The effect of reinforcement on stability of model of the dam on undermining soil ground

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ABSTRACT

A series of tests with models of the dam (reinforced and unreinforced) to compare the stability of structures with horizontal and vertical deformations. The results of the experiment are shown in the form of photos and graphics. The objects of study in this article are the deformation model of the dam, located on the subgrade. Purpose of this research a comparison of admissible deformations models earth dams, reinforced and non-reinforced, with the partial collapse of the base and at the same time the horizontal and vertical strains of dam.

Keywords: dam, stability, reinforcement.

1 INTRODUCTION

Relevance of hydraulic engineering structures reliability problem is quite important nowadays. The reason for this is a number of regular negative accidents currently happening throughout the world. These are various catastrophes related to dam collapses and bursts, which have a large percentage of wear at the moment due to their long-term service lives. The issue is interesting not only for specialists, but also for Kazakhstani and foreign researchers. Sufficient amount of hydraulic engineering constructions reinforcement variations have been proposed for the time being. But unfortunately the problems of soil dams protection from hazardous impact of different factors such as seismic or dynamic actions, foundation undermining, floods, underground mining activities, etc., in Kazakhstan still remain reasonably complex and poorly explored. In theory, there is a lot of suggestion on hydraulic engineering constructions reinforcement, but in reality there is not enough implementations about this critical problem. As a proof, disasters like soil weirs undermining with human deaths still take place despite the fact that we live in the 21st century. This article examines behavior of soil dam model in different variations of crack resistance deformations. Several model trials were carried out. One of them is an experimental investigation of reinforcement effects on stability of dam model impacted by horizontal deformations of soil undermining foundation.

2 EXPERIMENTS ON THE STAND

Experiments were carried out with the aid of three-dimensional test stand (Figure 1). The test stand (three-dimensional) for soil dam prototype deformations modeling is made in the form of separate U-shaped cross-sections (1). Elastic rubber pads of thickness = 10 mm are installed between the sections. Side ledges of U-shaped sections (1) are equipped with bolted joints (3) in the upper and lower levels horizontally. There are end face walls (4) in a cradle. The lower part of U-shaped sections (1) is equipped with adjustable footings (5), made in the form of roller supports, installed on a bed frame (6).

The test stand for deformations modeling [1] operates in the following way:

U-shaped sections (1) compression or tension is conducted with the aid of bolted joint (3) together with material deformation in the cradle. Horizontal deformations of soil tensorion occur due to compressed elastic (rubber) pads (2) flexible strain forces by loosening bolted joints (3). Horizontal deformations of soil compression occur due to elastic (rubber) pads (2) compression by bolted joints (3) pulling U-shaped sections (1) closer to each other. Vertical deformations occur due to a step-by-step lowering of U-beams (7) installed before the experiment start in accordance with junctions A and B (Figure 1).

As a material for dam and soil foundation model a mixture consisting of 97% fine silica sand and 3% straw oil by weight was chosen. The mixture has strong cohesion which enables to make prototypes of cohesive soils [2].

In order to determine mechanical strength and deformability properties of actual soils and equivalent materials under the vertical loadings a compression kind of stabilometer was applied for horizontal
deformations taking place in undermining conditions.

Fig. 1. Three-dimensional test stand for deformations modeling of soil foundation: a – 3D test stand with soil dam model image, b – 3D test stand diagram (plane view).

Sample put into compression device is matured till full consolidation under the given loading equal to 0.3 MPa.

To applied weightings of vertical loadings in 0.05-0.1 MPa limits.

Vertical deformations of soil sample were measured by clock-face type indicators with scale interval equal to 0.001 mm. Transmission of vertical loadings to the sample was conducted by weighting mechanisms through DOCM-3-5 dynamometer. The pressure was measured by pressure-gauge.

Required parameters are obtained by the results of the testing trials $E$, $c$, $\phi$, $\gamma$ (Table 1).

### Table 1. Physical parameters of full-scale and modeled dams.

| Type of soil                  | $\gamma$ (kN/m$^3$) | $c$ (kPa) | $\phi$ (deg) | $E$ (MPa) | $\nu$ |
|------------------------------|----------------------|-----------|--------------|-----------|-------|
| full-scale soil              |                      |           |              |           |       |
| 1. Loam                      | 20.5                 | 40        | 22           | 20        | 0.3   |
| model of the dam (model soil)|                      |           |              |           |       |
| 2. Sand - 97% + 3% spindle oil| 17.7                 | 0.90      | 39           | 0.27      | 0.25  |

Substitute the corresponding values for modeled and full-scale soil into the equation (1) and obtain linear scale of modeling.

$$m_c = \frac{c_m}{c_n} \times \frac{\gamma_m}{\gamma_n} = 0.9 \times \frac{40}{20.05} = 1/40 \quad (1)$$

Hence, linear scale of model and full-scale object (buildings, foundations, structures) is calculated as a proportion of strength properties (cohesion) of clay and equivalent material and equals 1:40.

As a soil dam model an embankment with the corresponding dimensions was chosen (Figure 1a):

- 700 mm * 350 mm (dam model foundation);
- 200 mm * 150 mm (dam model crest);
- 430 mm (dam model height).

### a) Foundations placement

Before laying a soil foundation, test stand should be installed in such a way so that in the future 1/3rd part of dam model footing was placed to the foundation, lifted to a certain distance with the aid of U-shaped sections (Figure 1 – Junctions A&B). The beams (Figure 1 - 7) are uplifted by bolts to 40 mm.

After preparation of equivalent material foundation can be placed to the 3D test stand. Equivalent material was arranged in layers of 7 cm and was compacted by a rolling press (7 full compaction cycles).

During the foundation preparation process mechanical strength of material should be checked carefully.

### b) Dam model placement without reinforcement

(Figure 2), level-by-level placement in 6 layers of 7 cm plus compaction. Colored sand of thickness equal to $\approx 2$ mm was placed between each layer. A soil sample of each layer should be taken to determine soil density.

### c) Reinforced embankment model preparation
(Figure 3) is carried out in a way of level-by-level placement in 6 layers of 7 cm plus compaction. An embankment was placed with the aid of special shape. Colored sand of thickness equal to \( \approx 2 \text{ mm} \) was placed between each layer. After arrangement of each layer plus coloured sand, a reinforcing net of area equal to dam model’s piling layer area was installed.

A soil sample of each layer should be taken to determine soil density.

d) The average density of foundation soil and soil of dam model with/without reinforcement without consideration of aluminum cup weight (\( \rho = 13, \text{ g/cm}^3 \)) is presented in Table 2.

![Reinforced dam model level-by-level placement.](image)

The process of dam model cracks, deformations and failure development in condition of both horizontal tension and vertical deformation happening in a soil foundation at the same time can be observed and fixed with the usage of a photo camera.

![Horizontal and vertical deformations effect on dam model functioning diagram.](image)

**Table 2. Average density of foundation soil and soil of dam model with/without reinforcement.**

| Layer                          | 1 | 2 | 3 | 4 | 5 | 6 |
|-------------------------------|---|---|---|---|---|---|
| Foundations w/o reinforcement | 118| 119| 119| 120| 119|   |
| Foundations with reinforcement| 119| 119| 118| 119| 118|   |
| Dam model w/o reinforcement   | 119| 119| 118| 119| 119| 118|
| Dam model with reinforcement   | 119| 20 | 119| 119| 118| 119|

An invention and development of digital photography allowed to scheme out a contactless photogrammetric method of prototype systems cracks and other deformations lifecycle monitoring.

Vertical and horizontal deformations of embankment foundation and model during experiments conduction process were obtained using photogrammetric approach. This method helps to determine deformations which occur in plane and are useful to examine flat objects. The method assumes that several images of prototype system can be obtained from one fixed point, e.g. first image obtained before deformations, second – during deformations development and the third – after deformations. Thus, camera should be installed in such a way that plane of applied frame was parallel to plane of an object where image orientation elements should be preserved. In this case a periodic shoot by equipment with high matrix resolving capacity (2000 pixels per 1 cm\(^2\)) should be implemented.

In the given article Canon EOS Rebel T3 / DS126291 camera with matrix resolution equal to 12,2MP was used. The shooting data was recorded for documentation of mechanical measurements at dam model slopes and crest.

The task was to examine model stability in 5 stages of horizontal deformations \( \varepsilon = (3,6,9,12,15) \times 10^{-3} \) and simultaneous vertical failure (Figure 4), using bolted joints to assemble soil foundation part with dam model in variations with and without reinforcement in order to determine conditions of embankment’s critical state [3].

A 3D test stand allows to create independent tension and vertical uplift lowering deformations in a significant range.

The following trial series were carried out:

a) Testing of dam model at different conditions of soil foundation part’s simultaneous lowering and horizontal tension of foundation without preliminary reinforcement.

b) Testing of dam model at different conditions of soil foundation part’s simultaneous lowering and horizontal tension of foundation without preliminary reinforcement.

In accordance with accepted model investigations programmer the following trial series were conducted:

a) Foundation deformation in horizontal direction without dam model reinforcement up to \( \varepsilon = 3 \times 10^{-3} \) and vertical lowering of soil foundation to \( \Delta d = 8 \text{ mm} \);

b) Foundation deformation in horizontal direction without dam model reinforcement up to \( \varepsilon = 6 \times 10^{-3} \) and vertical lowering of soil foundation to \( \Delta d = 16 \text{ mm} \);

aIII) Foundation deformation in horizontal direction...
without dam model reinforcement up to $\varepsilon = 9 \times 10^{-3}$ and vertical lowering of soil foundation to $\Delta d = 24$ mm;

a) IV) foundation deformation in horizontal direction without dam model reinforcement up to $\varepsilon = 12 \times 10^{-3}$ and vertical lowering of soil foundation to $\Delta d = 32$ mm;

a) V) foundation deformation in horizontal direction without dam model reinforcement up to $\varepsilon = 15 \times 10^{-3}$ and vertical lowering of soil foundation to $\Delta d = 40$ mm;

b) VII) foundation deformation in horizontal direction with dam model reinforcement up to $\varepsilon = 3 \times 10^{-3}$ and vertical lowering of soil foundation to $\Delta d = 8$ mm;

b) VIII) foundation deformation in horizontal direction with dam model reinforcement up to $\varepsilon = 6 \times 10^{-3}$ and vertical lowering of soil foundation to $\Delta d = 16$ mm;

b) IX) foundation deformation in horizontal direction with dam model reinforcement up to $\varepsilon = 9 \times 10^{-3}$ and vertical lowering of soil foundation to $\Delta d = 24$ mm;

b) X) foundation deformation in horizontal direction with dam model reinforcement up to $\varepsilon = 12 \times 10^{-3}$ and vertical lowering of soil foundation to $\Delta d = 32$ mm;

b) X) foundation deformation in horizontal direction with dam model reinforcement up to $\varepsilon = 15 \times 10^{-3}$ and vertical lowering of soil foundation to $\Delta d = 40$ mm;

After each trial soil was extracted from the tray and a new foundation was prepared for the following trial series.

Figure 5 shows comparison of dam model stability modeling key stages, as demonstrated on a 3D test stand with the usage of equivalent material.

3 CONCLUSIONS

Following the experiment results, conclusions can be made.

As it can be observed, the crest of a reinforced dam has remained in original state, without cracks which is different to dam model without reinforcement.

Cracks on an unreinforced dam model begin spreading parallel all over the shape with the very first seconds of deformations whether development of cracks on a reinforced model occurs under the reinforcement netting bed (Figure 5).

Model of a reinforced dam is more prone to shear than to crack formation and collapse; the upper part of model placed above the reinforcement net remained in initial state, without cracks in fact, under the condition of dam model shift to 2cm (Figure 6 - Junction B).

It can be concluded from the plot (Figure 7) that strengthening of dam model with the use of reinforcement net significantly affected its stability at horizontal and vertical deformations. Given choice of strengthening can be applied for hydraulic engineering structures as one of the methods to increase stability and safety.

3D test stand allows to examine behavior of dam model with/without reinforcement impacted by different combinations of soil foundation deformations.

REFERENCES

1) Patent 1250808. Test stand for undermining buildings’ foundations deformations modeling/Invented by Zhussupbekov A.Zh., Bazarov B.A., published in B.E.№48, 1991.

2) Zhussupbekov A.Z. Structural properties of buildings’ foundations in undermined areas. - Almaty: Gylym, 1994.
3) Tanaka T., Zhussupbekov A.Zh., Aldungarova A.K.. The influence of the stress-strain state of the soil on the stability of the dam model. «Perspective trends of theory and practice development in soil rheology and mechanics», XIV Soil rheology International Symposium materials, KazGASU–Kazan, 2014