Identification and Mathematical Modeling of Landslides and Slip Points Adversely Affecting Automobile Roads

Khayotjon Khayitov1, a), Rashidbek Hudaykulov1, b), Barno Salimova1, c), Khurshid Abdullaev1, d) and Dilshod Aralov1, f)

1*Tashkent State Transport University, 1 Temiryulchilar St., Tashkent 100167, Uzbekistan*

*Corresponding author: a)* [*xayotjonxayitov91@gmail.com*](mailto:xayotjonxayitov91@gmail.com) *b)* [*Rashidbek\_19\_87@mail.ru*](mailto:Rashidbek_19_87@mail.ru) *c)* [*barno.salimova@inbox.ru*](mailto:barno.salimova@inbox.ru) *d)* [*Mr.Khurshidbek93@mail.ru*](mailto:Mr.Khurshidbek93@mail.ru) *f)* [*dilshod.aralov.96@mail.ru*](mailto:dilshod.aralov.96@mail.ru)

**Abstract.** During the service life of mountain roads, landslides not only damage the road itself but also adversely affect vehicles and other road users. Moreover, in the mountainous regions of our country, landslides and slope movements not only compromise the integrity of the road network but also have detrimental effects on the local environment. This study examines methods for mitigating the impact of landslides on public roads and, through mathematical modeling, identifies advanced, highly effective countermeasures tailored to the specific conditions of landslide-prone areas.

**Keywords:** Automobile road; modeling; slope; slippage; slope angle; slope height; force; weather; soil; mountain landslides

# INTRODUCTION

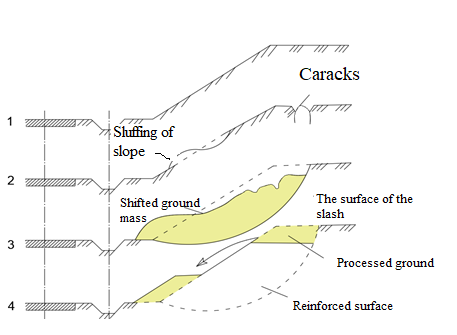
Highways are economically valuable engineered structures that face numerous challenges during design, construction, and operation. These difficulties are especially pronounced for roads traversing mountainous areas. Not only does routing a highway through rugged terrain demand substantial effort, but ensuring traffic safety and maintaining the pavement in good condition are also formidable tasks.

Consequently, studying the effects of landslides on mountain roads remains a pressing concern. Preventing such processes necessitates a range of engineering measures, including pre-assessment methods to predict landslide risk, installation of gabion structures on slopes, the construction of galleries, and the development of innovative, modern engineering solutions.

# RESEARCH METHODS AND RESULTS

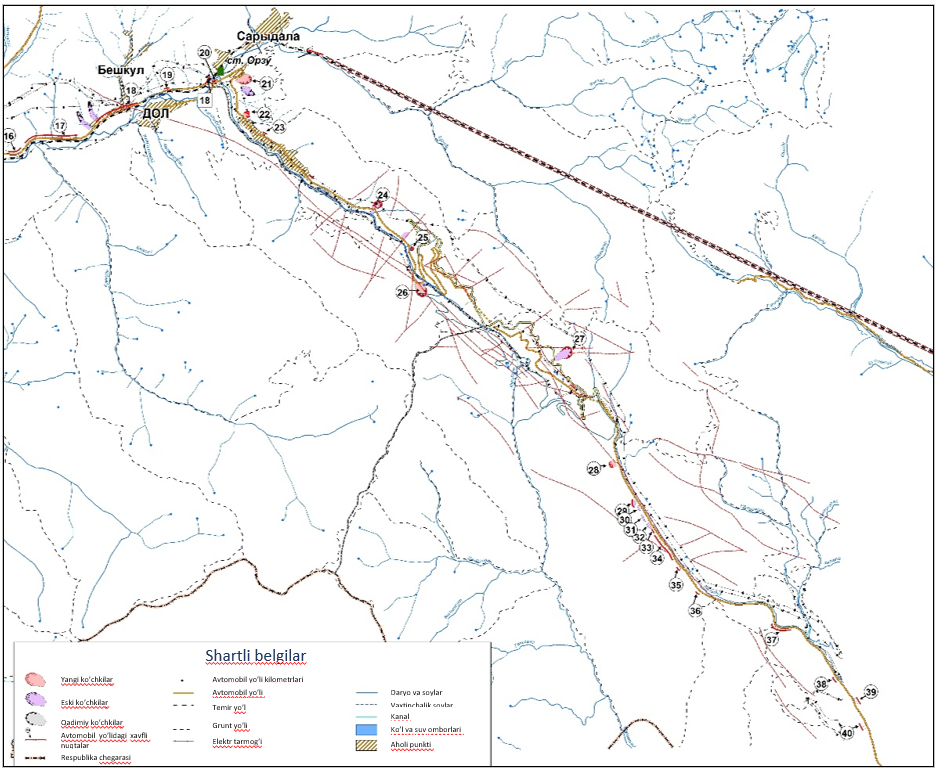
Slope movement of mountain inclines-commonly referred to as sliding-occurs when the balance between driving and resisting forces is lost, resulting in deformation of the lower layers of the soil mass along a potential slip surface (Figure 1). This phenomenon typically characterizes homogeneous soil slopes. Under the influence of its own weight, the soil in the slope develops excess shear stress proportional to its mass. Naturally, the potential failure surfaces in the slope tend to be curved, often taking the form of circular arcs [1].

The science of slope‐stability analysis evaluates stability by calculating safety factors for a series of possible slip surfaces. For each candidate surface, the factor of safety is defined as the ratio of the shear strength available (resisting moment) to the shear stress required to maintain equilibrium (driving moment) along that surface. The lowest computed safety factor among all considered surfaces is taken as the stability coefficient of the slope, and it indicates the margin by which the resisting shear strength exceeds the driving shear stress [2, 3]. Some of the commonly used methods for performing these calculations are described below.



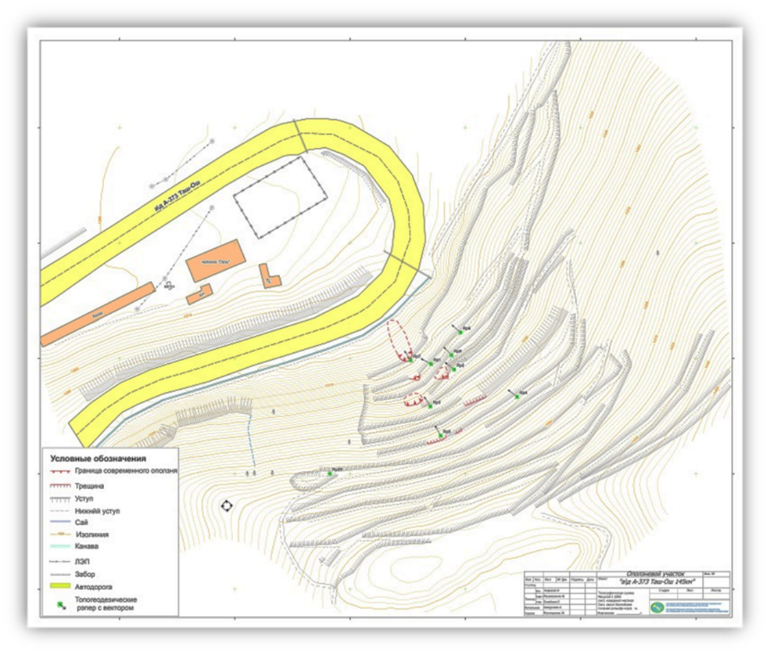
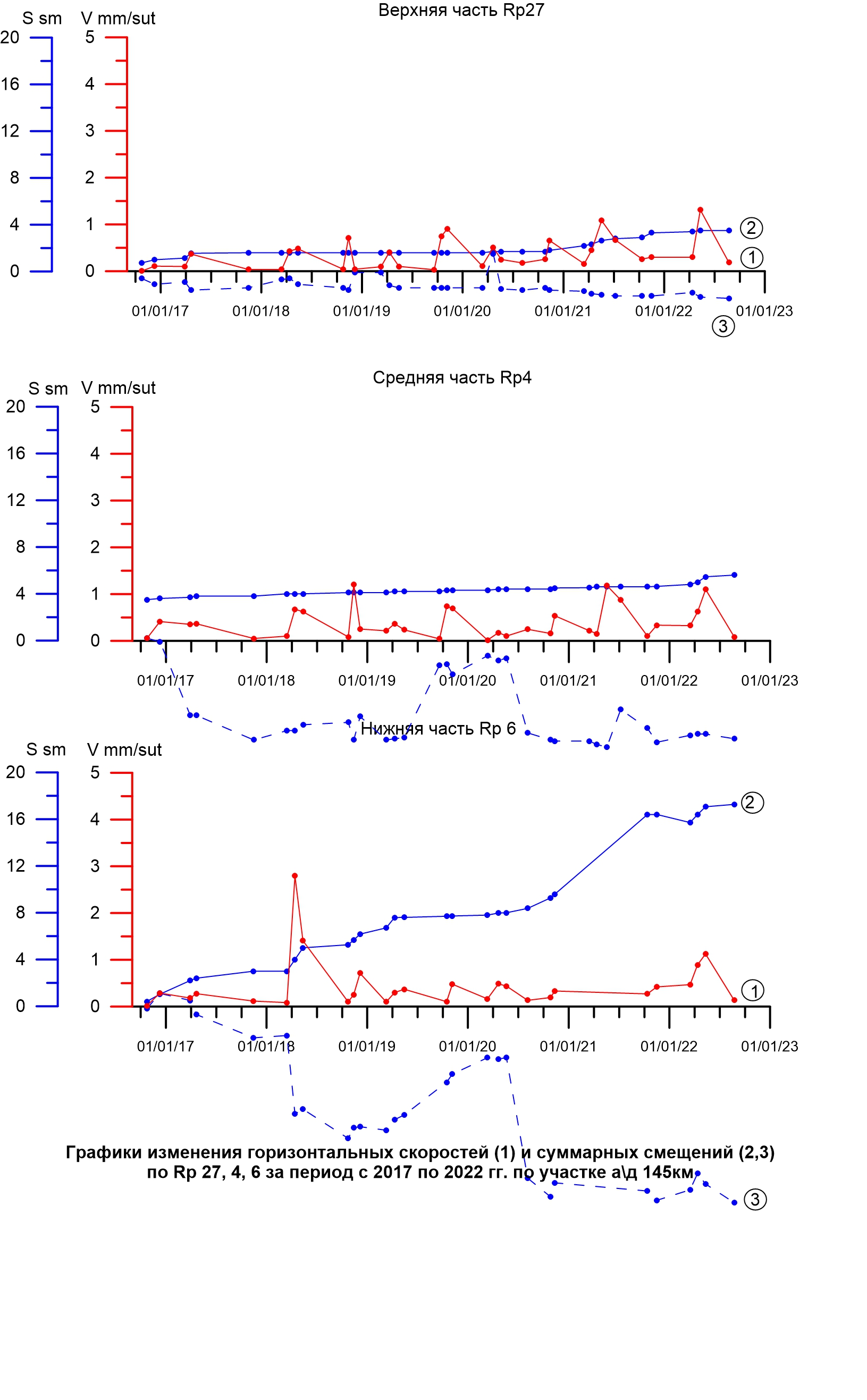
**FIGURE 1.** Schematic of Slope Movement: 1 – General view; 2 – Initial stage of failure; 3 – Sliding;   
4 – Reduction of slope mass

The study area is the “Qamchiq” Pass section of the A373 “Tashkent – Ohangaron – Angren – Kokand –Shahrikhon–Andijon” highway, where several locations are prone to landslides and slope movements and are under continuous monitoring. A GIS-based map of the hazard points for landslides and slope failures on the slopes adjacent to the roadway was developed (Figure 2). This map facilitates systematic monitoring of all hazardous exogenous points [2, 3, 4].

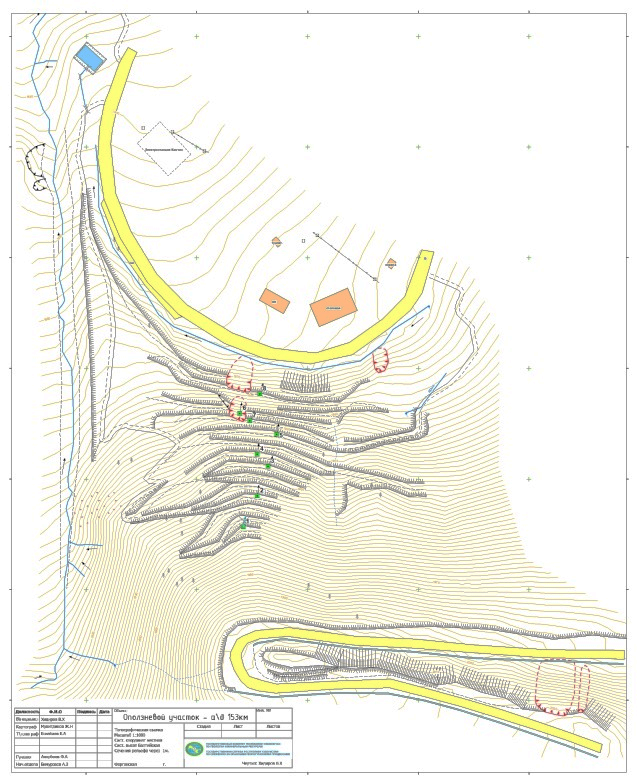
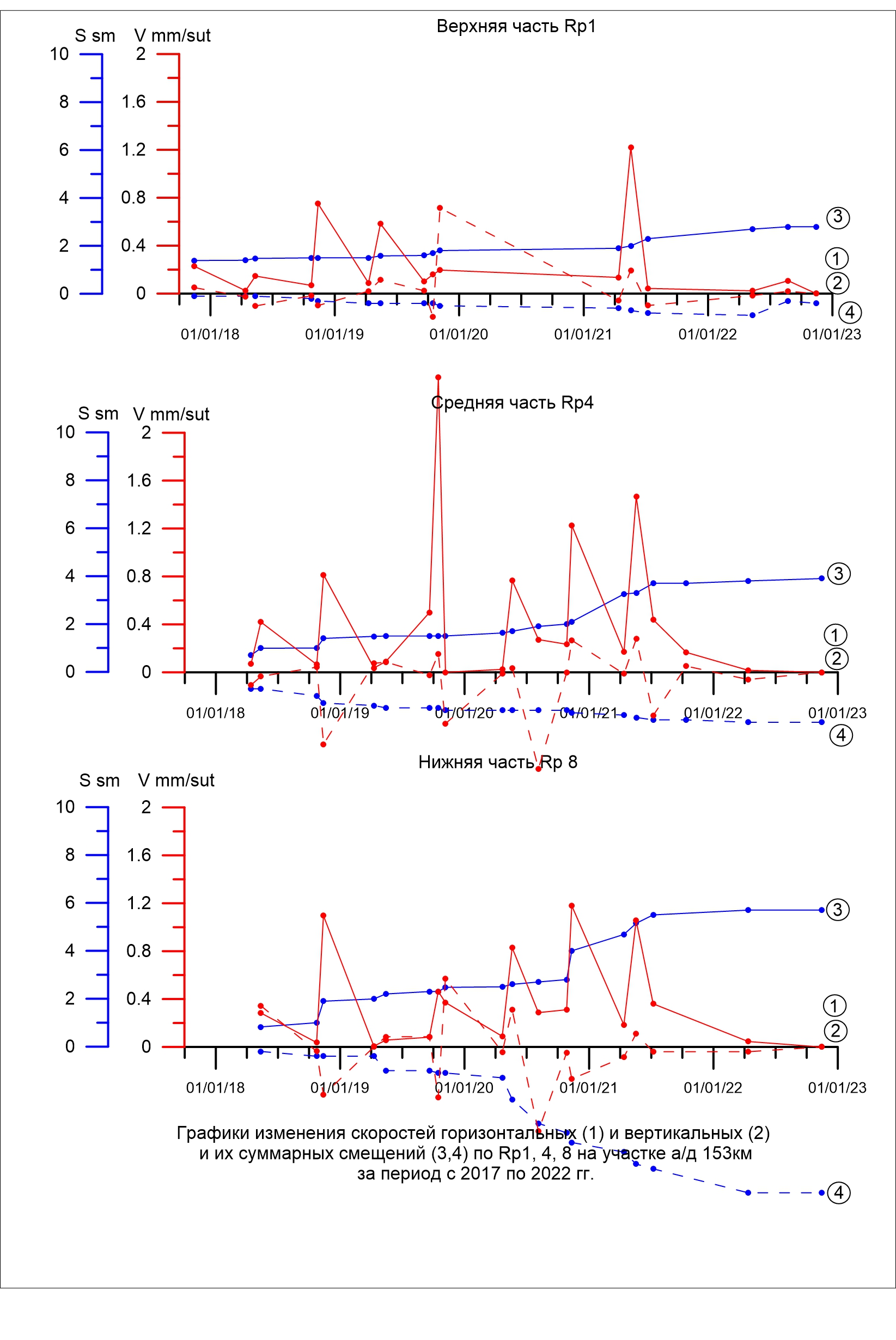
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**FIGURE 2.** GIS map showing the locations of hazardous exogenous process points in the “Qamchiq” Pass area

In the locations shown on the map above, the landslide and slope‐movement hazards were identified in collaboration with specialists from the Fergana Monitoring Station of the State Service for Monitoring Hazardous Geological Processes, based on existing cracks in the slopes, soil properties, and annual precipitation data. A list of all hazardous points was compiled [5]. In addition to producing the hazard map for the Qamchiq Pass, these points have been continuously monitored—on a monthly and yearly basis-using GPS surveys in partnership with the Fergana Station, and the necessary analyses have been performed. The results of these GPS observations are presented graphically in Figures 3 and 4 graphical representation of GPS monitoring results over months and years.

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**FIGURE 3.** Topographic survey and GPS monitoring results for the 222-km section of the A373 “Tashkent – Ohangaron –Angren– Kokand –Shahrikhon–Andijon” highway

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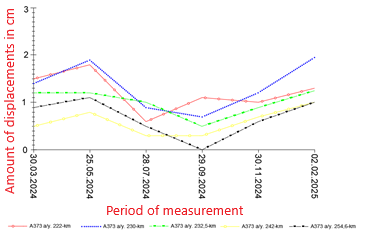
**FIGURE 4.** Topographic survey and GPS monitoring results for the 212-km section of the A373 “Tashkent–Ohangaron–Angren– Kokand –Shahrikhon–Andijon” highway

During the experimental work at the study site, in early spring 2024 and in collaboration with the “Qamchiqavtoyol” State Road Maintenance Department, monitoring benchmarks were installed on mountain slope sections identified as having a potential landslide risk, and slope movement was observed continuously for one year. By placing these benchmarks at landslide‐prone points affecting the highway, we tracked existing cracks and their development, determined which months of the four seasons exhibited the greatest tendency for slope displacement, and identified the principal influencing factors. The results of this monitoring are presented in Table 1.

**TABLE 1.** Values taken from “Tracking Repers” mounted points

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Locations of Monitoring Benchmarks on Mountain Slopes Adjacent to the Road** | **Total Displacements over the Inspection Period, in cm** | | | | | | **Coordinates of Monitoring Benchmarks** | **Elevations of Monitoring Benchmarks Above Sea Level** |
| **March** | **May** | **July** | **September** | **November** | **January** |
| 131 km. | 1,5 | 1,8 | 0,6 | 1,1 | 1,0 | 1,3 | 41.15325  70.44851 | 1354,23 |
| 139 km. | 1,4 | 1,9 | 0,9 | 0,7 | 1,2 | 1,94 | 41.10535  70.50062 | 1896,16 |
| 141,5 km. | 1,2 | 1,2 | 1,0 | 0,5 | 0,9 | 1,25 | 41.10564  70.50823 | 2027,83 |
| 151 km. | 0,6 | 0,8 | 0,3 | 0,3 | 0,7 | 1,0 | 41.06610  70.55747 | 2110,44 |
| 163,6 km. | 0,9 | 1,1 | 0,5 | 0 | 0,6 | 1,0 | 40.99724  70.63450 | 1493,15 |

The table above presents the monitoring benchmarks’ geographic coordinates, elevations above sea level, highway kilometer locations, and each point’s cumulative displacement over one year. These results are also illustrated graphically (Figure 5).

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**FIGURE 5.** Graph displaying the results obtained from the monitoring benchmarks

By monitoring landslide events and analyzing their rates of displacement, it becomes possible to predict in advance the risk, scale, and severity of landslides. Landslides and slope movements can also be categorized by their movement velocity, with observations carried out over months or even years (Table 2).

**TABLE 2.** Types of Landslides and Slope Movements by Rate of Development

|  |  |
| --- | --- |
| **Landslide Velocity** | **Velocity Indicator** |
| Very slow | 16 mm/year – 1.6 m/year |
| Slow | 1.6 m/year – 1.3 m/month |
| Moderate | 1.3 m/month – 1.8 m/hour |
| Fast | 1.8 m/hour – 3 m/minute |
| Very fast | 3 m/minute – 5 m/second |
| Extremely rapid (catastrophic) | > 5 m/second |

In the past decade, various methods based on sectionalizing landslide phenomena have been developed for calculating the stability of mountain slopes. Fundamentally, they are all similar: the differences lie in the assumptions made, how the forces acting on each segment boundary are accounted for, and how the relationship between shear forces and normal forces at the stability limit is defined.

Predicting landslide processes on slopes adjacent to mountain roads using mathematical expressions makes it possible to identify slopes prone to failure and classify their stability and strength limits. Modeling is also an essential tool for clearly visualizing the landslide process and for developing appropriate engineering countermeasures [6, 7, 8].

Several key data sets are required for modeling mountain landslides; their descriptions follow:

1. **Geological data:** Includes the types of soils or rock present on the slope and their physical–mechanical properties.

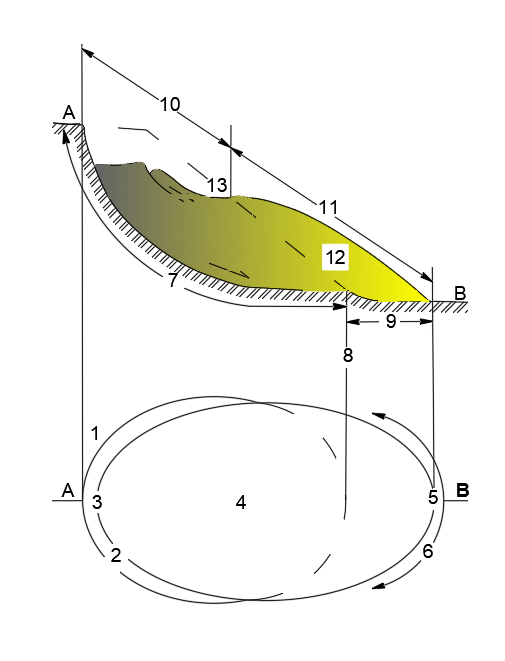
2. **Geomorphological data:** Covers the slope’s geometry, relief features, inclination angle, and height.

3. **Meteorological data:** Encompasses precipitation amounts and durations, records of extreme rainfall or snowfall, daily and seasonal temperature variations, and freeze–thaw cycle information.

Many researchers have investigated mountain environments and their processes; notable contributions to landslide analysis include the methods of Coulomb, Kramer, Culmann, and Bishop, which remain in use today for precise calculations. Among these, limit equilibrium analyses are widely applied to slope–stability problems. Such analyses assume that a landslide occurs along a particular potential surface, divide the sliding mass into slices, and compare the driving shear stresses along each slice with the resisting shear strength. By evaluating multiple candidate slip surfaces, the lowest computed factor of safety is taken as the slope’s stability coefficient. This coefficient represents the ratio of available shear resistance to the shear stress required to maintain equilibrium [9].

At locations on mountain slopes where landslide risk is present, shear deformations typically initiate at low rates and under low tangential stresses . If the structural strength of the rock or soil is low and no significant hydration of discontinuities occurs, then deformation rates increase gradually, leading to accelerated movement of landslide masses (Figure 6).

Assessing landslide susceptibility in advance depends directly on the slope’s stability characteristics, including its height and inclination. High moisture content in slope materials can bring the shear strength to its limit, and steep, compact slopes are prone to more rapid failure as instability develops [10].



**FIGURE 6.** Key components of the landslide mass and the mechanism for its description:

*1 – slope crest, 2 – main mass, 3 – upper boundary of the slide, 4 – slide body, 5 – lower boundary of the slide, 6 – slide toe (base), 7 – slip surface, 8 – displaced surface, 9 – displacement distance, 10 – detachment zone, 11 – accumulation zone of the slide mass, 12 – displaced mass, 13 – original slope surface*

The Fellenius method calculates the vertical push area by dividing it to pieces. The push surface is considered circles and normal forces between intersection and fragments are not taken into account.

There are different methods of calculating the stability of the slope in the ethic of origin, which allows them to predict the basis of various indicators. One of the mathematical expressions that allow for the same advantage is the FS equation in assessing the slope style. In this case, if FS> 1 is stable in the sloping, the slope is higher in the slope [2, 3].

(1)

here: FS- the stability indicator of the slope; c- physical parameter determines the slope-grounded facility in kPa; - the anterior friction of the slope of slope; - the location corner of the slope; H- the height of a slope.

This fellinius method is of the effective methods of calculating the slopes of the slopes. With the measurement results obtained in field studies, the stability of the mountain slope can calculate the most important factors such as the slope and angle of slope [11].

We can advance the level of traffic to prevent the highway and ensure the level of traffic, and the level of traffic to the roadside formula through the above formula. The value in the table below is formed as a result of measurement work carried out in the research facility. Taking into account the magnitude and wide range of data, the result of experience in the height of 30 meters in the height of the 30-meter levels is highlighted.

**TABLE 3.** Results of the Fellenius method of calculating the sustainability of the slope

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **H-** **height** | **α-** **corner** | **Sustainability Coeffs** | **Corelatary link** | **Reliability coefficient of formula** |
| 30 | 30 | 1,48 | -0,974 | R² = 0,9555 |
| 35 | 1,26 |
| 40 | 1,08 |
| 45 | 0,94 |
| 50 | 1,01 |
| 55 | 0,73 |
| 60 | 0,65 |
| 65 | 0,58 |
| 70 | 0,52 |

Table 3 was equal to the Curricitational Care (-0.974). The Korelational Connection is usually between   
(-1; 1), and the value of 0 means that there is no connection between the results of the formula. Direct connection and reverse connection 1 and the inverse connection 1 and (-1) the closer result. The results of this article were found to be inverse to the results of the results obtained in the books (Fig. 7).

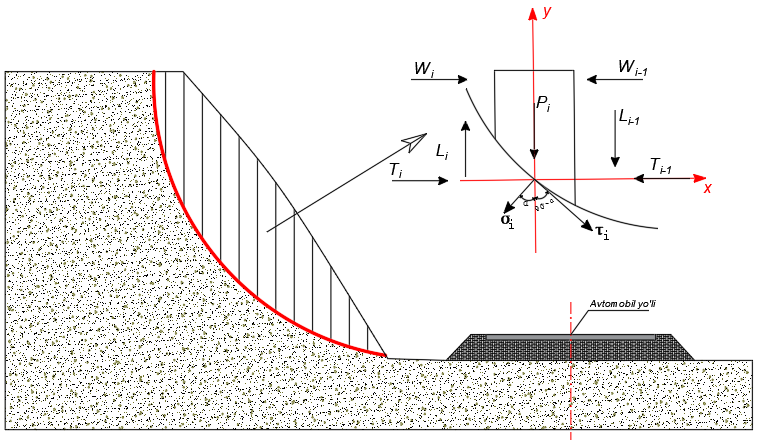
**FIGURE 7.** Schedule of interdependence of the Save Cofferine in the sloping burra and the avalanche

The graph above is formed as a result of the real parameters of the research facility. As seen from the graph, the slope height is more stability against the avalanche when the corner of the slope is less than 50o. In particular, the optimal slope corner is 50o, which is 50o in a slope of the height of 30 meters, is equivalent to FS = 1.01.

The Fellenius method of assessing the mountain assessment above is privately high, and in common cases, this method is slightly impregnated with the calculations.

This is determined in this regard to the emergence of a slope and ensure the conditions of equaluation of power balance. Since the first solution is long and complex, it is used in calculating slopes, causing simplified.

This method takes into account the normal power between the pieces not included by the Fellenius method. However, the intersection force between the pieces was ignored [12]. The mass vector is believed to affect the exact middle point of a fragmentary basis and does not take into account the point that affects normal power under the lane [13]. This method can be a sufficiently clear and recommended method for the framework surfaces (Figure 8).



**FIGURE 8.** The avalanche is a learning model into pieces

*Pi-* *the weight of the element in the consideration of the ground weight; Li-1 and Li -vertical organization of the power of interaction between the elements; Wi-1 and Wi - horizontal organization of the power of interaction between the elements; Ti-1 and Ti - the interaction of sustainable methods of stability in the avalanche; σi and τi Normal and attemptable voltages in the appropriate level of affecting the element migration boundary*

Through the fragmentation of the side slopes, it provides an average of the aircraft, which affects the surfaces of the power, which will ensure the stability of the selected section to ensure the stability of the selected section.

The scheme described in Figure 8 has developed the following mechanical model of the movement of the transfer.

(2)

(3)

In addition to these formulas, let's make a check in addition to the given expressions:

; ; (4)

Once the impositions are marked, the basic model of an anatical analysis of learning to divide the airline will be used to appear below:

; (6)

(7)

can be identified as follows in order to ensure the negative impact of slopes in order to prevent the adverse effects of the rocks:

(8)

If we enter the following condition for the above expression:

(9)

In that case (8) an expression occurs as follows:

(10)

Based on the above, it will be possible to determine the stability of mountain slices in the mountainous areas using the model below using the model below:

(11)

here: Ktur – the stability coefficient of the slope; – normal voltage in the lane; – a migrant boundary surface; – the anterior friction of the slope of slope; l – length of segment across the landslide; c – ground combination.

We will check the formula: o; l=5 m; slope angle =30o; P=100 kN;   
C=15 kPa when we examine the stability of the slope when there is a slope. That is:

Ktur = 1.165 9 (12)

This example varies depending on the number of fragments in the process of studying the slope and the average coefficient of the same slope of all Ktur.

Using the above formula, the mountain serve to calculate the maximum limit of the mountain, i.e. the maximum limit of the mountain in the sloping part of the street, that is, the critique values.

**CONCLUSION**

The mountain transactions will be able to prevent the effects of damages that may come to bee with the highways in advance. In this case, modeling, which contains a factor, such as the character, the composition of the slopes, the composition of the slopes, the need to analyze the landslide accident of the landslide.

Typical aspects of surface aspects of the lands, as well as the speed of migration speed and direction, will be able to apply measurements for the volume and coverage of landslides.

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