Application of gabions for strengthening marine coastal slopes

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Abstract. The work considers the use of gravitational retaining walls made of gabion structures to strengthen the sea slopes. A wide range of possibilities for using gabions in construction is noted. An analysis of the technical and regulatory literature leads to the conclusion that the issue of using gabion structures to strengthen marine coastal slopes is not well understood. The paper describes the experience of using gabions to strengthen and protect against erosion of the sea slope from the moment of creation to complete destruction. A change in the state of the structure during long-term operation and their causes are recorded.

1. Introduction
Gabion is a construction made of durable mesh and filled with natural or artificial stones. To give strength to the gabion structure, a frame made of rebar or other metal rods can be added. Gabions are promising multifunctional structures that are used in the construction of roads, bridges, shore strengthening. In the building regulations [1] it is noted that the use of gabion structures is possible to counteract various types of power and erosion effects of flood and inter-soil waters, ice drift, timber melt, as well as expands the possibilities of engineering and environmental solutions for the device strengthening, stabilizing, anti-filtration and retaining structures. Gabion structures in Russia are used for the construction of retaining walls in road construction, and have also shown their effectiveness in strengthening the banks of the Saratov and Uglich reservoirs, in lining the channel in the Nizhny Novgorod region, in the construction of a retaining wall in Sochi, etc. [2].

Relatively recently, gabions have been used to strengthen sea shores, the destruction of which has accelerated under the influence of a combination of factors. The rise of the world ocean level leads to a decrease in the width of the beaches and an increase in the wave load on the coastal slopes. Recently, there has been an increase in the intensity of the wave load during storms, which leads to the destruction of shore fortifications and slopes. Intensive development of coastal areas with residential buildings, sanatoriums and other facilities leads to an increase in the load on the edge and the surface of the slopes. At the same time, the issues of surface drainage are not always solved in a timely manner. Often there is a problem of leaks from old drainage systems. All these factors inevitably lead to the rapid development of landslides and suffusion processes, to the intensive destruction and processing of sea slopes.

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2. Research

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The advantage of the retaining wall of gabions are environmental cleanliness, preservation of the natural regime of groundwater, simplicity of construction. The increased drainage capacity of backfill and mesh structures significantly reduces the hydrostatic pressure behind the wall. It is important that gabion retaining walls do not interfere with the preservation of vegetation. The negative properties of gabions are weak resistance to the dynamic effects of waves and corrosion of the metal mesh under the influence of an aggressive environment.

These negative properties are manifested in the conditions of salty sea water and dynamic wave action directed perpendicular to the structure.

According to [3], the service life of structures operated in highly aggressive environments should be at least 25 years. Therefore, to protect the sea coast, where the main load is the shock force of the waves, gabions were practically not used before.

When designing marine coastal and wave canceling structures [4], the use of stone structures as emergency structures for a limited service life other than recreational areas is allowed. These include berm and rock cover, large stone, artificial sand and pebble beaches, structures of permeable structures.

The only valid document directly recommending the use of gabions for strengthening sea slopes is the Technical Instructions of the Ministry of Railways of the Russian Federation [5]. Gabions are included in the classification mainly as protection against erosion [5 p.1.2] and are intended to strengthen the subgrade.

The use of gabion structures for sea coasts is also regulated by the regulatory document: “Industry Road Methodological Document” [6], which is of a recommendatory nature. The document [6 p. 6.5.11.] analyzes the reason for the weak wave canceling effect of gabion. It is noted that vertical structures have a weak wave-quenching property and perceiving a direct impact of the wave, they reflect it back, which increases the intensity of erosion of its base. This document recommends measures to mitigate dynamic (wind, wave) impacts, but only in relation to road sections.

The aggressive effect of sea water affects the life of the galvanized wire mesh and armored panels. At a zinc density of 50 g/m³, the life expectancy of a zinc coating under normal conditions is 4 years, and in marine conditions it is 1-2 years [7]. Meanwhile, in gabion structures, a galvanized double torsion wire mesh (GOST 51285-99) is usually used.

However, there are no direct indications of the scope of application of gravitational retaining walls in the form of gabion structures, sizes of structural materials or prohibition of their use on the condition of sea shores in the regulatory literature.

Regulatory documents do not keep pace with the growing demand for this type of structure, and do not define clear boundaries for the possible field of application of gabions.

In connection with the foregoing, of particular interest is the experience of using gabions to strengthen the slope of the recreation zone of the Svetlogorsk coast of the Curonian Spit. This work was written according to published data and personal observations of the author.

Geologically, from the surface of the earth on the edge of the slope to the depths of 30.0 m, the coastal slope is composed of sand and sand and gravel deposits alternating vertically and wedging out horizontally. In total, in the indicated depth interval there are from 12 to 14 layers that differ in characteristics, including from 3 to 5 layers of sandy loamy soils. Below 30.0 m, the coastal slope is composed of glacial loams and sandy loams with gravel, pebbles and boulders. The slope has a variable height and reaches 45 m. Along the territory adjacent to the edge of the slope, coniferous and deciduous trees grow along the upper part of the slope. The diameter of tree trunks suggests that the slope on the studied part has not been subjected to large-scale landslide processes for a long period. At the same time, the soil between the trees, unprotected by the root system, is partially subject to creep.
One of the measures for the engineering protection of landslide hazardous slopes in 2009 steel retaining walls of the gabion type. Retaining walls have a length of 1200 m, are located on both sides of the existing embankment, have two, three steps, a width and a height of up to 3 m. The walls are made of gabions 1.0 m wide, stacked on top of each other with an offset of 0.5 m to a height of 3.0 m. The standard sizes of the applied mesh structures according to GOST R 52132-2003: 2.0x1.0x1.0m and 1.5x1.0x1.0 m. In gabions, coarse-crushed local natural material or artificial stone material with the necessary strength and frost resistance, obtained by crushing igneous, sedimentary and metamorphic rocks, was used. In all metal structures, a double-torsion galvanized wire mesh (GOST 51285-99) with hexagonal cells of size 8x10 mm is used. The diameter of the edge wire is 3.9 mm, the strapping and tie wire is 2.2 mm. The waves began their destructive activity immediately after the completion of the construction. (figure 1).

Figure 1. The beginning of destruction of steps of a gabion design by storm waves.

Already in 2012, retaining walls from gabions lost their structure (figure 2,3). The processes of corroding the gabion net, its deformation, and partial destruction due to the action of water, waves, and wind led to this. The destruction was facilitated by leaching of stones from the lower stages of the structure under the influence of reflected waves. From this period, the constructions were in pre-emergency condition.

Figure 2. View of gabions after two years of operation.  
Figure 3. Profile of the gabion wall.

At the beginning of 2019 the remaining sections of the wall were finally destroyed by the strongest storm over the past 50 years. It is interesting to note that even in the destroyed state, gabions did not
completely lose their function and prevented the suffusion of soil that occurred in unprotected sections of the slope (figures 4, 5).

Currently, reconstruction of the embankment is also underway, including gabion structures.

3. Conclusions

Based on field observations and analysis of the normative literature of observations, the following conclusions can be drawn.

Gabions were used mainly for low slopes of road embankments, and slopes not experiencing shock effects of storm waves.

Gabions have a number of serious design flaws that occur when they are used to strengthen the sea slopes:
- the main reasons for the destruction of gabions is the corrosion of the metal mesh and the removal of stone material by reflected waves, which is fully consistent with the regulatory literature [6].
- the retaining wall of gabion structures, subject to shock waves, begins to collapse in the first years of operation.

The destruction of the lower steps of gabions, which are practically not recessed in the base and do not have a hard foundation, is aggravated on the sandy slopes by the process of suffusion.

However, gabion structures in comparison with other technologies for strengthening coastal sea slopes have several advantages:
- a small number of technological processes during construction, low cost, the ability to quickly dismantle and reconstruct.
- increased drainage ability of backfill soils and mesh structures significantly reduces hydrostatic pressure behind the wall. As a result, the destruction of the lower steps of gabions does not lead to a complete loss of efficiency and prevents clogging of the soil.

In the traditional version, gabions can be used to strengthen the sea coast only as a temporary structure for no more than 2 years or as a permanent structure above the wave level in combination with other measures to protect the coast.

Observation of the gabion structure, which lasted about ten years under the extreme conditions of a sea slope from the moment of gabion construction to complete destruction, is unique experience that
allowed to include gabions in the new project of reconstruction of the embankment and strengthening of the slope.

In the period 2013-2018, reconstruction of the Svetlogorsk slope is underway. In some sections of the slope, gabion retaining walls are included. The modern project (2013) provides for gabion retaining structures of shorter length (319 m). The choice of their placement and design has significant differences from the first design.

Observations of the use of gabions as a strengthening of the sea coast confirm the need for practical application of the recently introduced concept of OM - the method of observational design, which suggests the possibility of adjusting the project based on the results of geotechnical monitoring. Recent updates certainly take this experience into account.

The results should also be taken into account in the regulatory literature to more clearly determine the scope of gabion structures.

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