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The influence of experimental studies on the stability of hydraulic structures

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The influence of experimental studies on the stability of hydraulic structures

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Abstract. The article shows the main causes of accidents dams, including the effect influence of the undermining of territories. The aim of this work was to evaluate the possibility the formations in the model of the dams a cracks with certain areas of their distribution, as well as the degree of influence of reinforcement on their overall stability. Failure analysis shows that the reliability of these types of structures is different and depends on the uptime of individual subsystems. For soil dams, the largest number of failures is associated with filtration problems in the body and foundation of the dam during emergency floods. The decrease in stability and the increase in the development of crack formation during deformation of the soil base is greater, the greater the horizontal and vertical deformation of the soil. The effect of the reinforcing effect during stretching of the soil base, i.e. reinforcing the soil dam with geotextiles significantly affects the increase in stability and the decrease in the development of cracking during deformation of the soil base.

1. Introduction

On the territory of the former USSR, more than 2500 reservoirs with a volume of more than 1 million m^3 are operated. Of the 36.2 thousand existing high dams currently in operation, 6.3 thousand are concrete or stone, 29.9 thousand are unpaved. According to statistics, the number of accidents on concrete dams is two times less than on unpaved ones. Failure analysis shows that the reliability of these types of structures is different and depends on the uptime of individual subsystems. For soil dams, the largest number of failures is associated with filtration problems in the body and foundation of the dam during emergency floods. For concrete dams, failures are caused mainly by foundation problems. Design loads on dams of this type are also different [1].

The negative social consequences of dam accidents - the most sensitive indicator of the attitude of society towards dam engineering - requires the most careful assessments, and the open publication and assessment of these data is a recognition of the probable nature of accidents and disasters.

The percentage of accidents of various types of dams is shown in Figure 1 and the percentage of causes of dam destruction is shown in Figure 2.

As can be seen from figure 1, about 53% of all accidents fall on the share of soil dams. Due to the destruction of the base, 40% of dam dams occur. This can be seen in Figure 2.

The following four characteristic groups of dam accident causes can be distinguished [2]:

1. Insufficient strength or stability of structures, foundations and banks on shear, as well as large deformations – precipitation, displacements, heaving, irreversible deformations.

2. Long-term effects of surface and filtration flows, causing mechanical suffusion, erosion of building materials, deterioration of its properties over time, weathering of rocks, clogged drainage.

3. Violation of the normal functioning of waterworks facilities.

4. Extraordinary impacts such as earthquakes, explosions, various natural disasters, hurricanes and the like, as well as during overloads caused by accidents of upstream hydropower plants, undermining of territories.

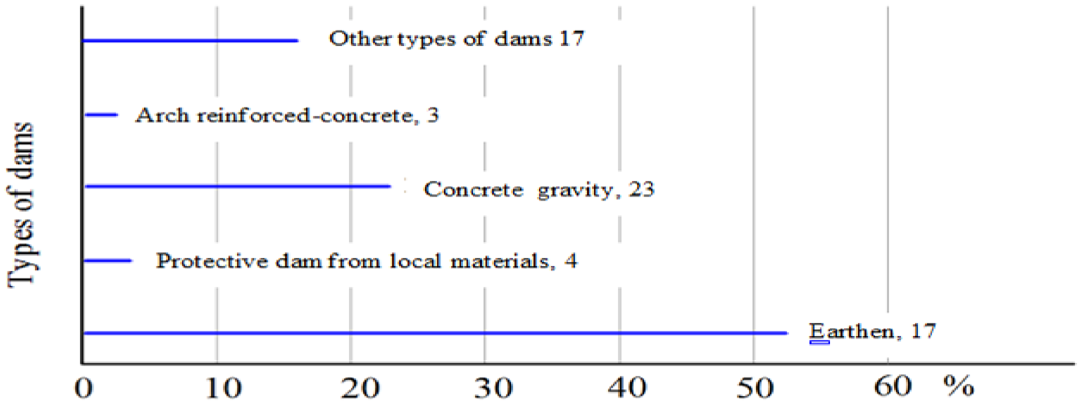


Figure 1. The percentage of accidents of various types of dams.

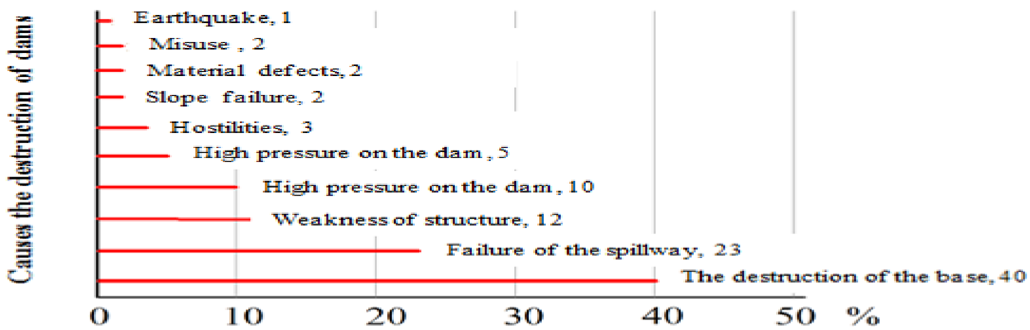


Figure 2. Reasons for the destruction of soil dams.

Today, the mineral resource complex (MRC) of Kazakhstan occupies a prominent position in the global mineral resource balance. It plays an important, and in a number of sectors, strategic role in the Euro-Asian region. In addition, it has a high potential for further development and increase of influence on the world mineral raw materials market [1, 2].

Currently, the leaders in the global production of mineral raw materials are such major countries as the USA, Australia, South Africa, Canada, China and Russia. A high level of economic development in most countries rich in natural reserves was achieved through the intensification of their production and processing. The experience of countries such as Canada and Australia shows the significant impact of the rational use of this potential on gross domestic product. In Kazakhstan MRC most quickly adapted to the requirements of the global market for the mineral resource complex. As a result, today the share of Kazakhstan in the world proven reserves is [3]:

1) fuel and energy resources: uranium - 18.9% (second place in the world); gas - 1.5%; oil - 3.2% (seventh in the world); coal - 3.1% of the world (sixth in the world);

2) solid minerals: barite - 47.2% (first place in the world); chromium ores - 37.6% (first place in the world); lead - 22% (first place in the world); zinc - 15.2% (first place in the world); Manganese - 30% (second place in the world); silver - 16% (second place in the world); copper - 7.1% (third place in the world); iron - 6% (fifth place in the world); cobalt - 3.9% (fifth place in the world); phosphorites - 1.5% (sixth place in the world); gold - 2.7% (eighth place in the world); bauxite - 1.4% (tenth in the world); nickel - 1.4% (twelfth place in the world);

3) The Republic of Kazakhstan in the extraction and production of mineral raw materials is in the world: for chromites - the second place; for titanium - second - third place; on uranium - the fifth; on zinc - the sixth; on lead - the sixth; on manganese - the eighth; silver is the ninth; for copper - the tenth; in oil, gas, coal and iron - one of the twenty leading countries in the world.

Consequently, Kazakhstan currently plays a significant role in the global market for copper, uranium, titanium, ferroalloys and steel. The republic is a monopolist in the Euro-Asian subcontinent for chromium and has a significant influence on the regional (CIS countries, primarily Russia) market for iron, manganese, aluminum, coal. As the transportation issues are resolved, Kazakhstan will be able to effectively dispose of its significant oil and gas reserves. A country can take its rightful place in the global oil and gas market.

In modern mining technologies for mineral resources, primary processes of destruction associated with drilling, blasting, splitting, grinding, transportation of the rock mass, its processing, and enrichment predominate. These processes are accompanied by manifestations of rock pressure, rock displacement, rock bursts, sudden emissions of gas, dust, endogenous and exogenous fires, etc. Often, some of them acquire a significant amount, especially dangerous for workers in gas and dust explosions in coal mines [4].

The most obvious possible types and scales of various types of impact of mining activity on the lithosphere can be traced on the example of open and underground mining of coal deposits in table 1.

Table 1. The magnitude of the impact on the lithosphere in various ways of developing coal deposits of the Karaganda and Ekibastuz basins in Kazakhstan.

Changing environment and the nature of the negative manifestations of anthropogenic impact	The effects at various ways of development	
	in open	in underground
Complete removal, mechanical destruction of varying degrees of degradation of soil cover	Within the mining lease, in some cases, the surrounding areas to careers	Within the mining lease
Changes in chemical and microelement composition of soil and soil microorganisms oppression work	On a large area exceeding ten times the size of the mining lease	Mainly confined to the mining lease
Activation of cryogenic processes (erosion solifluction, heave, landslides, etc.)	Within the mining lease, in some cases, the surrounding areas to careers	Within the mining lease
Alienation of additional space for placement of production waste (waste rock dumps, scrap metal, waste tire dump trucks and cars, etc.)	Areas that are comparable to the size of the quarry, cluttering within the mining lease area, expanding the zone of the WHO–action due to cutting waste dumps, stockpiles hit products of erosion to surface waters	The small volume of waste. Waste rock dumps occupy a small area within the mining lease

Note – Based on the analysis of environmental and economic activities of mines and cuts the two largest coal basins of the republic [5].

As follows from the analysis of the data presented, underground mining of coal deposits by the influence of such components of the natural environment as the lithosphere is much more profitable than the open method of coal mining. Significant changes in the terrain, the formation of huge volumes of production waste (waste dumps, tailings, metal, waste tires, etc.) are most characteristic of opencast mining.

As economic practice shows, the objects of especially high danger should include alluvial mining engineering structures - hydraulic dumps and tailings.

The loss of stability of the enclosing dams can lead to flooding of the adjacent territories and, consequently, to pollution by clay or toxic pulps of fertile lands, and also to additional (in relation to the filtration losses) pollution of surface and underground waters.

In this article, it is precisely the behavior of the soil dam model that is studied under various variants of horizontal and vertical deformations of the soil base, which is identical to the underworking of the soil thickness.

2. Methods

The experiment at the stand. The experiment was conducted on a volumetric bench (by Figure 3). The stand for modeling (volumetric) deformations of the soil dam model is made in the form of separate channel sections (1). Between sections (1) installed elastic rubber gaskets (2) with a thickness of 10 mm. The side flanges of the channel sections (1) are equipped with bolted joints (3) in the upper and lower levels horizontally. The tray has end walls (4). The lower part of the channel sections (1) is equipped with adjustable supports (5) made in the form of ball bearings mounted on a support frame (6).

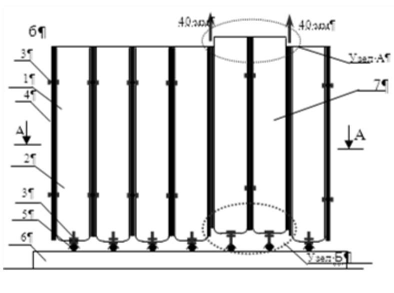
The stand for modeling strains [5-6] works as follows: with the help of a bolted joint (3), the channel sections (1) are compressed or stretched, with which the material is deformed in the tray. Horizontal tensile deformations of the soil are provided due to the elastic recovery forces of compressed elastic (rubber) gaskets (2) while loosening bolted joints (3). Horizontal deformations of soil compression are ensured by compression of the elastic (rubber) gaskets (2) using bolted joints (3), bringing together channel sections (1). Vertical deformations are ensured due to the gradual lowering of the channel sections (7), which were installed according to nodes A and B before the start of the experiment (by Figure 3).

The material of the dam and soil foundation model was a mixture consisting of 97% fine quartz sand and 3% spindle oil by weight, having adhesion, which allows modeling cohesive soils [7].

To determine the strength characteristics and deformability of real soils and equivalent materials under vertical load in the event of horizontal deformations caused by underworking, a compression type stabilometer was used.

a

b



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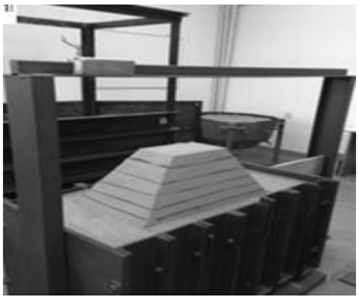

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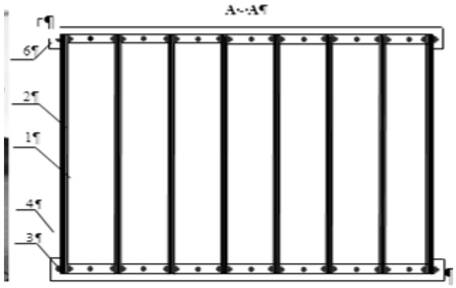

Figure 3. Volumetric stand for modeling deformations of the soil base.
a - photo of the volumetric stand, b - diagram of the volumetric stand (side view),
c - photo of a volumetric stand with a model of a dirt dam,
d - volumetric stand diagram (top view).

A sample placed in a compression device was maintained until complete consolidation under a given load of 0.3 MPa.

The step of loading with a vertical load Δδ1 was taken in the range of 0.05–0.1 MPa.

Vertical deformations of the soil sample were measured by dial gauges with a division value of 0.001 mm. The transfer of vertical loads to the sample was carried out by a loading device through a dynamometer of the DOSM-3-5 brand. Pressure was measured by a manometer.

Based on the results of these tests, the necessary parameters E, c, φ, γ were obtained (by table 2).

Table 2. Physico-mechanical characteristics of natural soil and equivalent materials.

Name of soils and model material	Specific weight, γ, (кN/м^3)	Clutch, c, (кPa)	The angle of internal fric–tion, φ (°)	Deformation modulus, E, (MPa)	Poisson's ratio, ν
Loam	2,05	40	39	20	0,3
Equivalent material	1,7	0,90	22	0,27	0,25

From the formula, after substituting the corresponding quantities for the model and full-scale soil, we obtain a linear modeling scale (1):

$$m_c = c_m / c_n \cdot \gamma_n / \gamma_m = 0.9/40 \cdot 2.05/1.7 = 1/40 \quad (1)$$

Therefore, the linear scale of the model and the natural object (buildings, foundations, structures) is determined by the ratio of the strength properties (adhesion) of loam and equivalent material and is equal to 1:40. The embankment model was an embankment with dimensions of 700 mm x 350 mm (base of the dam model), 200 mm x 150 mm (crest of the dam model), and the height of the dam model was 430 mm.

Laying the base. Before laying the soil foundation, we install the stand so that in the future 1/3 of the sole of the dam model is laid on the foundation, raised to a certain distance using the channel sections (by figure 3 - nodes A, B). Channel sections are raised upwards with bolts 40 mm.

After preparing equivalent material, we lay the base in a volume stand. Equivalent material was placed in a volume stand with 7 cm layers and compacted with a roller (7 full laying cycles).

In the process of preparing the base, the density of the material was controlled. Density is determined by measuring the selected soil sample on special scales.

Laying of models of dams (by Figure 4, 5) was carried out by layering in 6 layers of 7 cm + compaction. Between each layer, colored sand 2 mm thick was laid.

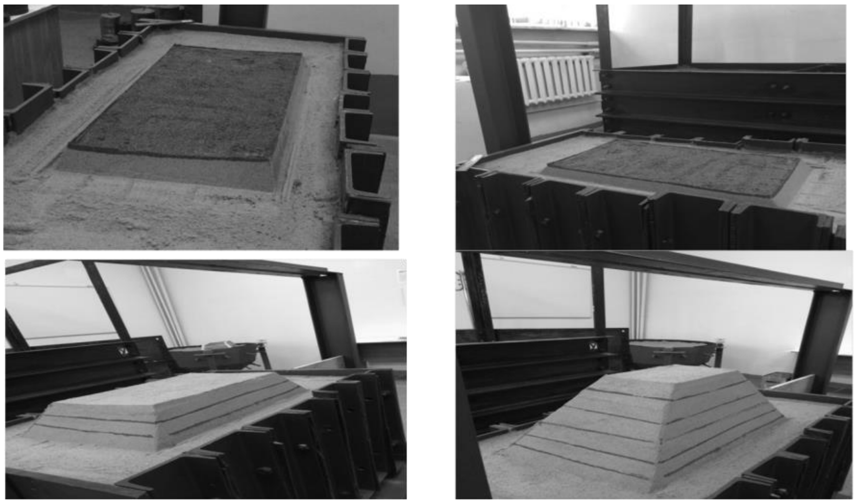

Figure 4. Layered laying of a dam model without reinforcement.

In the model of the dam with reinforcement after laying each layer and colored sand, a reinforcing mesh with an area equal to the area of the laid layer of the dam model was superimposed.

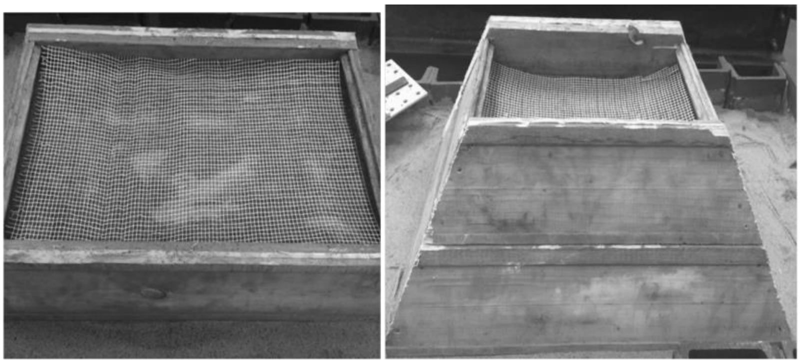

Figure 5. Layered laying of a model of a dam with reinforcement.

3. Results

The task was to study the stability of the model at 5 steps of horizontal deformations ($\varepsilon = (3,6,9,12,15) \times 10^{-3}$) and the simultaneous vertical collapse of part of the soil base in the options with reinforcing the dam model and without reinforcing, in order to identify the conditions of the critical state of the embankment [8-17].

The volumetric stand allowed in a significant range to create independent tensile and vertical lifting and lowering deformations of the soil base.

The following series of tests were carried out (by Figure 6):

a) Testing on the dam model under various conditions of simultaneous lowering of part of the soil base and horizontal extension of the base without preliminary reinforcement.

b) Testing on the dam model under various conditions of simultaneous lowering of part of the soil base and horizontal stretching of the base with reinforcement.

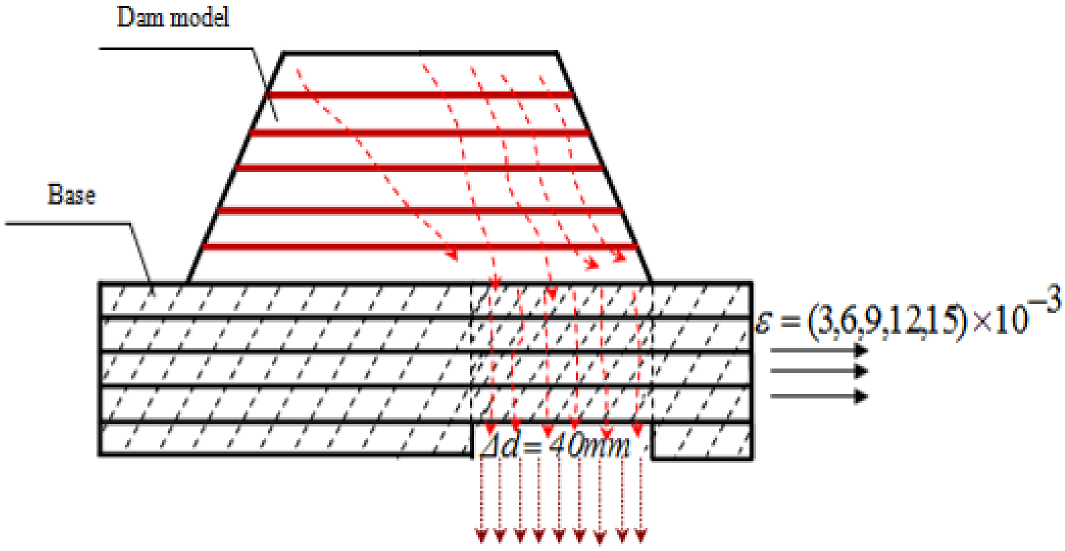

Figure 6. Scheme of the action of horizontal and vertical deformations on the operation of models of dams.

In Figure 7 are showed a comparison of the key stages of modeling the stability of a dam model demonstrated on a volumetric bench using equivalent materials.

a

b

Figure 7. Comparison of the key stages of modeling the stability of the dam model.
a - without reinforcement; b – with reinforcement.

According to the schedule (by Figure 8), we can conclude that the strengthening of the dam model by the reinforcing mesh significantly affected its stability under horizontal and vertical deformations. This option of strengthening can be considered in cases of designing hydraulic structures, as one of the ways to increase stability and reliability.

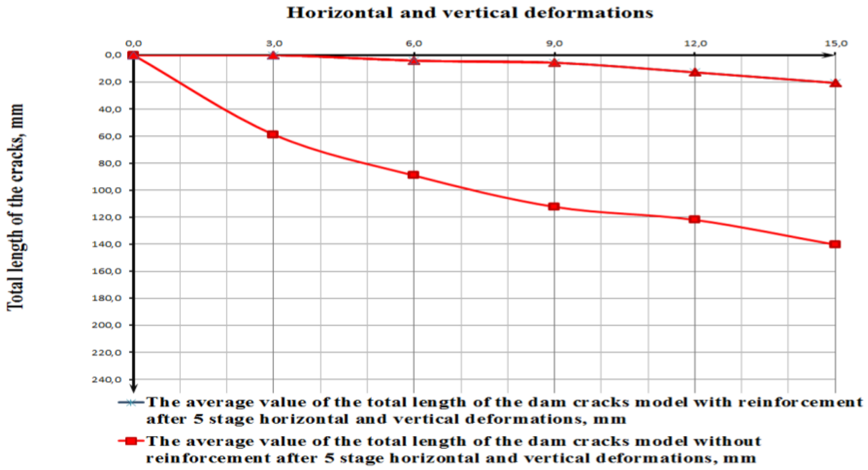

Figure 8. Graph of the stability of the model of reinforced and unreinforced dams on horizontal deformations.

When designing soil hydraulic structures in the developed areas, insufficient consideration of the horizontal and vertical tensile deformations of the base in the calculations leads either to an emergency decommissioning of the structure (which will require additional costs for reinforcement and repair), or its complete destruction, which entails huge material and human losses.

To find a way to solve this problem, the task was to determine the overall stability of the models of reinforced and unreinforced dams as a result of the influence of horizontal and vertical deformations of the soil base using the finite element method. In order to study the work of models of dams, with reinforcement with geosynthetic material and without reinforcement, it was customary to consider and compare their work, while the work of each individual model was considered within the framework of one engineering-geological element.

In figure 9 are showed the geometric models of numerical modeling of reinforced and non-reinforced models of a dam with a soil base, the horizontal and vertical deformations given to it, and the boundary conditions of the models.

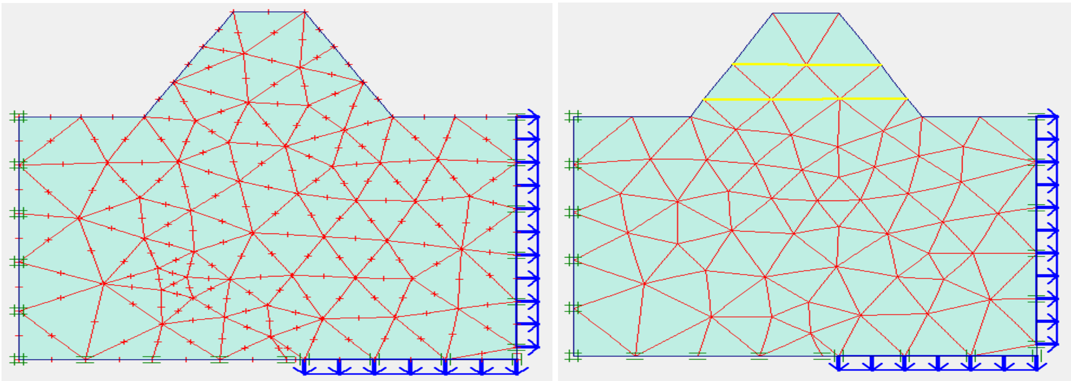

Figure 9. Model and boundary conditions of geometric models of reinforced and non-reinforced dams.

After selecting all the necessary parameters and constructing the initial stresses, a calculation is performed. Several design steps for modeling horizontal tensile strain along the x axis and vertical strain along the y axis with given parameters and were included.

In Figure 10 are showed a deformed grid of models of reinforced and non-reinforced dams at the end of the selected calculation stage.

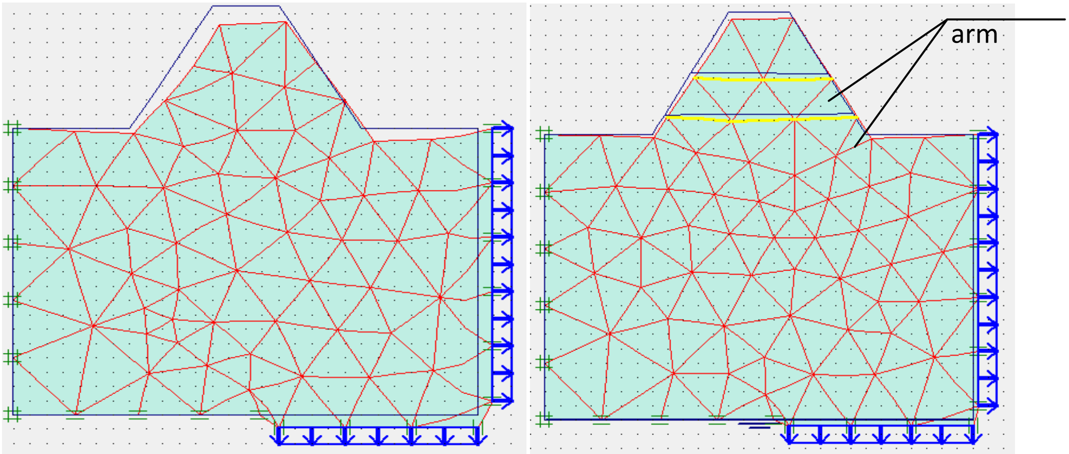

Figure 10. Deformed grid of models of reinforced and unreinforced dams at the end of the selected design stage.

In addition to the results of the final stage of calculations, curves of the dependences of displacements on displacements are obtained. In table 3 are showed the data of horizontal and vertical movements that correspond to each calculation step.

Table 3. Data of horizontal and vertical movements corresponding to each calculation step.

Step	Horizontal deformations	Vertical deformations, mm
0	0	0
1	$\varepsilon = 3\times10^{-3}$	$\Delta d = 8$
2	$\varepsilon = 6\times10^{-3}$	$\Delta d = 16$
3	$\varepsilon = 9\times10^{-3}$	$\Delta d = 24$
4	$\varepsilon = 12\times10^{-3}$	$\Delta d = 32$
5	$\varepsilon = 15\times10^{-3}$	$\Delta d = 40$

Based on the calculation results, a general graph of the “Deformation - Displacement” relationship was obtained for models of reinforced and unreinforced dams on a soil foundation (by Figure 11).

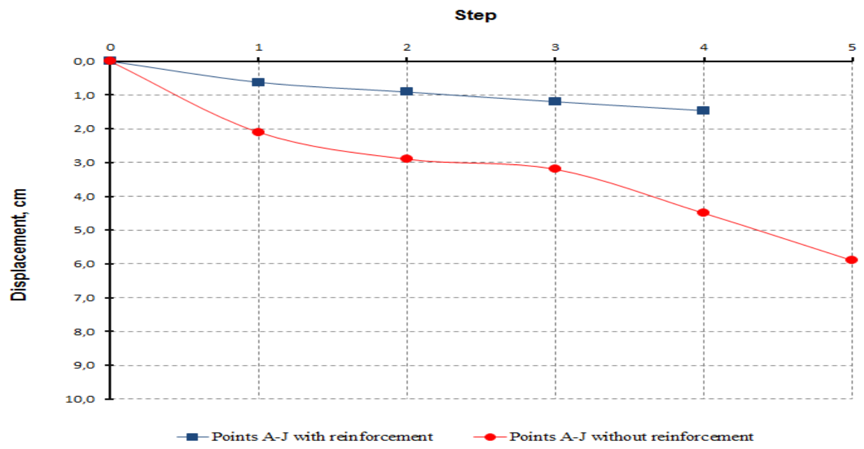

Figure 11. Dependence graph "Deformation - Displacement" of models of reinforced and unreinforced dams on a soil foundation.

4. Discussion

The main influence on the change in the overall stability and crack formation of soil dams on deformable bases is exerted by a change in the stress-strain state of the soil stratum under the influence of horizontal and vertical deformations resulting from underworking.

The decrease in stability and the increase in the development of crack formation during deformation of the soil base is greater, the greater the horizontal and vertical deformation of the soil.

The effect of the reinforcing effect during stretching of the soil base, i.e. reinforcing the soil dam with geotextiles significantly affects the increase in stability and the decrease in the development of cracking during deformation of the soil base.

The used volumetric stand for modeling base deformations allows us to expand the range of simulated phenomena close to the full-scale conditions of the underworking of hydraulic structures and allows us to study the mechanism of interaction of the soil dam with the undermined base.

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