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STUDY OF THE INFLUENCE OF THE SLOPE ANGLE OF A QUARTZ SAND LEDGE ON ITS STABILITY COEFFICIENT

Abstract. *Graphical dependences of the change in the stability coefficient of quartz sand scarp from the angle of working scarp were obtained using the normative method of graphical constructions and limit equilibrium methods in Rocscience Slide. It has been established that the character of change of graphical dependences of the working scarp stability coefficient on the slope angle is the same for both the methods of analysis in Rocscience Slide and for the normative method of graphical constructions (by G.L. Fisenko).*

Differences in the numerical values of the slope stability coefficient calculated by the method of graphical constructions with the values obtained by Bishop, Janbu and Spencer analysis methods in the Slide program have been established.

The numerical values of the stability coefficient calculated by the graphical plotting method are higher than the analysis methods in Slide. In particular, the values of stability coefficients are larger by 6...11% compared to their values obtained by Bishop and Spencer analysis methods and by 9...14% compared to Janbu values when the slope angle is changed from 25 to 50 degrees.

Key words: *quarry; quartz sand; working scarp; sliding surface; slope stability coefficient; graphical method.*

Introduction. In many cases, open-pit mining is accompanied by deformation processes in the sides and benches of quarries [1]. These processes can be both long-lasting and short-term or even instantaneous. In any case, deformations of quarry slopes reduce mining efficiency and cause material damage to the company. In particular, the proper and safe conduct of mining operations is disrupted, and mineral losses increase.

The main causes of deformations (landslides, cave-ins, landslides, etc.) include insufficient study of mining and geological conditions (structural features of the rock mass and its physical and mechanical properties); non-compliance of the angles of slopes of quarry slopes with regulatory requirements; misconception of the nature of deformations (underestimation); improper mining operations; lack of engineering landslide protection measures at the quarry; application of incorrect methods of assessment and analysis of safe slope stability parameters [2]. In this regard, slope stability should be assessed on an ongoing basis using available (engineering or computer) control methods based on reliable data on the condition of the rock mass and mining technology.

To ensure the stability of quarry slopes, it is also necessary to take into account several factors that may cause landslides. In addition, it is necessary to ensure constant monitoring of compliance while the established parameters of mining technology with forecasting the state of stability of the rock mass in case of possible violations. Therefore, establishing the dependence of the stability coefficient of the quartz sand bench on the angle of its slope in the conditions of the Sykhivske deposit is relevant.

Purpose and objectives. The purpose of research of the scientific article is to study the influence of the angle of slope of the working ledge of quartz sands on its stability coefficient for the conditions of Sikhovsky quarry.

The task of research is to establish the relationship between the value of the stability coefficient of the scarp slope and the angle of its inclination for different methods of analysis.

Material and research results. According to the working draft of the development of this deposit, the slope angle of the working bench should be $\alpha = 30°$. This angle meets the necessary conditions to ensure the stability of the slope. However, in some cases, the value of the slope angle is temporarily not observed due to certain technological reasons (in particular, failure of mining equipment, significant intensity of mining operations, etc.) Such a violation of mining technology and occupational safety rules can lead to the formation of landslides, cave-ins, and landslides. To prevent the occurrence of landslides and avoid their negative consequences, it is necessary to know the safety factor of the bench and the possible collapse surface of the massif.

At present, the normative method for determining the parameters of rock mass stability is the method of graphical constructions (according to G.L. Fisenko) [3]. This method of calculation is based on the Coulomb's equation of limiting equilibrium. After the sliding surface is constructed, the total length of its surface L, and the width of the shear wedge B are determined. Next, the stability is checked by calculating the slope stability coefficient. To do this, a shear wedge is constructed to scale and divided by vertical lines into a certain number of prisms of approximately equal width. At the intersection of the vertical lines with the sliding surface, the weight force of the rock in the block is decomposed into two components: normal N_i and tangential T_i of the block mass. Then, for each prism of possible collapse, the angle δ_i between Q_i and N_i is measured [4].

The normal (retaining) component N_i and the tangential (shear) component T_i of the block mass, tons, are defined as

$$N_i = Q_i \cos\delta_i; \qquad T_i = Q_i \sin\delta_i. \tag{1}$$

After that, the area of each S_i block is determined and the mass of rock in each block per 1 running meter along the length of the slope is calculated (b):

$$Q_i = S_i \gamma b \text{, т.} \tag{2}$$

The stability coefficient of the slope of the bench is calculated by the expression:

$$K_{st} = \frac{\text{tg}\varphi \sum_{i=1}^{n} N_i + C \cdot L}{\sum_{i=1}^{n} T_i}, \tag{3}$$

where φ is the angle of internal friction, degree; C is the coefficient of rock adhesion, MPa; L is the total length of the sliding surface, m.

According to the working design of the development, quartz sands of the Sykhivske deposit have the following physical and mechanical properties: bulk density – γ = 1,66 t/m^3; cohesion – C = 2 kPa; coefficient of loosening – K_r = 1,32; natural humidity – W = 2,83%; angle of internal friction - φ = 33°; porosity coefficient - e = 0,65. The height of the working bench is H = 20 m.

To determine the effect of the slope angle of the working bench on the stability factor, the sliding surfaces of a possible massif collapse for slope angles from 25° to 50° were depicted in AutoCAD using graphical constructions, and all the necessary parameters were determined. For the given properties of sand, the depth of the sliding surface was H_{90}=0,44 m, and the angle between the direction of the main stress and the elementary sliding surfaces was μ=28°30'.

According to formula (3), the stability coefficients of the working slope K_{st} were calculated for all studied values of the slope angles of quartz sands (according to the method of G.L. Fisenko).

Similar studies of the influence of the slope angle on the value of the stability coefficient were carried out in the Rocscience Slide software package using the method of limiting equilibrium. For each value of the slope angle, the critical sliding surfaces with the lowest value of the stability coefficient were obtained. The most commonly used analysis methods are Bishop, Janbu, and Spencer.

Based on the results of the calculations in Rocscience Slide and the method of graphical constructions (Table 1), graphical dependences of the change in the stability coefficient of the working bench on the angle of slope of quartz sands at the Sykhivske field were constructed (Figure 1).

Table 1 – Values of the stability coefficient K_{st} for different methods of analysis depending on the angle of slope of the bench α

Escarpment slope angle α, deg	Values of the minimum stability factor K_{st} for different analysis methods			
	Fisenko	Bishop	Janbu	Spencer
25	1,686	1,576	1,540	1,575
30	1,383	1,300	1,267	1,297
35	1,16	1,098	1,066	1,093
40	1,001	0,938	0,908	0,933
45	0,88	0,813	0,783	0,809
50	0,786	0,708	0,678	0,702

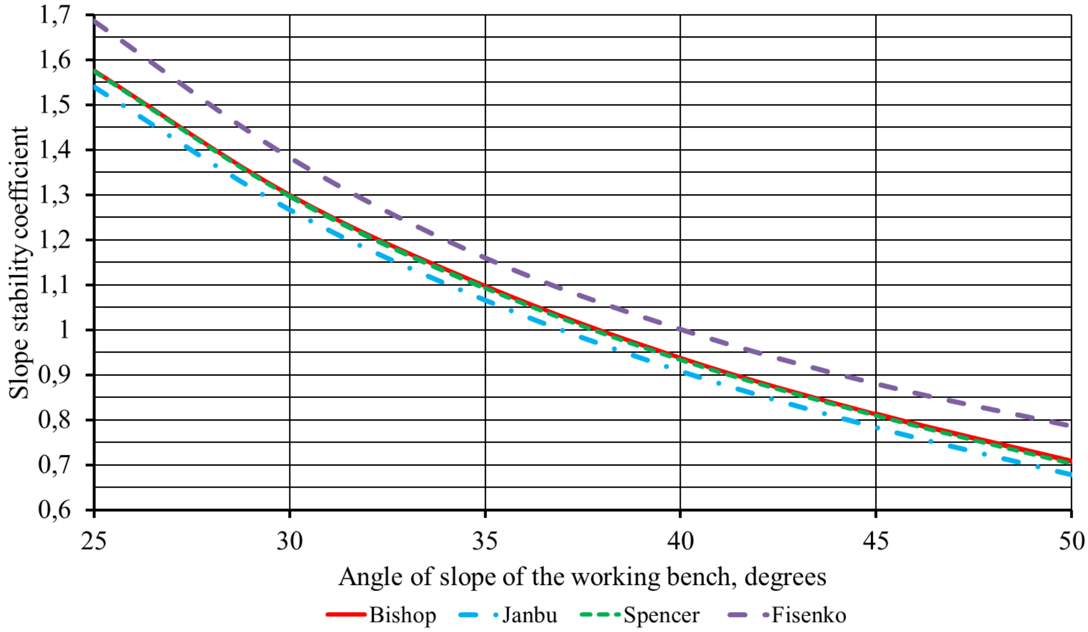

Figure 1 – Values of the slope stability coefficient K_{st} depending on the slope angle of the bench for different analysis methods

Conclusions. The analysis of graphical dependencies shows that the nature of their change is the same for both Slide analysis methods and the normative method of graphical constructions (according to G.L. Fisenko). However, the method of graphical construction provides higher values of the slope stability coefficient than the Slide analysis methods. Compared to the Bishop and Spencer methods, the value of K_{st} is 6...11% higher, compared to Janbu – 9...14% when the slope angle changes from 25° to 50°, respectively. At the same time, according to Bishop and Spencer, the graphs almost coincide, and the Janbu method provides lower results of the stability coefficient values within 2...4%.

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ДОСЛІДЖЕННЯ ВПЛИВУ КУТА УКОСУ УСТУПУ КВАРЦОВОГО ПІСКУ НА КОЕФІЦІЄНТ ЙОГО СТІЙКОСТІ

Анотація: *Отримано графічні залежності зміни коефіцієнта стійкості уступу кварцових пісків від кута робочого уступу з використанням нормативного методу графічних побудов і методів граничної рівноваги в Rocscience Slide. Встановлено, що характер зміни графічних залежностей коефіцієнта стійкості робочого уступу від кута укосу однаковий як для методів аналізу в Rocscience Slide, так і для нормативного методу графічних побудов (за Г.Л. Фісенком).*

Встановлено відмінності в чисельних значеннях коефіцієнта стійкості укосу, що розраховані методом графічних побудов, зі значеннями, що отримані методами аналізу Bishop, Janbu і Spencer у програмі Slide.

Чисельні значення коефіцієнта стійкості, розраховані за методом графічних побудов, є вищими за методи аналізу в Slide. Зокрема, значення коефіцієнтів стійкості більші на 6...11% порівняно з їхніми значеннями, отриманими методами аналізу Bishop і Spencer і на 9...14% порівняно зі значеннями Janbu за зміни кута укосу з 25 до 50 градусів.

Ключові слова: *кар'єр; кварцовий пісок; робочий уступ; поверхня ковзання; коефіцієнт стійкості укосу; метод графічних побудов.*

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