EXPERIENCE OF CONSOLIDATION OF LOESSIAL COLLAPSIBLE SOILS ON LANDSLIDE SLOPES ENERGY OF DEEP EXPLOSIONS

EXPÉRIENCE DE CONSOLIDATION DE SOLS PLIANTS LOESSIAL SUR L'ÉNERGIE DE PENTES D'ÉBOULEMENT D'EXPLOSIONS PROFONDES

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ABSTRACT: In article problems of development of the territories presented by a difficult relief and big thickness of loessial collapsible soil in seismically active regions are considered (on the example of the Republic of Tajikistan). The analysis of results of the pilot studies received at consolidation of collapsible soil by soaking and energy of deep explosions in the conditions of a difficult relief and a landslide - a dangerous slope is provided.

RÉSUMÉ : Dans l'article on examine les problèmes de la mise en valeur des territoires présentés par le relief complexe et une grande épaisseur de loess de ramollissement грунтов dans les régions sismiquement actives (à l'exemple de la République de Tadjikistan). On amène l'analyse des résultats des études expérimentales reçues à la condensation de ramollissement грунтов par l'humidification et l'énergie des explosions profondes dans les conditions du relief complexe et le glissement de terrain-dangereux de la pente.

KEYWORDS: hilly territories, difficult relief, a landslide - a dangerous slope, loessial collapsible soil, methods of the device of the bases, deep explosions, seismic influences

1 INTRODUCTION

The Republic of Tajikistan is located in a seismically active region and about 93% of its territory are mountains, which are characterized by "floor" change of terrain. There are four main floors (tiers): foothill, lower, medium and high mountains. Foothill (hilly) areas are found in all regions of the Republic, is represented by a complex (dismembered) relief and their area is more than 5000 km^2. The surfaces of many of the hills have soft outlines, which are due to them composing the loess soils, the thickness of which in some regions can reach 300 m or more. However, the subsidence properties have only the top 25-30 meters, which belong to the category of high compressibility.

Major depression (valley) of the Republic are the main places of settlement and human activities, developed well and is only 7% of the total area of the country. The basis for the development of the national economy is the agricultural sector, and therefore most of the lowland areas allocated for the production of cotton, fruits and vegetables. The shortage of land, the main reserve for development of all sectors of the economy, requires a reasonable use, and always have been particularly problem. One possible and feasible solution to this problem is the development of foothill areas under building of buildings and constructions of various purpose, which will allow you to release significant lowland areas.

It should be noted that the foothill (hilly) territories characterized by the presence of steep slopes from 25° to 65° or more, stacked collapsible soils related to the II type of settlement (expected drawdown from the self-weight of soil 20 cm). Increasing the natural moisture many of the slopes belong to the category of the landslide-threat. Therefore, during development it is necessary to use measures that will allow:

- eliminate subsidence properties of soils throughout the depth subsiding thickness;
- increase their strength and deformation characteristics, to ensure their stability in the context of increasing humidity of the soil mass;
- to ensure the stability of slopes in high seismicity areas.

In Table 1 shows a list of methods and ways that allow to solve the above problem.

Table 1. Recommended anti-subsidence and anti-landslide activities in the development of the hills

№	Methods of preparation of bases and the installation of foundations
1	The device of condensed soil cushions increased thickness ($h \geq 4$ m) with the use of water protection measures
2	The soil soaking and energy of deep explosions
3	The soil reinforcement by punching, pressing and rolling of the wells and their subsequent filling with material of high strength
4	The soil reinforcement jet and soil-limes piles
5	The soil reinforcement bored piles
6	The soil reinforcement precast piles and printed
7	Reinforcement of soils by grouting, silicatization, solitaria and chemical solutions.
8	Reinforcement of soil using the technology of high-pressure injection
9	The reinforcement of soils using brown-mixing technology
10	A high strength geosynthetic soil reinforcement materials

In practice, the most widely used first three methods, which are characterized by a simple production technology works, low complexity and low cost. In addition, he conducted the corresponding experimental and theoretical investigations. Other methods have not found application as they require:

- use of special equipment and technologies;
- a large volume of preparatory works in conditions of complicated relief;
- characterized by high complexity and cost.

In addition to them, there are no relevant experimental studies.

Existing experience shows that in complex terrain and loess subsidence of soils is often more effective is the use of the method of soaking with subsequent hardening of the soil, the energy of deep explosions (NIISK of Gosstroy of the USSR 1984; Mangushev, Usmanov and etc. 2012), which has the following advantages:

- allows to significantly improve the efficiency (quality) compaction and subsidence of ground in comparison with the usual soaking, to increase their strength and deformation characteristics, to ensure the stability of their indicators with a possible further increase in the moisture content of the soil;

- explosive simulate seismic effects that contribute to the manifestation of all possible deformations of the soil (including the so-called post seismic) and to provide seismic stability of slopes;

- the method requires the use of sophisticated equipment, is very simple production technology works, the least complexity and cost compared to other methods and ways.

The essence of the method lies in the fact that initially, the sealing pad comes off the pit at a depth of 1.0...1.2 m (Mangushev, Usmanov and etc. 2012). Further, according to a certain grid (4·4, 5·5 or 6·6 m – depending on soil conditions) at a depth h = (0,7...0,8)H_{sl} (H_{sl} – collapsible column) are drilled drainage wells with a diameter of not less than 180 mm, which is lowered to the special design of the explosive columns, and the remaining space is filled with filter material (sand or gravel). In practice, they are known as combined drainage and blasting wells (Figure 1).

The design of the explosive column consists of a tightly connected to the protective tube diameter $d \geq 50$ mm and welded to the container (with a diameter slightly less than the borehole diameter) to accommodate the explosives. As protection of pipes and containers can be used for pipes of metal, PVC or other materials. The height of the explosive column should be 0.3…0.5 m to exceed the level of the surface of the earth.

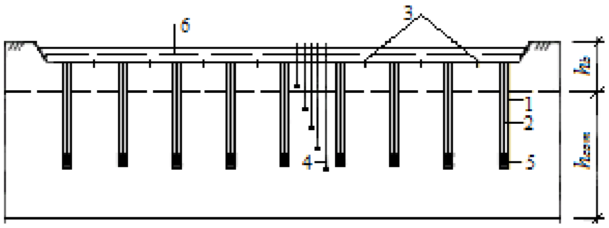

Fig. 1. Schematic section of the pad when soaking through the excavation: 1 - drainage-explosive well; 2 - the explosive column; 3 - surface stamps; 4 - deep brand; 5 - explosive substance; 6 - water column; h_{com} – sealing, the thickness of the soil; h_b – buffer non compacted area

The soaking of soil is carried out by maintaining the water level in the pit to a height of 0.8…1.0 m to a complete drenching of the entire thickness (to the degree of ground moisture content $S_r \geq 0.8$) and reaching the conditional stabilization drawdown of their body weight (an increase of deformation not more than 1 cm in the last two weeks). To speed up filtration of water in the depth of soil on the bottom of the pit slept draining layer of sand with thickness of 5-10 cmю After soaking in a container of an explosive well placed explosives and performed their simultaneous blasting. Using this method, the top layer thickness of soil (thickness 2…3 m) remains not compacted (buffer layer), which is then compacted heavy rammers or replaced with compacted soil cushion.

However, the use of hydro explosive method in the complex terrain associated with the risk of disturbance of slope stability in the explosions. Therefore, the authors over a number of years has conducted studies to determine the feasibility and improve the technology application of this method under specified conditions. The following are the results of experimental studies on the compaction of a large thickness of the loess subsidence of soils is improved by soaking method at the base of the complex of buildings erected in complex terrain (landslide hazardous slope) with the seismicity of the territory of 9 points.

1.1 *Research Methodology*

The study was conducted in one of the southern regions of the Republic of Tajikistan, having hollow accumulative relief with General slope to the East. From the West the area is bounded by the slope of the channel, to the East is a three-stage slope at an angle of 45...60° (Figure 2).

The construction area is composed of loess-like loams and loams solid consistency, which at a depth of 25 to 30 m thick layer of land pebble deposits. Soils are characterized by low values of density in the dry state (ρ_d = 1.25…1.45 t/m^3) and refer to high collapsible (subsidence from own weight of soil when soaking according the compression test is $S_{sl,g}$ = 21 cm). Groundwater at depths greater than 30 m were not detected.

Previously there were calculations of stability of slopes, located on the East side (where the drain-explosive wells are at a distance of 1.5 m from the edge of the slope), analytical methods using the method circular-cylindrical sliding surfaces (Il'ichev, Mangushev and etc. 2016). The calculations showed that the slope can become unstable not only when hydro-explosive, but prolonged soaking of the array. Nevertheless, the training project of the buildings provided for the compaction and subsidence of ground preliminary soaking through the pit and the energy of deep explosions (hydro-explosive etc.).

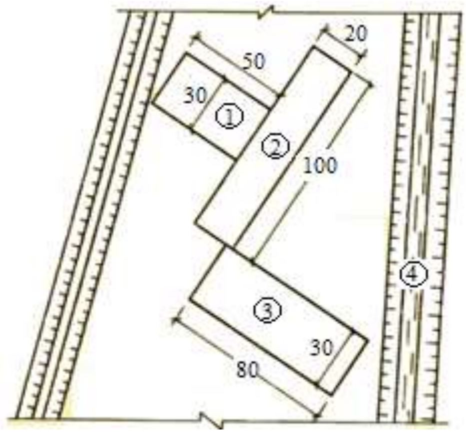

Fig. 2. Site plan construction: 1, 2, 3 – sealing areas; 4 - water conveyance channel

It should be noted that the soaking of soils through the excavation has a number of disadvantages: a large amount of earthwork in the dredge excavation, a large volume of water on the surface of the array, the complexity of carrying out measurements of deformations of the surface and deep brands, reduced filtration of water in the depth of soil due to possible clogging of the bottom of the pit, the complexity of the placement of explosive charges in containers, a large volume flow of water etc.

Taking this into account was proposed and implemented method for metered soaking (Mangushev, Usmanov and etc. 2012), which is devoid of all these shortcomings. The pit does not come off (not selected layer will act as an additional load), and soaking of the soil is from the surface through a special distribution network (Figure 3).

At the same time, from the surface to the required depth are drilled drainage wells for subsequent installation in them of explosive columns. The soaking of soil is performed by spraying water through a special water distribution network, located on the earth's surface and consisting of a water-supply main pipes and flexible hoses, water outlet for each drain-explosive well. The volume of water supplied in each hole can be controlled by valves (dosed soaking), which allows uniform and high-quality soaking the entire thickness. Industrial experience shows that this method can reduce water up to 30%

compared to using the soak pit, with high quality seal ground column.

The project compaction, this method involved the drilling and construction of a 271 combined drainage and blasting of wells located in a square grid with a step 5•5 m. Extreme the wells were located near the edge of the slope: from the East side at a distance of 1.5 m, and from the West – 3.5 m (see Figure 4). Drainage wells with a diameter of 180 mm was reburials to a depth of 16…17 m. For measuring the overall and layer-by-layer deformations of the soil mass was set superficial marks on the grid 5•5 m - across the sealing area and depth marks at depth 3, 7, 11 and 15 m in the center of the sealing area.

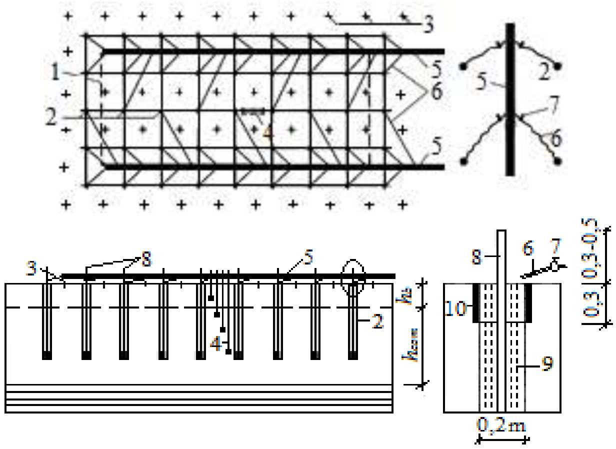

Fig. 3. Schematic plan and section of site: 1 - the contour of the projected object; 2 - drainage-explosive wells; 3 - surface stamps; 4 - deep brand; 5 - main water-supply pipe; 6 - flexible water-supply hose; 7 - valve; 8 - the explosive column; 9 – sand or gravel; 10 - protective headband

The explosion parameters were calculated based on the compaction of the upper 20-meter thickness, assuming that the lower layers are effectively compacted under the weight of the overlying layers of soil in the process of soaking and in the period after explosive consolidating water-bearing strata. Explosive charges weighing 8 kg of grain water-resistant packaging and labelling was located at a depth of 11 m below the surface (see Figure 4).

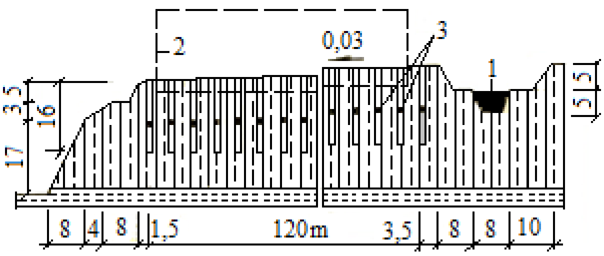

Fig. 4. Schematic section view of the construction site: 1 - water conveyance channel; 2 - loop design of the building; 3 - location of explosive charges

1.2 *The results of the research*

Soil compaction was carried out in stages while the site No. 1 was drilled 70 wells at the site No. 2 - 105 wells; site No. 3 - 96 wells.

Site No. 1 were soaked for 14 days. The calculated amount of water was supplied directly to each well via a temporary water separating system and was regulated by the valves (according to the scheme in Figure 3). Observations have shown that the process of soaking was not the case the appearance of water on the surface of the slope and the violation of its stability. The drawdown surface in the process of soaking was 25...35 cm, i.e. larger than expected.

Explosions produced will produced on hook from 14 wells, i.e., two rows of seven wells. The mass of simultaneously exploding the explosive charge was 112 kg. Thus, at site No. 1 was carried out five explosions. It should be noted that from the effect of explosions no signs of collapse or landslides was not observed, although extreme well is located at a distance of 1.5 m from the edge of the slope. Apparently the stability of the slope has not been violated due to the strictly regulated and accelerated flow of water directly to wells, as well as the explosions of explosive charges below its elevation, i.e. at a depth of 11 m.

After the explosions there was a sharp lowering of the surface at 90...100 cm. Intense squeezing of water from the interior of the ground through wells to the surface testified to the presence of after explosive process of consolidation of water-saturated loess strata of the damaged structures. After explosive deformation in the first day proceeded with great speed, and then sharply decreased. Conditional stabilization of deformation occurred 18 days after explosion, and after explosive consolidation was 60...80 cm. The total deformation of the seal at site No. 1 made S_{tot} = 180...210 cm.

In Figure 5 shows graphs of the deformations in depth. Subsidence deformation appeared after three days from the moment of water flow, characterized by the appearance of cracks around the court. According to the testimony of the deep drawdown brands originally appeared in the layer 11...15 m as the most subsidence. In the layers below 15, and 7...11 m drawdown manifested through four, and in the layer 3...7 m – seven days. By the end of the soaking drawdown was evident in the upper three-meter layer. As can be seen, in process 15-day soaking dipped almost the whole subsidence thickness. Subsidence deformation indicate sufficient uniformity of the seal not only in the process of soaking, but in the period after explosive consolidation.

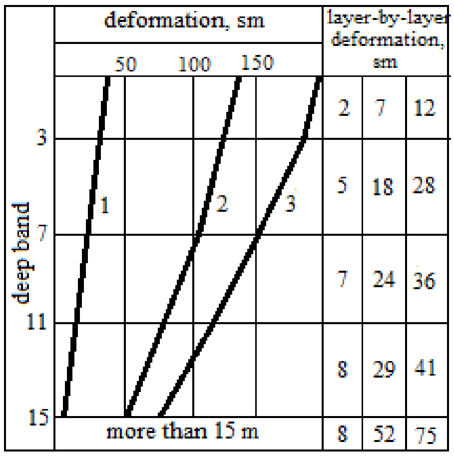

Fig. 5. The development of layer-by-layer deformation in the depth subsiding strata site №1. Curves: 1 - before explosions; 2 - immediately after the explosions; 3 - after the stabilization of all the strains

After the successful completion of works on site No. 1 was compacted collapsible soils and on sites No. 2 and 3. At site No. 2 soaking of the soil and blasting was carried out for 11 and No. 3 within 13 days.

In Table 2 the data of the calculated and actual deformation of collapsible soil thicknesses for all sites. As you can see, the actual deformation is 10 times higher than expected drawdown from the self-weight of soil defined according to the compression test. However, actual deformation is slightly higher than calculated and when hydro-explosive method. This suggests that after compaction the dry density of the soil becomes greater than 1.6 t/m^3, based on which were determined the estimated deformation (Ruziev 1988). From the last column of the table shows that the deformation of the seal is about 10...11% of the capacity of the compacted layer.

Table 2. The values of the calculated and actual deformation of the sealing sections

Sites	The expected subsidence from own weight of soil, cm	The total deformation after hidro-explosive, cm
1	21	180...210
2	21	200...230
3	21	180...200

To assess the quality of compaction within 2 months after the explosions, the ground No. 1 and 2 were based on two of the test pit to a depth of 10 m with a selection of the monoliths every 1 m in depth. Laboratory results showed that the dry density of the soil below 2...3 m policies to ρ_d = 1.60...of 1.68 t/m^3 and the relative settling at pressure p = 0.3 MPa was less than $\varepsilon_{sl} \leq 0.01$, i.e. subsidence properties of soils eliminated over the entire depth strata. An increase in deformation and strength characteristics of soil: the value of deformation modulus in saturated condition increased from E = 5...7 MPa to E = 12...14 MPa, and the values of angle of internal friction and adhesion, respectively, amounted to φ = 18...20°, c = 18...22 kPa.

This method at the construction site with difficult hilly terrain was condensed about 150 thousand m^3 of soil subsidence. The cost of 1 m^3 compacted soil was 40 cents ($0.4).

2 CONCLUSION

1. Experimental research and production practice, the high efficiency and the feasibility of using the accelerated method hydro explosive in the difficult hilly terrain.

2. In such conditions, soaking the soil to be made with use of measured soil subsidence soaking strictly calculated amount of water by feeding it directly into each well. Using this method allows you to refuse the development of the pit and on 20...30% decrease in the volume of water required for soaking.

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