the rock mass are considered as one of the recommended types of sloping revetments. It is recommended to use gravity-type groins (including rubble-mound groins) to hold an artificially filled-out beach.

According to this document, in order to construct rubble-mound groins and protective coatings, the homogeneous work stone from sedimentary, crystalline or metamorphic rocks with a compressive strength in the water-saturated state of at least $6 \cdot 10^7$ Pa, should be used. To determine the minimum mass of stone for the construction of rubble-mound structures, reference is made to Appendix B of SP 38.13330.2018.

The construction rules and regulations SNiP 3.07.02-87 *Hydraulic Marine and River Transport Facilities* contain requirements for the performance of work on the construction of new, reconstruction and expansion of existing marine and river transport hydraulic structures, including ones made from natural stone (Chapter 4). Concerning requirements for the natural stone quality, an instruction is given to use stone materials in construction that comply with VSN 5-84/MMF.

Guidelines for the Design and Construction of Flexible Reinforced Concrete Slope Coating of Transport Facilities [2)] are used in the design of wave-damping structures to protect the slopes of transport structures and river banks against the water flow impact. The document provides some requirements for the size of the natural stone in specific structures, but its scope does not allow its provisions to be used for the purposes of this paper.

Regulatory document RD 31.31.55-93 *Instructions for the Design of Marine Berthing and Coast Protecting Structures* as a requirement for the quality of the stone contains the following reference to VSN 5-84/MMF: "The stone for the construction of backings, beds under the berthing facilities and the formation of berthing slopes must meet the requirements of VSN-5-84/Minmorflot."

The departmental document VSN 5-84/MMF, which is referred to in SP 416.1325800.2018, SNiP 3.07.02-87 and RD 31.31.55-93, contains requirements for the natural stone and applies to the design and construction of marine HSs (mooring, land retention, coast protecting, etc.), located on the coasts of seas, estuaries, lagoons or at the mouths of rivers. The document establishes technical requirements for the natural stone quality (determination of the temporal compressive strength of the rock in dry and water-saturated states, softening coefficient, frost resistance, dry rock density, petrographic composition, water absorption, density of grogs, SO_3 content). Recommendations are given on the ratio of the largest size of the rubble stone to the smallest (for land retention and coast protecting structures it makes no more than 3, for all others – no more than 4).

International strictly formalized regulatory documents in the field of coast protection (*Design Manuals* or *Codes*) have not been developed, since there the design of coast protection is based on accumulated experience and operational engineering assessment [6]. Special *Design Guidelines* are used in foreign countries in the design process, as they contain grounded guidelines. Such guidelines can be applied freely enough and are developed with the involvement of specialized scientific organizations.

In 1984, the British Standards Institution (BSI) developed and issued *Maritime structures. Code of practice for general criteria* [3)]. The document deals

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[2)] TsNIIS, 1984. [*Recommended Practice for the Design and Construction of Flexible Reinforced Concrete Slope Covers for Transport Structures*]. Moscow: TsNIIS, 55 p. (in Russian).

[3)] BSI, 2000. *Maritime Structures: Code of Practice for General Criteria*. *BS 6349-1:2000*. London: BSI, 254 p.

with the use of the stone as a material for the construction of coast protecting structures. Moreover, the provisions are given regarding the quality control of the stone and the specification of the size of the fractions. Nevertheless, the document is non-regulatory, and its use abroad is advisory.

The following document is also applied in Great Britain – *The Rock Manual. The Use of Rock in Hydraulic Engineering* [4)]. In addition to guidelines for the design, construction and monitoring of the state of natural stone structures, it provides a set of requirements for the stone itself, overview of the properties and functions of the quarry stone, forecast of the rock quality, durability and service life, specification of the stone according to its size, testing and measurement, quality control, etc.

In the USA, where the US Army Corps of Engineers controls coast protection, *Shore Protection Manual* of 1984 had been applied until 2002. This manual was widely used throughout the world. In 2002, the document was republished under the name *Coastal Engineering Manual* taking into account modern European achievements in the field of coast protection. No technical requirements for natural stone are contained in the document.

Requirements for the natural stone used in the construction of rubble-mound structures are contained in *ISO* 21650:2007 *Actions from Waves and Currents on Coastal Structures*. In particular, the document says that the stone for breakwater construction must be hard and have sufficient resistance to destruction, since it is subject to abrasion and crush.

The document also provides calculation provisions for determining the quantitative characteristics of stone structures. A general formula is given for calculating the minimum mass of individual elements of the mound (the probability of destruction of a stone subject to abrasion and crush is characterized by the energy of the wave impact and the energy required to destroy the stone). The formula takes into account the density of the stone, its dimensions and the height of the waves. The mass of an individual element of the mound is taken into account when calculating the stability of the structure and when determining its dynamic balance profile. In the probabilistic analysis of the durability of structures exposed to waves and currents, the strength parameters of the material are taken into account, as well as the coefficient of friction at the interface between different materials. The slope of rubble-mound breakwaters is a function of the depth and particle size distribution of the mound material.

The Spanish document *ROM* 0.5-94 *Geotechnical Recommendations for the Design of Maritime and Harbour Works* [5)] contains recommendations for choosing the size of the stone that can be obtained in a particular quarry, as well as for checking its perviousness and mechanical properties (strength and deformability).

[4)] CIRIA, 2007. *The Rock Manual. The Use of Rock in Hydraulic Engineering*. London: C683, 1304 p.

[5)] Spanish National Port Authorities, 2005. *ROM 0.5-94 Geotechnical Recommendations for the Design of Maritime and Harbour Works*. Puertos del Estado, 430 p. Available at: https://www.puertos.es/es-es/_layouts/download.aspx?SourceUrl=/es-es/BibliotecaV2/ROM%200.5-94%20(EN).pdf [Accessed: 10 June 2022].

According to the document, if there is only low-quality rock near the construction site (compressive strength makes less than 50 MPa or specific gravity makes less than 26 kN/m^3), the area of its use should be limited to the core of the breakwater or at most an intermediate layer. In such cases, the outer mound layer must be constructed with the use of elements of a different type.

Durability can be indirectly determined by laboratory tests, followed by comparison of the results obtained with the recommended reference values of the relevant parameters in each area of the breakwater. The quality of the rock in the laboratory should also be checked when choosing aggregates for concrete. The document also provides recommendations for determining the rubble-mound resistance to shear stress, its perviousness and deformability.

The use of natural stone in marine hydraulic engineering construction is considered in the published works of one of the authors of this paper [7, 8]. The published paper proposes qualitative and quantitative criteria for the applicability of some types of structures of artificial islands in marine areas. Specifically, the slope profile structures with the natural stone slope protection are considered. It is important to note that when constructing slopes of natural embedding (sandy or pebble ones, which are not reinforced with the stone), significant deformations of the slopes are often predicted or observed, up to their complete erosion [9, 10].

Natural stone slope protection is recommended with its sufficient feasibility study: as a rule, such protection makes it possible to increase the slope steepness and, accordingly, reduce the consumption of materials and the cost of construction. The expediency of the use of thrust elements of an underwater banquet, e.g. made of large stone, is determined by a decrease in the volume of the stone filled into the banquet body. At the same time, it is emphasized that the economic feasibility of the artificial island sloping structures construction depends primarily on the depth of the water area at the construction site. As a rule, it is more appropriate to use vertical structures at significant depths. What is more, it is necessary to provide for regular measures to replenish the loss of beach material in accordance with the results of calculations and (or) modeling.

Technical requirements for the natural stone characteristics

The natural stone, along with profile solid monoliths (such as hexabits, tetrapods, etc.), is one of the most common types of elements used for the construction of coast protection and protecting HSs. The stone, as well as profile solid monoliths, is used in the construction of stone wave-damping blankets (berms), designed to provide protection of natural coastal cliffs (including dune slopes), sloping revetments, seawalls and other facilities located in the inshore and nearshore zones of the sea against wave impact (slaps, surges and underwashing).

Stone blankets in areas, which are composed of non-eroded soils and are not used for resort purposes, are equivalent to beaches in terms of wave-damping efficiency, but unlike the latter, they are more stable and practically do not require any regular replenishment of volumes.

According to the experience of design (including the use of physical modeling methods), construction and operation of wave-damping blankets, among the main factors determining the wave-damping capacity, the accent is given to the porosity of the mound, the shape of the stone, the steepness of the slope from the sea side and the mark of the mound top.

The stone and crushed stone are the main materials for the construction of wave-damping coast protection and protecting structures. In recent decades, stone has been used in the construction of hydraulic structures in the ports of Sochi, Imeretinskiy, Vanino, Kuryk, etc.

It is important to understand that the stone of proper quality with strictly defined characteristics should be used for effective wave damping. Otherwise, there is a rapid destruction of wave-damping coast protection and protecting structures due to the erosion by waves, which causes significant economic and environmental damage. To achieve these goals, the staff of the Subdivision of JSC TsNIITS "Research Center "Sea Coasts" in the City of Sochi developed and approved the national standard GOST R 70021-2022 *Natural Stone for Marine Coast protection and protecting Structures. Specifications*. This document stipulates the technical requirements for the natural stone used for the construction of marine coast protection and protecting structures of all classes, as well as berthing slopes and beaches.

The developed standard will contribute to the following:

– reduction of the level of danger during the operation of the stone wave-damping coast protection and protecting structures;

– reduction of the risk of emergencies and subsequent social and economic, environmental and other types of damage;

– reliability improvement of the stone wave-damping coast protection and protecting structures;

– reduction in expenses for repair and reconstruction of the stone wave-damping coast protection structures;

– increase of the wave-damping efficiency of the stone structures.

Conclusions

Currently, the natural stone is used everywhere in the construction of coast protection and protecting structures in marine areas, since it has such significant advantages as environmental friendliness, free deformability, versatility and easy handling.

In the Russian hydraulic engineering, the natural stone mounds are used increasingly due to the simplicity of construction technology, high reliability and significant effectiveness of slope protection against erosion. Such structures are used more and more often, since when designing coast protecting structures, much attention is paid to the recreational function of the coast, as well as to the environmental component.

Rubble-mound berms have also found wide application due to their low labor intensity during construction, ease of repair and restoration. At the same time, it is necessary to provide for the protection of bulk soil from sloughing and suffusion (using geotextiles or other means).

In the hydraulic engineering practice, beaches are considered the best wave-damping structures with good reason. In turn, the protection of beaches with rubble-mound structures is generally accepted as the best way to protect the coast due to the possibility of combining coastal protection and recreational functions, environmental friendliness, as well as the possibility of preserving the natural landscape. With the proper quality of construction work, such structures look rather aesthetically pleasing. It is important to note that laying the top layer of a natural stone structure in order to form a flat surface is not necessary in many cases, since it is more of an aesthetic nature and is associated with additional labor costs. Therefore, the implementation of such laying is advisory.

Foreign and domestic experience in the design and construction of marine coast protecting HSs, as well as the accumulated experience of surveying coastal sections protected by rubble-mound structures, such as groins and breakwaters, have shown their high efficiency as beach-holding structures. In the water area protected by such structures, no dead regions are formed, since even with weak waves stable water exchange processes are observed. Structures in the form of rubble mounds are freely deformable. Therefore, with deformation or even destruction of individual parts, the structure continues to perform its functions. Moreover, elimination of the resulting damage does not require large expenses. As a rule, the natural stone porous mounds are biopositive, as favorable conditions are created in the pores for the habitat of mollusks and other marine fauna representatives.

The method used in Russia to calculate mound coast protection includes determining the required size of a homogeneous stone or deformation of a protecting structure (when using non-uniform size materials of a given particle size distribution), as well as the required protection thickness. At the same time, the basis for the marine HSs design is the correct consideration of the natural conditions of the site. Abroad, design standards for marine coast protection structures are generally non-regulatory and advisory.

For effective wave damping, a stone with certain characteristics and of the proper quality should be used. To improve the reliability of wave-damping coast protection and protecting structures due to the wave impact and to prevent significant economic and environmental damage from such destruction, the staff of the Subdivision of JSC TsNIITS “Research Center “Sea Coasts” in the City of Sochi developed and approved the national standard GOST R 70021-2022. The application of the newly approved standard will prevent significant economic and environmental damage caused by the rapid destruction of wave-damping coast protection and protecting structures due to the erosion through exposure to the waves.

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