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APPLICATION OF CENTRIFUGAL MODELING FOR THE STUDY OF LANDSCAPE STRUCTURE STABILITY

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ABSTRACT

The calculation of stability by mathematical methods of complex shapes of slopes with a diverse geological structure is reduced to simple formulations and assumptions for finding curves of sliding surfaces and for forecasting possible forms of stability loss. The method of centrifugal modeling allows us to conduct in-depth studies of the experimental, reproduced, reduced scale of the slope and to reliably identify the nature of the existing deformations after rotation on a centrifuge, analyze them and draw conclusions about the stability of the studied slope.

The centrifugal simulation can be divided into four stages, each of which is described in detail in this article with reference to photo materials and descriptions.

The obtained results of the centrifugal modeling of the shifting slope of the Krasnopovstanska ravine and the analysis of the deformed state of the model before and after placement of soil cement piles in the body of the slope.

Centrifugal modeling is not a new method for studying the stability of slopes. This method requires special complex hardware and hardware, therefore, it is used rather infrequently. Conducting this type of research is accompanied by a small amount of informative literature on the methodology of the simulation itself. This article is devoted to the question of conducting and successfully using the method of centrifugal modeling of landslide slopes with the observance of certain features.

Application of the technique of centrifugal modeling allows solving problems of calculating the stability of natural slopes with complex geological structure.

Key words: centrifugal modeling, landslide slope, shear, ground cement pile, sliding surface, deformations.

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1. INTRODUCTION

The theoretical basis of the centrifugal modeling method is the dynamic similarity of Newton. In order to observe the similarity conditions, it is necessary that the volume of the model material be as many times as large as the volume of the rocks weight of the simulated soil, so many times the size of the studied area of the soil array is larger than the size of the model. From this it follows that during centrifugal modeling of static processes it is necessary that the model act on volumetric forces exceeding the forces of gravity as many times the size of the model is smaller than the natural dimensions of the slope.

This circumstance puts a number of technical barriers to the implementation of the method of centrifugal modeling in solving the problem of geomechanics, so this method is often used in conjunction with other methods of simulation, for example, with the method of equivalent materials. The scale of the centrifugal modeling is related to the angular rotational speed of the centrifuge and the radius of rotation of the model with the following relation:

$$K = \sqrt{\frac{e^4 R^2}{g^2} + 1} = 0,102\sqrt{\omega^4 R^2 + 96.24} \quad (1)$$

where =9,81 m/s^2 – acceleration of gravity.

In laboratory practice, an approximate relationship between the number of centrifugal revolutions per minute and the scale of the centrifugal modeling:

$$n = 30\sqrt{\frac{K}{R}} . \quad (2)$$

Of particular note is that the similarity conditions that are observed for models with the location of individual areas of simulation at different distances from the center of rotation is practically not feasible, since it is impossible to provide a rotation of these areas of simulation with different angular velocities. This indicates some incorrect results obtained during centrifugal simulation (DBN B.1.1-24: 2009. Inzhenernyy zakhyst terytoriy, budynkiv i sporud vid zsuviv ta obvaliv. Osnovni polozhennya). At the same time, this method is most effective in studying the processes of controlling the stability of real natural and man-made objects under the influence of gravity and mountain pressures.

The results of the centrifugal modeling of the sloping slope are in fact difficult to predict. Their reliability depends to a large extent on many factors and conditions, the failure to observe or neglect which distorts the actual situation and the development of events for the model when rotating at the centrifuge.

The disadvantages of this investigation method can be attributed to the high probability of error and a large error in case of non-compliance with the simulation conditions.

Due to the high labor intensity of centrifugal simulation, this method of research should be used as an additional one, that is, confirming or refuting the duplicate calculation in the software complex in case of obtaining doubtful or incomparable results.

2. MATERIALS AND METHODS

The modeling of a slope landslide site of the Krasnopovstanska ravine was conducted in the soil laboratory of the department "Bridges and tunnels" of the Dnipropetrovsk National

University of Railway Transport named after academician Lazarian at a centrifuge in the month of July 2017.

Soil samples for centrifugal modeling were taken from wells of the construction site of the residential complex "Ekaterinoslavsky" in the Dnipro-city, the territory of which is located at the street Shevchenko, 51, located near the studied ravine.

Figure 1 The centrifuge was used to study the stability of the Krasnovpostanska ravine slope

According to the physical and mechanical characteristics, the soils of wells and the studied part of the Krasnovpostanska ravine slope have the same structure, stratigraphic index and the same origin, which completely allowed them to be used for the centrifugal modeling of the studied slope.

The accuracy and reliability of the obtained results of centrifugal modeling entirely depends on the accuracy of the reproduction of the slope model soil, namely, the geometric parameters of the model, the determined density of the soaked soil layers and their moisture content according to the geological survey data.

Centrifugal simulation can be divided into several stages:

1. Preparing (creating a model):

– determination of the optimum scale of modeling and rotational time in accordance with the parameters of the centrifuge;

– preparation of the necessary tools and materials required for carrying out the experiment;

– sowing of soil in shallow water;

– winding of the lateral demountable wall with a thin polyethylene film and lubricating the inner surface of the metal form walls of machine oil to enable the model to freely deform under the action of the load;

– the straightening of the soil layers in the metal form to a certain density by applying a set number of stroke loads that are raised and released from the same height through a distribution board covering the entire surface of the soil and accepting strikes from the ram; the density of layers of soil soaked must correspond to the data of geological exploration;

– removal of the metal form wall and cutting of unnecessary soil in accordance with the outline of the defined slab by which the slope simulation is performed; much attention should be paid to the accuracy of the geometric shape reproduction of the studied slope;

Figure 2 Thickness of the soil to a certain density

Figure 3 Slicing the soaked soil according to the profile of the slope

Figure 4 Slope model at scale 1: 100 after cutting of unnecessary soil

– placement of a grid in the size of 2×2 cm on the surface of the soil on the side of the model using a ruler and a pencil;

– installation of a metal wall and twisting of all the bolts that hold it;

– weighing the model;

– weighing of the counterbalance for balancing on a centrifuge;

– installation of the model and centrifuge counterbalance.

2. Centrifuge rotation:

– adjustment of engine rotation parameters according to the model scale;

– engine start and counting of the calculated rotation time of the centrifuge;

– engine stop;

– checking the model and centrifuge status;

– unloading of the centrifuge.

3. Analysis of the deformed model:

– unscrewing the bolts and removing the side wall of the metal form;

– execution of measurements of linear deviations of deformed grid;

– photofixation of deformed parts of the model, soil damage – cracks, shrinkage and deformations that arose as a result of rotation on the centrifuge;

Figure 5. Creation of cracks and separation surfaces, drainage of soil after centrifuge rotation

4. Creation of the model of soil with placement of soil cement piles:

– creation of a model similar to that used for the analysis of deformations in the case of a projected shift;

– arrangement of ground cement piles in the body of the slope by injecting the cement mortar into pre-drilled holes in the soil;

– waiting period of at least 1 day for the set of strength of the soil cement mixture for further rotation on a centrifuge;

– rotation on a centrifuge;

– Analysis of the deformed model with the piles and comparison of the results with the results of the previous experiment.

Figure 6 Positioning of ground cement piles in the body of the slope

Figure 7 Ground cement piles in the body of the slope after excavation of the soil part

3. OUTPUT DATA OF THE EXPERIMENT

Weight of the container with the model of the ground slope: 154.4 kg;
Weight of container with counterweight: 154.4 kg;
Scale simulation: 1:10000 (1 working time is 10,000 hours);
Engine speed: 5.2 Hz;
Rotation time: 82 minutes (1 hour 22 minutes is 570 days);
Transmission coefficient of the central gearbox: 1.576;
(1 centrifuge rotate = 1.576 engine revolution);

$a_c = \omega^2 R$, (3)

$\omega = 2\pi f$, (4)

where f – number of revolutions of the centrifuge (desired value):

$$a_c = (2\pi)^2 f^2 R, \quad (5)$$

$$f^2 = \frac{a_c}{4\pi^2 R}, \quad (6)$$

$$f = \sqrt{\frac{a_c}{4\pi^2 R}}, \quad (7)$$

where R is the effective radius of the centrifuge (R = 2.28 m);

a_c – centrifugal acceleration (a_c = 100 g);

$$f = \sqrt{\frac{100 \cdot 9.81}{4 \cdot 3.14^2 \cdot 2.28}} = 3.3 \text{ Hz} = 3.3 \text{ rotate per second.} \quad (8)$$

Engine speed:

$$n_e = 1.576 f = 5.2 \text{ Hz} = 5.2 \text{ rotates per sec} = 312 \text{ rotate per minute.} \quad (9)$$

The number of cement piles in the model: 14 piles to the width of 220 mm cassettes.

4. CONCLUSIONS

Based on the research carried out, the following conclusions can be drawn:

1. Application of the method of centrifugal modeling stability of the landslide slope allowed to determine the conditions of its stability, taking into account the real forces of gravity, both when found in the natural state, and when it is strengthened in the bottom of the ground cement piles, which cut the imaginary sliding surface of the slope with shear.

2. In the course of pilot studies without piles, a breakthrough crack was created at the bottom of the sloping slope, while the model, which was fixed by ground cement piles, was not the appearance of such a crack.

3. Vertical deformations of the ground slope model obtained in the cassette without piles were 6 mm and exceeded them by 3 times compared to the models of piles.

4. Calculations of deformations made using the finite element method have made it possible to determine the degree of reliability of the conclusions based on the centrifugal modeling taking into account the parameters of the physical and mechanical properties of the real natural slope.

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6. CONFLICT OF INTEREST

The authors wish to confirm that there are no known conflicts of interest associated with this publication.

7. SUMMARY

In this article, the course of implementation of the method of conducting centrifugal modeling of the problem of stability of the natural slope on the example of a real model at a scale of 1: 100 is considered and formulated. On the basis of the conducted research the characteristic features of the stages of centrifugal modeling were analyzed, the dependence of the change in the nature of deformation of the slope model in different conditions was revealed and substantiated, in comparison with the use of soil cement piles, which showed high efficiency, and without them. An example of a simulation of a shear at a centrifuge has proved the effectiveness of the use of ground cement retaining pile constructions as engineering protection of the slope. In conclusion, the author proposes to use the method of centrifugal modeling as auxiliary, in the case of obtaining questionable results of computer end-element modeling, requiring refutation or confirmation.

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