Modelling of the optimal height of the variable edge of a volumetric anti-filtration geotextile coating for restoring failed water supply structures

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Abstract. This article presents the results of numerical modelling of the optimal height of the variable edge of a volumetric anti-filtration geotextile coating for the restoration of failed water supply structures. After a long period of operation, hydraulic structures continue to operate without scheduled repairs, so it is necessary to perform technical reconstruction of the structure on the basis of innovative, as well as previously proven repair technologies. Most of the long-term operated hydraulic structures in Russia are in unsatisfactory condition, requiring modernization and reconstruction. Volumetric anti-filtration geotextile coating is used for technical restoration of long-term water supply structures that have failed. The volumetric cellular structure is filled with soil and has a variable height of the edge from the ridge to the bottom of the slope. Operational reliability and durability of the volumetric coating are provided by a cellular structure with a variable ridge height, to eliminate the formation of landslides in the underlying soil and in the filling, as well as the loss of water for filtration. A solid-state model of the stress-strain state of a bulk anti-filtration geotextile coating was constructed. The number of elements and the number of units of the ensemble was 127830 and 102740, respectively. The source information was encoded in terms of the increment method, taking into account the fragmentary representation of a three-dimensional anti-filtration geotextile coating with a variable edge height in the form of simple geometric objects-plates. The work of the coating from the load from its own weight and filling the volume cells of the soil at various parameters was numerically modelled. The results obtained are adequate to the calculations and do not exceed the operational parameters of the design. Processing of the obtained simulation results showed the presence of minor displacements, both horizontally and vertically along the structure, which indicates the presence of a large margin of safety of the bulk anti-filtration geotextile coating.

1. Introduction

Most of the long-term operated hydraulic structures in Russia are in a unsatisfactory condition, requiring modernization and reconstruction. After a long period of operation, hydraulic structures continue to operate without scheduled repairs, so it is necessary to perform technical reconstruction of the structure on the basis of innovative, as well as previously proven repair technologies [1].

Bulk anti-filtration geotextile coating is used for technical restoration of long-term water supply structures that have failed.

The bulk cellular structure is filled with soil and has a variable height of the ridge to the rib to the
bottom of the slope. Operational reliability and durability of the bulk coating are provided by a cellular structure with a variable ridge height to eliminate the formation of landslides in the underlying soil and in the filling, as well as the loss of water for filtration [2].

During long-term operation of water supply structures, many structural elements fail, this is the complete destruction of the reinforced concrete structure of the water supply structure, the formation of defects that violate the normal operation of the water supply structure; for example, the violation of butt joints, as well as the destruction of individual elements of the structure, etc.

In the water management construction in Russia, waterproof nylon fabrics with rubber and polymer coating are used, produced by Ufa, Kursk, Yaroslavl, Ivanovo and other factories of polymer products and structures. The mass of 1 m² of single- and double-layer coated fabrics is from 1.2 to 3.5 kg with a fabric thickness of 0.9 to 3.0 mm. According to the technological parameters of manufacturing at domestic factories, preference is given to single-layer fabrics [3].

Structures made from the mentioned materials are mostly seasonal or temporary. In the USA, Japan, France, Italy and other countries, stronger and heavier fabrics are used in water management. Structures made from them are mainly classified as permanent structures. In the USA, two- and three-layer materials made by DuPont, Goodyear, Firestone and others are used with a mass of 1 m² from 2.4 to 7.2 kg.

By the recommendation of the "Committee of the study of large dams made of rubberized fabrics" (Japan), the company "RUBBER DAM" shifted to the use of heavy fabrics that provide a 50-year service life of soft water or air-filled dams [4]. So, the three-layer material on a nylon (nylon) basis of the FABRIDAM company has a thickness from 3.0 to 7.0 mm, and the three-layer material of the RUBBER DAM company – from 10.0 to 25.0 mm. Currently, Japanese companies have built more than 5,000 dams made of fabric materials.

The analysis of the work of various companies around the world shows that a wide range of fabric-based composite materials is used in the water sector. Depending on their purpose, their strength ranges from 100 to 1000 kN/m [5].

Designs of rubberized fabrics differ in the following features:
- textile base – material, method of interweaving threads, number of layers and type of duplication;
- protective coating – material, method of application, quantity (single or double-sided coating).

2. Results

In the course of numerical modelling, it is necessary to determine the possible conditions for further operation of the coating, namely, the formation of various defects. The numerical experiment included the construction of a solid-state model of the stress-strain state of the coating [6].

The use of anti-filtration geotextile coatings to restore the operability of water supply structures is to ensure the operational reliability and durability of anti-filtration coatings of water supply structures, excluding foci of water loss for filtration in the operation of water supply structures [7].

This technical result is achieved in that the applied two-layer coating of geotextile, which ensures no loss of water through seepage from water conveyance channels, the coating is placed around the perimeter of the channel and then into the cavity between the two layers of the coating through the neck, located on the edge of a panel, pumped concrete, which imparts rigidity and structural strength of the coating, both coating layer are connected by a local longitudinal seams staggered (Figure1) [8].

On underlying soil 1 along the entire perimeter of the water supply structure, a two-layer coating is spread out, made of geotextile material 3, formed from two panels connected to each other by longitudinal local seams 5 arranged in a staggered order, for uniform distribution of concrete 2 throughout the two-layer coating, through necks 4 located on the edge of the panel fixed on the edge of the channel.

The operational reliability and durability of the anti-filtration coating of water supply structures is ensured by the joint work of concrete 2, which further solidifies, betrays the rigidity and strength of the coating structure, and geotextile material 3 ensures that there is no loss of water for filtration from water supply channels [9].
The use of the coating will increase the operational reliability of anti-filtration coatings of water supply channels, due to its rigidity and strength, and a double layer of film (geotextile material) will prevent water loss, preventing waterlogging, salinization and flooding of agricultural land. Even if the upper layer of the film facing the water fails during prolonged operation of the coating, the lower layer will continue to exclude water loss for filtration [10].

![Figure 1](image1.jpg)  
**Figure 1.** Anti-filtration geotextile coating of water supply structures: a – in cross-section; b – top view.

Also, the use of this coating is possible without concrete, when it can be replaced with a mixture of soil and water, which will later exit through the membranes of the geotextile coating and only the soil will remain, which can also give rigidity to this structure.

Bulk anti-filtration geotextile coating is used for technical restoration of long-term water supply structures that have failed [11].

The bulk cellular structure is filled with soil and has a variable height of the ridge from the rib to the bottom of the slope. Operational reliability and durability of the bulk coating is provided by a cellular structure with a variable ridge height to eliminate the formation of landslides in the underlying soil and in the filling [12], as well as the loss of water for filtration [13].

Figure 2 shows the anti-filtration geotextile coating of a low-pressure earthen dam, which can be used for the construction of an anti-filtration coating of a low-pressure earthen dam, that is, the sides of water supply structures.

![Figure 2](image2.jpg)  
**Figure 2.** Anti-filtration geotextile coating of water supply structures, in cross-section

The technical result achieved by this anti-filtration geotextile coating of a low-pressure earthen dam is to prevent water losses for filtration and ensure the operational reliability and durability of the anti-filtration geotextile coating of a low-pressure earthen dam.
This technical result is achieved in that the cellular structure is mounted on waterproof geotextile material panel which is laid on the underlying layer at the raised slope of the low-pressure earthen dam, and the cell structures are filled with soil and have a variable depth which gradually increases from the crest to the foot of the dam and \( t_2 > t_1 \) [14].

where \( t_1 \) – depth of the ridge of the dam, \( t_2 \) – depth of the cell at the foot of the dam [15].

On the underlying layer of soil 1 along the upper slope of low-pressure earthen dam 2, a coating is spread, fixed on ridge 3 and bottom 4 of the dam, and made of a layer of geotextile material 5 in the form of a cellular structure of variable depth 6 filled with soil 7 and attached to coating 5.

Operational reliability and durability of impervious geotextile coating low-pressure earthen dam are provided, cellular structure 5 having a changeable depth of the cell, which gradually increases from ridge 3 to bottom 4 of the dam and \( t_2 > t_1 \), where \( t_1 \) is the depth of the cells on the ridge of the dam, \( t_2 \) – the depth of the cell at the bottom of the dam. They prevent the formation of landslide processes in the soil filling it 7, which protects the geotextile material 5 from damage, and the geotextile material 5 prevents water loss for filtration through a low-pressure earthen dam [16].

It is necessary to determine the possible conditions for further use of the coating, namely the formation of various defects. The numerical experiment included the construction of a solid-state model of the stress-strain state of the coating [17].

The work of the coating of the load from its own weight and filling the volume cells of the soil at various parameters was numerically modelled. The results obtained are adequate to the calculations [18] and do not exceed the operational parameters of the structure (Figure 3) [19]

![Figure 3. Results of numerical simulation: a – plot of total stresses; b – plot of total displacements.](image)

The result of modelling is characterized by the presence of total displacements that are not dangerous for the coating operation, which indicates the presence of a large margin of safety of the coating [20]. The formation of various defects was also modelled, namely the most dangerous – subsidence of the underlying soil. The formation of a deflection of the coating along the length is shown in the plot of total displacements (Figure 4) from the subsidence of the underlying soil.

Horizontal stresses occur in the support zone, and vertical stresses along the coating occur in the support zone and in the middle of the considered part [21].

In the course of numerical modelling of a volumetric cellular anti-filtration geotextile coating, we obtained diagrams of stresses and displacements from various defects that occur during the operation of the structure, which will increase the reliability of coatings.

The variable height of the edge of the coating cell prevents the formation of landslide processes, and reduces the consumption of geotextile material. One of the most urgent tasks in the field of ensuring the safety of long-term water supply structures is the correct assessment of the remaining resource [22, 23], and this can only be shown when performing numerical modelling of the development of various damages, both individually and in a group.
3. Conclusion
The use of impervious geotextile cover will improve the operational reliability of impervious surfaces, low-pressure earth dams due to the cellular structure having a variable depth, filled with soil. This reinforces the upstream slope, and prevents the formation of landslide processes, as well as waterproof coating with geotextile material prevents the loss of water to filter, preventing blooding, salinization, and waterlogging of agricultural land.

During the development of methods of extending the life cycle of water supply structures, anti-filtration geotextile coatings were obtained thanks to which, if the residual resource of the structure is correctly estimated, it is possible to extend its life cycle.

The question arises of the need to assess correctly and timely the remaining resource and load-bearing capacity of the water supply structure, to assess the technical condition and extend its life cycle. To do this, we can apply the proposed anti-filtration geotextile coatings depending on the type of water supply structures of anti-filtration geotextile coating for restoring the operability of water supply channels; anti-filtration geotextile coating for sealing the butt joint of tray channels of irrigation systems and underwater pipelines; anti-filtration cellular geotextile coating of water supply channels and low-pressure embankment dams.

Thanks to the use of modern anti-filtration geotextile coatings, it is possible to extend the life cycle of water supply structures with minimal economic costs.

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