Methods of restoration of deformed retaining walls in seismic conditions

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ABSTRACT

According to the results of a preliminary survey of the state of retaining walls, slopes and data of engineering and geological conditions in the foothill areas of Zailiysky Alatau, the most dangerous and characteristic areas were identified. Their geological structure has been established and options have been given for restoring retaining walls, ensuring the operational reliability of slopes and slopes of various steepness. The calculated justification confirmed the effectiveness of the proposed methods and gave specific constructive measures.

Keywords: slope, collapsing soils, retaining wall, active pressure, ground anchors, reinforcement, earthquake zone

1 INTRODUCTION

Intensive development of the economy of the Republic of Kazakhstan, raising the standard of living of the middle strata of the population has led to the active development of environmentally friendly and beautiful natural places. For the most part, these places are located in the foothill and mountainous areas of the Trans-Ili Alatau. The territories are formed by loess aeolian and deluvial sediments represented by loam. Loams are structurally unstable soils, especially in the case of active moisture and seismic loads.

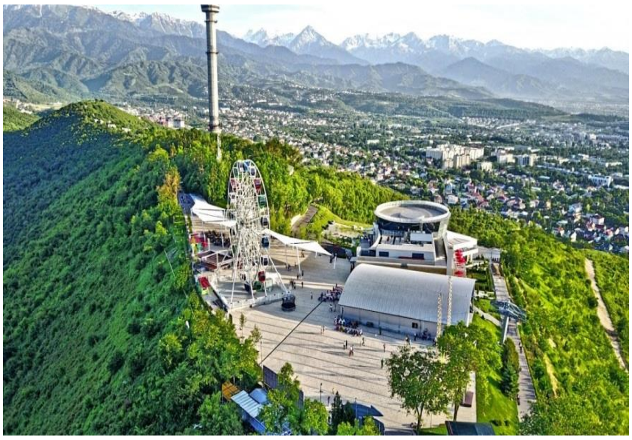

Fig. 1. The slope of the mountain Kok-Tube. Behind the mountain, individual construction sites begin.

To ensure the sustainability of the slopes formed by loess drawdown soils in the city of Almaty, retaining structures of various constructive solutions are used. However, when they are erected, technological errors are made, such as poor compaction of the backfill soils, use for backfilling of construction debris and heterogeneous soils, irregular geometrical dimensions of retaining walls, etc.

2 GEOLOGICAL CONDITIONS

Most of the mountain slopes of the Trans-Ili Alatau have a slope angle of more than 15 degrees to the horizon. According to the construction standards of the Republic of Kazakhstan (The Code of Rules, 2017), such areas are unfavorable in seismic terms. However, individual construction is very intensive and with a change in the steepness of natural slopes and slopes. To ensure the stability of the slopes erected retaining structures (Gorbunov-Posadov et al. 1985, Ginzburg 1979).

In Remizovka gorge (Almaty city) a large number of retaining walls 10-12 meters high and of different configurations were built. But due to improper operation, many of them were not suitable for work. The results of the survey showed that under the influence of surface and atmospheric waters, the grounds of the slope are moistened and the retaining walls lose stability, bend or settle, and have large cracks and fractures. This is because the base under the walls are loam-macroporous, subsidence, from solid to semi-solid consistency. The thickness of the layer of such deposits ranges from several meters to tens of meters. More durable non-subsidence soils are much lower.

2.1 Engineering Geology Data

The lithological structure of mountain regions is represented by a thick stratum of Upper Quaternary sediments of proluvial genesis. It is a loamy material enriched in carbonate salts, carried out by temporary flows from the mountains and composing the foothill areas and the foot of the Zailiisky Alatau removal cone.

The thickness of the loam is variable and varies from 10 to 50 meters. A thick mass of pebble soils lying below covers Paleogene-Neogene lake sediments, represented by red clay, mudstones and sandstones with marl and limestone interlayers. Most often, based on the results of engineering geological research, the following engineering geological elements (IGE) can be distinguished:

IGE-1. Bulk vegetative soil, humified, black, with woody roots and debris (crushed stone, pieces of concrete and bricks). Layer thickness up to 2.0 m.

IGE-2. The loam is subsiding yellow or brown in color, macroporous, tight or soft-plastic consistency, with rare inclusions of salts (carbonate) in the form of gimlets and small shells. The thickness of the layer is different, but more often up to 14.0 m.

IGE-3. The loam is non-sluggish, porous, from semi-solid to soft plastic consistency, with rare inclusions of a small shell. Maximum opened layer thickness usually does not exceed 10.00 m. It is covered with boulder-pebble deposits of proluvial origin.

Groundwater occurs at a depth of several tens of meters in gravel soils and does not have a significant effect on the operation of the slopes, since the filtration capacity of the gravel is rather high.

Geotechnical elements are characterized by approximately the following indicators of physical and mechanical properties, which are described in Table 1.

Table 1. The main physic-mechanical parameters of base soils

№ IGE	Name ground	$\gamma_н$, кН/м3	γ_d, кН/м3	C_{II}. кПа	φ_{II}, Град	E, МПа
1	Bulk soil	12,5	-	-	-	-
2	Loam subsiding	17,0	13,5	$\frac{17}{14}$	$\frac{15}{13}$	$\frac{5,4}{3,0}$
3	Loam unsettled	18,7	15,2	21	19	7
4	Pebble soil	22	21	33	39	63

Loam with moisture and additional pressures above 0,100 MPa shows collapsing properties. The collapsing of the ground's own weight (σ_{zq}) is manifested in the lower layers. Closer to th surface is usually absent. Ground conditions for subsidence base can be either of the first or second type. Below are the values of the initial subsidence pressure (P_{sl}) and the values of relative subsidence at the appropriate depth.

Table 2. Initial drawdown pressure

Depth	4м	6м	8м.	10м	12м	14м
P_{sl}в МПа	0,125	0,140	0,200	0,200	0,220	-

Table 3. Relative subsidence (ε_{sl}) under external load (σ_{zp}).

Depth, м	4	6	8	10	12
σ_{zp}=0,1МПа	0,125	0,140	0,200	0,200	0,220
σ_{zp}=0,2МПа	0,016	0,015	0,010	0,010	отсут.
σ_{zp}=0,3МПа	0,022	0,016	0,012	0,017	0,014

Analyzing the results of the indicators of subsidence, it can be seen that when soaking and an additional load of 0.100 MPa, the loam does not show subsidence properties throughout the depth. With an external load in the range of 0.125-0.200 MPa, the loam exhibits subsidence properties up to 11 m. The initial seismicity of the mountain regions is equal to 9 points on the MSK 1964 scale. However, in connection with the subsidence properties of the surface layers, 10 points were used in the calculations.

2.2 Reinforcement of the retaining wall in the gorge Remizovka

The retaining wall is located in Remizovka gorge and blocks the site from three sides. The wall was built in 2010 and is made of reinforced concrete. The dimensions of the wall in terms of 105 meters. The maximum height of the retaining wall is 12 meters. Retaining wall in cross section has a corner shape. In 2017, as a result of uncontrolled inflow of water from the water supply system and overmoistening of the soil, cracks appeared in the walls and its destruction began. Arresting and stratification of concrete appeared especially intensively in corners. Figure 2 shows the type of deformations. The use of amplification in the form of buttresses was not possible. Outside the walls is the territory of other owners. To maintain the wall in a steady state, it is proposed to use ground anchors. The layout of the anchors is shown in Fig.3. To fix the wall, especially in the corner parts, it was proposed to use metal belts consisting of two rolled I-beams, with a wall height of 220 mm.

Fig. 2. Opening cracks in the corners of the retaining wall.

Calculations to ensure the operational reliability of the decision made on PC PLAXIS. As a result, the anchor was used Titan series R32N., An average length of 19m., Located in a staggered manner in a vertical direction with a step of 2m, in a horizontal 2.5m. The anchor part of the anchor is deepened into loam not subsiding. A metal belt was installed along the perimeter of the retaining wall for the joint operation of the anchors and the reinforced concrete part of the wall.

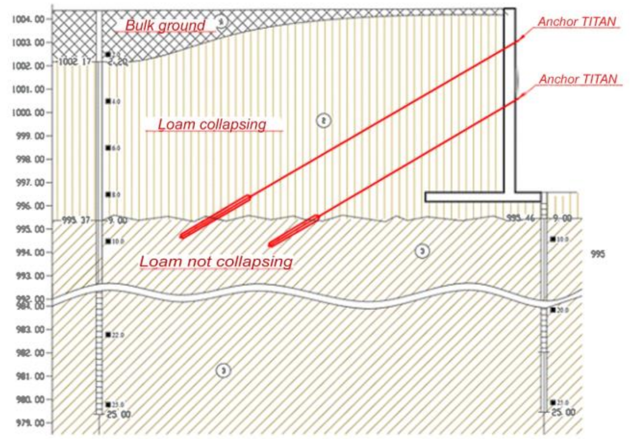

Fig. 3. The reinforcement scheme of the retaining wall in Remizovka.

2.3 Strengthening the retaining wall in the Baganashil gorge.

The retaining wall is located along the mountain slope. The length is 50m., Height is 10m. The retaining wall was built in 2016 and had a three-step outline in section. The thickness of the plate part of the lower wall step was 100 cm, the wall thickness was 60 cm. In the upper parts of the size decreased. In 2017, due to heavy rainfall, intensive moistening of the backfill soil occurred. The density of the backfill soil was very small and therefore the bases under the second and third steps sank heavily. These steps bent down strongly and the vertical slab of the bottom wall began to squeeze out. The horizontal deformation of the upper parts of the wall was 80 cm. there was a catching of the underlying elements of the wall and the destruction of concrete.

To prevent the progressive destruction of the wall, it was decided to disassemble the upper two and half of the bottom wall. From the whole structure only the lower part with a height of 3m remained. The existing backfill soil was excavated because it was in a loose state, with a lot of old concrete pieces, boulders, and debris. Instead, a new backfill was made with local soil with compaction to maximum density at optimum humidity.

Piles perceived most of the landslide pressure and changed the stress state of the soil at the base of the slope. The piles also changed the constructive solution of the wall from the corner view to the frame structure. The reliability check of the adopted circuit is made in PLAXIS. To restore the wall to its working capacity, its constructive solution was changed, Fig.4.

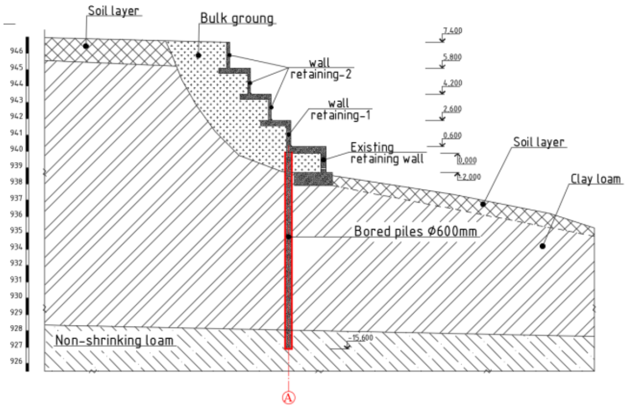

Fig. 4. Slope reinforcement using bored piles.

To ensure the stability of the slope and retaining walls use bored piles supported on non-subsidence loam. Piles with a diameter of 600mm., 10m long., With a pitch of 2m. Concrete class B20. Reinforce piles from 8Ø25mm., Class A-400.

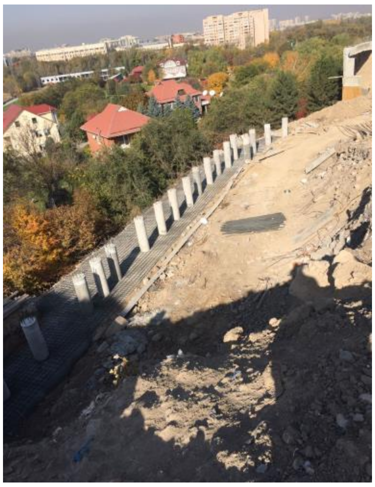

Fig. 5. General view of the reinforcement of the retaining wall after the installation of bored piles.

The remaining part of the retaining wall is attached to the bored piles using a horizontal reinforced concrete slab, Fig.5. The plate is reinforced with a double reinforcing mesh Ø22mm., With a step of 200mm. The top of the piles is combined with a horizontal grillage. Subsequent retaining walls were installed in steps. The dimensions of the walls in height were about 2.0 m.

2.4 Strengthening the retaining wall in the Kargala gorge

The retaining wall is located in the southwestern part of the slope of the Kargala gorge. Slope steepness is more than 26 degrees. The wall supports the area from three sides of the perimeter. Dimensions in terms of length 60x50x30m, height 3.5m and made in three steps.

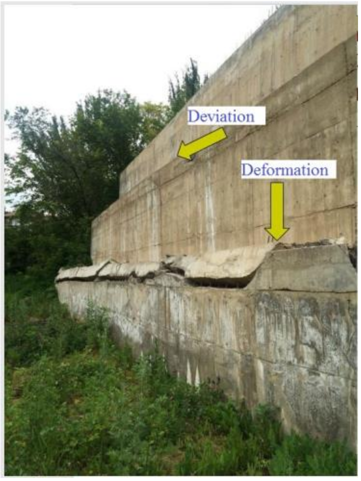

Fig. 6. Deformation and destruction of concrete retaining walls.

The retaining wall has a rectangular configuration and was erected in 2017. In 2018, after intensive rains, the soil of the backfill and foundation moistened. The wall completely deformed and began to collapse. As a result of the survey, it was determined that there are no drainage holes in the wall, and the backfill soil is in a loose state. As a result of water saturation of the soil, the bearing capacity of the base under the walls has decreased. The walls began to settle and destroy the concrete in the joints, Fig.6. The house and the outbuildings located up the slope began to deform.

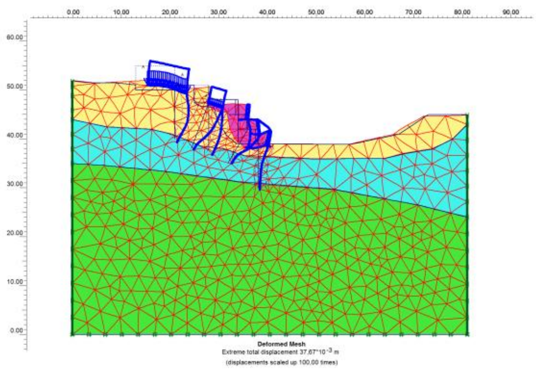

Рис. 7. The design scheme of strengthening of retaining walls and a slope under seismic effects.

It was decided to strengthen the retaining wall and the slope by transferring the main landslide load to bored piles and ground bearing elements according to the scheme in Figure 7. Piles link with a grillage and install buttresses. Use Jet Grouting technology to fill the voids under the bottom of the retaining wall that formed during the wetting process. Reinforce the base of the existing extensions using ground dowel pins. The diameter of the dowel should be no less than 300mm, 8m long, resting them in non-collapsing loam. Verification calculations are performed using PLAXIS.

CONCLUSION

1. The mountain slopes of the Trans-Ili Alatau are formed by subsiding soils, have a steepness of more than 15 degrees and a seismicity of 9 or more points on the MSK scale. These sites are unfavorable for construction. However, individual construction is intensive due to the beautiful nature and good ecology.

2. To ensure the sustainability of slopes and erected buildings, retaining walls of various constructive solutions are used. However, the construction rules are often violated by insufficient compaction of the foundation soils, the lack of measures to eliminate subsidence and drainage systems and devices. Exogenous geological processes are actively developing along the slope, leading to destruction, erosion, and landslide formation.

3. For reinforcement of deformed retaining walls, schemes are recommended where bored piles perceive the main landslide load. Piles should be buried below the shear site in a strong ground to perceive the shear load from the sliding ground. Ground anchors are used to provide a more stable position of the retaining wall. The length of the anchors is selected on the basis of the load transfer to the non-slip or other durable layer.

4. To ensure the stability of small buildings and structures, it is advisable to use soil dowels. They are arranged according to the technology of ground anchors and are carried out to a depth of solid ground. The recommended diameter of the soil dowel pins with a cement composition of at least 300mm. When injected cement mortar under pressure compaction of the soil occurs, and increases the adhesion nagel with the ground. After installing the dowel, the working rod can be replaced with conventional reinforcement to reduce the cost of work. On the upper part, dowels are united by a grillage, which is fed under the existing foundation.

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