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Influence of deformations of foundations on the stability of building structures

Abstract. *Today, modern technologies effectively carry out work on predicting the stability of structures, determine the optimal solution and choose methods to eliminate the predicted negative impacts on the operation of building structures. The choice of the most optimal one depends on specific tasks. For example, a solid foundation is responsible for the safe operation of the entire building. Accordingly, the structure must be particularly strong and durable. Nevertheless, there are cases when the foundation is weakened and deformed under construction structures, especially those erected a very long time ago. The emergency state and destruction of objects with all the sad accompanying consequences, that is, tragedies with fatal outcomes, which lead to significant damage to the economy of the Republic of Kazakhstan as a whole. It is necessary at the very beginning of planning all stages of work to pay special attention to design, taking into account all deformations of the foundation of the foundations.*

In general, if we correctly position the correct distribution of the stages of construction of new structures using innovative methods of strengthening, a preliminary analysis of their stability, then in aggregate, after a period of time, we will come to the correct approach to solving this problem. The use of innovative methods for predicting support systems is of particular importance, since the safety of the entire structure depends on the correct and timely implementation of measures. The paper describes the observation for the behavior of soil dams, located on undermined territories, base is exposed to According to the results of observations plotted graphs «Deformations-Settlement».

Keywords: *stability, foundations, numerical methods.*

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Introduction. All hydraulic structures refer to objects, which are defined by a high level of responsibility. Destruction of these facilities is accompanied by considerable damage to the economic, social and environmental character. This particularly applies to hydraulic structures that prevail among built structures to the present time. The analysis of statistics of accidents and damage to hydraulic structures shows that the probability of even major accidents and destruction of any dams, including the most modern, cannot be completely eliminated. The obvious necessity of applying modern methods of analysis of a variety of stored and newly received operational information about the possible causes of the reduction in security level. The greatest number of accidents happening on the ground dams. The percentage of accidents of various types of dams is shown in h figure 1, and the percentage of the causes of the destruction of dams is shown in figure 2. As seen in accordance with figure 1, the share of earth dams gets about 53% of all accidents. Due to the destruction of the base 40% of accidents occur embankment dams. This can be seen in accordance with figure 2.

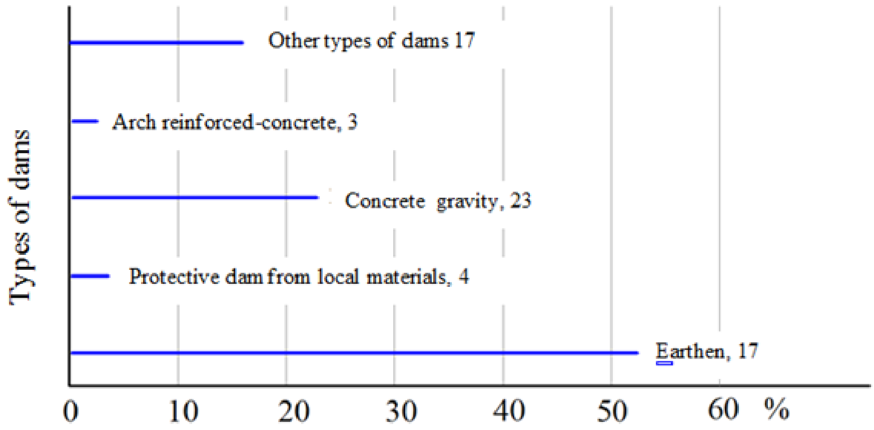

Figure 1. Percentage of accidents of various types of dams

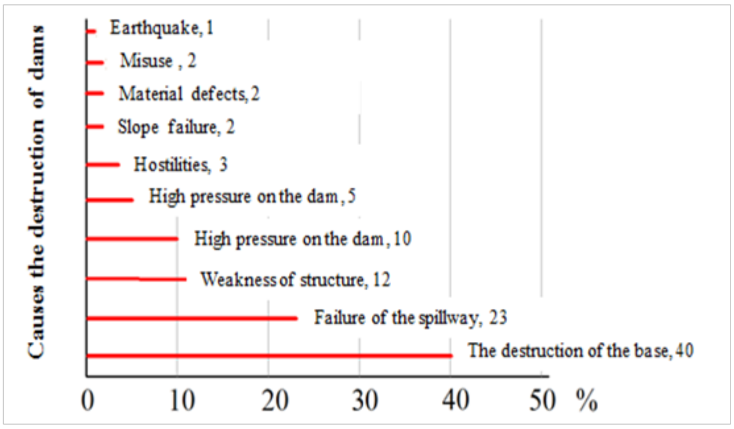

Figure 2. The causes of the destruction of earth dams

Concerning was determined to aim of the experimental work, which is to study the stability of reinforced and unreinforced soil dams under the influence of horizontal and vertical deformations of the subgrade and on the basis of the results of these studies to assess the possibility of formation in models of ground mounds cracks with the definition of the area of their distribution, and determining the degree of influence of reinforcement on their overall sustainability.

Numerical modeling of the dam model and soil base interaction under horizontal and vertical deformations. In recent years, in an era of high–performance computer technology, numerical simulation is one of the most popular and progressive methods of theoretical research. Numerical simulation based on the finite element method allows accurately and, most importantly quickly produce analytical calculations and forecasting of various geotechnical problems. Numerical simulation enables the theoretical study, which is not always feasible in practice, and sometimes simply impossible.

In order to study the work of models of dams, with the strengthening of geosynthetics and without strengthening, it was decided to review and compare their work with the work of each model will be considered within the same geological engineering element [1].

To achieve the objectives identified by the following conditions:

– the use of geometric values specified models of ground dams dimensions, on the basis of which will be determined by their stability, at a fixed horizontal and vertical deformation;

– for a fixed value of horizontal deformation subgrade models dams accepted parameters $\varepsilon = (3,6,9,12,15) \times 10^{-3}$ within which explores the work of ground models;

– for a fixed value of vertical deformation of soil foundation models dams accepted parameters $\triangle d$ = 40mm within which explores the work of ground models.

It was carried out two-dimensional work simulation of the reinforced and unreinforced dams models on soil found in the software package Plaxis Modeling the impact of horizontal and vertical ground deformations on the stability of the dam unreinforced model it was carried out under the terms of a two–dimensional model of the plane problem.

Figures 3-5 is represented by step input parameter setting geometrical model of numerical simulation of unreinforced dam model with ground base and set it horizontal and vertical deformation.

In the second model of the dam enabled geotextile (2 lattice) at a distance defined by coordinates (Figure 6):

– (•)11 (39,107);
– (•)12 (100,107);
– (•)13 (48,121);
– (•)14 (92, 121).

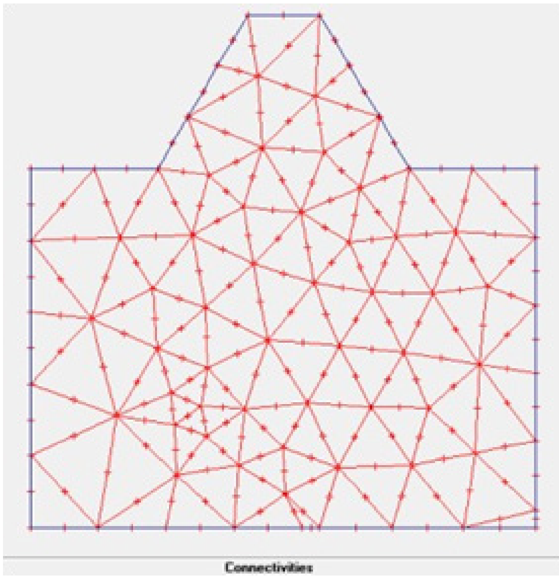

Figure 3. The general geometrical model of unreinforced model of the dam on grade

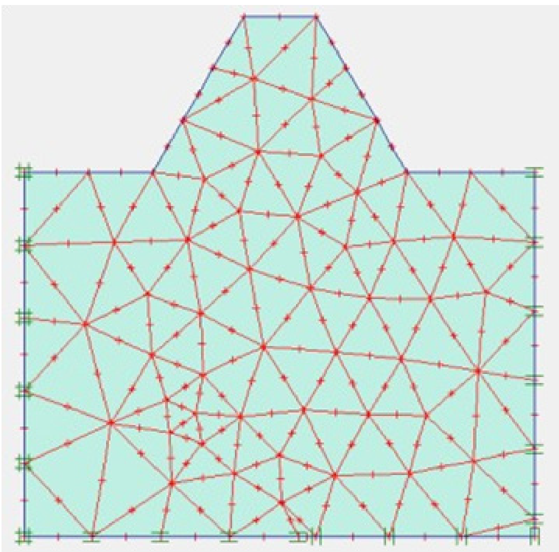

Figure 4. Closing geometric model of unreinforced of the dam on grade

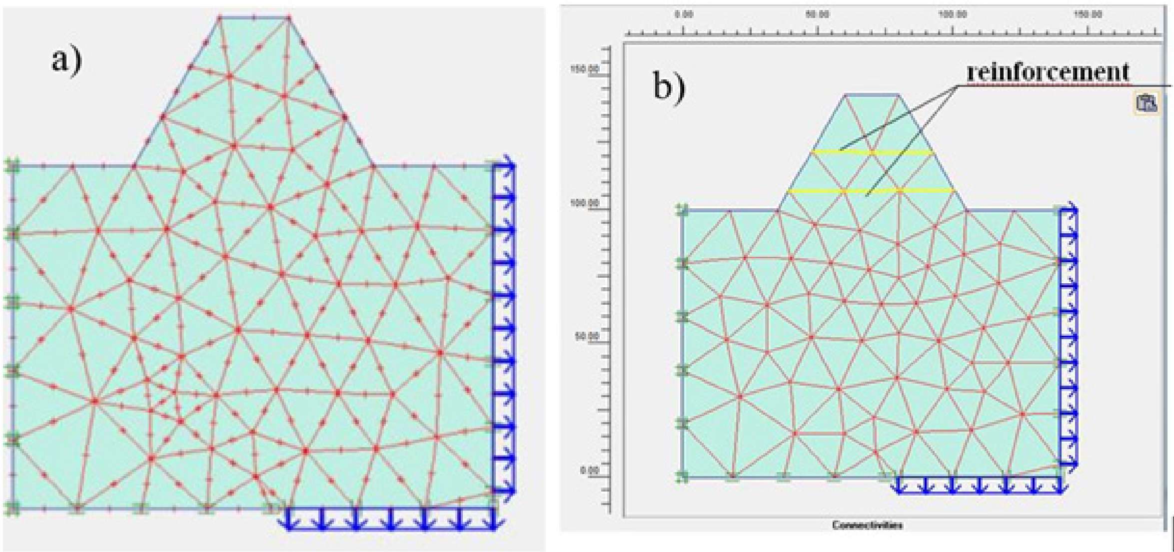

Figure 5. The boundary conditions of geometrical model of dam on grade
(- a) unreinforced, - b) reinforced)

Given the study model of the dam and its subgrade assigned to the same parameters of physico–mechanical properties of the soil (Table 1), obtained from the results of laboratory tests, and model as the unreinforced dam and its foundation soil it was constructed from a single the equivalent material [2].

Table 1 - Characteristics of soil model unreinforced dam and subgrade

Parameters	Designation	Value	Unit
Model soil	*Model*	Mohr – Coulomb	–
Type of soil behavior	*Type*	drain	–
The specific weight of the soil	γ_{unsat}	17.0	kN/m^3
The proportion of saturated soil	γ_{sat}	20.0	kN/m^3
The permeability of the soil in horizontal direction	k_x	3,000E^{-4}	m/day
The permeability of the soil in the vertical direction	k_y	3,000E^{-4}	m/day
Young's modulus (constant)	E_{ref}	260	kN/m^2
Poisson's ratio	ν	0.25	–
Clutch (constant)	c_{ref}	1.0	kN/m^2
The angle of friction	ϕ	21.0	°
The angle of dilatancy	ψ	0.0	°

It includes several computational modeling steps horizontal tensile deformation along the x axis and the vertical deformation along the y axis with the given parameters ε and Δd.

First current stage includes modeling of natural stresses caused by gravity. In later stages of the model has been applied evenly distributed strain in the form of horizontal and vertical movements, stretching emitting subgrade.

Displacements in the software package Plaxis specified in units of force per unit area related (kN/m2). The amount of movement for the reinforced models dam on grade are shown in Table 2.

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Geotextile assign the following characteristics (Figures 6-7).

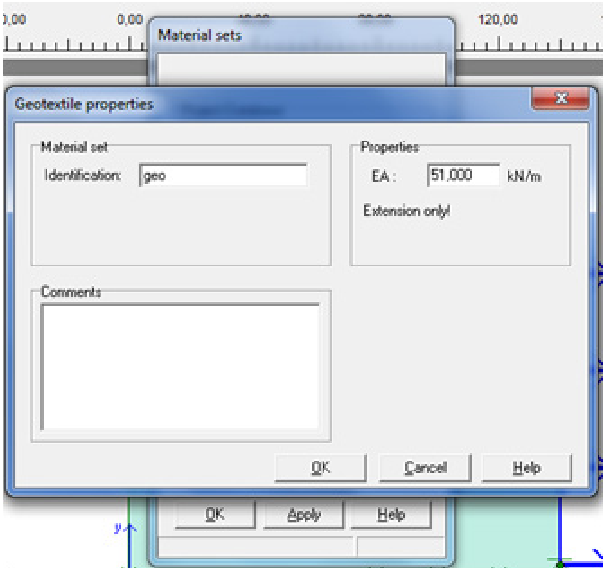

Figure 6. Setting the model under certain parameters of the geotextile

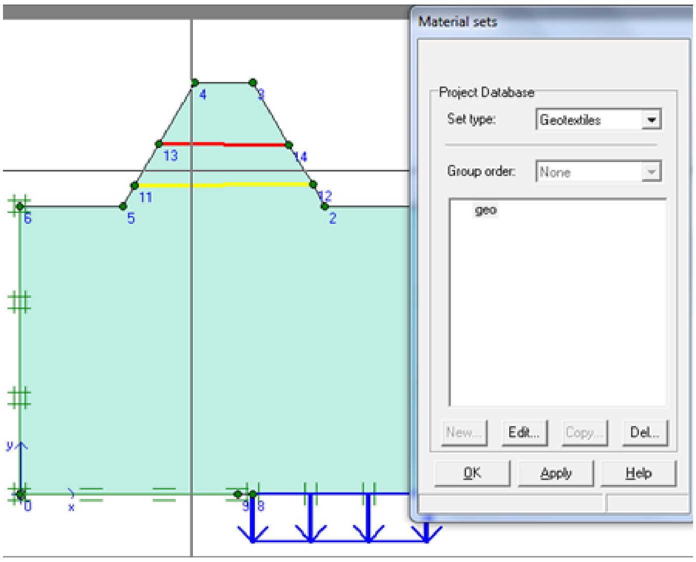

Figure 7 – Assignment of the characteristics of EA, kN/m, geotextile model

Table 2 - Characteristics of soil model unreinforced dam and subgrade

stage	The values of the horizontal and vertical stretching		stage	The values of the horizontal and vertical stretching	
	ε	Δd		ε	Δd
1	0	1	**5**	0,006	5
2	0	2	**6**	0,009	6
3	0	3	**7**	0,012	7
4	0,003	4	**8**	0,015	8

After setting the design parameters chosen nodes or stress points for plotting the displacement of the deformation (Figure 8).

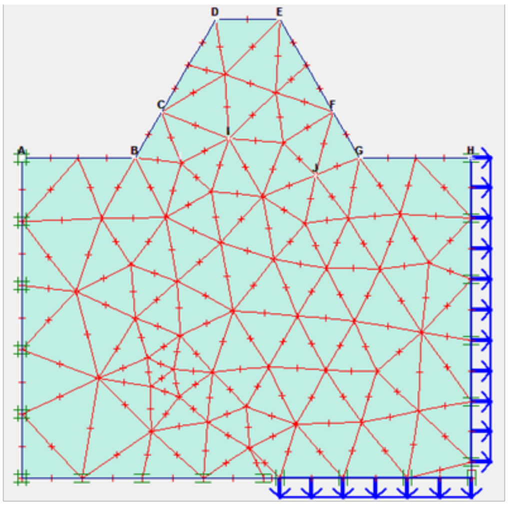

Figure 8 – Points of voltages for plotting the offset from the horizontal and vertical deformations

After completion of the calculation, the results were evaluated program output (Output program). Are obtained and the offset voltage in the full geometric model. Figure 9 shows the deformed mesh (which is based on such a scale that you can see the bias) at the end of the selected calculation phase.

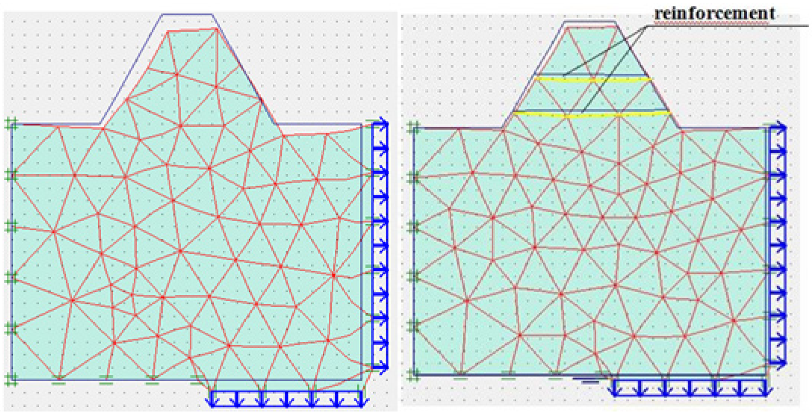

Figure 9 – The deformed mesh model of unreinforced dam calculated at the end of the selected phase

In addition to the results of the final stage of the calculations obtained from the curves of the displacement movement. Table 3 shows the data of horizontal and vertical movements, which correspond to each step of the calculation.

Table 3 - These horizontal and vertical displacements corresponding to each step of the calculation

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

When compared the numerical results modeling software and data movement patterns reinforced and unreinforced embankments on grade can be observed the following: if we consider some points selectively, such as points B, C, D, E, I, the essential visible difference between S_{reinf} and $S_{unreinf}$ (Table 4).

Table 4 - The numerical values of the maximum displacement of points in the test model

point	S_{reinf}	$S_{unreinf}$	point	S_{reinf}	$S_{unreinf}$	point	S_{reinf}	$S_{unreinf}$
A	0	360	**E**	45	75	**H**	1	0
B	17	133	**F**	0	31	**I**	0	46
C	25	116	**G**	0	27	**J**	0	31
D	47	89						

According to the settlement stage - built simulation curves of displacement of point A–J of the horizontal and vertical movements on the results of numerical simulations to compare the numerical parameters of deformation reinforced and unreinforced ground models. According to the parameters obtained the general plot of « Displacement-Step» models reinforced and unreinforced embankments on grade (Figure 10).

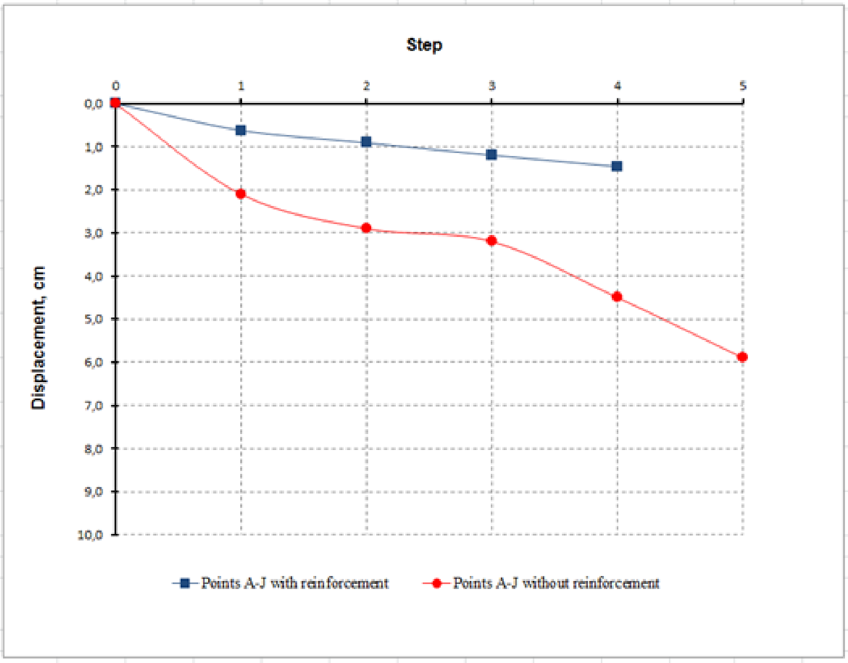

Figure 10. Graph of «Displacement-Step» reinforced and unreinforced models of dams on the grade

The used in calculation of model of the dam it was modeling in next experiment [3].

Model studies. In the study of the model of the dam in the horizontal and vertical deformation of its base is used for simulation of equivalent materials. According to the method of equivalent materials proposed by G.N. Kuznetsov, with data on the characteristics and mechanical properties of the full-scale model of the soil NH and NM can be for a given ratio γ_M / γ_H and a specified ratio NM/NH to calculate the scale of the model 1/L=m1. For determining the physical and mechanical characteristics to be taken are the characteristics that play in the process leading role. In the selection of materials – the equivalent of loose soil and plastic can in the first approximation as the defining characteristics of a set of values to use cohesion and angle of internal friction c, φ. To provide conditions similar to the process of destruction is necessary to observe equalities 1-2:

$$c_M = \frac{1}{L} \cdot \frac{\gamma_M}{\gamma_H} \cdot c_H \quad (1)$$

$$\tan \varphi_M = \tan \varphi_H \quad (2)$$

where:
1/L=m – linear scale models;
γ_M and γ_H – the proportion of the model and materials;
c_M, c_H – grip material models and the real nature of soil.

Consequently, the simulation of cohesive soils (loam, in my case) data equivalent material to determine the scale model, m1 i.e. we must first define the following physical and mechanical properties of the sand mixture: c, φ, γ.

The material model of the dam and foundation soil in this experiment was a mixture consisting of 97% of fine quartz sand and 3% by weight spindle oil having a grip that allows modeling of cohesive soils.

For determination of strength and deformability characteristics real soils and equivalent materials occurs under load due to horizontal and vertical deformations was used triaxial compression type.

The sample is placed in a compression device is held to the full consolidation under a given load of 0,3 MPa.

Step load vertical load Δδ_1 taken within 0,05 – 0,1 MPa.

The vertical deformation of soil samples was measured with a dial gauge scale division 0.001 mm. Transfer the specimen vertical loads carried by the dynamometer load device mark DOSM – 3–5. Pressure gauge measured.

The results of these tests, necessary parameters E, C, φ, γ. (Table 5).

The equation by substituting the corresponding values for the model and full–scale ground obtains a linear scale simulation (equality 3).

$$m_c = c_M / c_H \cdot \gamma_H / \gamma_M = 0.9/38 \cdot 19/17.7 = 1/40 \quad (3)$$

Consequently, the linear scale models and full-scale facility (building foundations, structures), is defined by the strength properties (adhesion) and loam equivalent material and still 1:40.

Table 5 - Physical and mechanical characteristics of the soil and the full–scale equivalent materials

Name of soils and model material	Specific weight, (кN/м3)	Clutch, (кPa)	The angle of internal friction, (º)	Deformation modulus, (MPa)	Poisson's ratio
Physical and mechanical properties of the full–scale dams					
Loam	19,0	38	38	27	0,35
Physical and mechanical parameters of the model dam					
Equivalent material	17,7	0,90	21	0,26	0,25

Experiments were carried out on the stand volume (Figures 11). Stand for simulation (volume) strain model dirt dam is designed as a single channel-section (1). Between the sections (1) are arranged elastic rubber seal (2) with a thickness of 10 mm. Side flanges of channel sections (1) are provided with threaded connection (3) in the upper and lower horizontal levels. The tray has end walls (4). The lower portion of channel sections (1) is provided with adjustable supports (5) are designed as ball bearings, mounted on the support frame (6).

Stand for modeling deformation [4] of the base model of the dam works as follows: using bolting (3) produces compression or stretching of the sections of channel (1), with which the material deforms in the tray. Horizontal tensile strain ground forces provided by elastic recovery of compressed elastic (rubber) gaskets (2) when loosening bolted connections (3). Horizontal strain compression of soil compresses the elastic (rubber) gaskets (2) by bolting (3), bring together the sections of channel (1). The vertical deformation is provided for by gradual lowering of channel sections (7), which before the experiment were installed according to the nodes A, B (Figures 11).

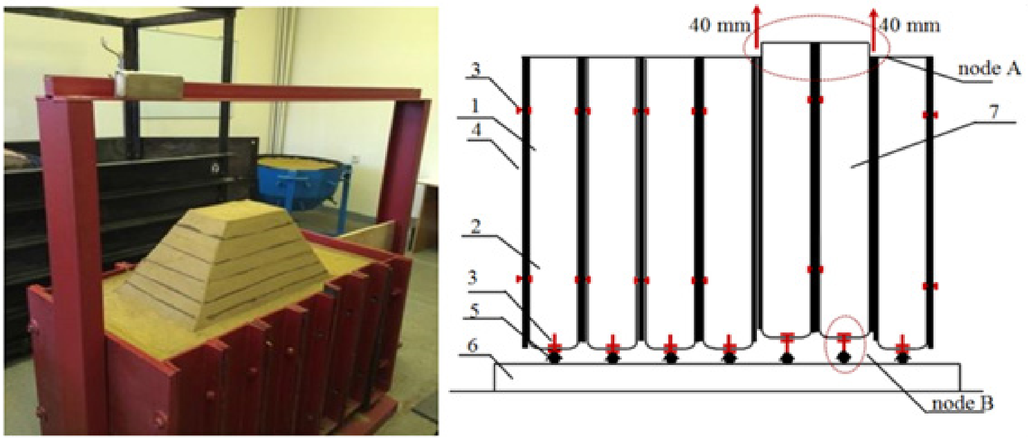

Figure 11. a) Photo of the stand b) Stand (volume) for the simulation of deformation model dirt dam (side view)

The model serves as a dirt dam embankment with dimensions in terms 700mm×350mm (base model of the dam), 200mm×150mm (crest of the dam model), the height of the dam model 430mm (Figures 12).

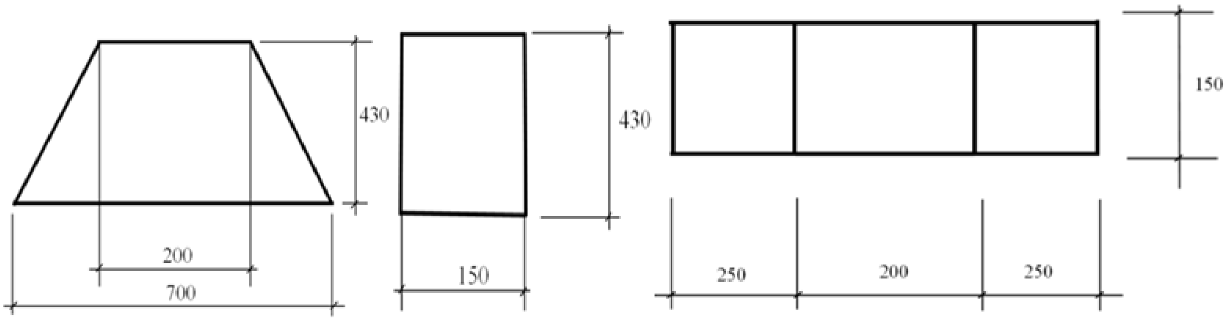

Figure 12. The model of the dam (side view, front view, top view), mm

Linear scale model of the dam determined by the ratio of strength properties (adhesion) loam, equivalent material and is 1:40.

After preparing an equivalent material in bulk stand laid the foundation for a model of the dam without reinforcement. An equivalent material is deposited in layers surround the stand 7 cm and Rollers (7 cycles of complete installation).

After laying the foundation for a model of unreinforced dam began layering of the model (Figures 13). Stacking of layers was carried out in 6 to 7 cm. Each layer rollers. Between each layer laid with colored sand thickness of 2 mm.

Preparation of the model with reinforced embankment (Figure 14) made by layering an equivalent material in the layers 6 to 7 cm tall. After each layer of superimposed colored sand layer thickness of 2 mm.

The mound was packed using a special form. After laying 1 and 3 layers with colored sand superimposed reinforcing mesh area equal to the area of layer model of the dam

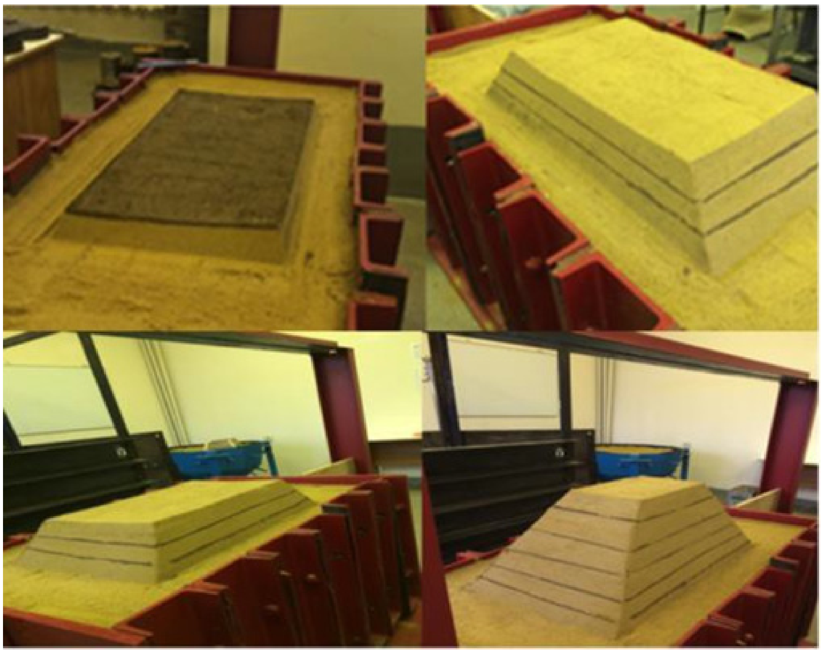

Figure 13. Dam model level-by level placement without reinforcement

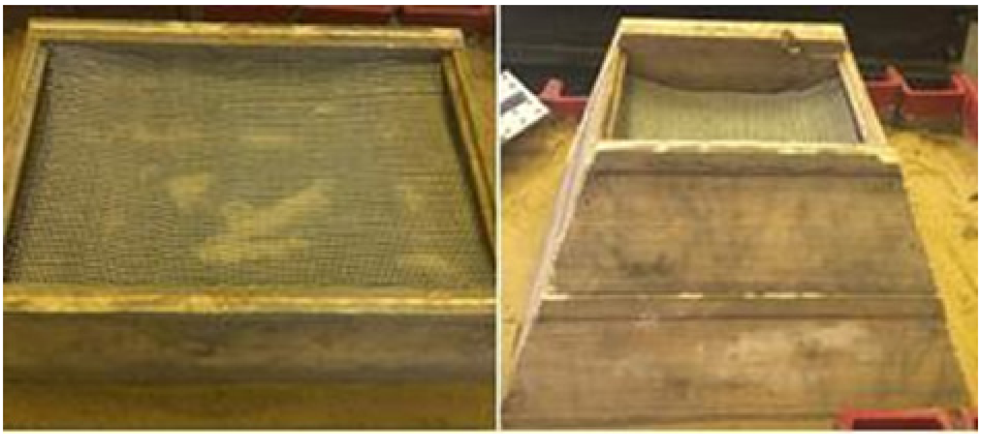

Figure 14. Reinforced dam model level-by-level placement

In the process of development of cracks, deformation and collapse of the dam model under simultaneous horizontal and vertical tensile deformation of soil foundation, it was possible to visually observe and record with the camera.

The emergence and development of digital photography has allowed developing a non–invasive method of monitoring vital functions photogrammetric cracking and other deformations of the objects.

Vertical and horizontal deformation of the base model of the mound and in the course of experiment, the photogrammetric method.

Photogrammetric method to determine the strain arising in the plane, and serves for the study of flat objects.

The essence of the method is that one and the same fixed point get several pictures of an object, such as the first to deformation during the deformation of the second and third after deformation. This camera is mounted so that the plane of the frame was applied parallel to the plane of the object and image orientation elements were preserved.

In this case, made of a periodic survey equipment with high resolution matrix (2 thousand Pixels per 1 cm2). In our particular case, we use the camera Canon EOS Rebel T3//DS126291 matrix with a resolution of 12,2 MPixel.

These surveys were entered into the net for documenting mechanical changes on the slopes and crest of the dam model.

The development of cracks in the reinforced and unreinforced model dams monitored by layers. The thickness of each layer model dams was 7cm. All measurements on each layer were summarized and the total length of cracks tabulated data.

The objective was to study the stability of the model, with 5 levels of horizontal deformations $(\varepsilon = (3,6,9,12,15) \times 10^{-3})$ and simultaneously the vertical collapse $\Delta d = 40mm$ by bolting of the subgrade in versions with reinforced dike model and without reinforcement, to reveal the conditions of the critical condition of the mound.

The volumetric stand allows a considerable range to create independent tensile strain and vertical lifting and lowering (Figure 15).

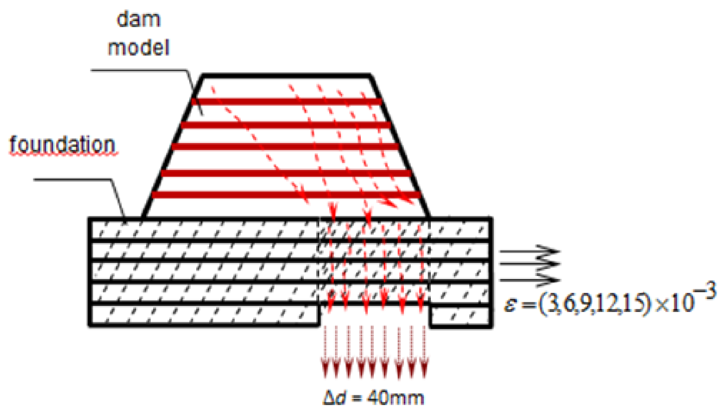

Figure 15. Driving the action of horizontal and vertical deformations employment patterns dams

The following series of tests were conducted:

Performance of tests with models of the dam under various conditions of simultaneous lowering of the subgrade and horizontal stretch base without reinforcement:

aI) deformation of the base in the horizontal direction without reinforcing the dam to a value model $\varepsilon = 3{\times}10^{-3}$ and a vertical lowering the value of the subgrade by an amount Δd =8mm;

aII) deformation of the base in the horizontal direction without reinforcing the dam to a value model $\varepsilon = 6{\times}10^{-3}$ and a vertical lowering the value of the subgrade by an amount Δd =16mm;

aIII) deformation of the base in the horizontal direction without reinforcing the dam to a value model $\varepsilon = 9{\times}10^{-3}$ and a vertical lowering the value of the subgrade by an amount Δd =24mm;

aIV) deformation of the base in the horizontal direction without reinforcing the dam to a value model $\varepsilon = 12{\times}10^{-3}$ and a vertical lowering the value of the subgrade by an amount Δd =32mm;

aV) deformation of the base in the horizontal direction without reinforcing the dam to a value model $\varepsilon = 15{\times}10^{-3}$ and a vertical lowering the value of the subgrade by an amount Δd =40mm;

Performance of tests with models of the dam under various conditions of simultaneous lowering of the subgrade and horizontal stretch base with reinforcement:

bI) deforming the base in the horizontal direction with reinforcing dam pattern to the value $\varepsilon = 3{\times}10^{-3}$ and a vertical lowering the value of the subgrade by an amount Δd =8mm;

bII) deforming the base in the horizontal direction with reinforcing dam pattern to the value $\varepsilon = 6\times10^{-3}$ and a vertical lowering the value of the subgrade by an amount Δd =16mm;

bIII) deforming the base in the horizontal direction with reinforcing dam pattern to the value $\varepsilon = 9\times10^{-3}$ and a vertical lowering the value of the subgrade by an amount Δd =24mm;

bIV) deforming the base in the horizontal direction with reinforcing dam pattern to the value $\varepsilon = 12\times10^{-3}$ and a vertical lowering the value of the subgrade by an amount Δd =32mm;

bV) deforming the base in the horizontal direction with reinforcing dam pattern to the value $\varepsilon = 15\times10^{-3}$ and a vertical lowering the value of the subgrade by an amount Δd =40mm.

Tests in the series aI–bV accompanied unloading base. When modeling research works of the dam without reinforcement with reinforcement was carried out on 5 levels of horizontal and vertical deformation of the base [5].

After each experiment, the soil was taken out from the tray, and is preparing a new foundation for the next series.

Figure 16 shows a comparison of the key stages of the simulation model the stability of the dam, as demonstrated on the stand volume using equivalent materials.

Model of reinforced dam less responsive to tensile deformation of soil foundation and its partial vertical collapse due to «reinforcing effects» of the work, namely, the total length of the cracks in the case of the model dirt dam without reinforcement exceeded in steps in a significant amount of time than the model reinforced soil dams.

According to the graph (Figure 17) shows that the strengthening of dam model reinforcing grid material impact on its stability under the horizontal and vertical deformation.

Figure 16. Comparison of stability modeling key stages for dam model
(a) without reinforcement; (b) with reinforcement).

This option could be considered to strengthen in cases of design of hydraulic structures, as a way to improve their stability and reliability.

Conclusions. On the basis of a combination of results of numerical, model and natural researches of the deformable soil bases values of a limit of stability of the reinforced and not reinforced dams depending on horizontal and vertical deformations of soil thickness are received.

The main influence on change of the general stability and a cracking of soil dams on the deformable bases renders change of an intense and deformable condition of soil thickness as a result of the horizontal and vertical deformations which resulted from a side job.

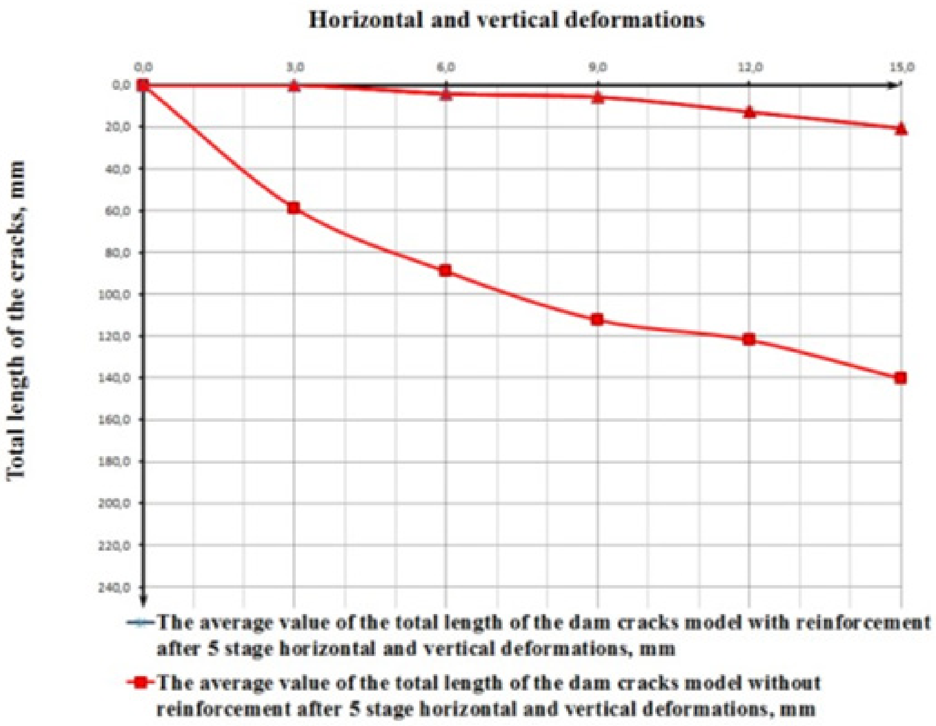

Figure 17. Graphs of reinforced and non–reinforced dam model crack length dependence on horizontal and vertical deformations

Influence of the reinforcing effect at stretching of the soil basis is experimentally proved, i.e. reinforcing of a soil dam geotextile considerably influences increase of stability and reduction of development of a cracking at deformation of the soil basis.

The provided data of an intense and deformable condition of soil thickness in the course of influence of deformations significantly influence the size of disclosure of cracks in the massif of soil without reinforcing, and considerably differ towards reduction of size of disclosure of cracks in the massif of soil with reinforcing.

For research of the behavior of system «a dam – the soil basis» is expedient to use the method of final elements (FEM) which allows to define the general loss of stability and to calculate the intense deformed condition of system «a dam – the soil basis» with any boundary conditions, considering system as a unit.

The used volume stand for modeling of deformations of the basis allows to expand the range of the modeled phenomena close to natural conditions of a side job of hydraulic engineering constructions and allows to study the mechanism of interaction of a soil dam with the earned additionally basis.

The mechanism of the behavior of loss of stability of not reinforced dam model considerably differs from the behavior of work of the reinforced dam model because of the reinforcing effect of the soil massif.

The main achievement of the offered complex technique of determination of the general stability and development of cracking is opportunity to predict change of stability and development of cracks in hydraulic engineering constructions in the course of a side job, and also to define influence of the reinforcing effect on the specified characteristics of research that is significantly important at design of hydraulic engineering constructions, without damage to them in a zone of excavations [6].

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Іргетас деформацияларының құрылыс құрылымдарының тұрақтылығына әсері

Аңдатпа. Бүгінгі таңда заманауи технологиялар құрылымдардың тұрақтылығын болжау жұмыстарын тиімді орындайды, оңтайлы шешімдерді анықтайды және құрылыс конструкцияларының жұмысына болжамды теріс әсерлерін жою әдістерін таңдайды. Олардың ең оңтайлы түрін таңдау нақты міндеттерге байланысты. Мысалы, берік іргетас бүкіл ғимараттың қауіпсіз жұмысына жауап береді. Тиісінше, дизайн берік болуы керек. Дегенмен, құрылымдар құрылысы кезінде іргетас әлсіреп, деформацияланатын жағдайлар кездеседі, әсіресе, ұзақ уақыт бойы салынған жағдайда. Төтенше жағдай және барлық қайғылы ілеспе салдарлары бар объектілердің қирауы, яғни, тұтастай алғанда, Қазақстан Республикасының экономикасына елеулі залал келтіретін өліммен аяқталған трагедиялар. Жұмыстың барлық кезеңдерін жоспарлаудың басында іргетас негізінің барлық деформацияларын ескере отырып, дизайнға ерекше назар аудару керек.

Жалпы, егер біз күшейтудің инновациялық әдістерін қолдана отырып, жаңа конструкцияларды салу сатыларының дұрыс бөлінуін дұрыс орналастырсақ, олардың тұрақтылығына алдын ала талдау жасасақ, онда белгілі бір уақыт өткеннен кейін біз осы мәселені шешудің дұрыс тәсіліне көшеміз. Қолдау жүйелерін болжаудың инновациялық әдістерін қолдану ерекше мәнге ие, өйткені бүкіл құрылымның қауіпсіздігі іс-шараларды дұрыс және уақытылы орындауға байланысты болады. Мақалада негізі салынған «деформация-жауын-шашын» кестелерін бақылау нәтижелері бойынша әсер ететін жыртылған аумақтарда орналасқан топырақ бөгеттерінің мінез-құлқын бақылау сипатталған.

Түйін сөздер: тұрақтылық, іргетастар, сандық әдістер.

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Влияние деформаций фундаментов на устойчивость строительных конструкций

Аннотация. Сегодня современные технологии эффективно выполняют работы по прогнозированию устойчивости конструкций, определяют оптимальные решения и выбирают методы устранения прогнозируемых негативных воздействий на эксплуатацию строительных конструкций. Выбор наиболее оптимального из них зависит от конкретных задач. Например, прочный фундамент отвечает за безопасную эксплуатацию всего здания. Соответственно, конструкция должна быть особенно прочной и долговечной. Тем не менее, бывают случаи, когда фундамент ослабляется и деформируется при строительстве сооружений, особенно тех, которые возводились очень давно. Это приводит к чрезвычайному положению и разрушению объектов со всеми печальными сопутствующими последствиями, то есть трагедиями со смертельным исходом, и значительному ущербу экономике Республики Казахстан в целом. Необходимо в самом начале планирования всех этапов работ уделять особое внимание проектированию, учитывая все деформации основания фундаментов.

В целом, если мы правильно распределим этапы строительства новых конструкций с использованием инновационных методов усиления, проведем предварительный анализ их устойчивости, то в совокупности, через определенный промежуток времени, мы придем к правильному подходу к решению этой задачи. Использование инновационных методов прогнозирования систем поддержки имеет особое значение, так как от правильного и своевременного выполнения мероприятий зависит безопасность всей конструкции. В статье описаны наблюдения за поведением грунтовых плотин, расположенных на подорванных территориях, основание которых подвергается воздействию по результатам наблюдений построенных графиков «деформации-осадки».

Ключевые слова: устойчивость, фундаменты, численные методы.

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