Strengthening technology and modeling of dams from reinforced soil

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Abstract. The aim of the work is to develop a methodology and technique for modeling reinforced soil for further use and application in hydraulic facilities to ensure their stable operation. The objectives of the study are to substantiate the efficiency of using dams of large canals made of reinforced soil at hydraulic structures of pumping stations of the Republic of Uzbekistan, taking into account local conditions, developing recommendations for the rational design of retaining walls and dams from reinforced soil. To achieve this goal, it is necessary to solve the problems of coordinating the operating modes of the pumping station with the introduction of retaining walls and dams from reinforced soil on full-scale structures. The article discusses the implementation of the method of building them in the management of water distribution on irrigation systems in Bukhara and Kashkadarya regions. The theoretical foundations of modeling and design of test stands for the study of volumetric models of dams of large channels made of reinforced soil have been developed. Studies on volumetric models of dams made of reinforced soil were carried out in compliance with the criteria of approximate similarity, which made it possible to obtain new physical ideas about the operation of structures at the stage of destruction. The conducted studies of the models of the built-up part of the dams made it possible to estimate the bearing capacity by the value of the breaking load of the reinforced model to the value of the breaking load of the unreinforced (reference) model. The presence of reinforcement in the soil increases the bearing capacity of the model in comparison with the unreinforced one: even with the volume percentage of reinforcement $\mu = 0.064\%$, the hardening coefficient is equal to $C_{\text{hard}} = 2.60$; with $\mu = 0.032\%$ $C_{\text{hard}} = 1.70-2.07$. With the same percentage of reinforcement $\mu = 0.032\%$, an increase in the vertical spacing of the reinforcement leads to a decrease in the bearing capacity by 12-15%. A more even arrangement of reinforcing elements in the ground (close vertical and horizontal spacing between them $S_v \approx S_h$) ensures the maximum bearing capacity of a reinforced soil structure.

1. Introduction

In recent years, in many countries, experimental and theoretical studies to increase the strength of slopes and foundations of hydraulic structures, as well as roadbeds using reinforced soil, have become widespread. The analysis of the investigated and constructed structures carried out to date shows that...
to date a number of issues related to the assessment of the bearing capacity of structures made of reinforced soil have not been resolved. In these studies, there are no similarity criteria, and the models are used mainly as a tool for testing various calculation methods. In connection with the above, in assessing the performance of structures made of reinforced soil under static and dynamic influences, the results of physical modeling with the available calculation methods can be of great help and to refine them. Large-scale scientific research aimed at improving technologies for increasing the reliability of the irrigation system is carried out in leading research centers and higher educational institutions of the world: Department of Mechanical Engineering University of Ottawa (Canada), Department of Electrical and Computer Engineering Texas University (USA), Chensin University, Wuhan University (China), Wageningen University (Holland), Universität Hohenheim (Germany), Krakow University (Poland), Tashkent Technical University, Tashkent Institute of Irrigation and Agricultural Mechanization Engineers, Moscow University of Civil Engineering.

They are characterized by extensive development of works based on an experimental assessment of reliability, revision of the concept of randomness and obligatory failure, the relationship between the causes of failure and the proposed designs is studied [1,2].

Further experimental and theoretical study of water permeability in the presence of local damage will make it possible to develop objective control criteria taking into account the prevention of filtration [3,4].

To date, a number of authors in the world have carried out experimental and theoretical studies of a large number of structures made of reinforced soil for various purposes [5, 6].

Fastening of soil slopes of hydraulic structures is arranged: to protect against erosion by the current or wave of water; destruction by ice; erosion by a filtration stream flowing out of the dam body, for example, when the water level in the pool drops or when waves roll back; erosion by rain and melt water flowing down the slope of the dam or channel; destruction by wind; uneven settlement of the body and base of soil structures.

All this shows the need to improve the construction of new and reconstruction of existing hydraulic facilities, the use of modern non-traditional methods and materials in construction. Initially, reinforced soil was used in the construction of retaining walls, bridge abutments in France, Japan, USA, Germany, Spain in the form of a combination of bulk soils and linear metal elements (reinforcement).

The number of constructed structures is growing from year to year: by 1985 - more than 7000 structures; in total there are currently about 30,000 structures. The rapid development of the described technology is evidenced by the fact of holding a number of International Congresses on Reinforced Soils [7, 8, 9, 10, 11].

In the literature, there are data related to the study of various models of retaining walls, a description of the models, a methodology for their research is given, however, information about studies from reinforced soil concerns mainly the issues of soil reinforcement with metal reinforcement; however, there are no similarity criteria for the use of different materials as reinforcement [12, 13, 14, 15].

The aim of the work is to develop a methodology and technique for modeling reinforced soil for use in hydraulic facilities to ensure their stable operation.

Research objectives:
- substantiation of the efficiency of using dams of large canals made of reinforced soil at the structures of pumping stations of the Republic of Uzbekistan, taking into account local conditions;
- development of methods for calculating the stability of slopes and their comparison with the results of model studies; determination of parameters after testing.

2. Methods
In the process of research, methods of physical modeling of dams of large channels made of reinforced soil were used, theoretical foundations of modeling were developed, the design of test stands for the study of volumetric models of dams from reinforced soil and fragments for
their augmentation, technology for making models, a technique for conducting experiments with the implementation of results on full-scale structures.

The available physical concepts of the work of reinforced soil make it possible to consider it necessary to take into account the following basic physical and mechanical characteristics of soil and reinforcement when modeling. For soil: specific gravity \( \gamma' \); deformation modulus \( E' \); shear characteristics \( \operatorname{tg}\varphi \); for reinforcing elements: modulus of elasticity \( E_a \); tensile and shear strength \( R_a \), \( \tau_a \), shear characteristics at the «soil-reinforcement» boundary.

In the general case, similarity ratios should be established between the specified characteristics of the soil and reinforcement.

3. Results and Discussion

Field studies carried out by research organizations for many years have made it possible to establish that the main losses of water from lined channels occur through expansion joints and cracks [16, 17].

The operating experience of large systems of machine water lifting allows concentrating the relevant data in a form that is convenient for the operating personnel [18, 19].

Structures, the destruction of which leads to disruption of the normal operation of large canals, are considered to be the main ones in terms of water conservation. Special systematic studies of the state of canals of pumping stations, carried out with the participation of the authors during 2018-20, showed that the geometry of the canal undergoes significant changes due to erosion, sedimentation, as well as artificial cleaning throughout the entire period of operation (Figure 1).

![Figure 1. Erosion of the pumping station inlet channel in the Bukhara region.](image)

The main goal of preserving the reclamation pumping station is to ensure its stability and durability. Fulfillment of the development goal of pumping stations - its reconstruction. The objectives of the system management can be tactical, carried out by operational personnel and strategic, carried out by the management personnel of the operation services [20, 21].

Various types of reinforcement can be used to reinforce dam elements from non-cohesive soils, for example, rolled (nylon mesh, fiberglass, geotextiles, etc.) or strip (metal strips). For all types of reinforced slopes investigated, a significantly lower deformability was established compared to unreinforced models (a 2-6 times decrease in ridge settlement was noted).

The studies described above, as well as a number of other works on the study of the operation of structures made of reinforced soil using model studies, information about which are available in the literature, were carried out practically without observing the similarity criteria [12, 23]. Therefore, in these cases, we can only talk about obtaining a high-quality picture of the operation of the structure.
The transfer of the quantitative results obtained on such models to real full-scale structures is highly controversial.

The authors carried out studies of a fragment of the structure of the increasing part of the dams. In contrast to previous studies, where the models were installed in trays that bound a fragment of the structure, which influenced the stress-strain state of the model when it was loaded due to the presence of friction between the model and the walls of the tray, the studies described below were carried out without the walls limiting the side surfaces. This gives a clearer idea of the distribution of forces in reinforced soil in the absence of friction forces along its lateral surfaces [24, 25].

The results of the experiments were supposed to make it possible to obtain quantitative (relative values of breaking loads) and qualitative (pictures of destruction) ideas about the behavior of models during tests with bringing to destruction, as well as to assess the possibility of building dams. The studies were carried out in an experimental stand, which is a metal welded structure in the form of a tray with a rigid bottom and side walls (Figure 2).

![Figure 2. Scheme of the experimental stand: 1 - tested model; 2 - rigid base; 3 - stamp; 4 - rod; 5 - articulated joint; 6 - lever; 7 - cargo; 8 - channel; 9 - tray wall.](image)

A lever system was used as a loading device to create vertical loads. Lever 7 by hinge 5 was attached to channels 9 located across the tray and rigidly welded to it. The channels have a hole (d = 20 mm), the axis of which coincides with the axis of the test specimen or model. The vertical pressure is transmitted by means of a steel rod 4 (d = 18 mm) through a stamp 3 to the model. The verticality of the load transfer is ensured by means of a hinge (ball d = 20 mm) at the end of the rod, abutting against the recess in the center of the stamp. There is a container on the free shoulder. The lever arms are 208 and 1090 mm respectively. Thus, due to the difference in the arms, the force applied to the free arm increases by 5.24 times. The load was created using a fraction with its subsequent weighing. The load was transferred to the model through a rigid die 3 with dimensions of...
200x200x100 mm made of durable plaster. The weight of the stamp 4.18 kg was taken into account when determining the loads. At the moment of destruction of the sample, the stamp was kept from falling by device 6.

The lower part is made of plexiglass, which played the role of facing the lower edge, in three versions (flexible, rigid solid and rigid vertically cut) 10 mm thick in the form of a vertical retaining wall (Figure 3).

Self-weight was applied directly inside the model using metal anchors $d_a = 30, 50, 80$ mm in diameter and 3 mm thick. The anchors had holes in the middle with a diameter $d_{holes} = 3$ mm. Through the holes to the anchors were attached rods made of nylon lines.

![Figure 3. Types of dam facing: a - flexible; b - rigid solid; c – hard split; 1 - reinforcing element; 2 - hole for the passage of the reinforcing element; 3 - bolt; 4 - washer; 5 - facing; 6 - seam; 7 - sensors.](image)

Fine-grained homogeneous sand with a moisture content of $\omega = 2\%$ was used as a material for the manufacture of models. As a reinforcing material, tracing paper with a thickness of 0.03 mm was used, the width of armored strips was 10 mm. Such a material was chosen in connection with the desire to obtain a picture of the distribution of forces within the sample, judging by the places of reinforcement.
breakage. The base of the stand was covered with a layer of varnish and sprinkled with sand to create a rough surface on which the model was installed.

The model was manufactured in a detachable form of plexiglass, which did not allow distortion of the sample dimensions and retained the specified soil moisture ($\omega = 2\%$) until the start of the test. The dimensions of the model were 200x200x400 mm. The soil was laid in layers of 25-50 mm with compaction to a specific gravity of $y = 20 \text{ kN} / \text{m}$. The mold was removed from the sample after placing a stamp on it immediately before loading. Given the low bearing capacity of unreinforced models, a sheet of thick plywood was used as a stamp for them, on which a container was installed in the center, into which the shot was poured. For unreinforced specimens, fracture occurred at a stress of $0.0052-0.0056 \text{ MPa}$. The test results are shown in Figure 4.

![Graph showing the coefficient of hardening of the $K_{hard}$ model when changing from the % reinforcement $\mu$.](image)

**Figure 4.** The coefficient of hardening of the $K_{hard}$ model when changing from the % reinforcement $\mu$.

Analyzing the graph, we can conclude that a proportional increase in the volumetric percentage of reinforcement does not lead to a corresponding increase in the bearing capacity of the reinforced model, as in the case of the broadening of the part of the reinforcing elements fixed to the cladding (Figure 5).
Figure 5. The ratio of the bearing capacity of the dam from the percentage reinforcement

Experiments have shown that with a sufficiently rigid facing, the maximum stresses in the reinforcing elements occur at the points of attachment to the facing [26, 27]. Therefore, an increase in the bearing capacity of structures made of reinforced soil is possible by increasing the strength of the reinforcing elements at the points of attachment to the cladding by broadening or thickening them.

4. Conclusions

- Cladding of living sections of earth canals is one of the important load-bearing elements in structures made of reinforced soil. The higher its deformability, for example, in the presence of a large number of joints or when using some types of polymers, the lower the load-bearing capacity of the structure.
- Analysis of the order of breaks of the reinforcing elements shows that the maximum tensile stresses in the reinforcement occur approximately at a depth of 1/3 of the height from the top of the ridge. The beginning of the failure of the first reinforcing elements does not lead to a complete loss of the bearing capacity of the reinforced model; apparently, in this case, there is some redistribution of stresses between the surviving reinforcing elements. After the breakage of the first armored belts, there is no instant destruction of the model as a whole, but it continues to bear the load. In this case, the upper layers of reinforcing elements are usually not torn, but pulled out.
- Studies on volumetric models of dams made of reinforced soil were carried out in compliance with the criteria of approximate similarity, which made it possible to obtain new physical ideas about the operation of structures at the stage of destruction.
- Self-weight on models of dams, retaining walls and other reinforced soil structures can be modeled using tensioned vertical elastic elements (nylon threads), the presence of which practically does not affect the bearing capacity of the models, the fracture pattern and the hardening coefficient.
- The conducted studies of the models of the built-up part of the dams made of reinforced soil made it possible to estimate the bearing capacity by the value of the breaking load of the reinforced model to the value of the breaking load of the unreinforced (reference) model.
presence of reinforcement in the soil increases the bearing capacity of the model in comparison with the unreinforced one: even with the volume percentage of reinforcement $\mu = 0.064\%$, the hardening coefficient is equal to $K_{\text{hard}} = 2.60$; with $\mu = 0.032\%$, $K_{\text{hard}} = 1.70-2.07$.

- With the same percentage of reinforcement $\mu = 0.032\%$, an increase in the vertical spacing of the reinforcement leads to a decrease in the bearing capacity by 12-15%. Consequently, a more uniform arrangement of reinforcing elements in the soil (close vertical and horizontal spacing between them $S_v \approx S_h$) ensures the maximum load-bearing capacity of a reinforced soil structure.

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