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Technology for reducing the risk of landslides by unloading the landslide mass

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Abstract. The work has developed measures to reduce the risk of a landslide in the area near the village of Toktogul, Uzgen district of the Kyrgyz Republic. This landslide area was studied on the basis of field research on the ground and the results of desk work. The sliding of soil masses in the area can cause destruction and debris of residential and administrative buildings, roads and power lines, as well as injury and death. Considering the equilibrium of the system of forces acting on the mass of filler soil of the slope section and analyzing them, measures for unloading the landslide body in this section are proposed. The proposed longitudinal profiles of drainage channels to reduce the moisture content of subsidence soil and transverse profiles of developed soil to reduce the weight of subsidence soil are presented. Based on the results of processing research data and analysis, it is recommended to reduce the weight of unstable (subsidence) soil by stepwise development along the slope of the site and transporting it up to 5 km for subsequent brick production. It is also recommended to protect subsidence soil from waterlogging by installing drainage channels. Based on the results of the research, a real project was developed to protect the site from landslides near the village of Toktogul. The proposed measures make it possible to reduce the risk of a landslide in the area under consideration using methods and technical means that are inexpensive and accessible to government agencies and local administrations.

1 Introduction

In recent years, there has been an increase in landslides in the mountainous regions of the Kyrgyz Republic due to the intensification of interacting geodynamic movements, rising groundwater levels, climate change, as well as human engineering and economic activities. About 7.5% of the territory of the republic is subject to landslide processes and the largest number of landslides are located in the Osh and Jalal-Abad regions [1]. In 1993-2013 256 people died in landslides and the economic damage from landslides averaged 2.5 million US dollars per year [2-3].

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Landslide is a sliding displacement of masses of soil and rocks down the slopes of mountains and ravines, steep banks of lakes and rivers under the influence of gravity. From the onset of a landslide and its movement to another level until complete extinction, successive changes in the composition, state and properties of the landslide occur, manifested in the deformations that make up the rock landslide. The causes of a landslide are most often the erosion of the slope, its waterlogging by heavy rainfall, earthquakes or human activity. Colluvial, proluvial, and colluvial formations stabilized over a long period of time at the foot transform into a statically unstable state due to gravity, a decrease in friction forces in the sliding plane, and an increase in the permeability of atmospheric precipitation [4-5].

The volume of soil during a landslide can reach tens and hundreds of thousands of cubic meters, and in some cases more. Landslides can move slowly at speeds of a few meters per year, and sometimes at speeds of 100 m/s or more in the form of catastrophic collapses. The movement of huge soil masses along a slope under the influence of gravity can cause destruction of buildings and engineering structures, pipelines, electrical lines and loss of life [4].

Geomorphologically, the landslide area is located within the southwestern foothills of the Fergana Range, in the valley of the Zerger River (Figure 1). Landslides occur periodically in this area. At 6:40 am on April 29, 2017, a landslide with a volume of more than 1 million cubic meters occurred in the village of Ayuu, Zerger rural district, Uzgen district. According to the Ministry of Emergency Situations of the Kyrgyz Republic, the earthen mass covered 7 houses, in which there were 24 people.

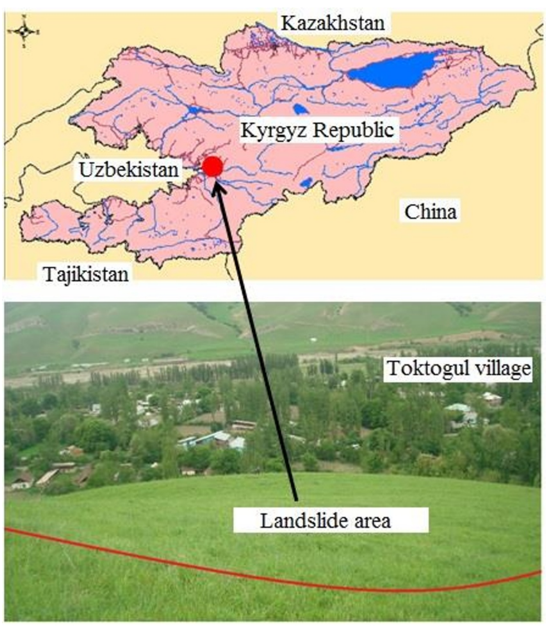

Fig. 1. Location of the landslide area: a) study area on the map (red dot); b) top view of the landslide area (the landslide separation line is shown in red).

Engineering surveys and design work were carried out to identify and reduce the risk of landslides in the study area. Based on the results of the research, it can be said that there is no immediate threat from a landslide to the safety of a populated area in the short term. But the landslide mass is in motion and, if excessively moistened, can be destructive. Therefore, it is recommended to organize periodic observations of the state of stability of the rocks that make up the upper, watershed part of the massif, especially in spring and autumn, when the greatest amount of precipitation falls. It is also advisable to carry out preventive work to eliminate possible ways of penetration of surface melt and storm water through cracks [6-9]. Preventive work should be carried out to level the surface to avoid the accumulation of melt water and precipitation.

It is recommended to select and implement the most suitable and economically acceptable engineering measures to reduce the risk of landslides [9-10].

The relief of the area under study is a slope of western exposure, with a steepness of about 25-300, a relative height of 110-130 m. The surface is covered with dense herbaceous vegetation and sparse shrubs. On the surface of the study area, relief elements of a smaller order are distinguished: hollows, terraces, terrace ledges, as well as artificially created embankments and excavations along the canal.

The hydrographic network is represented by the river. Zerger and its side components. An earthen channel with a width and depth of 2.05 and 2.0 m, respectively, was laid at the foot of the slope. The slope of the river bed is insignificant. The channel is currently inactive.

Hydrogeological conditions are characterized by the distribution of anhydrous rock complexes of the Quaternary and pre-Quaternary periods. The groundwater level has not been established by drilled wells up to 15 m deep and geophysical research (vertical electrical sounding - VES). Presumably they lie at a depth of more than 40 m. Along the perimeter of the base of the slope, water in the form of springs or hollows are not observed anywhere.

The geological structure is represented from the surface by a thick thickness (15-20 m or more) of loess-like loams, light and dark brown, hard, semi-solid and refractory, highly porous, highly subsident [11]. Below depths of 24-26 m in the watershed part, according to VES 4-7, there are bedrock rocks - siltstones with a resistivity value in the range of 18-32 Ohm.m.

The physical and mechanical characteristics of soils were studied in laboratory conditions using selected samples of disturbed and undisturbed structures.

Physico-geological phenomena and processes manifest themselves in the form of type II subsidence, with the formation of cracks oriented subparallel to the watershed line (Figure 2). By the time of the survey, the cracks had closed almost completely and remained on the surface of the relief in the form of a barely noticeable ledge. They have an intermittent step-by-step character and disappear in places. The time of their occurrence and maximum disclosure, according to the Ministry of Emergency Situations of the Kyrgyz Republic, falls on 1992-1993.

Fig. 2. Cracks on the landslide surface.

Judging by the absence of a ledge in the relief, indicating a clear manifestation of subsidence, it can be said that the manifestation of the initial, hidden phase of the formation of a landslide-subsidence may have taken place. And, apparently, after the cessation of water supply to the irrigation canal at the foot of the slope over the past few years, the subsidence process has slowed down or stopped. Even in the high-water year of 2017, when landslide processes intensified in the region, no new cracks appeared in this area.

The climatic conditions of the study area are given according to long-term observations at the "Uzgen" weather station of the Agency for Hydrometeorology (Kyrgyzhydromet) under the Ministry of Emergency Situations of the Kyrgyz Republic. In general, this area is characterized by hot, dry summers with an average annual precipitation of 587 mm.

According to long-term observations at the above weather station, the amount of precipitation for the period November-March is 308 mm, for April-October - 279 mm, the daily maximum is 83 mm. The greatest amount of precipitation falls in March - May, the least in August - September. The weight of snow cover on 1 m^2 of horizontal surface of the earth is 86 kgf/m^2.

The air temperature, according to the "Uzgen" weather station, is as follows: average annual air temperature – 11.1°C; absolute minimum air temperature – 26°C; absolute maximum air temperature + 39°C; the estimated temperature of the coldest five-day period is 13°C; the average temperature of the coldest five-day period (ventilation) is 7°C. Wind speed at a height of 10 m above the ground is 19 m/s.

The maximum penetration depth of the zero isotherm is 89 cm. The standard depth of seasonal soil freezing under the open surface of a horizontal platform bare of snow is as follows: loams and clays - 50 cm; sandy loam, fine and dusty sands – 61 cm; gravelly, large and medium-sized sands – 65 cm; coarse soils – 74 cm.

The seismicity of the area is 9 points according to the "Seismic Zoning Map of the Kyrgyz Republic". The updated seismicity of the site is 9 points [12-13].

2 Materials and methods

The main goal of the study is to develop measures to reduce the risk of a landslide at a site in the village of Toktogul, Uzgen district, Osh region of the Kyrgyz Republic.

To achieve this goal, the following research tasks should be solved [14]:

- Carry out office work to collect data on the landslide area (topographic maps and plans, soil maps, geological maps, satellite images, hydrometeorological information, etc.
- Conduct field research (study of relief and hydrological conditions, collection and examination of soil, measurement and mapping of cracks on the body of a landslide, etc.
- Propose measures to unload the landslide body and install protective structures in this area.

The Ministry of Emergency Situations of the Kyrgyz Republic provided relevant cartographic materials for the study. Figure 3 shows a georeferenced and digitized topographic plan of the area against the background of a satellite image from the Google Earth mapping service.

The section of the landslide slope was studied in detail to determine the main causes of the landslide, that is, the boundary conditions were determined when the balance of the system of forces acting on the thickness of the subsidence soil was disturbed.

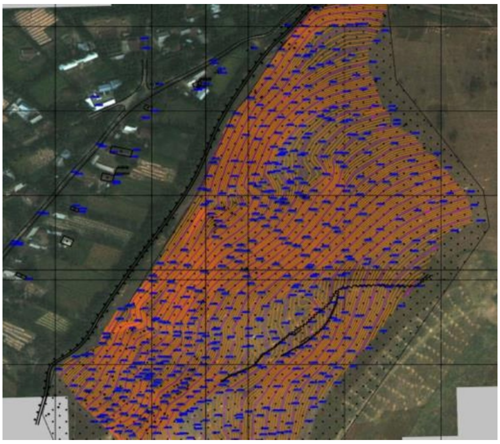

Fig. 3. Digital topographic plan of a landslide area against the background of a satellite image of the area.

Figure 4 shows a diagram of the landslide slope section and the forces acting on the soil.

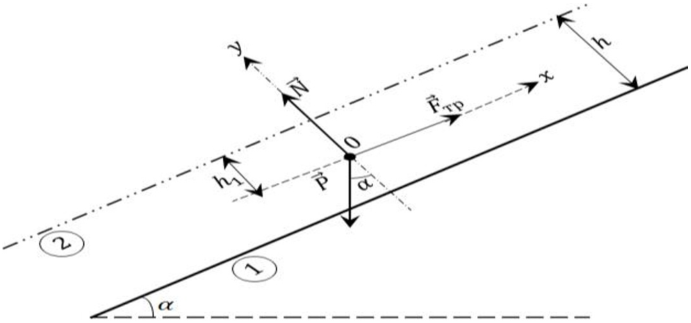

Fig. 4. Design diagram of a landslide slope of an area with a soil mass of thickness *h*: 1 – strong bedrock; 2 – subsidence soils with thickness *h*=(10÷20) m; *α*-angle of inclination of the slope of the site to the horizontal plane.

Here we consider a simplified diagram of the equilibrium of a system of forces that is easily understood by readers. Of course, it was possible to consider other schemes, for example, the shift of the soil thickness along a straight surface or along a cylindrical surface, considering the soil as a dispersed body [14-16].

The figure shows that the following forces act on the thickness of subsidence soil: $\vec{P}$- self-weight of subsidence soil with thickness h; $\vec{N}$-normal pressure force; $\vec{F}_{\text{friction force}}$ force between sliding surfaces of subsidence soils or subsidence soil and siltstone (bedrock).

Let the sliding occur at a depth h_1, then the vector expression for the equilibrium of the system of forces.

$$\vec{P}+\vec{(F_{fr})}+\vec{N}=0 \quad (1)$$

Let us analyze expression (1) according to the slope stability condition. To do this, we project expression (1) onto the coordinate axes x,y.

The sum of the projections of all forces on the x-axis:

$$\sum x_i = F_x = F_{fr} - P\cdot \sin\alpha = 0 \quad (2)$$

Sum of projections – on the y-axis:

$$\sum y_i = F_y = N - P \cdot \cos\alpha = 0 \quad (3)$$

Expressions (1), (2) and (3) are the equilibrium conditions for the system of forces in Figure 2, wherein (1) are vector equations, (2) and (3) are scalar equations (SNiP KR 11-01-98).

It is known that the friction force is defined as:

$F_{fr}=N \cdot f$, where f is the coefficient of friction between contacting surfaces during shear.

From expression (3) we have, $N=P \cdot \cos\alpha$ and substituting these values into the friction force formula $F_{fr}=f \cdot P \cdot \cos\alpha$, we obtain from expression (2) $F_x=N \cdot f-P \cdot \sin\alpha=f \cdot P \cdot \cos\alpha-P \cdot \sin\alpha$, from here

$$F_x = f \cdot P \cdot \cos\alpha - P \cdot \sin\alpha \quad (4)$$

Where F_x is the shear force along the slope.

Let us examine expression (4) according to the slope stability conditions:

- $F_x = 0$, $f \cdot P \cdot \cos\alpha - P \cdot \sin\alpha = 0 \Rightarrow f = (P \cdot \sin\alpha)/(P \cdot \cos\alpha) = tg\alpha$. $f=tg\alpha$-slope is in limit equilibrium when the friction coefficient f is equal to the tangent of angle α.
- $F_x > 0$, $f \cdot P \cdot \cos\alpha - P \cdot \sin\alpha > 0 \Rightarrow f > tg\alpha$-slope is in a stable position with a margin, provided $F_{fr} > P \cdot \sin\alpha$, since F_x is directed to the right along the x-axis, top along the slope.
- $F_x < 0$, $f \cdot P \cdot \cos\alpha - P \cdot \sin\alpha < 0 \Rightarrow f < tg\alpha$-slope loses stability and a landslide occurs, provided $F_{fr} < P \cdot \sin\alpha$, since F_x -is directed down the slope.

In the first and second cases there will be no landslide. The angle of inclination of the slope to the horizontal plane is α=const.

In the third case, there will definitely be a landslide, since P increases and f decreases, α=const, therefore, a landslide will occur when the soil becomes waterlogged (f decreases) and the thickness of the soil increases (P increases).

To avoid a landslide, you can increase the friction coefficient f and reduce the weight of subsidence soil (unloading). An increase in the friction coefficient - f is achieved by reducing the moisture content of the subsidence soil.

Let us examine expression (3) according to the slope stability conditions:

- $F_y=0$, $N-P \cdot \cos\alpha=0$, $N=P \cdot \cos\alpha$ - the soil thickness is in limiting equilibrium.
- $F_y > 0$, $N-P \cdot \cos\alpha > 0$, $N > P \cdot \cos\alpha$ - separation of the soil thickness from the bedrock occurs. This can happen during explosions and earthquakes with vertical shock.
- $F_y < 0$, $N < P \cdot \cos\alpha$ - compression of the upper layer of soil to the bedrock occurs and the soil becomes compacted, increasing the stability of the slope.

Figure 5 shows a diagram of a stable slope. Here, the friction coefficient takes into account both the friction between particles of loess soil and the adhesion between particles. As humidity increases, the friction coefficient decreases.

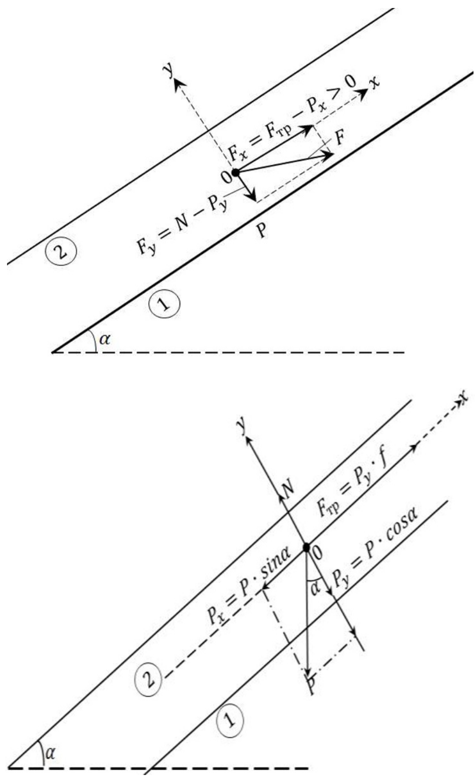

Fig. 5. Scheme of a stable slope: a) forces acting on the thickness of subsidence soil; b) projection of all forces onto the coordinate axes *x*, *y*, that is, forces F_x and F_y.

3 Results and Discussion

Based on the analysis of the stability of a slope with subsidence soil (15÷20 m thick), it is recommended to develop the subsidence soil with a stepped profile along the slope to reduce the weight and thickness of the subsidence soil. The removed soil is transported to a dump and cavaliers at a distance of up to 5 km to the side, located nearby a dry sai (bed) and stored along the river in the proper order for subsequent brick production.

To transport developed soils on slopes, berm roads up to 5 m wide are provided, and to drain melt and rainwater, monolithic reinforced concrete ditches (R = 0.6 m) are erected along the corresponding berms to reduce the moisture content of subsiding soil. This leads to an increase in the coefficient of friction, which contributes to the stability of the slope.

The project provides for the unloading of soil, starting from the upper edge of the watershed, a slope area prone to landslides over an area of more than 110,000 m^2. The total volume of soil to be developed is 1,381,713 m^3.

The volume of excavation work was calculated based on data obtained from the topographic plan and measured longitudinal profiles of the area. Figure 6 shows the plan of the berm-road after the development and transportation of soil for the project.

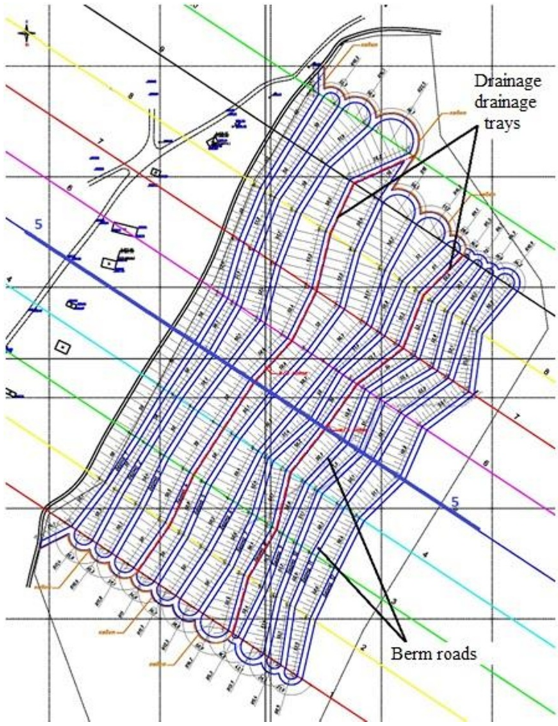

Fig. 6. Plan of a berm-road and drainage ditches in a landslide area.

Drainage ditches and road berms have a double-slope profile with a slope from the middle of the road to the edges; their longitudinal slope is about 2.5%. Along the edges of this area, transverse monolithic reinforced concrete trays are provided, along which water will flow into low-lying areas outside the landslide area.

All of the above ditches are constructed from hydraulic concrete of class B25 on a gravel-sand cushion 20 cm thick. For reinforcement, reinforcing mesh 6 m long is used and installed (increased) with an overlap. Reinforcing mesh is made from reinforcement grade AIII ϕ12 [16]).

Figure 7 shows a reinforced concrete drainage tray.

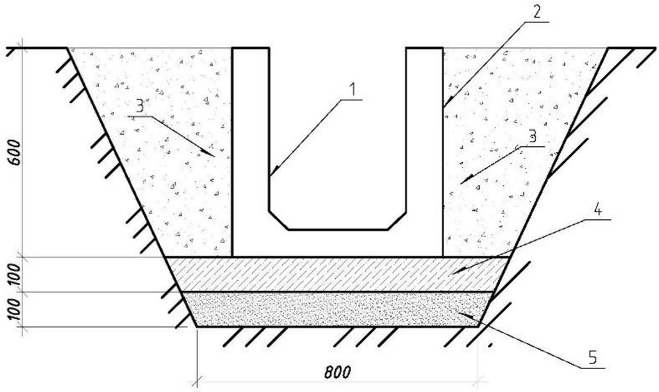

Fig. 7. Road drainage tray: 1 – tray according to GOST 32955-2014; 2-bitumen mastic; 3 - backfill; 4 - concrete base; 5 - underlying layer.

Figure 8 shows a diagram of the landslide area. The reference marks of the local backbone network are marks on the plinth (Pп1) and on the stairs (Pп2) of private residential buildings. Coordinates of reference points: Pп1 - X=523.58 m, Y=161.14 m, Z=1088.72 m; exit 1 coordinates - X=266.24 m, Y=90.22 m, Z=1091.20 m; coordinates Pп2 - X=628.57 m, Y=246.92 m, Z=1091.06 m; coordinates of exit 2 - X=700.00 m, Y=345.72 m, Z=1092.50 m. Direction angles: between Pп1 and exit 1 - α1=195o; between Pп2 and exit 2 - α2=54o. Distances: from Pп1 to exit 1 - L1=266.9 m; from Rp2 to exit 2 - L2=121.9 m.

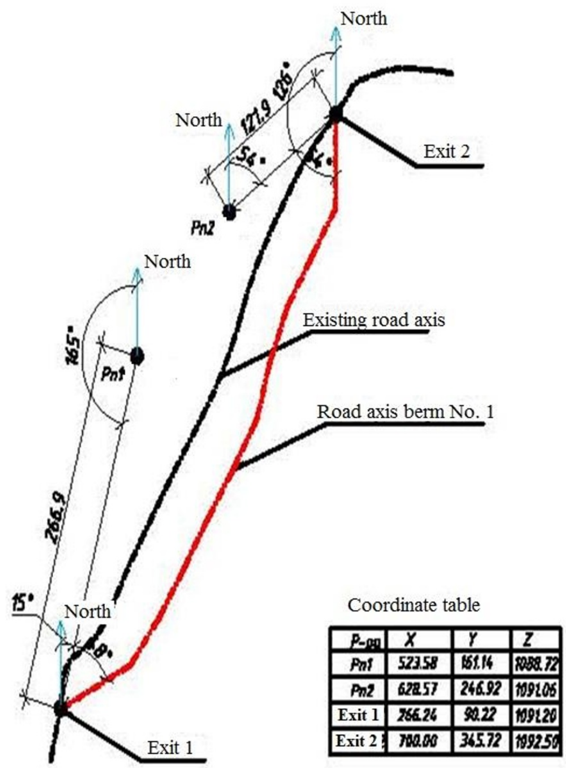

Fig. 8. Scheme of linking the landslide area to the local support network.

In the spring-autumn period of the year, during intense rainfall, as well as in winter from the melting of seasonal snows, surface water flowing from above the slope is diverted by specially constructed ditches to the side so that it does not enter the subsidence soil of the landslide zone.

The main types of work that will be carried out are excavation work, i.e. cutting off the soil-vegetative layer up to 20 cm thick, developing the landslide soil itself with a thickness of 5 to 30 m (depending on the terrain), leveling the terrain (more than 110,000 m^2), installing a gravel-sand cushion for drainage ditches, erecting the above monolithic reinforced concrete trays.

The soil and vegetation layer is removed, starting from the top of the slope being developed, using backhoe excavators. Next, the removed soil is loaded onto dump trucks and transported at a distance of 1 km to 5 km to low-lying areas, with a dump on a hollow of dry sais along the river, to territories agreed with the local administration. After completion of unloading work, these soils should be used for reclamation activities [17].

Figure 9 shows the cross-section of the middle part of the slope of the landslide area according to the project.

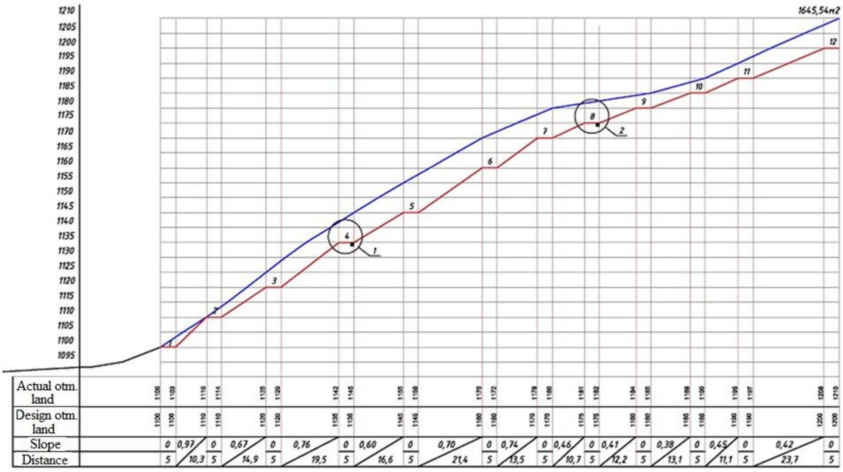

Fig. 9. Transverse profile of the landslide area along the slope (section along section 5-5 in Figure 6).

The soils in the dump areas are leveled using bulldozers. The unloaded soils are removed from the very top part of the slope, a little higher from the edge of the failure, where the landslide body was separated from the main mass of the rocks of the slope. When developing the soil mass of a slope with an excavator, the slopes are maintained from m=1.5 in places to m=3.0. The development height is up to h=5.0 m, with the installation of a berm width b=5.0 m. In this sequence, work will be carried out until the end of unloading the designed soil thickness.

In the study area there are paved and partially field roads leading to the project site. All roads are in good condition and can be used at any dry time of the year to deliver the necessary machinery and materials to the construction site. Also, on the slope itself, at the discretion of the contractor, it is possible to arrange technological ramps between berms - roads.

According to SNiP 1.04.03-85 “Construction Duration Standards”, the standard duration of the above excavation and construction work is seven months, including the preparatory period.

When organizing construction and carrying out work, the contractor should take the necessary measures to minimize the negative impact on the environment, prevent air and water pollution, soil erosion, and unreasonable destruction of vegetation. When performing excavation work and transporting excavated soil, it is necessary to organize watering of the site and roads as necessary. The construction organization must comply with the current rules for controlling and reducing river water pollution in accordance with the Law of the Kyrgyz Republic “General Technical Regulations for Ensuring Environmental Safety in the Kyrgyz Republic” (No. 151 dated May 8, 2009).

Household and food waste must be collected in appropriate containers and, when full, transported to an organized landfill. When drawing up a construction site plan, provide for the installation of a temporary container toilet and a mobile shower for 2-3 people. The shower room must be equipped with a temporary sewerage system and an antiseptic pit made of prefabricated reinforced concrete rings for subsequent disposal and removal off-site.

The construction contractor must carry out construction activities using methods that prevent construction debris and other pollutants or waste from entering drains and dry river beds. Used oils and other waste petroleum products and tanks for them should be located no closer than 6.0 m from drains and river beds. Construction waste and other environmentally polluting waste must be removed only to sanitary areas approved by local authorities and private parties.

Temporary buildings and structures of the construction base must be dismantled and removed after construction is completed. The entire soil surface damaged during excavation work must be reclaimed using modern methods and technologies [18,19,20]. When developing a reclamation plan, it is necessary to ensure further agricultural use of the land with regular monitoring of the condition of the landslide area.

4 Conclusion

In the context of a significant increase in landslide activity on the territory of the Kyrgyz Republic due to climate change, reducing the risk of landslides in populated areas plays a special role. The volume of soil during a landslide in mountainous areas can reach tens and hundreds of thousands of cubic meters. Sliding of a large mass of soil can cause significant destruction and blockage of residential, public and industrial buildings, engineering infrastructure, pipelines and power lines. Landslides with casualties occur very often.

Based on the results of the surveys carried out during this research, it can be said that there is no immediate threat from the landslide to the safety of the village of Toktogul in the short term. Nevertheless, it is recommended to organize periodic observations of the state of stability of the rocks that make up the upper, watershed part of the massif, especially in spring and autumn, when the greatest amount of precipitation falls. It is also necessary to carry out preventive work to eliminate possible ways of penetration of surface melt and storm water into the landslide area.

Based on the analysis of the stability of a slope with subsidence soil, it is recommended to unload the landslide mass with the removal of subsidence soil to reduce its weight and thickness with the formation of a stepped profile along the slope of the site. The removal of the removed soil is organized to a dump and cavaliers at a distance of up to 5 km towards the nearby dry river bed with leveling in the proper order. This volume of soil can then be used for the production of building bricks.

The main types of work that will be carried out are excavation work, i.e. cutting off a soil-vegetation layer up to 20 cm thick, developing the landslide soil itself with a thickness of up to 30 m, leveling an area of more than 110,000 m^2 and installing monolithic reinforced concrete drainage ditches.

The construction contractor must carry out construction activities using methods that prevent construction debris and other pollutants or waste from entering drains and dry river beds. Used oils and other waste petroleum products and tanks for them should be located no closer than 6 m from drains and river beds. Construction waste and other environmentally polluting waste must be transported to sanitary areas agreed upon with local authorities and private parties.

Upon completion of construction work, all temporary buildings and structures on the site must be dismantled and removed. Particular attention should be paid to the reclamation and restoration of the destroyed vegetation layer of soil for the further use of the studied site to safely meet the economic and environmental needs of the local community.

References

1. MES KR. Monitoring and Forecasting of Disasters on territory of the Kyrgyz Republic. Bishkek, Ministry of Emergency Situations of the Kyrgyz Republic, Kyrgyzstan (2021)

2. I.A. Torgoev, System monitoring landslides in Kyrgyzstan, Civil Security Technology, **10**, **4**, **38**, 68-71 (2013)
3. I.A. Torgoev, Y.G. Alioshin, Monitoring landslides in Kyrgyzstan, FOG - Freiberg Online Geoscience, TU Bergakademie Freiberg, Freiberg, 130-139 (2013)
4. E. Intrieri, T. Carla, G. Gigli, Forecasting the time of failure of landslides at slope-scale: A literature review, Earth-science reviews, **193**, 333-349 (2019) DOI: 10.1016/j.earscirev.2019.03.019
5. F. Guzzetti, S. Peruccacci, M. Rossi, C.P. Clark, The rainfall intensity-duration control of shallow landslides and debris flows: an update, Landslides, **5**, 3– 17 (2014) DOI:10.1007/s10346-007-0112-1
6. P. Lehmann, D. Or, Hydromechanical triggering of landslides: from progressive local failures to mass release, Water Resources Research, **48**, **2**, W03535 (2012)
7. C. Villarraga, D. Ruiz, J. Vaunat, F. Casini, Modelling landslides induced by rainfall: a coupled approach, Procedia Earth Planet Sci, **9**, 222–228, (2014) DOI: 10.1016/j.proeps.2014.06.025
8. R.W.H. Lee, R.H.C. Law, D.O.K. Lo, Importance of surface drainage management to slope performance, HKIE Transactions, **25**, **3**, 182-191 (2018) DOI: 10.1080/1023697X.2018.1499449
9. K.Y. Choi, R.W.M. Cheung, Landslide disaster prevention and mitigation through works in Hong Kong, Journal of Rock Mechanics and Geotechnical Engineering, **5**, 354-365 (2013) DOI: 10.1016/j.jrmge.2013.07.007
10. GOST 25100-2011, Soils. Classification, Standartinform, Moscow, 42 (2018)
11. K.E. Abdrakhmatov, K.D. Dzhanuzakov, A.G. Frolova, V.N. Pogrebnoy, Map of seismic zoning of the territory of the Kyrgyz Republic (Explanatory note), IS NAS KR, Bishkek, 51 (2012)
12. E.V. Bezuglova, Landslide hazard and soil displacement risk on the slopes (Dissertation of Candidate of Technical Sciences), Kuban State University, Krasnodar, 209 (2005)
13. K.Sh. Shadunts, Analysis of the landslide process based on risk theory, Bulletin of the Volgograd State University of Architecture and Civil Engineering, **10**, **29**, 7-10 (2008)
14. R.V. Klyuev, I.I. Bosikov, E.V. Egorova, O.A. Gavrina, Assessment of mining-geological and mining technical conditions of the Severny pit with the use of mathematical models, Sustainable Development of Mountain Territories, **3**, 418–427 (2020) DOI: 10.21177/1998-4502-2020-12-3-418-427
15. GOST 32955-2014, Public roads. Road drainage trays. Technical requirements, Moscow, 22 (2014)
16. E.A. Voronchikhina, Reclamation of disturbed landscapes: theory, technology, regional aspects: Monograph, Perm, 163 (2010)
17. R. Gracheva, T. Urushadze, Landslides in a rural mountainous region: damaging and resourceforming impacts (South Caucasus, Georgia), Geography, environment, sustainability, 4 (2011) DOI:10.15356/2071-9388_01v04_2011_06
18. T. Chuman, Restoration Practices Used on Post Mining Sites and Industrial Deposits in the Czech Republic with an Example of Natural Restoration of Granodiorite Quarries and Spoil Heaps, Journal of Landscape Ecology, 8 (2015) DOI:10.1515/jlecol-2015-0007
19. V.I. Smetanin, Reclamation and improvement of disturbed lands (KolosS, Moscow, 2003)