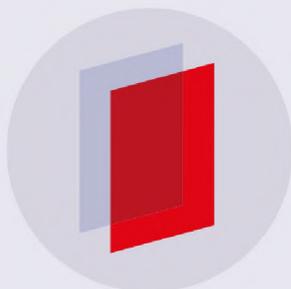


PAPER • OPEN ACCESS

On stability of slopes in mountain zones. Case study

To cite this article: D A Sagdullayeva *et al* 2019 *J. Phys.: Conf. Ser.* **1425** 012016

View the [article online](#) for updates and enhancements.



IOP | ebooksTM

Bringing you innovative digital publishing with leading voices to create your essential collection of books in STEM research.

Start exploring the collection - download the first chapter of every title for free.

On stability of slopes in mountain zones. Case study

D A Sagdullayeva¹, Sh A Maxmudova¹, F F Adilov¹, R A Abirov¹,
I O Khazratkulov² and I A Nasirov³

¹Institute of mechanics and earthquake engineering, 100125 Tashkent, Uzbekistan, E-mail: mahzun86@mail.ru

²Tashkent Institute of Irrigation and Agricultural Mechanization Engineers, Tashkent, Uzbekistan, phone: +998 (90) 908-68-25;

E-mail: zhavlon.varashov@bk.ru, islomjon_xazratkulov@mail.ru

³Fergana Polytechnical Institute, Fergana, Uzbekistan, phone: +998(90) 562-20-72; E-mail: theormir@mail.ru

Abstract. Stability of railway roadbed in mountain area are considered in proposed issue. Real object in new railway with taking comprehensive analysis of geological data in site and morphology of slide slopes in seismic prone area was investigated.

Keywords: slope, stability, stress, deformation, plasticity

1. Introduction

The aim of the study is to assess the slope stability on a natural hillside depending on its complex engineering-geological structure based on an analysis of the stress state and to build possible fracture trajectories.

An assessment of the overall stability of hillside slope interacting with the road bed is based on the developed methods taking into account the first limit state - bearing capacity (under extreme equilibrium conditions).

The slope stability provided by potential shear surfaces (circular-cylindrical ones) revealing the most dangerous sliding triangle (collapse prism), characterized by the minimum ratio of the generalized limit reactive resistance forces to the active shear forces, and conducting an elastic-plastic calculation for the soil body

Calculations of the overall stability of a slope, its foundation, are performed on the main combination of acting loads and effects from:

- the weight and pressure of slope soil;
- the weight of the structures of permanent way and the moving temporary load;
- hydrostatic effects of water, if there are areas of flooding.

To assess the seismic affect, the seismic forces applied to the sliding triangle are taken into account, with the seismicity coefficient K equal to 0.1, 0.2, 0.4, for the intensity of the calculated seismic effect of 7, 8 and 9 points, respectively, on the MSK scale.

Considering that trains with different combinations of axle loads (empty and loaded ones) and railway cars of various types (four-, six- and eight-axle) move the railway track, it is advisable to determine the stress on the main site of the road bed from the influence of a standard unit of rolling stock prevailing in the train.



In this regard, when modeling the slope strength, the load on the main site of the road bed is determined by the maximum allowable stress for the soil of the main site of road bed, which is 0.8 kg/cm^2 under normal operating conditions.

Calculation methods of the mountain slopes stability based on circular cylindrical sliding platform in combination with the finite element method have been developed to calculate the slopes of arbitrary profile. The term "slope stability" means the stability of its prism or a part of the slope against slipping down as a result of external and internal forces imbalance, composed of its own weight, hydrostatic pressure of water and seismic forces.

Since the optimal stability criteria are set as a result of stability calculation, the correct choice of the calculation method and the validity of the initial data to evaluate the forces are of particular importance. Therefore, the following aspects should be carefully studied and correctly selected:

- design characteristics of the materials of hillsides, slopes and base soil;
- safety factors;
- characteristic calculated cross sections of the hillsides slopes;
- design cases presenting the most unfavorable combinations of force effects under various conditions.

Analysis of the stress state by the FEM, taking into account the elastic-plastic work of soils, satisfies the conditions of static equilibrium and allows us to evaluate the changes in stresses caused by the variation in elastic properties, inhomogeneity and geometric shapes.

Here, the sliding triangle is considered discretely, dividing it by a finite number of elements; an increase in the number of elements leads to the accuracy in calculations.

Rigid boundaries are set at a sufficient distance from the hillside, so their presence does not affect the stress state of the slope.

In stability calculations, the assumptions are made regarding the angle of action of the normal component of soil thrust, which is assumed constant or as a known function of the angle of inclination of the sliding platforms. Standard safety factors K_{safe} are established by the corresponding state standards SNiP (Building Norms and Rules) and are in the range from 1.05 to 1.1 for basic combinations of loads and from 1.1 to 1.3 for the basic combinations of loads.

The implemented algorithm of the program, in addition to the analysis of the stress state, provides the grid formation for a mountain slope model, graphical construction of this grid and isobars, and calculation of the safety factor - K_{safe} . The determination of the safety factor K_{safe} is accurate, done by selection, since K_{safe} is expressed implicitly in the formula. The selection of K_{safe} is carried out with such a degree of accuracy that the difference in neighboring definitions of K_{safe} does not exceed 0.1%.

To consider the state of soil medium, we will take a calculation model of the theory of limit equilibrium, under the assumption that at all points of soil there are the platforms on which the conditions of limit equilibrium are satisfied [1, 2]. This is the beginning of initiation of plastic strains, shear or violation of soil strength. The strength of the material is determined by the magnitude of the maximum and minimum principal stresses only

$$\sigma_1 - \sigma_2 = (\sigma_1 + \sigma_2 + 2\sigma_c) \sin \varphi, \quad (1)$$

here σ_1, σ_2 are the principal stresses, $\sigma_c = c / \text{tg} \varphi$, c - cohesion, φ is the angle of internal friction. Equation (1) is one of the forms of the Mohr-Coulomb equation as $\tau_{lim} = \sigma_n \text{tg} \varphi + c$, here τ_{np} is the ultimate shear stress on the sliding platforms; σ_n is the normal stress on the sliding platforms. In the general case, tangential and normal stresses, as well as normal fictitious stresses σ_c (Fig. 1, a) act at the point of the soil medium.

The resultant of these stresses, called the total reduced stress, will deviate from the normal to the platform by an angle θ . From previous studies [3, 4], we can say that the state of limit equilibrium

is reached at a given point under the condition $\theta_{\max} = \varphi$. The principal stresses are expressed through the stress components along two mutually perpendicular platforms by the dependencies

$$\left. \begin{matrix} \sigma_1 \\ \sigma_2 \end{matrix} \right\} = \frac{1}{2}(\sigma_x + \sigma_y) \pm \frac{1}{2}((\sigma_x - \sigma_y) + 4\tau_{xy})^{1/2} \tag{2}$$

Then the condition of limit equilibrium (1, a) expressed through the stress components $\sigma_x, \sigma_y, \tau_{xy}$, takes the form

$$(\sigma_x - \sigma_y)^2 + 4\tau_{xy}^2 = (\sigma_x + \sigma_y + 2\sigma_c)^2 \sin^2 \varphi \tag{3}$$

Stresses $\sigma_x, \sigma_y, \tau_{xy}$ are calculated by the finite elements method.

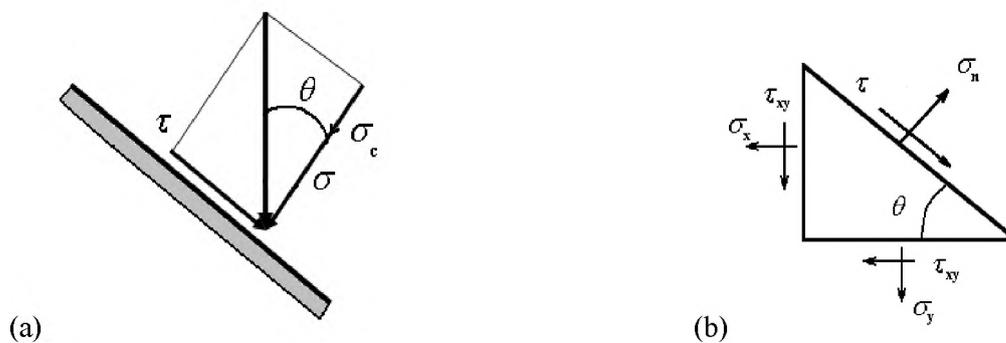


Figure 1.

(a) stresses acting on the elementary platform, (b) normal and tangential stresses on the sliding platform.

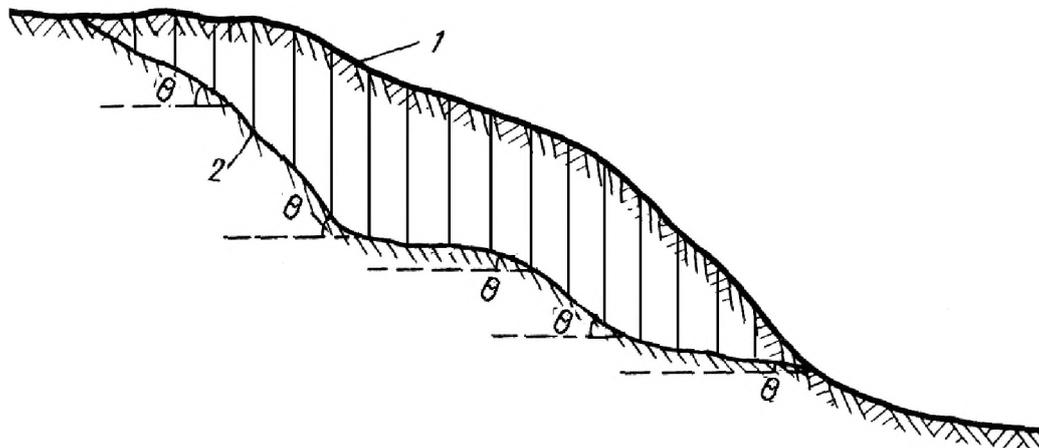


Figure 2. Scheme to calculate the landslide pressure:
1 - earth surface profile; 2 - sliding platform profile

It is known that if the sliding platform forms an angle θ with the horizontal, the normal and tangential stresses can be calculated as

$$\sigma_n = \frac{1}{2} (\sigma_x + \sigma_y) - \frac{1}{2} (\sigma_x - \sigma_y) \cos 2\theta - \tau_{xy} \sin 2\theta,$$

$$\tau = \frac{1}{2}(\sigma_x - \sigma_y) \sin 2\theta - \tau_{xy} \cos 2\theta \quad (4)$$

As a result of the analysis by the finite element method, all stresses along the sliding platform become known, so, the normal and tangential stresses in the center of each finite element can be calculated using equations (4).

Based on calculated stresses, the shear strength can be obtained from the Mohr-Coulomb condition (1, b). The total shear strength and the total shear can be found by summing their values for all points of the sliding platform, where the safety factor is

$$K_{safe} = \frac{\sum_{i=1}^M (\tau_{lim} = \sigma_n \operatorname{tg} \varphi + c) \delta L}{\sum_{i=1}^M \tau \delta L}, \quad (5)$$

here, δL is the length of a single finite element.

2. Initial assumptions

Below the railway site's stability in new mountain road zone was considered. To achieve the aims, it is necessary to solve the following tasks:

1. to select specific sections of the new railway line Tashguzar-Baysun-Kumkurgan passing through the steepest slopes (data provided by Uzbekistan railways JV company);
2. to determine the stress-strain state of the natural slope using the finite element method based on the previously presented methods and developed software;
3. to assess the overall stability of the landslide slope and develop recommendations for ensuring the overall stability of the natural slope, taking into account its geological structure and built road bed.

Boundary conditions are specified as follows:

- along the vertical borders of the design scheme there are no displacements in the horizontal direction;
- along the lower horizontal border there are no vertical displacements;
- no restrictions are imposed on the displacements of other points.

The area under investigation is divided into isoparametric finite elements. The initial data for solving the problems include:

- transverse profiles for landslide unloading at specific sections (pickets) of the Tashguzar-Baysun-Kumkurgan railway;
- properties of the elements (density, elastic modulus, Poisson's ratio, cohesion and angle of internal friction of soil);
- surface loads and boundary conditions.

Quantitative studies of the stress-strain state and stability of a hillside require well-grounded schematization. When constructing geomechanical schemes for research at the stages discussed in this work, the following prerequisites were considered: rocks layers similar in engineering-geological characteristics and indices of physical-mechanical properties were combined into single packs with averaged characteristics. When developing the calculation scheme, we proceeded from the features of the developed method, which allows us to vary the change in indices on the basis of integrated approach.

3. Case study- Calculation of the hillside on the railway line Tashguzar-Baysun-Kumkurgan. The stage section Acravat – Aknazar

In the investigation site, the rocks are characterized by extremely complex bedding conditions. Slope rocks are argillite with mudstone strata and siltstones with limestone and sandstone strata. Argillite is a highly over-consolidated rock with a thin layer, and sometimes, indistinctly marked texture. It contains mainly (more than 50%) clay particles (<0.005 mm) intensively destroyed at clay cement predominance. Siliceous and calcareous cement varieties are more resistant to weathering. Under natural conditions, argillites are interbedded by marlstones, sandstones and siltstones. Siltstone is a heavily compacted soil. The number of (silt) particles (0.05-0.005 mm) exceeds 50%. They are intensively destroyed when clay cement predominates. In the presence of siliceous and calcareous cement, siltstones are more resistant to erosion and weathering processes.

In natural composition siltstones are often interbedded with marlstones, sandstones and argillites. Siltstones are weakly cemented soils, characterized by plasticity (I_p in average is 17%). They have natural moisture-content from 0.23 to 0.36 at an average value of 0.29. Their density in natural composition varies from 1.71 t/m³ to 1.95 t/m³, at the average value of 2.15 t/m³. The average value of moisture content at the yield limit is 50%, the average value of moisture content at the border of rolling is 34%. The density of soil particles is taken equal to 2.1 t/m³.

Calculated values of shear resistance characteristics of siltstone under natural conditions are taken equal to [7-9]: $\varphi = 30$, $C = 42,7$ KPa, and the strain modulus $E = 1300$ MPa. The calculated density of argillite-like soils is taken equal to 2.4 t/m³. The strength characteristics of these rocks can be taken as the test data in the normal state: $\varphi = 25$, $C = 71$ KPa. Recommended values of the elasticity modulus is $E = 1000$ MPa.

Calculation schemes with two options are compiled, based on the given physical and geometric data. Particularly, the transverse profile of landslide-hazardous rock mass (without and with unloading of soil slide) on the hillside slope. For both options, the calculated seismicity of the construction site road bed is 8 points on the MSK scale.

The slope stability was estimated based on the data on the safety factor at each individual point in the soil mass. The method adopted in this case for checking the bed stability of the rock mass was based on the condition, that stress and strain patterns of soil stratum were first determined.

The lines and directions of the sliding platforms in the assumed points of stability loss of the slope are calculated. To see the stress state, we need to calculate and build the distribution of normal and principal stresses in the slope body. Figures 3 show the isochromatic values of the components of shear stresses, obtained by calculating the slope stability factors. In this case, N. Yanbu's graph [5] was used to determine the coordinate points of circular cylindrical surfaces rotation. Figure 4 shows the minimum safety factors for the two calculation options obtained in calculations.

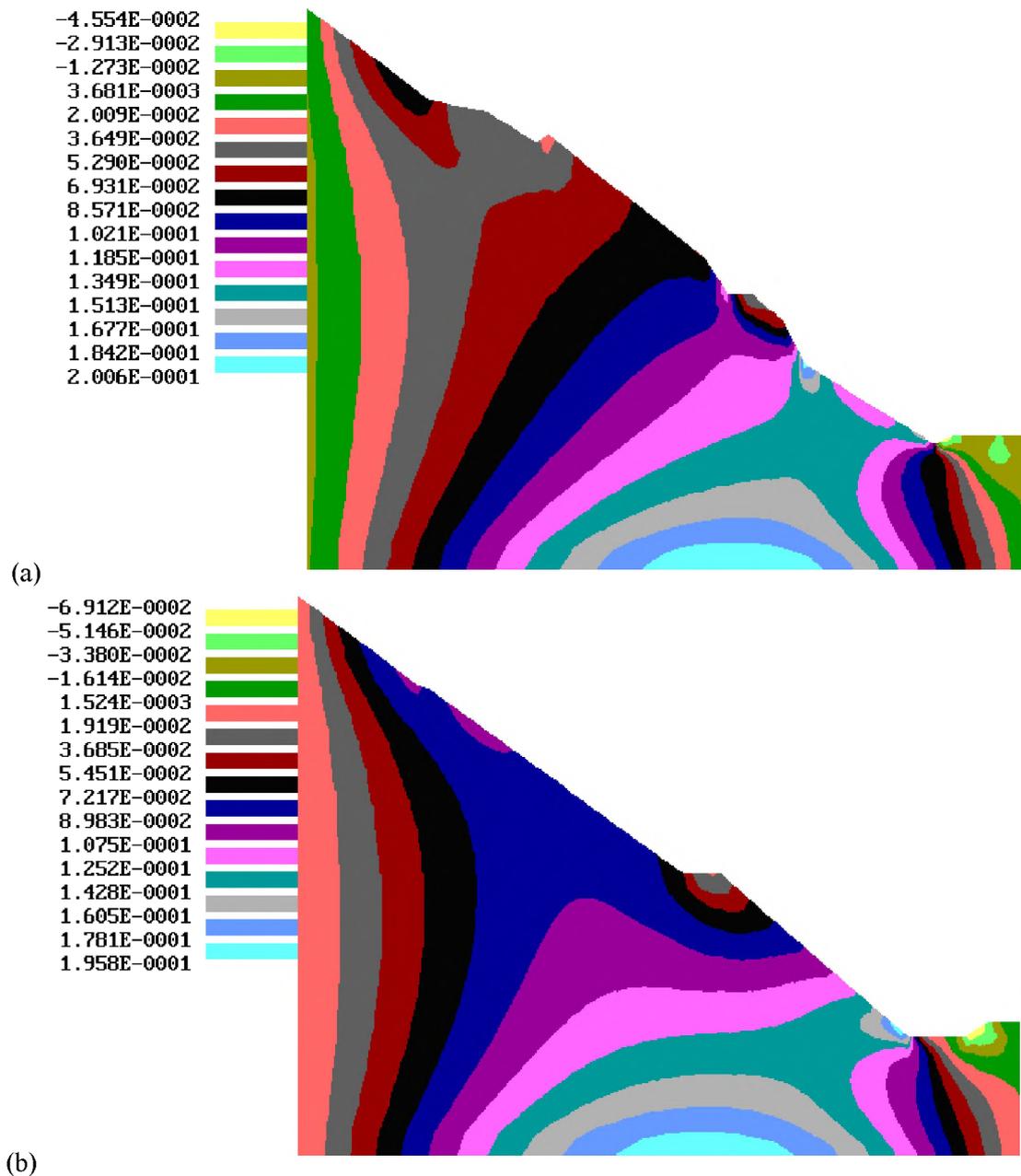


Figure 3. Distribution of shear stresses σ_{xv} (MPa).
 (a) without unloading of soil slide, (b) with unloading of soil slide.

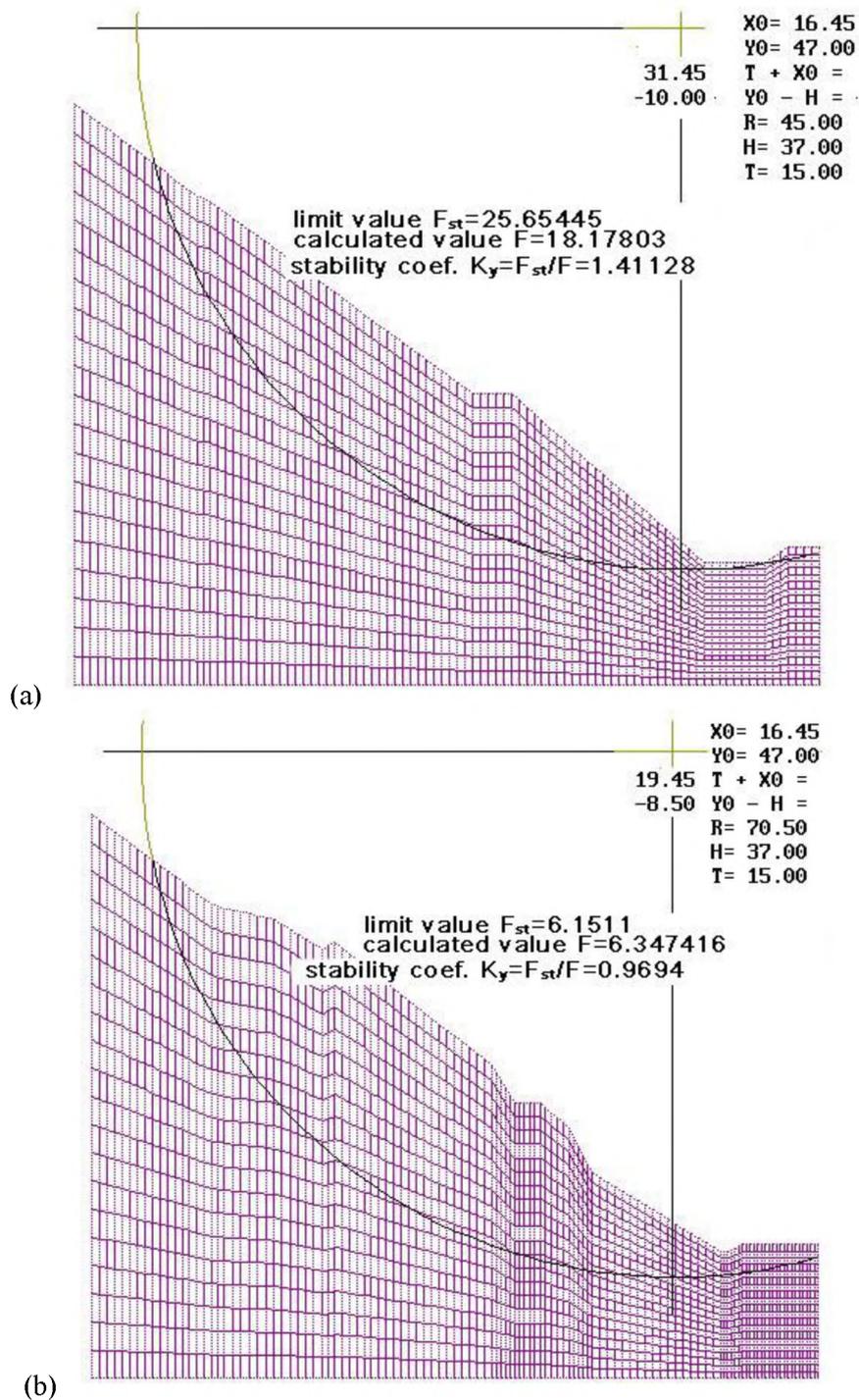


Figure 4. Slope stability.

(a) without unloading of soil slide, (b) with unloading of soil slide.

In the first case, it is clear that the hillside stability is not ensured, since the hillside slope relative to horizontal axis does not provide the necessary level of stability of the stress state, which can lead to soil sliding. In the second version, the slope unloading, which leads to the slope stability is proposed.

The results obtained by other authors regarding the error of the method of circular cylindrical sliding platforms [5, 6] when determining the margin of safety of slopes revealed that this method always gives a significantly overestimated result compared to the results obtained by the methods based on solving problems of the theory of elasticity or mechanics of deformable rigid body.

In this regard, to identify the most characteristic points or surfaces of a possible loss of stability in the slope body subject to sliding, the principal stresses are determined in calculations and the lines of possible slip are constructed in each element of the calculated scheme (fig. 5). The calculations show that on the slope surface, where the rock weathering occurs, there are areas of rock movement. In the first option, they are more significant and have a maximum depth into the rock of about 4-6 meters. On the slope where the unloading of possible landslides occurs, the most dangerous sections of sliding are not found.

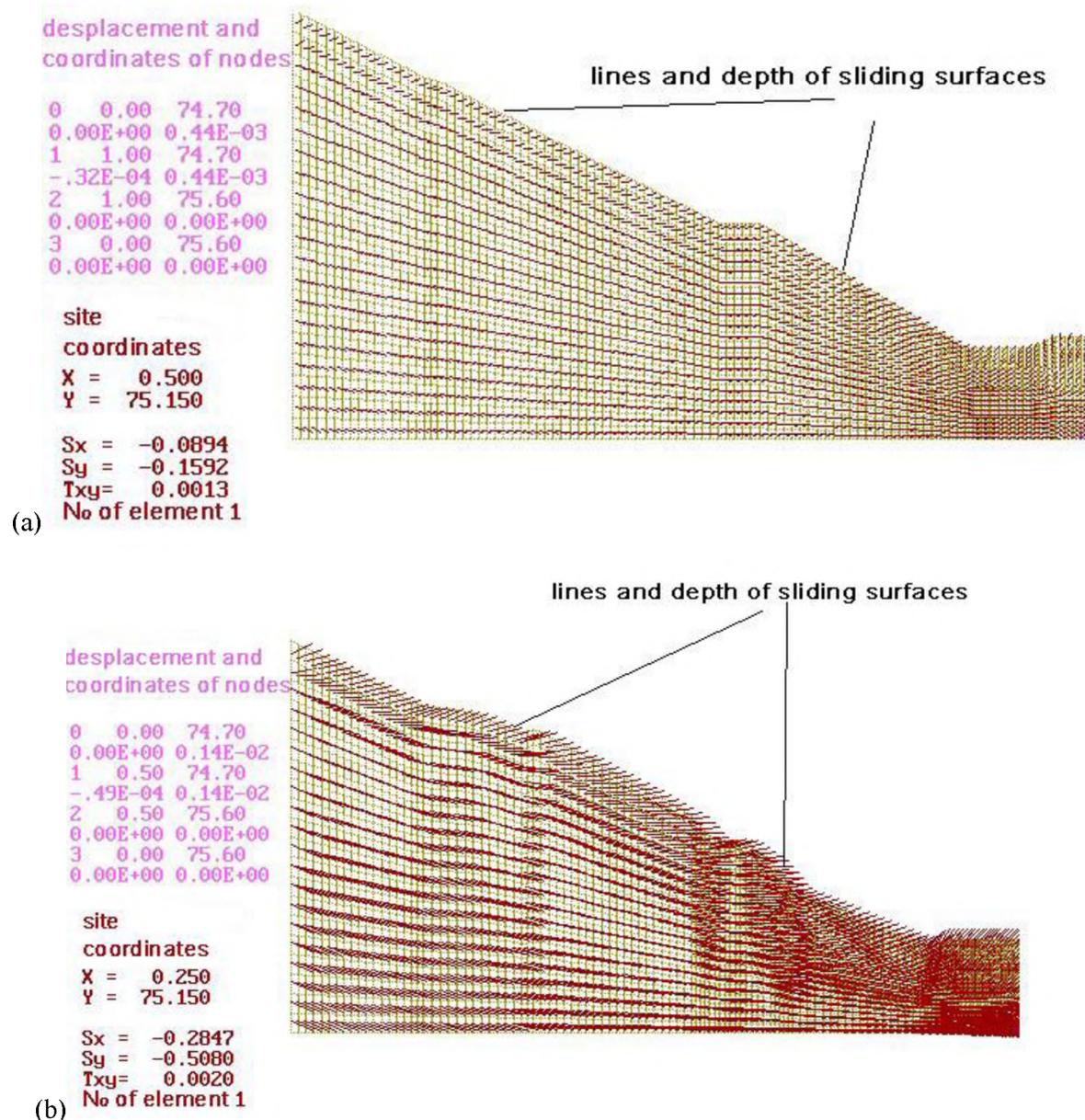


Figure 5. Probable sliding surfaces.

(a) without unloading of soil slide, (b) with unloading of soil slide.

At known values of the principal stresses and the calculated indices of shear resistance at each point (element), the maximum allowable (critical) tangential stresses for this point were calculated. The safety factors at this point were determined as the ratio of the critical tangential stress to the acting tangential stress. Next, the average (integral) slope safety factor was calculated for both options.

Calculation is carried out by incremental method, the possible plastic elements are calculated for each portion of load in the slope body. By a plastic element we mean the elements of rock, where they were destroyed at the sliding platform. Figure 6 shows the distribution of the Mohr-Coulomb yield function (plasticity) in the calculated slope plane.

The values of these functions indicate the distribution of unstable values of the functions at the surface points of the slope. Thus, the increasing dynamics of changes in the plasticity function and safety factor from the upper points of rock mass to the lower ones is observed; it allows us to prefer the second version of the design scheme and consider it the safest in operation and excavation of the road bed.

As one can easily see, for such projected slope profile the transition to the limit state does not occur. However, to maintain the overall stability of the hillside slope, in sections of the first slope crest of the excavation within 1-2 m it is necessary to increase the soil strength (that is, the strength characteristics, such as the coefficient of cohesion and the angle of internal friction) either by compaction or by replacement with more solid rocks.

References

- [1] Terzaghi K 1996 etc. Soil mechanics in engineering practice John Willey & Sons Inc, New York 526 p
- [2] Kang Tae San 2005 Analysis of factors of landslide pressure in calculation // Science and youth, Novosibirsk Russia p 15-18
- [3] Muneo Hori 2006 Introduction to computational earthquake engineering, Imperial College press 330 p
- [4] Chai H Yoo and Sung C Lee 2011 Stability of structures. Principles and Applications Elsevier 523 p
- [5] Yang H Huang 1986 Stability analysis of earth slopes Van Nostrand Reinold Company NY 240 p
- [6] Verruijt Arnold 2001 Soil Mechanics Delft University of Technology 315 p
- [7] Mirsaidov M M, Sultanov T Z, Sadullaev A 2013 Determination of the stress-strain state of earth dams with account of elastic-plastic and moist properties of soil and large strains. Magazine of Civil Engineering 40(5) Pp 59-68
- [8] Mirsaidov M M, Toshmatov E S. Spatial stress state and dynamic characteristics of earth dams. Magazine of Civil Engineering. 2019 No 89(5) Pp 3–15 DOI:1018720\MCE.89.1
- [9] Mirsaidov M M, Sultanov T Z, Khodzhaev D A 2012 Assessment of the stress-strain state of earth dams. Civil-Comp Proceedings 100