Research of stability of slopes on soil models in the conditions of static and seismic influence

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ABSTRACT

Results of pilot laboratory, field and analytical studies on stability of slopes are presented. The analysis of a condition of slopes is made in connection with construction of the alpine skiing track in the natural boundary the Cook Zhaylau to Alma-Ata, Kazakhstan. Researches are conducted in the conditions of static and seismic impact on slopes. Laboratory researches are executed in a special tray of 200x1500x800(h) mm where natural soil – collapsible loam was modelled by specially picked up composition of soil. The configuration of slopes is picked up on actual by data geodetic measurements и geological researches. Special powder sensors are applied to fixing of destructions in a tray. As a result of researches platforms on which there is a destruction of slopes are visually recorded. Regularities of their formation depending on location and force of static influence, and also for seismic influence with a force of 8 and more than points on a scale MSK 1964. In addition on slopes analytical calculations with use to the Calculation of Stability of Slopes and Plaxis programs are executed. Calculations are executed on static and seismic influences. Data on coefficient of stability and registration of isolines of tension and deformations are obtained. Comparison of experimental and settlement data allowed to increase the accuracy of definition of some boundary conditions put at experimental modeling of slopes and to increase reliability of calculations for determination of coefficients of stability.

Keywords: slope, shear plane, stability of slopes, researches platforms, slope model

1 INTRODUCTION

Almaty is one of intensively developing cities of the Republic of Kazakhstan. The reasons causing such development the different. The city is in places of Zailiysky Ala Tau with very beautiful nature. It allowed to build many world-class sporting venues, such as a mountain skating rink of "Medeo", a complex of alpine skiing springboards, biathlon stadium here, etc. Construction of the subway and numerous automobile outcomes improved infrastructure of the city. However it is necessary to make still much more in communication the demand of the city of Almaty for holding 22 winter Olympic Games. One of construction objects is "The ski slope 2A" which will be located on picturesque slopes Kokzhaylau and Kumbel (the city of Almaty - Kazakhstan). Design and construction of the route happens successfully, even despite rather difficult geological conditions of the region. Complexity consists in distribution of macroporous loessial soil and high seismic activity of the area.

2 GEOLOGICAL REGION STRUCTURE

Zailiysky Ala Tau has a complex geological structure. It is connected with broad development Precambrian and the nizhnepaleozoyskikh of metamorphic educations, various on structure and age of intrusions. The Stratigrafichesky section of deposits of the area is presented effuzivno - a sedimentary formation of Devon, intrusive educations and deposits of quarternary system. The main part of the studied territory is put by intrusive educations - cambrian, ordovician and Devonian.

Cambrian intrusions are presented by olivinovy norita, gabbonorita. Ordovician intrusions are developed in the area most widely. They are presented by adamellita and granites, granodiorita meet less often. Devonian intrusions are presented largely and coarse-grained granites.

Northern Ridges Tien Shan and Zailiysky Ala Tau are the most seismodangerous regions of Central Asia. Last century there was about ten strong and catastrophic earthquakes here, Vernenskoye, Chilikskeye, Zhalanash-Tyupskoye.

The area of researches is located in the active

tectonic zone formed by system of the pulled together breaks having the general northeast direction. Magnitudes of the expected maximum earthquakes for them are made by $M_{max} = 7-8$. As probable intensity of earthquakes near the designed routes can reach $J = 9-10$ points on a scale MSK 1964, effects of general destruction of buildings and constructions, cracks in soil, high waves in a reservoir are possible here.

Accelerations in soil massifs at $J=9$ reach $A_h = 200-400$ cm/sec., the speed of fluctuation of soil $V = 16-32$ cm/sec., at $J=10$, respectively, $A_h = 400-800$ and $V = 32-64$ cm/sec.

On a construction site "The ski slope 2A" in a geological structure four engineering-geological elements are allocated:

IGE-I - loams collapsible, brown color, a firm consistence. Initial collapsible pressure makes 0.225-0.350 MPa. Type of soil conditions on a prosadochnost – II. Depth of collapsible thickness near 5.0m.

IGE-2 – gravel soil with inclusion of blocks to 20-25%. Filler – loam from 10-15% to 15-20% on volume.

IGE-3 – clumpy soil with inclusion of crushed stone to 10%. Filler – loam to 15-20% on volume.

IGE-4 – radical granites, weathered to 0.3-0.5m.

Engineering-geological researches of a site were conducted by three companies. It should be noted that final data of researches differ.

The main are brought in table 1 of values of physicomechanical properties of the soil received by the different companies.

Table 1 - Properties of soil by results of field researches

Name Prospecting organization	№ IGE	Parameter			Data on seismicity
		Density, τ/m^3	Angle of Internal friction, ϕ град	Cohesion, κPa	
TOO «Desing Concept»	1	1,69	20	21	The area - 9 ball, Category of soil - II
	2	1,94		-	
	3	2,01		-	
	4	2,82		-	
TOO «Дергач»	1	1,9		-	Area-10 ball., platform - the 10 ball, Category of soil II
	2	1,92	-	-	
	3	2,06	-	19	
	4	2,13	23	24	
TOO «Казэн ерго наладка»	1	1,49	16		Area-9 ball., platform - the 10 ball, Category of soil II
	2	2,28	39		
	3	2,6	38		
	4	2,68			

The ski slope passes across the ridge and has length of 2903 meters. The difference of levels of heights of the route makes 695 meters and an average bias to 25%. However slopes of ridge have a

bias from 20 to 46 degrees to a horizontal. For determination of stability of slopes in calculations 3 main IGE are accepted. It is loam collapsible - IGE 1, shchebenisty soil with loamy filling - IGE 2 and the IGE 3 rocky soil. In our opinion in the first two, especially in loams perhaps intensive development of landslide processes. Physicomechanical parameters of this soil are specified in table 2.

Table 2 - The properties of soil accepted for calculation

Parameter	Loam collapsible - ИГЭ 1	Pebble soil - ИГЭ 2	Rocky soil - ИГЭ 3
Depth, м	1,5-3	2	There are no data
Density, τ/m^3	1,5	2,15	2,6
Cohesion, κPa	27	35	-
Angle of internal friction, град	21	40	-

3 METHOD OF CALCULATION OF STABILITY OF THE SLOPE

Methods for calculation of limit balance of slopes are defined by geometry of a slope and a geological structure. Methods change from simple transmitting sliding along the equal plane, before movement along the sliding plane with a difficult relief, including curved and flat surfaces. The simplest forms of a curved surface include circular arches. Further we will consider surfaces of this kind which usually correlate a turning point of MO at a turn point by the returning MR moment:

$$F = \frac{M_R}{M_G}; \quad (1)$$

To consider unstable conditions along a surface of sliding and in the most slipping weight, breakdown of the slipping weight on cuts is usually applied, and stability of each cut pays off in turn. Results on each cut are summarized for receiving general meanings on slopes and coefficient on which value of reliability of soil shares to simulate slipping.

At calculation of the drained conditions (effective tension) the actual strength on shift along the plane represents function of the effective normal tension and effective cohesion operating on this plane. At calculation of not drained conditions (total tension) the actual strength on shift represents function of actually not drained durability that considerably simplifies calculation.

The coefficient of reliability of F is determined by a formula:

$$F = \frac{M_R}{M_G} = \frac{\sum(c_{eff} \cdot l_i)}{\sum((w_i + q_i) \sin \alpha_i)}; \quad (2)$$

Calculations for the slopes formed by pebble of soil and the long-term slopes formed by melkozernistny soil should be made on the basis of effective tension. Action of the normal tension directed on the sliding plane on lateral faces of cuts is conducted to uncertainty of the main equation, and

to impossibility to receive the closed decision forms.

Methods similar on the most widespread method of Bishop for kruglotsilindrichesky sliding (differently called "The Uproshcheny method") allow the simplifying assumptions concerning interslice forces, and with application of iteration allow to receive F - global coefficient of reliability of a slope. Advantage of the most widespread method of Bishop is that it completely meets conditions of balance of the moment and horizontal forces (but not balance of vertical forces though this condition doesn't matter)[1]. For other surfaces of sliding alternative decisions were also received.

Reliability coefficient on the most widespread method of Bishop pays off as follows:

$$F = \frac{\sum_i \left\{ \frac{c' + (w_i + q_i - u_i) \tan \varphi_i}{1 + \tan \alpha_i \left[\frac{\tan \varphi_i}{F} \right]} \right\}}{\sum_i [(w_i + q_i) \sin \alpha_i]} \quad (3)$$

Where b_i – width of a cut of 'i'; u_i – porepressure of water; c' - effective cohesion; φ – angle of resistance to shift along the basis of this cut; and other variables pay off in the known way.

Check of stability of slopes taking into account seismic loading is executed by introduction to calculation of additional horizontal forces. These forces are defined by multiplication of weight of soil by coefficient [2]. Values of the coefficient considering seismic impact on the moving compartment of the soil massif according to norms is accepted equal 0,05; 0,075 and 0,15 respectively for settlement seismicity of 7, 8 and 9 balls on a scale MSK 1964.

As the territory of an arrangement of slopes is in areas with seismicity of 10 points, values of coefficient are recommended to be accepted equal 0,3[4].

Having calculated equally effective soil compartment weight forces, the horizontal force of seismic influence is determined by a formula:

$$G_{si} = G_i \sqrt{1 + k_{hf}^2}; \quad (4)$$

Further the horizontal force of seismic influence within a compartment it is displayed on components: normal N_{si} and tangent T_{si} . Determination of full values of the shifting and holding forces, taking into account seismicity, acting within the allocated compartment, figure 1, it is necessary to carry out with use of the following equations:

$$T_{c\partial s} = G_i \sin \alpha + G_{si} \cos \alpha \quad (5)$$

$$T_{yo} = (G_i \cos \alpha - G_{si} \sin \alpha) \tan \varphi + c_i l_i \quad (6)$$

At an unstable condition of a slope it is necessary to provide engineering actions for ensuring stability of a slope. For example soil fixing with anchor piles or construction of retaining walls on local sites. In a design retaining walls can be in the form of classical retaining walls and the tape bases or on the pile bases, and also walls from the bored piles located "to

each other" or in the form of "the splitting piles" can be designed.

Fig. 1 - The scheme of an arrangement of vectors of forces in a compartment of the soil massif at calculation on seismic loadings.

4 LABORATORY RESEARCHES

With the purpose to study geometry of formation of a surface of sliding at destruction of a slope of test were carried out on slope model to Geotechnics in Construction laboratories of the Kazakh Leading Academy of Architecture and Civil Engineering. Experiment is executed in the special tray having a transparent wall for a visual fikvation of process of destruction. The volume of a tray makes 0,2 m3. Length 120sm, height 80sm, width 21sm.

Description of model of soil. For modeling of cohesion soil like loam, mix with the following ratio of components was used: sand silty - 83%, rubber shaving - of 7%, a veretenka oil - of 10%. The mass of ispytayemy soil makes 100kg. Density of soil was set approximately ravny as for IGE 1, table 2.

Vertical load of a brow of a slope was transmitted a jack through a stamp, the size 20x20sm. The size of loading was fixed by DIN-1 dynamometer. Tests were carried out both in static, and in the dynamic mode. At static tests the question as removal of loading from a brow of a slope was investigated influences geometry of formation of a platform of sliding. Loading was put by steps on 0,5-1,0kH. I made the maximum pressure on a sole of a stamp to 100kPa. The dynamic mode modelled one vector seismic influence in the horizontal direction. Intensity corresponded about 9 points on a scale MSK 1964. The angle of a natural slope of model made 43-45 degrees to a horizontal.

On an external surface of a transparent wall of a tray the measuring grid with a cell step 2sm is drawn. For control of geometry of deformation of a slope in a zone of possible shift vertical beacons sensors were established. Beacons represent the vertical strips made of powder of talc which is deformed together with soil. It allows to see shift traces after the appendix of steps of loading.

During test there is a soil sliding. Nature of deformation of beacons allows to track nature of formation of the planes of sliding. In the course of experience vertical deformations of a stamp and

horizontal shift of a surface of a slope. Data of measurements are provided in tables 3.

Some results of static tests are given in fig. 2 of fig. 5 Experiment No. 1 the Sequence of results of experiment is given in fig. 2 - 6.

Fig. 2. A general view of an experimental slope in a tray

Fig. 3. A soil settlement after a step of-150 kg.

Fig. 4. A soil settlement after a step of-200

Fig. 5. A soil settlement after a step of-250 kg.

Table 3- Main results of static tests

№ loading	loading N κH	Horizontal S, M	Vertical S, M
Results on experiment №1			
0	0	0	0
1	0,80	0.007	0.02
2	1,50	0.018	0.038
3	2,0	0.025	0.05
4	2,50	0.04	0.08
Results on experiment №2			
0	0	0	0
1	1,0	0,008	0.02
2	2,0	0.034	0.04
3	3,0	0.06	0.06
4	4,0	0.08	0.10

Final results of formation of a shear plane in experiment 2 are given in fig. 6 In figure - 6 the total last deformable stage is shown. Experiment in a tray with the same structure in the same tray with nagruzoky to 400kg.

Fig. 6. A soil settlement after 400 kg.

Results of dynamic researches are processed and in this article aren't given in connection with large volume of information.

5 CALCULATION OF STABILITY AND CHOICE OF ANTIDEFORMATION ACTIONS

At design of the Skiing run more than 100 options of potentially unstable hillsides were chosen. However we will show the general approach of carrying out test calculations and check of the chosen antideformation actions on two slopes, it is a slope 69 and a slope 96. Calculation of stability of slopes is executed with use of the Slope 5 program. The program is recommended for calculation of stability of earth slopes for on the round surfaces of sliding. The coefficient of a stock of stability of a slope is determined by the following three methods of calculation: method Bishopa; K. Tertsagi's Method, Method "Weight pressure" (Chugayev's method).

In the program characteristics of soil are set, coordinates of a surface of a slope, a curve depression and borders of soil are entered. The area of the centers and radiuses of surfaces of sliding set manually. In the program calculation of a slope taking into account action of seismic forces and an external prigruzka on it is possible.

When using a hypothesis of a round form of a potential surface of sliding value of coefficient of a stock of stability is established proceeding from a condition of static balance, a formula (1).

This program divides a slope into 100 compartments generally and allows to increase quantity of compartments to 1000. Standard coefficients of a stock of stability of Kz are established corresponding Construction Norms and Regulations and are ranging from 1.05 to 1.1 for special combinations of loadings and from 1.1 to 1.3 for the main combinations of loadings.

Fig. 7. General view of the settlement scheme of a slope 69.

Fig. 8. General view of the settlement scheme of a slope 96.

Calculation of stability of slopes on seismic intensity on a scale 1964 was carried out MSK to 10 points about use of the Excel program for the technique described in section 3 on formulas (4)-(6). The results of calculation are given in table 4.

Value of coefficient of reliability of F is less demanded 1,2 for these constructions therefore strengthening of a slope is required. We apply a retaining wall on piles with anchor fastening to the soil massif to strengthening [3]. Settlement schemes for a slope 96 are given in fig. 9 and fig. 10. Piles plunged below a surface of shift and perceived the shifting loading. Anchor devices provided steadier provision of a retaining wall.

Name of slopes	Values of coefficient of reliability of F		
	At СНиП II-7-81	At СНиП РК 2.03-30-2006	
	9 balls	9 balls	10 balls
Slope 69	1,94	1,35	0,9
Slope 96	1,46	1,42	1,08

Fig. 9. General view of the settlement scheme of strengthening of a slope 96.

Fig. 10. Horizontal tension of soil of a slope 96.

6 CONCLUSIONS

1. Data of geological researches of a site of construction "The ski slope 2A" showed that on slopes layers, potentially dangerous and inclined to sliding, are: loam collapsible and shchebenisty soil with loamy filler. In this soil, especially in at water saturation, decrease in parameters of durability φ and c to 30% is observed. It leads to reduction of forces holding a slope in equilibrium state.

2. By tests in laboratory of models of soil slopes "The ski slope 2A" in a special tray in the conditions of static and dynamic loading it is received that the form of a shear plane is formed in the form of an ellipse or a circle. In the conditions of action of static loading it is received that than external loading is farther from a brow of a slope and the more an ultimate load and the more deeply the shear plane is located.

3. The results of calculations received on Construction Norms and Regulations of II-7-81 and use of methods of Bishop, a method of Tertsagi at seismic activity to 9 points showed that in natural state slopes are steady and the coefficient of stability fluctuates in the range 1,46-1,94.

4. Results of calculations for a method of round-cylindrical surfaces of sliding, with seismicity coefficients according to tab. 5.5 Construction Norms and Regulations of PK 2.03-30-2006 [5] showed that at seismic activity of 9 points in natural state slopes are steady and the coefficient of stability of slopes fluctuates in the range of 1,35-1,42. At seismic activity of 10 points the coefficient of stability changes in the range of 0,9-1,08. In general by the executed calculations the stability coefficient for the checked slopes is less or is equal 1,0 that testifies that slopes unstable.

4. We apply a retaining wall on piles with anchor fastening to the soil massif to fixing of slopes. Piles plunged below a platform of shift and perceive the shifting loading from the slipping soil. Soil an anchor like "Titan" provide additional stability and durability of a retaining wall.

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