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Geotechnical Justification for Designing Landslide Prevention Measures

Abstract

When designing anti-landslide measures, slope stability assessment is an important factor and is determined by conducting comprehensive engineering and geological studies on a slope with potential landslide risks. The results of correct engineering and geological justification for the design of anti-landslide measures lead to the preservation of the structure and safe operation of infrastructure facilities.

Our experience shows that to eliminate the negative effects of landslide processes, it is necessary to accurately determine the engineering and geological conditions of the slope, including the stability of the slope, taking into account natural dynamic phenomena (seismicity of the territory and tectonic processes) and, if possible, to see the complete elimination of the causes that lead to landslide processes when developing anti-landslide measures. To achieve these goals, the geotechnical justification of the design is the only correct solution.

Geotechnical justification of protective measures intended to protect the structural elements of the Baku-Russian Federation State Border highway, which is part of the north-south transport corridor and passes through the foot of a potentially landslide-hazardous slope west of the city of Shabran, is one of the most important conditions that increase the effectiveness of these measures.

On a slope located 1500 meters southwest of the current research area, the results of our scientific research were not properly utilized and many of our warnings were not heeded, resulting in a landslide during construction, leading to serious damage to the road's structural elements (Fig. 1) and additional costs.

This event once again confirms that 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.



Figure 1. Complications of sliding

The purpose of this study is to determine the geotechnical conditions of the slope that is the object of research, analyze and assess the stability of the slope and provide geotechnical data for geotechnical justification for the design of landslide protection structures.

Thanks to the application of the project solutions developed based on the results of the studies presented in the article, the danger of landslides on the mentioned slope has been completely eliminated and the safe operation of infrastructure facilities has been ensured.

Keywords: *geotechnical measures, design, landslide, slope, stability, soil*

Introduction

A landslide is a ground displacement phenomenon that includes rock falls, shallow debris flows, and deep slope failures (Varnes, 1978).

Landslides are defined as the downward movement of rock, debris and earth along a slope under the action of gravity. A landslide is one of the most common types of slope hazards that can cause significant casualties and economic losses. Slope study and analysis are essential to understand their characteristics and in particular their stability, robustness and deformation (Amashi et al., 2016).

In connection with the above, the study and analysis of the slope located northwest of the city of Shabran is important for understanding their characteristics, for geotechnical justification of the design of anti-landslide measures and for the stability and reliability of infrastructure facilities.

The slope corresponding to the Gusar-Shabran syncline belongs to the structural-denudation foothill and marine abrasion-accumulative relief type and is characterized by a general lowering and leveling of the relief. The upper part of the slope consists of a large area and a gentle section extending to the foot of the Gainardzhi mountain range (Shiraliyev et al., 2024).

The slope has a variable relief with convex, flat and protruding forms in some areas, and the factors that determine the modern appearance are the agroforestry measures carried out in the 1970s (replacing the slope relief with stepped terraces, planting various trees, etc.).

In February 2009, following a landslide on the slope under the reservoir located in the southwestern part of the city of Shabran (PK11+100 – PK12+300), various works were carried out to remove soil from the slope, which led to a change in its natural relief.

As the engineering-geological, geological, geomorphological and morphometric features of the slope were not taken into account during the excavation works, the relief of the slope became more critical and as a result some parts of the slope became a potential landslide area.

Research

The studied slope with potential landslide hazard occupies an area 580 meters long and 140-175 meters wide. The natural slope inclination is $16^{\circ}30'$ - $24^{\circ}30'$ (in some places up to 30°), and the height fluctuates between 42-58 meters (Fig. 2).



Figure 2. Research area

The slope, due to its genetic characteristics, belongs to the polygenic type and is characterized as a moderately steep slope. The natural formation of the slope was due to the endogenous and exogenous development of the relief and the harmonious coordination of climatic and orographic processes. The formation of the current state of the slope, as noted above, is closely related to anthropogenic factors and factors.

In order to determine the stability of the slope and the geotechnical justification for the design of anti-landslide measures, in August 2009, comprehensive engineering and geological surveys (Fig. 3 and Fig. 4) were conducted in the area of the slope in accordance with the requirements of the relevant rules and standards (SP, 2003; ODM, 2013).



Figure 3. Episodes of geotechnical research on the slope

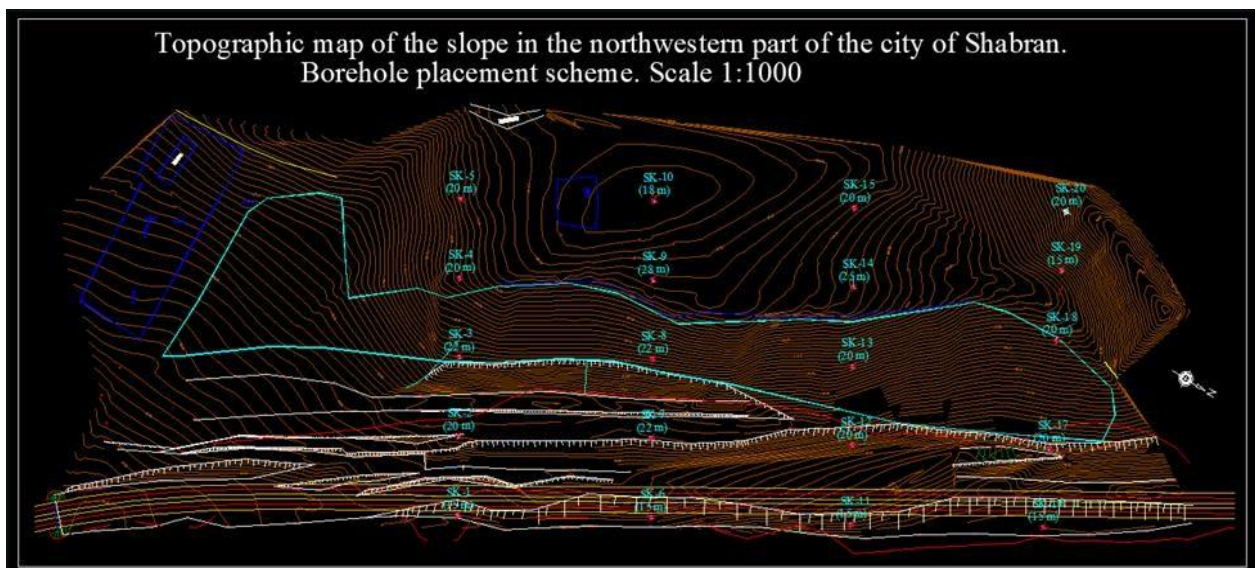


Figure 4. Topographic map of the research area

Engineering and geological surveys are carried out to assess the stability of a slope over the entire area of a dangerous or potentially dangerous slope, covering areas adjacent to its upper edge and base up to the expected boundary of the stable part of the slope, for coastal slopes - with mandatory coverage of their underwater parts, including in cases where the territory of the designed object occupies only part of the slope (Nevolin, 2014).

In the geological structure of the 28-meter depth interval of the slope area, sedimentary rocks are developed, consisting of sandy and clayey soils of technogenic and marine origin.

Geological data determined as a result of engineering-geological studies and the values of physical and mechanical indices of soils were analyzed statistically and analytically and on the basis of the obtained data the slope stability was calculated using the Horizontal Forces (Maslov-Beer) method for the limit state I (Ponomarev et al., 2022).

Currently, the following methods for determining the stability coefficient of slopes and slopes

are most widespread (Ukhov et al., 2022; Ginzburg, 2007):

- rectilinear sliding surface method,
- circular cylindrical sliding surface method,
- broken sliding surface method,
- Maslov-Behrer method.

All these calculation methods have one common drawback: one (only) slope creep coefficient, which is defined as the ratio of the sum of the holding forces (i.e. forces or moments) to the sum of the shear forces (Andreyev et al., 2017).

The degree of slope stability is assessed by the value of the safety factor K_s , determined by the formula:

$$K_s = \frac{\sum T}{\sum H}$$

Where:

T – part of the thrust (pressure on the block wall), perceived by friction and adhesion in the ground (on the sliding surface);

H is the thrust (pressure on the block wall) in the absence of friction and adhesion in the soil between the blocks;

The meaning of the letters used in the formulas for calculating slope stability in tables 1-6:

ψ_p – the angle of resistance to shear on the sliding surface of a given block under normal stress P ;

α – the angle of inclination of the sliding surface of a given block to the horizon,

Q – block weight,

R – unextinguished part of the pressure (active pressure),

F_p – shear resistance coefficient,

P – normal shear stress,

S_p – total shear resistance of the rock,

ρ – soil density,

h – average height of the calculation block,

ϕ – angle of internal friction of soil.

Taking into account the engineering and geological conditions, morphometric parameters and characteristics of the slope relief and indicators of the physical and mechanical properties of the soils that make up the geological environment, the slope stability coefficient was determined using 3 profiles.

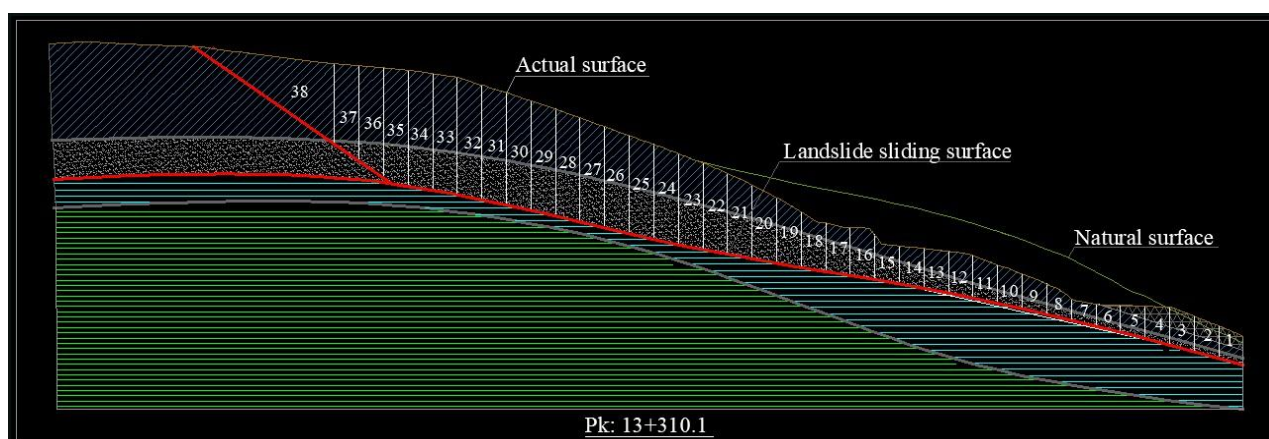


Figure 5. Geomodel for determining slope stability along profile Pk 13 + 310

Determination of the slope stability coefficient for the profile PK 13+310																		
Block number	F m ²	Q = F · ρ t/m	α degree	tg α	ψ _p degree	α - ψ _p	tg (α - ψ _p)	H = Q · tg α t/m	R = Q · tg (α - ψ _p) t/m	T = H - R t/m	ρ t/m ³	h m	P = ρ · h t/m ²	φ degree	tg φ	C t/m ²	$\frac{C}{P}$	Fp = tg φ + $\frac{C}{P}$
2	34,8	63,7	15	0,268	32	-17	-0,287	17,1	-18,3	35,4	1,83	7,0	12,8	18	0,325	3,7	0,29	0,615
4	36,3	66,1	15	0,268	31	-16	0,287	17,7	19,0	-1,3	1,82	7,3	13,3	18	0,325	3,8	0,28	0,607
6	24,9	47,6	15	0,268	34	-19	-0,344	12,8	-16,4	29,1	1,91	5,0	9,6	19	0,344	3,2	0,34	0,683
8	27,4	51,9	14	0,249	32	-18	-0,325	12,9	-16,9	29,8	1,89	5,7	10,8	19	0,344	3,2	0,29	0,637
10	37,3	71,5	12	0,213	30	-18	-0,325	15,2	-23,2	38,5	1,92	7,5	14,4	19	0,344	3,3	0,23	0,572
12	43,5	82,6	11	0,194	29	-18	-0,325	16,0	-26,8	42,9	1,90	8,7	16,5	20	0,364	3,1	0,19	0,552
14	39,9	73,2	11	0,194	28	-17	-0,306	14,2	-22,4	36,6	1,83	8,0	14,7	21	0,384	2,4	0,16	0,546
16	50,1	91,6	10	0,176	27	-17	-0,306	16,1	-28,0	44,2	1,83	10,3	18,8	21	0,384	2,4	0,13	0,510
18	51,8	92,1	10	0,176	27	-17	-0,306	16,2	-28,2	44,4	1,78	10,2	18,1	22	0,404	1,8	0,10	0,505
20	71,3	129,8	10	0,176	25	-15	-0,268	22,8	-34,8	57,6	1,82	14,3	26,0	21	0,384	2,3	0,09	0,472
22	85,9	157,7	11	0,194	25	-14	-0,249	30,6	-39,3	69,9	1,84	17,2	31,6	21	0,384	2,4	0,08	0,461
24	95,6	176,3	12	0,213	24	-12	-0,213	37,6	-37,6	75,1	1,84	19,1	35,2	20	0,364	2,5	0,07	0,436
26	103	190,2	13	0,231	24	-11	-0,194	43,9	-36,9	80,8	1,85	20,5	38,0	20	0,364	2,6	0,07	0,434
28	109	203,4	14	0,249	23	-9	-0,158	50,6	-32,1	82,8	1,87	21,8	40,8	20	0,364	2,8	0,07	0,432
30	114	215,4	13	0,231	23	-10	-0,176	49,8	-37,9	87,7	1,88	22,8	43,0	20	0,364	2,9	0,07	0,433
32	119	225,6	11	0,194	23	-12	-0,213	43,8	-48,1	91,8	1,90	23,8	45,2	20	0,364	3,1	0,07	0,433
34	119	227,8	9	0,158	22	-13	-0,231	36,0	-52,6	88,6	1,91	23,8	45,5	19	0,344	3,2	0,07	0,414
36	105	203,8	35	0,700	23	12	0,213	142,7	43,4	99,3	1,94	21,0	40,8	19	0,344	3,6	0,09	0,431
38	236	483,4	35	0,700	30	5	0,087	338,4	42,1	296,3	2,05	8,4	17,2	17	0,306	4,7	0,27	0,577

Table 1. Determination of slope stability along profile PK 13 + 310

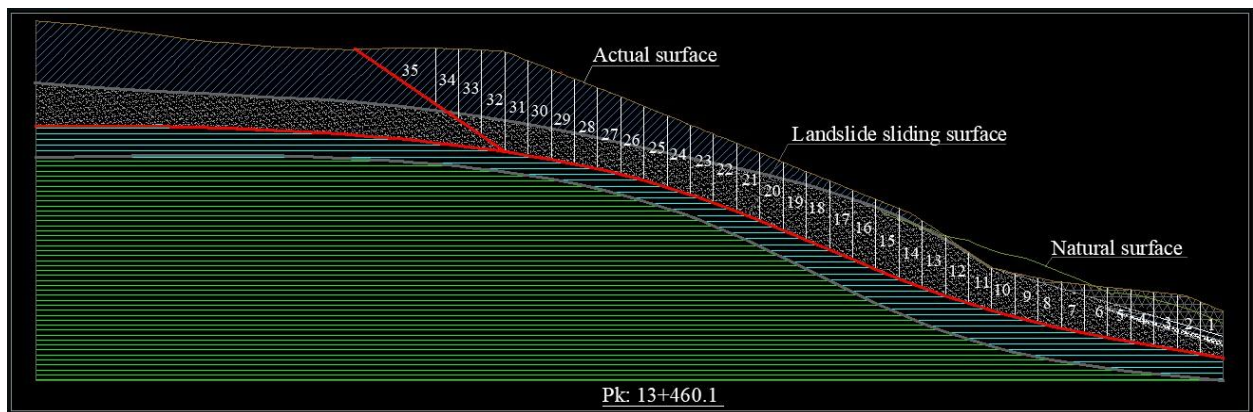


Figure 6. Geomodel for determining slope stability along profile Pk 13 + 460

Determination of the slope stability coefficient for the profile PK 13+460																		
Block number	F m ²	Q = F · ρ t/m	α degree	tg α	ψ _p degree	α - ψ _p	tg (α - ψ _p)	H = Q · tg α t/m	R = Q · tg (α - ψ _p) t/m	T = H - R t/m	ρ t/m ³	h m	P = ρ · h t/m ²	φ degree	tg φ	C t/m ²	$\frac{C}{P}$	Fp = tg φ + $\frac{C}{P}$
1	53,3	103,6	9	0,158	27	-18	-0,325	16,4	-33,6	50,0	1,94	10,7	20,8	19	0,341	3,6	0,17	0,512
3	59,4	113,2	10	0,176	26	-16	-0,287	20,0	-32,5	52,4	1,91	11,9	22,7	19	0,353	3,2	0,14	0,493
5	55,8	99,1	11	0,194	26	-15	-0,268	19,3	-26,6	45,8	1,78	11,1	19,7	22	0,397	1,8	0,09	0,490
7	51,6	88,5	12	0,213	26	-14	-0,249	18,8	-22,1	40,9	1,72	10,3	17,7	23	0,418	1,2	0,07	0,485
9	48,3	80,3	14	0,249	25	-11	-0,194	20,0	-15,6	35,6	1,66	9,5	15,8	24	0,437	0,6	0,04	0,477
11	50,6	83,0	17	0,306	25	-8	-0,141	25,4	-11,7	37,0	1,64	10,1	16,6	24	0,445	0,4	0,02	0,469
13	69,0	115,4	20	0,364	25	-5	-0,087	42,0	-10,1	52,1	1,67	13,8	23,1	23	0,433	0,7	0,03	0,465
15	76,3	128,8	22	0,404	25	-3	-0,052	52,0	-6,8	58,8	1,69	15,3	25,8	23	0,428	0,9	0,03	0,463
17	75,3	127,8	23	0,424	25	-2	-0,035	54,3	-4,5	58,7	1,70	15,0	25,5	23	0,425	1,0	0,04	0,464
19	74,0	128,0	23	0,424	25	-2	-0,035	54,3	-4,5	58,8	1,73	14,7	25,4	22	0,413	1,3	0,05	0,466
21	73,9	131,1	22	0,404	25	-3	-0,052	53,0	-6,9	59,9	1,77	14,7	26,2	22	0,398	1,8	0,07	0,467
23	75,8	138,0	19	0,344	25	-6	-0,105	47,5	-14,5	62,0	1,82	15,0	27,3	21	0,382	2,3	0,08	0,466
25	79,4	147,6	16	0,287	25	-9	-0,158	42,3	-23,4	65,7	1,86	15,9	29,6	20	0,369	2,7	0,09	0,460
27	86,2	162,6	13	0,231	24	-11	-0,194	37,5	-31,6	69,2	1,89	17,3	32,6	20	0,360	3,0	0,09	0,451
29	95,0	181,1	11	0,194	24	-13	-0,231	35,2	-41,8	77,0	1,91	18,9	36,0	19	0,353	3,2	0,09	0,441
31	105,7	202,8	9	0,158	23	-14	-0,249	32,1	-50,6	82,7	1,92	21,2	40,7	19	0,349	3,3	0,08	0,430
33	85,5	169,5	35	0,700	24	11	0,194	118,7	33,0	85,8	1,98	17,1	33,9	18	0,328	4,0	0,12	0,445
35	105,6	216,5	35	0,700	34	1	0,017	151,6	3,8	147,8	2,05	6,2	12,7	17	0,306	4,7	0,37	0,673

Table 2. Determination of slope stability along profile PK 13 + 460

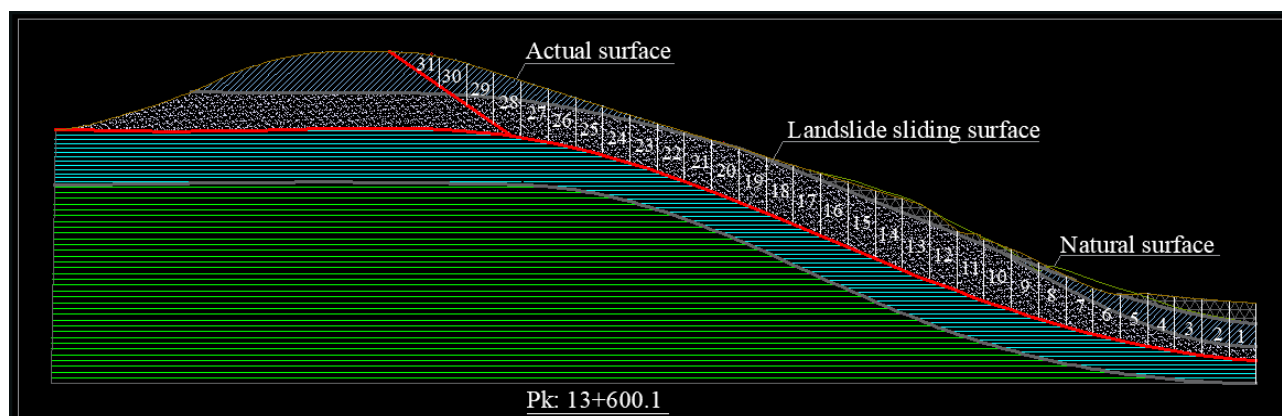


Figure 7. Geomodel for determining slope stability along profile Pk 13 + 600

Determination of the slope stability coefficient for the profile PK 13+600																		
Block number	F m ²	Q = F · ρ t/m	α degree	tg α	ψ _p degree	α - ψ _p	tg (α - ψ _p)	H = Q · tg α t/m	R = Q · tg (α - ψ _p) t/m	T = H · R t/m	ρ t/m ³	h m	P = ρ · h t/m ²	φ degree	tg φ	C t/m ²	$\frac{C}{P}$	Fp = tg φ + $\frac{C}{P}$
1	61,7	121,4	5	0,087	26	-21	-0,385	10,6	-46,7	57,3	1,97	12,4	24,4	18	0,333	3,8	0,16	0,489
3	63,7	124,7	9	0,158	26	-17	-0,302	19,7	-37,7	57,4	1,96	12,8	25,1	19	0,336	3,7	0,15	0,484
5	53,6	100,9	12	0,212	27	-15	-0,264	21,4	-26,7	48,1	1,88	10,8	20,3	20	0,361	2,9	0,14	0,505
7	40,9	70,2	15	0,268	27	-12	-0,208	18,8	-14,6	33,4	1,72	8,1	13,9	23	0,418	1,2	0,09	0,504
9	48,0	78,7	18	0,325	25	-7	-0,126	25,6	-9,9	35,5	1,64	9,6	15,7	24	0,445	0,4	0,03	0,470
11	44,6	73,1	20	0,364	25	-5	-0,093	26,6	-6,8	33,4	1,64	8,7	14,3	24	0,445	0,4	0,03	0,473
13	45,4	74,5	22	0,404	25	-3	-0,057	30,1	-4,3	34,3	1,64	9,1	14,9	24	0,445	0,4	0,03	0,472
15	43	70,5	23	0,424	25	-2	-0,041	29,9	-2,9	32,8	1,64	8,7	14,3	24	0,445	0,4	0,03	0,473
17	39,1	64,1	23	0,424	25	-2	-0,043	27,2	-2,8	30,0	1,64	7,8	12,8	24	0,445	0,4	0,03	0,476
19	41,5	68,1	22	0,404	25	-3	-0,058	27,5	-4,0	31,5	1,64	8,6	14,1	24	0,445	0,4	0,03	0,473
21	36	59,0	21	0,384	26	-5	-0,080	22,7	-4,7	27,4	1,64	7,2	11,8	24	0,445	0,4	0,03	0,479
23	42,4	69,5	18	0,325	25	-7	-0,129	22,6	-9,0	31,6	1,64	8,5	13,9	24	0,445	0,4	0,03	0,474
25	40,4	66,3	15	0,268	25	-10	-0,184	17,7	-12,2	29,9	1,64	8,1	13,3	24	0,445	0,4	0,03	0,475
27	50,8	89,8	10	0,176	26	-16	-0,294	15,8	-26,4	42,3	1,77	10,2	18,0	22	0,400	1,7	0,10	0,496
29	43,2	81,8	35	0,700	29	6	0,113	57,2	9,3	48,0	1,89	8,6	16,3	20	0,358	3,0	0,19	0,544
31	25,6	52,5	35	0,700	44	-9	-0,164	36,7	-8,6	45,3	2,05	3,4	7,0	17	0,306	4,7	0,67	0,976

Table 3. Determination of slope stability along profile PK 13 + 600

As a result of calculations carried out on the specified profiles, the following slope stability coefficients were determined:

1. Pk 13+310 $K_s = 1.78$ $\alpha = 16^\circ$ $\varphi = 23^\circ$ (Fig. 5, Table 1)

Pk 13+310 $K_{ss} = 1.38$ $\alpha = 16^\circ$ $\varphi = 20^\circ$

2. Pk 13+460 $K_s = 1.62$ $\alpha = 19^\circ$ $\varphi = 27^\circ$ (Fig. 6, Table 2)

Pk 13+460 $K_{ss} = 1.22$ $\alpha = 19^\circ$ $\varphi = 22^\circ$

3. Pk 13+600 $K_s = 1.76$ $\alpha = 19^\circ$ $\varphi = 29^\circ$ (Fig. 7, Table 3)

Pk 13+600 $K_{ss} = 1.27$ $\alpha = 19^\circ$ $\varphi = 24^\circ$

K_s is the stability coefficient, K_{ss} is the stability coefficient taking into account seismicity (ODM, 2010), α is the average value of the probable slope of the sliding plane, φ is the average value of the angle of internal friction of the soils of the sliding block.

Based on the analysis of the engineering and geological conditions of the territory and the assessment of certain slope stability coefficients, it can be concluded that the slope in question is in a completely stable state under real conditions.

The slope stability factor is the ratio of the true values of the strength characteristics of the soil to the values of the strength characteristics of the soil at which the destruction of the massif occurs (Tabuyev, 2010).

It should be noted that as a result of excavation work carried out without taking into account the engineering and geological conditions and geomorphological structure of the slope, potentially dangerous landslide areas were created on a significant part of the slope. As a result, the slope

stability coefficients taking into account seismicity ($K_{ss} = 1.22-1.27$) along the PK 13 + 460 and PK 13 + 600 profiles are less than the reserve stability coefficient ($K_{sf} = 1.3$).

Due to the fact that the slope stability coefficient is lower than the stability reserve coefficient and the presence of local potential landslide zones formed as a result of anthropogenic factors and taking into account the change in the ratio of forces ensuring the stability of the soil massif as a result of undercutting the heel of the slope during the construction of the highway, in order to ensure reliable slope stability and safe operation of the highway, it is necessary to design anti-landslide engineering and protective measures.

To this end, in order to reduce the load on the sliding area and thus increase the stability of the slope, options for cutting the upper part of the slope along various lines were investigated, the slope stability coefficient for new surfaces was calculated, and the most optimal option for the formation of a new slope morphology was determined.

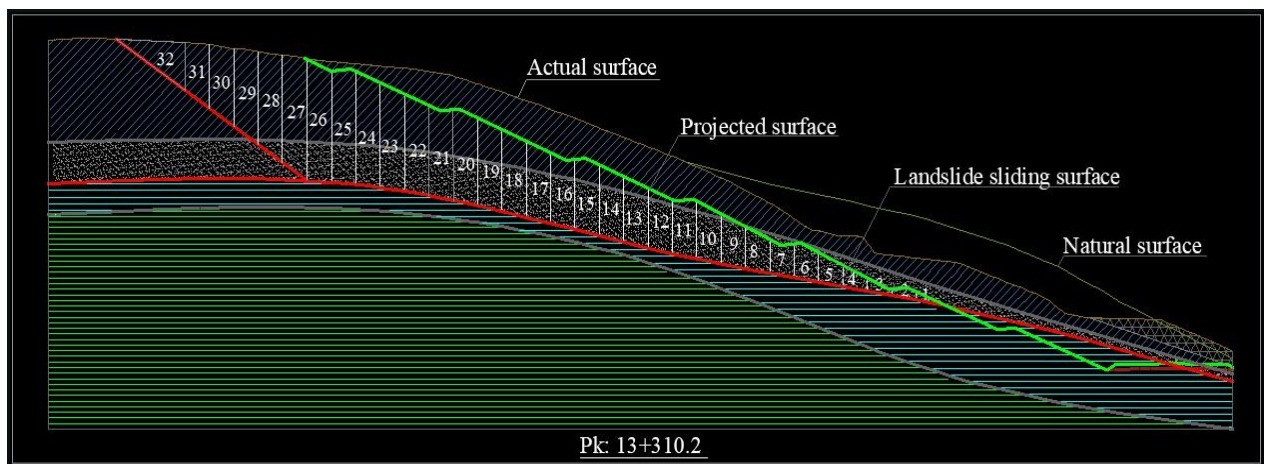


Figure 8. Geomodel for determination of stability on a newly designed slope surface along the profile PK 13 + 310

Determination of stability on a newly designed slope surface along the profile PK 13+310																		
Block number	F m ²	Q = F · ρ t/m	α degree	tg α	ψ _p degree	α - ψ _p	tg (α - ψ _p)	H = Q · tg α t/m	R = Q · tg (α - ψ _p) t/m	T = H - R t/m	ρ t/m ³	h m	P = ρ · h t/m ²	φ degree	tg φ	C t/m ²	$\frac{C}{P}$	$Fp = tg \varphi + \frac{C}{P}$
2	8,9	14,6	10	0,176	30	-20	-0,364	2,6	-5,3	7,9	1,64	1,9	3,1	24	0,445	0,4	0,13	0,573
4	17,2	28,2	10	0,176	27	-17	-0,306	5,0	-8,6	13,6	1,64	3,5	5,7	24	0,445	0,4	0,07	0,515
6	32,3	53,0	9	0,158	26	-17	-0,306	8,4	-16,2	24,6	1,64	6,6	10,8	24	0,445	0,4	0,04	0,482
8	37,3	61,2	10	0,176	25	-15	-0,268	10,8	-16,4	27,2	1,64	7,5	12,3	24	0,445	0,4	0,03	0,477
10	52,8	89,9	11	0,194	26	-15	-0,268	17,5	-24,1	41,5	1,70	10,5	17,9	23	0,423	1,1	0,06	0,482
12	55,3	93,8	12	0,212	25	-13	-0,231	19,9	-21,6	41,6	1,70	11,0	18,7	23	0,425	1,0	0,05	0,478
14	66	115,6	13	0,231	25	-12	-0,212	26,7	-24,6	51,2	1,75	12,9	22,6	22	0,406	1,6	0,07	0,475
16	67,1	117,8	14	0,249	25	-11	-0,194	29,3	-22,9	52,2	1,75	13,2	23,2	22	0,405	1,6	0,07	0,474
18	77,1	139,3	13	0,231	25	-12	-0,212	32,1	-29,6	61,7	1,81	15,3	27,6	21	0,387	2,1	0,08	0,464
20	87,9	162,4	11	0,194	24	-13	-0,231	31,5	-37,5	69,0	1,85	17,6	32,5	20	0,373	2,6	0,08	0,452
22	91,1	169,8	9	0,158	24	-15	-0,268	26,9	-45,5	72,4	1,86	18,3	34,1	20	0,367	2,7	0,08	0,447
24	105,6	200,5	7	0,123	23	-16	-0,287	24,6	-57,5	82,1	1,90	21,1	40,1	20	0,356	3,1	0,08	0,433
26	114,6	218,9	4	0,070	23	-19	-0,344	15,3	-75,3	90,6	1,91	22,5	43,0	19	0,352	3,2	0,07	0,427
28	97,0	193,5	35	0,700	23	12	0,212	135,4	41,1	94,3	2,00	19,4	38,7	18	0,324	4,1	0,11	0,429
30	68,4	140,2	35	0,700	25	10	0,176	98,1	24,7	73,4	2,05	13,7	28,1	17	0,306	4,7	0,17	0,472
32	65,6	134,5	35	0,700	39	-4	-0,070	94,1	-9,4	103,5	2,05	4,6	9,4	17	0,306	4,7	0,50	0,801

Table 4. Determination of stability on a newly designed slope surface along the profile PK 13 + 310

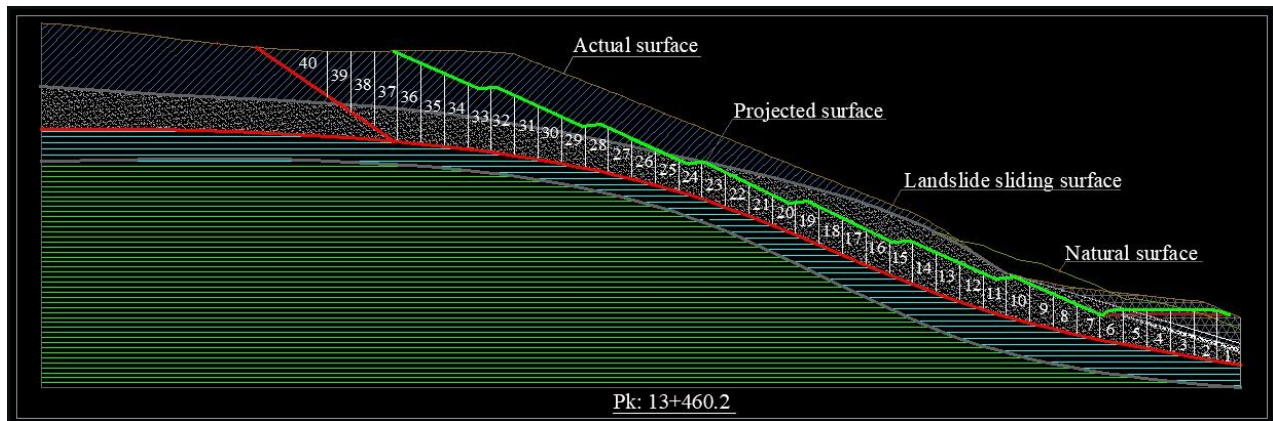


Figure 9. Geomodel for determination of stability on a newly designed slope surface along the profile PK 13 + 460

Block number	F m ²	Q = F · ρ t/m	α degree	tg α	ψ _p degree	α - ψ _p	tg (α - ψ _p)	H = Q · tg α t/m	R = Q · tg (α - ψ _p) t/m	T = H · R t/m	ρ t/m ³	h m	P = ρ · h t/m ²	φ degree	tg φ	C t/m ²	$\frac{C}{P}$	$Fp = tg \varphi + \frac{C}{P}$
2	52,4	100,2	10	0,176	27	-17	-0,309	17,7	-31,0	48,7	1,91	10,40	19,9	19	0,351	3,2	0,16	0,514
4	44,3	80,8	10	0,176	28	-18	-0,318	14,2	-25,7	39,9	1,82	8,90	16,2	21	0,381	2,3	0,14	0,524
6	32,5	53,3	11	0,194	26	-15	-0,262	10,4	-14,0	24,3	1,64	6,74	11,1	24	0,445	0,4	0,04	0,481
8	34,8	57,1	13	0,231	26	-13	-0,224	13,2	-12,8	26,0	1,64	7,00	11,5	24	0,445	0,4	0,03	0,480
10	43,3	71,0	15	0,268	25	-10	-0,182	19,0	-12,9	31,9	1,64	8,80	14,4	24	0,445	0,4	0,03	0,473
12	40,8	66,9	18	0,325	25	-7	-0,130	21,7	-8,7	30,4	1,64	8,20	13,4	24	0,445	0,4	0,03	0,475
14	45	73,8	21	0,384	25	-4	-0,075	28,3	-5,5	33,8	1,64	9,00	14,8	24	0,445	0,4	0,03	0,472
16	37,1	60,8	23	0,424	26	-3	-0,045	25,8	-2,7	28,5	1,64	7,40	12,1	24	0,445	0,4	0,03	0,478
18	40,3	66,1	23	0,424	25	-2	-0,042	28,0	-2,8	30,8	1,64	8,10	13,3	24	0,445	0,4	0,03	0,475
20	32,9	54,0	23	0,424	26	-3	-0,049	22,9	-2,6	25,5	1,64	6,40	10,5	24	0,445	0,4	0,04	0,483
22	38,4	63,0	21	0,384	26	-5	-0,080	24,2	-5,0	29,2	1,64	7,30	12,0	24	0,445	0,4	0,03	0,478
24	35,5	58,2	18	0,325	26	-8	-0,135	18,9	-7,8	26,7	1,64	6,90	11,3	24	0,445	0,4	0,04	0,480
26	40,6	66,6	15	0,268	25	-10	-0,184	17,8	-12,2	30,1	1,64	8,10	13,3	24	0,445	0,4	0,03	0,475
28	48,4	85,7	12	0,212	27	-15	-0,260	18,2	-22,3	40,5	1,77	9,80	17,3	22	0,399	1,8	0,10	0,500
30	53,9	96,8	10	0,176	26	-16	-0,293	17,1	-28,4	45,4	1,80	10,80	19,4	21	0,391	2,0	0,10	0,495
32	68,1	125,6	8	0,140	25	-17	-0,313	17,6	-39,4	57,0	1,85	13,60	25,1	21	0,374	2,5	0,10	0,475
34	74,1	137,5	7	0,123	25	-18	-0,325	16,9	-44,7	61,6	1,86	14,80	27,5	20	0,370	2,7	0,10	0,466
36	90,8	165,1	5	0,087	26	-21	-0,378	14,4	-62,4	76,8	1,82	12,61	22,9	21	0,383	2,3	0,10	0,481
38	73,4	144,1	35	0,700	25	10	0,177	100,8	25,5	75,4	1,96	14,60	28,7	18	0,334	3,8	0,13	0,465
40	73,6	150,9	35	0,700	38	-3	-0,052	105,6	-7,8	113,4	2,05	4,8	9,8	17	0,306	4,7	0,47	0,780

Table 5. Determination of stability on a newly designed slope surface along the profile PK 13 + 460

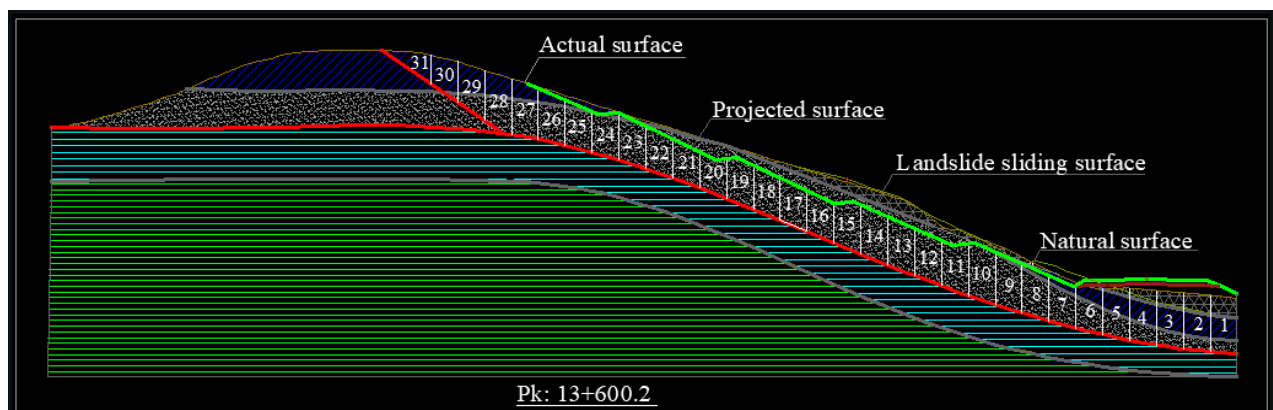


Figure 10. Geomodel for determination of stability on a newly designed slope surface along the profile PK 13 + 600

Determination of stability on a newly designed slope surface along the profile PK 13+600																		
Block number	F m ²	Q = F · ρ t/m	α degree	tg α	ψ _p degree	α - ψ _p	tg (α - ψ _p)	H = Q · tg α t/m	R = Q · tg (α - ψ _p) t/m	T = H · R t/m	ρ t/m ³	h m	P = ρ · h t/m ²	φ degree	tg φ	C t/m ²	$\frac{C}{P}$	$Fp = tg \varphi + \frac{C}{P}$
1	61,7	121,4	5	0,087	26	-21	-0,385	10,6	-46,7	57,3	1,97	12,4	24,4	18	0,333	3,8	0,16	0,489
3	63,7	124,7	9	0,158	26	-17	-0,302	19,7	-37,7	57,4	1,96	12,8	25,1	19	0,336	3,7	0,15	0,484
5	53,6	100,9	12	0,212	27	-15	-0,264	21,4	-26,7	48,1	1,88	10,8	20,3	20	0,361	2,9	0,14	0,505
7	40,9	70,2	15	0,268	27	-12	-0,208	18,8	-14,6	33,4	1,72	8,1	13,9	23	0,418	1,2	0,09	0,504
9	48,0	78,7	18	0,325	25	-7	-0,126	25,6	-9,9	35,5	1,64	9,6	15,7	24	0,445	0,4	0,03	0,470
11	44,6	73,1	20	0,364	25	-5	-0,093	26,6	-6,8	33,4	1,64	8,7	14,3	24	0,445	0,4	0,03	0,473
13	45,4	74,5	22	0,404	25	-3	-0,057	30,1	-4,3	34,3	1,64	9,1	14,9	24	0,445	0,4	0,03	0,472
15	43	70,5	23	0,424	25	-2	-0,041	29,9	-2,9	32,8	1,64	8,7	14,3	24	0,445	0,4	0,03	0,473
17	39,1	64,1	23	0,424	25	-2	-0,043	27,2	-2,8	30,0	1,64	7,8	12,8	24	0,445	0,4	0,03	0,476
19	41,5	68,1	22	0,404	25	-3	-0,058	27,5	-4,0	31,5	1,64	8,6	14,1	24	0,445	0,4	0,03	0,473
21	36	59,0	21	0,384	26	-5	-0,080	22,7	-4,7	27,4	1,64	7,2	11,8	24	0,445	0,4	0,03	0,479
23	42,4	69,5	18	0,325	25	-7	-0,129	22,6	-9,0	31,6	1,64	8,5	13,9	24	0,445	0,4	0,03	0,474
25	40,4	66,3	15	0,268	25	-10	-0,184	17,7	-12,2	29,9	1,64	8,1	13,3	24	0,445	0,4	0,03	0,475
27	50,8	89,8	10	0,176	26	-16	-0,294	15,8	-26,4	42,3	1,77	10,2	18,0	22	0,400	1,7	0,10	0,496
29	43,2	81,8	35	0,700	29	6	0,113	57,2	9,3	48,0	1,89	8,6	16,3	20	0,358	3,0	0,19	0,544
31	25,6	52,5	35	0,700	44	-9	-0,164	36,7	-8,6	45,3	2,05	3,4	7,0	17	0,306	4,7	0,67	0,976

Table 6. Determination of stability on a newly designed slope surface along the profile PK 13 + 600

Stability coefficients on the new surface formed after the existing surface of the slope has been changed:

1. Pk 13 + 310 $K_s = 1.88$ $\alpha = 15^\circ$ $\varphi = 27^\circ$ (Fig. 8, Table 4)
Pk 13 + 310 $K_{ss} = 1.35$ $\alpha = 15^\circ$ $\varphi = 23^\circ$
2. Pk 13 + 460 $K_s = 1.92$ $\alpha = 19^\circ$ $\varphi = 30^\circ$ (Fig. 9, Table 5)
Pk 13 + 460 $K_{ss} = 1.38$ $\alpha = 19^\circ$ $\varphi = 24^\circ$
3. Pk 13 + 600 $K_s = 1.84$ $\alpha = 19^\circ$ $\varphi = 30^\circ$ (Fig. 10, Table 6)
Pk 13 + 600 $K_{ss} = 1.32$ $\alpha = 19^\circ$ $\varphi = 24^\circ$

After changing the slope relief along a given line, the slope stability reserve condition ($K_{sf} \geq 1.3$) is met for all profiles.



Figure 11. Image of the study area after landslide measures

Conclusion

When providing geotechnical justification for the design of complex engineering anti-landslide measures on similar slopes, it is advisable to take into account the following factors:

- Changing the topography of slopes is a cost-effective and practically easy measure to prevent landslide processes (decreasing the steepness of the slope, removing unstable soil mass, decreasing tensile reactive forces, increasing retaining tangential forces);

- When determining the slope of a new slope, along with the slope stability coefficient, the seismicity of the area and the angle of internal friction of the soil under conditions of maximum moisture should be taken into account;
- To reduce the impact of varying levels of wear and erosion processes that may occur on the newly created slope surface, terraces should be created on the slope surface and berms 4-6 meters wide at the foot of the terraces;
- When replacing a new slope surface, the width of the terraces formed after excavation work should not exceed 20-22 meters, and the slope of the surface should not exceed 24° in accordance with existing geological conditions;
- The slope of the berms should be 3-4 degrees towards the foot of the terrace on the upper section;
- The flow of atmospheric precipitation (snow and rainwater) along the upper part of the slope must be regulated;
- To regulate the surface water level on terraces, separate telescopic reinforced concrete gutters should be installed at the foot of the terraces and the water flow should be directed to safe areas;
- To protect the surfaces of terraces and berms from over-wetting, wear and erosion processes, and the negative impact of rain and snow water, these areas should be filled with clay soils that do not have specific properties, 15-20 cm thick; after leveling the surface, special types of plants (almonds, rosemary, etc.) should be planted.
- To improve slope stability and maintain soil dryness, agroforestry measures should be carried out, including planting pistachio, almond, and acacia trees on the outer part of the berms;
- Excavation work on the slope should be carried out in the direction from the edge of the slope to the foot;

To ensure the reliable and long-term stability of the slope, the above measures must be comprehensively and fully implemented.

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