ISSN: 2707-1146
e-ISSN: 2709-4189

EARTH SCIENCES AND GEOGRAPHY

https://doi.org/10.36719/2707-1146/48/39-47

Novruz Shiraliyev
Water and Amelioration Scientific Research Institute PLE
novruzs@gmail.com
Jale Ceylan
TSM Group
jaleceylanus@gmail.com
Sevinj Mirjafarli
Water and Amelioration Scientific Research Institute PLE
mirjafarlis@gmail.com

Determining the Stability of a Potentially Dangerous Landslide Slope

Abstract

Due to the acceleration of construction of civil, industrial and infrastructure facilities in our republic and the expansion of their area, the construction of many facilities is carried out in mountainous, and foothill areas with complex relief and geomorphological conditions, which in most cases are potentially dangerous landslide slopes.

To protect these facilities from the negative impact of dangerous geological, natural-technogenic, and anthropogenic processes, to assess the risks arising from the impact of these processes on building structures, to promptly prevent negative phenomena and dangerous situations, to assess the engineering and geological conditions of the construction area to determine the stability of the slope, conducting research in these areas is of great practical importance.

Mountainous regions are characterized by the complexity and diversity of geological, hydrological, hydrogeological, and tectonic conditions.

Landslides are the most common natural and man-made processes that pose a threat to the safe operation of infrastructure facilities, civil and industrial construction in mountainous and foothill areas.

In addition to infrastructure facilities, landslides can destroy vegetation, destroy the habitat of fauna, and also destroy fertile soils located in the area of their activity (Nikolic, 2015; Krivoguz & Bespalova, 2020).

The main objective of this article is to apply the results of practically implemented and verified studies in other territories of our republic with similar geomorphological structure and engineering-geological conditions, to correctly assess the negative manifestations caused by landslides and other man-made and anthropogenic impacts, as well as to calculate the stability of the slope and scientifically and technically substantiate measures for engineering protection against landslides.

Keywords: *landslide, slope, geological, stability, road, sand, clay, loess, soil, groundwater*

Introduction

In connection with the construction of the state border highway of the Baku-Guba-Russian Federation, when choosing the route for the construction of the road line without entering the city of Shabran, according to the results of the technical and economic evaluation of all options, the option of passing the road through the foothills of the slope located in the northwestern part of the city of Shabran was preferred.

A very important point in the design of embankments and excavations, for example in the construction of railways and highways, is the prediction of the stability of slopes and embankments (Chalkova & Cherepanov, 2007).

ISSN: 2707-1146
e-ISSN: 2709-4189

Taking into account the impact of natural factors and processes on a road is one of the fundamental principles in the design of a road both as a transport structure and as an engineering structure (Zhukov, 2019; Makhmudova, 2021).

The probability of landslide development due to road construction, i.e. as a result of man-made impacts on a slope where a landslide process has not yet manifested itself, is not taken into account sufficiently. This is one of the weak links in the design of mountain roads. At the same time, tracing is carried out without quantitative assessments of the degree of stability of the geotechnical complex "slope + roadbed" (Makhmudova, 2021; Khairullaevna & Odilova, 2023).

In order to design the structural elements of the road and, if necessary, anti-slip devices, engineering-geological and hydrogeological studies should be carried out on the slope, the physical and mechanical properties of the soils involved in the geological structure of the slope should be determined, and the stability of the slope should be calculated.

In many cases, the importance of determining the negative manifestations that may arise in the stability of the slope due to the disruption of the natural structure of the slope by drilling and cutting during construction, makes it necessary to carry out relevant research.

For the design of the roadbed, which is the main structural element of the road erected on a slope or on a potential landslide slope, the determination of the slope stability and, accordingly, the slope stability factor is more relevant.

Based on the interpretation of the noted information, it can be concluded that in connection with the passage of a motorway at the foot of the slope, an important design condition is to determine the stability of the soil massif forming the slope. Thus, as a result of construction work, the imbalance on the slopes, accompanied by a landslide of a large soil massif, leads to catastrophic processes leading to the collapse of civil and infrastructural construction projects located on the slope and at the foot of the slope.

Research

The slope with a potential landslide hazard is located in the western part of Shabran city and covers an area of 1000 meters in length and 170 meters in width (along the surface of the slope).

The maximum steepness is 40-450 meters and the height is 120 meters in the parts of the slope considered as a potential landslide zone (Figure 1).

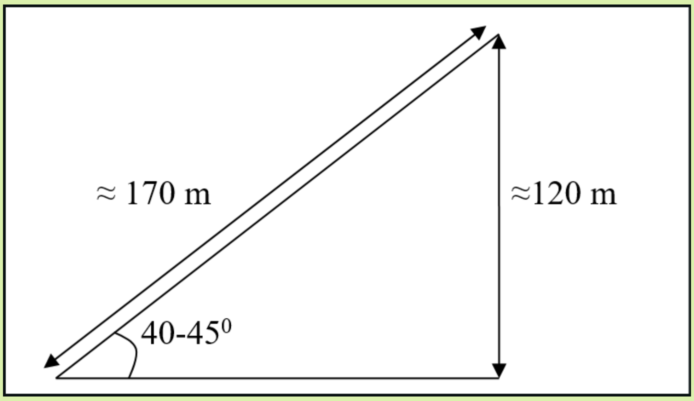

Figure 1. General schematic dimensions of the slope

The upper part of the slope is a large area with a slight slope. Previously, certain protective measures were taken to prevent the risk of landslides in the area of the slope.

The entire surface of the slope is gradually divided into terraced parts along the bed lines and the boundaries of layers of different lithological composition. In order to eliminate atmospheric precipitation, small trenches were built in these areas, and the stability of the slope was restored by providing a balance between the weight of the soil mass forming the slope and the force of sliding resistance (Figure 2 and Figure 3).

ISSN: 2707-1146
e-ISSN: 2709-4189

The slope has a variable relief with convex, flat and protruding shapes in some areas, and the agroforestry reclamation measures carried out in the 1970s are one of the main factors determining the current shape of the slope relief.

Figure 2. Area with potential landslide hazard

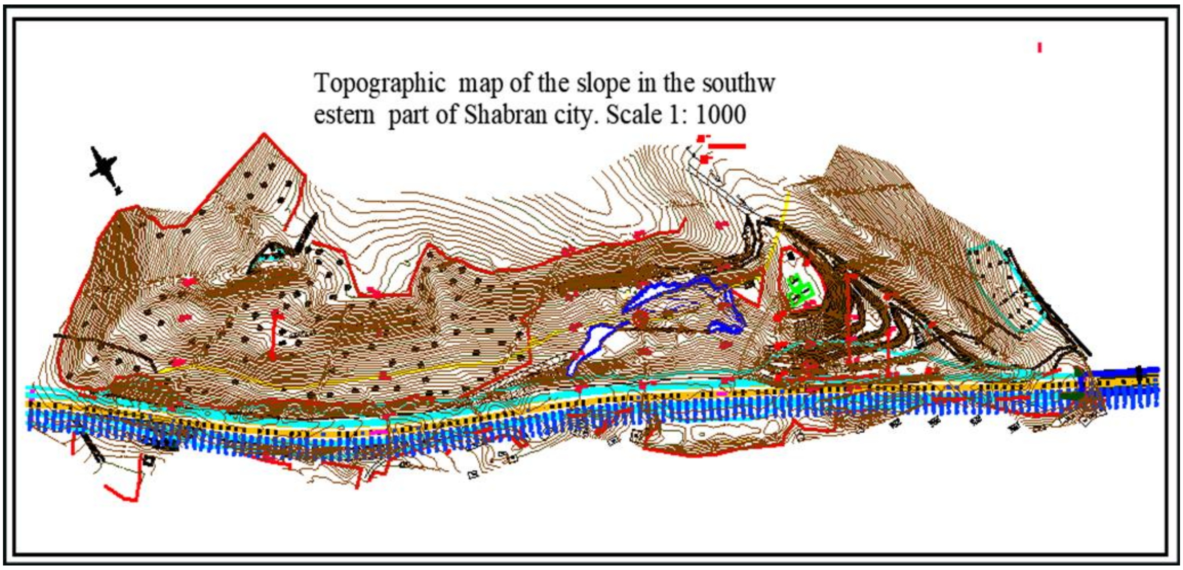

Figure 3. Topographic map of the slope in the southwestern part of Shabran city

The research work was carried out on a 200-meter section of the northern part of the specified territory (Figure 4).

As a result of the research, it was established that the geological structure of the soil massif forming the slope consists of loess semi-hard loams of continental origin, loam of semi-hard consistency, clays of hard and semi-hard consistency, and a layer of fine-grained sand of medium density.

ISSN: 2707-1146
e-ISSN: 2709-4189

Figure 4. Research area

At the foot of the slope there is a layer of argillite with a thickness of 15-20 cm, and in the middle part of the geological structure of the slope there is a wet and loose layer of sand. The moisture content of the sand layer allows us to assume the possibility of the presence of a source of nutrition in this layer. Among the mentioned soils, sands, loess loams and loams have the ability to soak and wash away.

According to the results of engineering and geological studies conducted in the initial part of the potentially dangerous landslide zone, the angle of internal friction in clay soils participating in the geological structure is $17\text{-}30^0$, the adhesion force is 0.36-0.84 kgf/cm^2, the angle of slope of sand is 30^0, and in a water-saturated state – 26^0.

The angle of internal friction in the loess clay and clay layers involved in the geological structure of the soil massif can be assumed to be $17\text{-}26^0$, and the adhesion force is 0.19-0.47 kgg/cm^2 (AzDTN 2.15-1 Soil foundations of buildings and structures).

Landslide processes mainly occur on slopes and embankments with large inclinations, in the geological structure of which clayey and loess-like soils participate (Zuska, 2014).

Landslides that have occurred in nature, depending on the lithological composition of the soil massif, tectonic, physical and engineering-geological, man-made and anthropogenic processes and factors, mainly occur on slopes with an inclination angle of more than 15^0.

In cohesive dispersed soils, the factors that exert opposite influence on displacement are friction and cohesion forces, while in non-cohesive dispersed soils this factor consists only of friction forces. The force of gravity created by the mass of rocks that make up the slope is the force that tries to move the mass of soil in contrast to these forces.

The slope stability was calculated for two soil conditions, since local sections of the slope geological structure involve unbound dispersed soils (sand layer), while the geological structure of the slope geological environment involves predominantly bound dispersed (silty-clayey) soils.

The friction force F and the gravity force P act on each soil particle in loose dispersed soils (sand layers) that participate in the geological structure of the slope (Figure 5). And the gravity force P consists of the force Q, which moves the particles down the slope, and the force N, which pushes the particles toward the slope (Alekseyev, 2007).

ISSN: 2707-1146
e-ISSN: 2709-4189

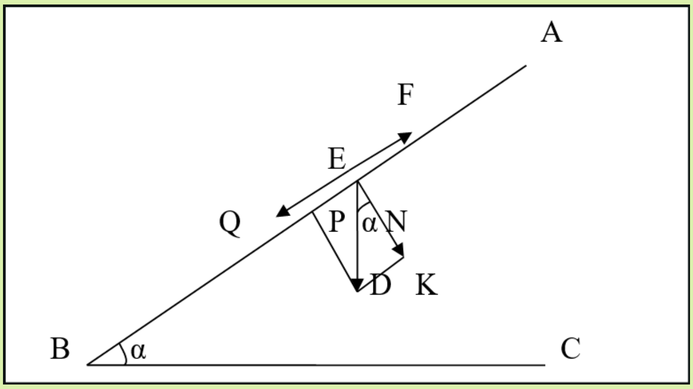

Figure 5. Conditions of stability of uncohesive loose soils

As shown in the picture:

$$Q = P \cdot \sin\alpha$$
$$N = P \cdot \cos\alpha$$

α is the angle between the perpendicular H to the slope surface and the vertical force P. In addition, α is equal to the angle of repose (inclination), since, < ABC= < DEK.

$$\frac{Q}{N} = \frac{P \cdot sin\alpha}{P \cdot cos\alpha} = \mathrm{tg}\alpha$$

From here:

$$Q = N \cdot \mathrm{tg}\alpha$$

For soil particles to move, the force Q must be greater than the frictional force F moving in the opposite direction.

It is known from soil mechanics that the frictional force is equal to the product of the internal friction coefficient of the soil and the compressive force:

$$f = \mathrm{tg}\varphi$$

φ – is the angle of internal friction of the soil. From here:

$$F = N \cdot f = N\ \mathrm{tg}\varphi$$

In unstable equilibrium the condition Q=F is satisfied:

$$N \cdot \mathrm{tg}\alpha = N \cdot \mathrm{tg}\varphi \text{ or } \mathrm{tg}\alpha=\mathrm{tg}\varphi$$

In case of stable equilibrium:

$$Q<F,$$
$$N \cdot \mathrm{tg}\alpha < N \cdot \mathrm{tg}\varphi$$

From here:

$$\mathrm{tg}\alpha < \mathrm{tg}\varphi$$

conditions must be met.

Considering that the angle of inclination of the sand layers participating in the geological structure of the slope is 30^0, and in some cases, the slope surface inclination is $40\text{-}45^0$, we can conclude that, directly on the sand layers, the slope is unstable.

It is known that landslides of the konsekvent type occur on any given surface (Pellinen, 2012). In many cases, landslides occur on slopes composed of uniform layers of loess clays, alternating horizontally at a certain angle.

The main causes of landslides are:

- spontaneous undercutting of the slope heel, the balance of natural forces that ensure the stability of the slope is disrupted;
- washing of the surface and base of the slope by atmospheric deposits;
- additional load on the soil mass that forms the slope (construction of artificial structures on the slope, filtration of rain and snow water into the soil layer, etc.);
- violation of the natural structure of the soil as a result of the activity of groundwater and other accompanying factors (Dalmatov, 1988).

ISSN: 2707-1146
e-ISSN: 2709-4189

The displacement of the soil mass forming the slope occurs against the background of successive sliding of the mass consisting of blocks on a curved line close to the circular cylindrical sliding surface, and the sliding depth covers the interval from 5 meters to 10-15 meters.

The research area for cohesive dispersed soils occupies an area 80 meters wide, 100-150 meters long, and sometimes more, which has a terraced surface as a result of dissection of the soil mass along certain cracks (Figure 6 and Figure 7).

To calculate the stability of a slope composed of cohesive soils, the method of a circular cylindrical sliding surface was used (Kremnev, Glukhov, & Vishnyakov, 2011).

As the foot of the slope, the length (width) of the slope surface is taken as 115 meters, referring to the natural cut-valley (avalanche) accompanied by the 15 meters from the residential house built at the foot of the slope.

The absolute height of the slope is 81 meters, the radius of rotation at the 0 point of the sliding body R is 76.6 meters (Figure 8).

Taking into account that the slope angle in the area after 115 meters of the slope surface is small, that area was not included in the research object.

The physical and mechanical parameters of the soils used in the report were determined based on the results of the engineering-geological studies conducted in the area and the information of the normative documents.

Figure 6. Research area with potential landslide

Figure 7. Photographs of the research area

ISSN: 2707-1146
e-ISSN: 2709-4189

The sum of the forces arising from the weight of the soil mass (Figure 9):

$$\Sigma \text{ Ti} = 28608 \text{ kN/m}$$

The sum of the forces holding the soil massive of a slope in equilibrium:

$$\Sigma \text{ Fi} + \Sigma \text{ c} * \text{Li} = 28127 \text{ kN/m}$$

According to the equilibrium formula:

$$\Sigma \text{ Ti} - \Sigma \text{ Fi} - \Sigma c_i * L_i = 0$$

It is determined from the formula and the quantities of forces acting on the sliding body that the conditions of the equilibrium formula are not satisfied in our case.

So that:

$$28608 - 21971 - 6156 = 481 \text{ kN/m}$$

As a result of the calculations, it was determined that the forces that try to move the soil mass downwards due to the weight of the soil massif forming the slope are greater than the sum of the resistance forces of the slope against those forces.

The stability coefficient of the slope is calculated by the following formula:

$$\eta = \frac{\Sigma Fi + \Sigma c * Li}{\Sigma Ti} = \frac{28127}{28608} = 0{,}98$$

As a result of the calculation, the determined stability coefficient of the studied slope (η=0.98) is less than unity, so the slope is evaluated as a potentially dangerous landslide area.

The degree of stability of a slope (slope) is estimated by the value of the stability coefficient (stability, safety margin). A slope, slope or its morphological element is considered stable if its stability coefficient is higher than one (η > 1). The value of the slope (slope) stability coefficient approximately equal to one (η ~ 1) corresponds to the state of limit equilibrium observed at the moments of the beginning and end of a landslide displacement (Matsiy, 2011).

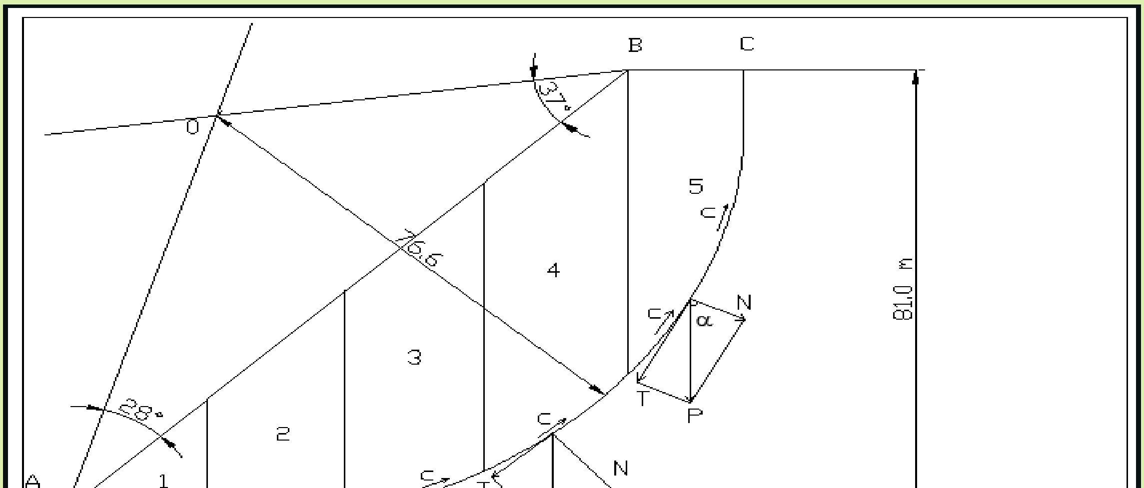

Figure 8. The scheme of calculating the stability of the slope

ISSN: 2707-1146
e-ISSN: 2709-4189

s/s	$A_i m^2$	γ, kN/m^3	$Q_i=\gamma*A_i$, kN/m	α_i, degree	sin α_i	$T_i=Q*\sin\alpha_i$, kN/m	cos α_i	$N_i=Q_i*\cos\alpha_i$, kN/m	φ, degree	tg φ	$F_i=N_i*$tg φ, kN/m	c, kPa	L_i, m	$c*L_i$
1	234	17,8	4165	-6	-0,11	-458	0,99	4123	22	0,40	1649	46	20	920
2	845	17,8	15041	5	0,09	1353	1	15041	22	0,40	6016	46	20,1	925
3	946	17,8	16840	21	0,36	6062	0,93	15661	22	0,40	6264	46	21,4	989
4	1153	17,8	20523	40	0,64	13128	0,77	15795	22	0,40	6318	46	28,1	1293
5	538	17,8	9576	63	0,89	8523	0,45	4309	22	0,40	1724	46	44,1	2029
Σ						28608					21971			6156

Figure 9. Slope stability calculation table

The results of calculating the slope stability for two soil conditions showed that the slope under consideration, in the geological structure of which non-cohesive dispersed soils (sands) and cohesive dispersed soils (silty-clayey) participate, is unstable.

In order to avoid negative phenomena taking into account the instability of the slope under study and to prevent catastrophic consequences from dangerous landslide processes when designing infrastructure facilities adjacent to such mountainous areas, a comprehensive engineering and geological study should be carried out, as a result of which designers should design anti-landslide measures based on existing regulatory documents.

Conclusion

To protect infrastructure facilities from the negative impact of dangerous geological, natural-technogenic, and anthropogenic processes, to assess the risks arising from the impact of these processes on building structures, to promptly prevent negative phenomena and dangerous situations, to assess the engineering and geological conditions of the construction area to determine the stability of the slope, conducting research in these areas is of great practical importance.

Landslides are the most common natural and man-made processes that pose a threat to the safe operation of infrastructure facilities, civil and industrial construction in mountainous and foothill areas.

A very important point in the design of embankments and excavations, for example in the construction of railways and highways, is the prediction of the stability of slopes and embankments.

In order to design the structural elements of the road and, if necessary, anti-slip devices, engineering-geological and hydrogeological studies should be carried out on the slope, the physical and mechanical properties of the soils involved in the geological structure of the slope should be determined, and the stability of the slope should be calculated.

The slope stability was calculated for two soil conditions, since local sections of the slope geological structure involve unbound dispersed soils (sand layer), while the geological structure of the slope geological environment involves predominantly bound dispersed (silty-clayey) soils.

The results of calculating the slope stability for two soil conditions showed that the slope under consideration, in the geological structure of which non-cohesive dispersed soils (sands) and cohesive dispersed soils (silty-clayey) participate, is unstable.

The conducted studies give grounds to state that, when designing infrastructure facilities located in mountainous and foothill areas, the scientific and technical approach to assessing the stability of slopes is the only alternative.

For the feasibility study of designing infrastructure facilities located through slopes, the presented methods for calculating the stability of the slope in such geological conditions are sufficient.

ISSN: 2707-1146
e-ISSN: 2709-4189

References

1. Alekseyev, S. I. (2007). *Soil mechanics*. St. Petersburg State University of Railway Engineering.
2. Chalkova, Y. S., & Cherepanov, B. M. (2007). Landslide processes, their forecasting and control. *Polzunovsky Vestnik*.
3. Dalmatov, B. I. (1988). *Soil mechanics, foundations and foundations* (Including a special course in engineering geology) (2nd ed.). Stroyizdat.
4. Khairullaevna, I. F., & Odilova, E. D. (2023). Requirements for the stability of the roadbed of highways. *International Scientific Journal*, (9)3, Education News: Research in the 21st Century.
5. Krivoguz, D., & Bespalova, L. (2020). Landslide susceptibility analysis for the Kerch Peninsula using weights of evidence approach and GIS. *Russian Journal of Earth Sciences*, 20, ES1003. https://doi.org/10.2205/2019ES000682
6. Kremnev, A. P., Glukhov, D. O., & Vishnyakov, N. N. (2011). Determination of the most dangerous sliding surface when calculating the stability of slopes using the method of circular cylindrical sliding surfaces. *Bulletin of Polotsk State University, Series F. Applied Sciences. Construction*, 37–41.
7. Matsiy, S. I., Bezuglova, E. V., & Pleshakov, D. V. (2015). *Assessment of landslide risk of transport structures: Monograph.* KubSAU.
8. Makhmudova, D. A. (2021). Study of water-thermal regime of roadbed. *Universum: Technical Sciences*, 5(2), 86.
9. Nikolic, T. (2015). Direct and indirect impact of landslide on environment. *In Engineering geology for society and territory* (Vol. 5, pp. 1237–1241). Springer International Publishing. https://doi.org/10.1007/978-3-319-09048-1_236
10. Pellinen, V. A. (2012). Principles of landslide classification: Review. *Bulletin of Irkutsk State Technical University*, (8), 67.
11. Zhukov, V. I. (2019). *Surveys and design of highways in difficult conditions*. Sib. Fed. University.
12. Zuska, A. V. (2014). *Kinematic model of landslide slopes: Monograph*. National Mining University.

Received: 05.07.2024
Revised: 20.08.2024
Accepted: 06.09.2024
Published: 20.09.2024