THE INFLUENCE OF THE POROSITY COEFFICIENT (R_U) ON THE SAFETY FACTOR (Fs) WITH THE APPLICATION OF NUMERICAL METHODS.

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Abstract

A landslide can occur as a result of natural changes in the geological environment of a slope (changes in the groundwater regime, erosion, earthquake action), or as a result of human activities (removal of vegetation and positive root activity, filling and excavation in the process of road construction, additional loads placed on slopes due to the erection of buildings or road fillings, bridge construction, piles of waste material). When the mass of soil on a slope cannot ensure the balance of the forces acting on it, a landslide occurs, the area of the mass that is involved in the landslide is called a landslide body. When a slope landslide occurs, it is clear that there is a lack or weakening of the shear resistance of the sliding surface in order to maintain the equilibrium of the sliding body. The calculations of the safety factor are usually carried out according to the methods of limit equilibrium and the arcuate sliding surface. In the case of more complicated tasks (more complex, more complex conditions, the state of the rock mass and the size of the object) their solution by limit equilibrium methods is called into question. In such cases, numerical methods of calculation are also implemented, any of the methods for calculating the full state of stress and deformation of the given model. After that, the results obtained by the limit equilibrium methods are compared and the final conclusions are drawn by numerical methods.

Keywords: Safety factor, methods, programs, r_u

Introduction

When preparing the analyses, the main goal is to determine the safety factors and ru , according to the three mentioned methods and their comparison when varying the values of the geomechanical and geometric parameters.
For these reasons, in some of the obtained safety factors, safety factors lower than Fs=1.15 were calculated, which indicates the fact that this is a slope with unacceptably low safety. For greater clarity, all analyzed sliding surfaces according to the Bishop, Janbu and Spencer methods are numbered and the obtained results are shown in a table below in the text.
In addition, the distribution of the analyses and results throughout the paper is carried out by sections: for a general slope inclination (β=190), for which cases calculations were performed with the GGU and SLIDE software, and within which the 4-4` profiles were analyzed and where the geomechanical parameters were varied, and within which general slope the pore pressure coefficient ru is varied in the range 0,0. 0.2 and 0.3.

Geomechanical parameters adopted for the stability analysis

It is undeniable that the selection of the values of the geomechanical parameters of materials is one of the most complex and sensitive tasks in stability analysis.
Therefore, in solving this problem, all available data from previous research and testing were used in order to obtain the most reliable and relevant data possible, and the adopted geomechanical parameters are shown in Table 2.1.

Table 2.1 Adopted geomechanical parameters for profile 4-4'

Nr.	**Material description**	**Geomechanical tag**	**c (kPa)**	**φ (°)**	**γ (kN/m³)**	**r_u**
1	Quarter	SFc/GW	10.00	16.70	20.40	0.00
						0.20
						0.30
2	Organic, medium to high plastic clay	OH/OI	10.00	16.40	17.00	0.00
						0.20
						0.30
3	Coal	L	50	25	13.5	0.00
5	Silty sands	SFc	20.37	21.71	21.41	0.00
						0.20
						0.30
7	Medium plastic clay	CI	18.00	18.00	19.90	0.00
8	Coal with coal clay	L/OH	20.00	17.80	17.90	0.00

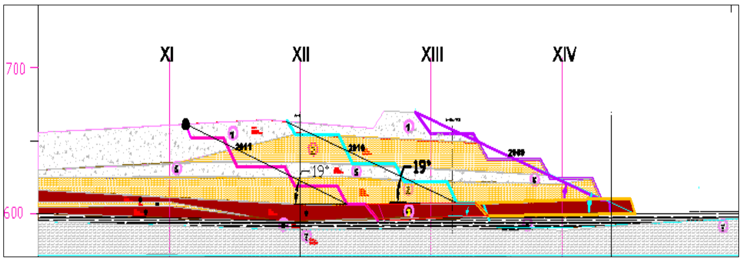

Figure 2.1 Profile 4-4' ($\beta=19^0$)

Determination of general (normative) and calculated values of parameters for shear resistance.

For a set of data obtained on the basis of experimental tests within the boundaries of separate engineering-geological elements, it is adopted that the general values (X°) of all soil characteristics, with the exception of specific cohesion (c), and the angle of internal friction φ, equal to the arithmetic mean values (X), are calculated according to the formula . However, for determining general values (c°) and (φ°), the processing of the experimental results is carried out by calculating by the method of least squares the linear dependence of the shear resistance for all the general values (τ) obtained by experiments in the engineering-geological elements.

$$\tau = \sigma\, tg\varphi + c$$

Where:
τ- shear strength (MPa)
σ – normal stress (MPa)
tgφ – tangent of the angle of internal friction

c – cohesion (MPa)

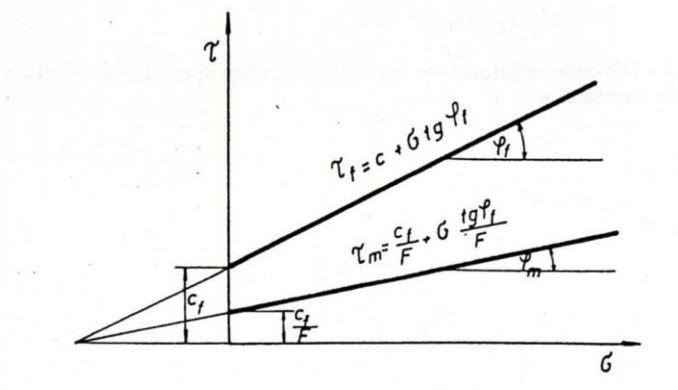

Figure 3.1 – Safety factor for the linear failure criterion in limit equilibrium methods) is considered a constant value for the entire sliding surface and is in constant proportion to the cohesion and the angle of internal friction.

3.1 Statistical processing of geomechanical classification parameters: The statistical processing of the obtained parameters was performed using the following equations:

- **Arithmetic mean value.**

$$\bar{x} = \frac{\sum_{i=1}^{n} x_i}{n}$$

Where:
n- is the number of samples.
Xi- is the characteristic value of one sample.
$\bar{x}$ - is the mean value

- **Standard deviation - σ=**

$$\sqrt{\frac{\sum_{i=1}^{n}\left(x_i - \bar{x}\right)^2}{n-1}}$$

- **Coefficient of variation -** V= $\frac{\sigma}{\bar{X}} \cdot 100$ %

3.2 Statistical processing of strength parameters: Method: Least square linear dependence of shear strength for all total values (τ) obtained by the experiment in an engineering-geological element.

τ=σ tangφ+c

The statistical processing of the strength parameters obtained from the triaxial direct shear test and determination of residual strength was performed according to the expressions listed below.

A. Direct shear.

- Statistical processing of the results obtained from the direct shear test is based on the following expressions:

$$\Delta = \mathrm{n} \sum_{(i=1)}^{n} (\sigma_i)^2 - \sum_{n-1}^{n} (\sigma_i)^2$$

$$C = \frac{1}{\Delta} \left[\sum_{(i=1)}^{n} \tau_i \sum_{(i=1)}^{n} \sigma_i^2 - \sum_{(i=1)}^{n} \sigma_i \sum_{(i=1)}^{n} \sigma_i \tau_i \right]$$

$$tg\varphi = \frac{1}{\Delta} \left[n \sum_{i=1}^{n} \tau_i \sigma_i - \sum_{i=1}^{n} \tau_i \sum_{i=1}^{n} \sigma_i \right]$$

Where:
i – are the normal stress [kN/m2]
i – are the tangential stress [kN/m2]

B. **Determination of Residual Strength**

When determining the residual strength, certain values for cohesion were obtained, although the shear contact had already been broken. This is due to the way the results are processed according to the Mohr-Coulomb failure criterion, where the dependence $\tau=\sigma\, tg\varphi+c$ is interpreted as a straight line. This is the so-called "apparent cohesion" and when analyzing the stability of slopes in the excavation, it should adopt a value of Crez=0.

C. Statistical processing of strength parameters obtained by triaxial testing

The statistical processing of the results of the strength parameters obtained by triaxial testing is done according to the following formulas:

$$tg\varphi = \frac{a-1}{2\sqrt{a}}, [^{0}]$$

$$C = \frac{b}{2\sqrt{a}}, \left[\frac{kN}{m^2}\right]$$

$$a = \frac{1}{\Delta}\left(n\sum \sigma_1\sigma_3 - \sum \sigma_1 \sum \sigma_3\right)$$

$$b = \frac{1}{\Delta}\left(\sum \sigma_3^2 \sum \sigma_1 - \sum \sigma_3 \sum \sigma_1\sigma_3\right)$$

$$\Delta = n\sum (\sigma_3)^2 - (\sum \sigma_3)^2$$

where:
σ_1, σ_3 – are the main maximum and minimum stresses, [kN/m2]

The safety coefficients (factors) that analyzed sliding surfaces for treated slopes must meet in order to be accepted are adopted based on the "Rules for Technical Norms for Surface Exploitation of Mineral Deposits (Stability of Surface Mine Slopes)", and their minimum values are as follows:

Table 3.2 Adopted reliability coefficients

Slope type Fs	**Fs**
Working slopes that are changed once a month	1.0 to 1.1
Working slopes on which mechanization and transport move	1.1 to 1.15
Working slope system when mechanization is working and when transport is carried out	1.15 to 1.20
Slopes that have a longer service life, side and end slopes	1.3

Analyses performed

The stability analyses in this doctoral dissertation were conducted in order to determine the influence of various geomechanical, geometric and hydrogeological parameters on the safety factors for the same failure surfaces and to determine the differences in their values that occur when applying the Bishop, Spencer and Janbu methods.
Moreover, the distribution of the analyses and results throughout the paper is carried out by sections: for a general slope inclination (□=19o), for which cases calculations were performed with the GGU and SLIDE software, and within which a 4-4` profile was analyzed.

Table 4.1 β=19°, Stability analyzes for profile 4-4'.

4-4’	**ru=0**	**ru=0,20**	**ru=0,30**			
	Bishop	Janbu	Bishop	Janbu	Bishop	Janbu
1	1,1	1,1	0,9	0,9	0,8	0,8
2	0,81	0,83	0,68	0,69	0,6	0,62
3	1,14	1,17	0,93	0,95	0,83	0,83
4	1,38	1,38	1,28	1,26	1,22	1,21

ru=0	**ru=0,20**	**ru=0,30**
J/B	J/B /	J/B
1	1	1
1,024691	1,014706	1,033333
1,026316	1,021505	1
1	0,984375	0,991803

Otherwise, both from the aspect of the research for the doctoral dissertation, and from the aspect of the stability of the slopes of the surface mine, it is very important to highlight the observation that the values of Fs at ru=0.0 are up to 30% higher than the values of Fs at ru=0.30. From the results shown in Table 4.1 and the diagrams for profile 4-4’, the values of the factor of safety (Fs) for the four sliding surfaces meet the stability condition (Fs=1.15) only for ru=0.00.

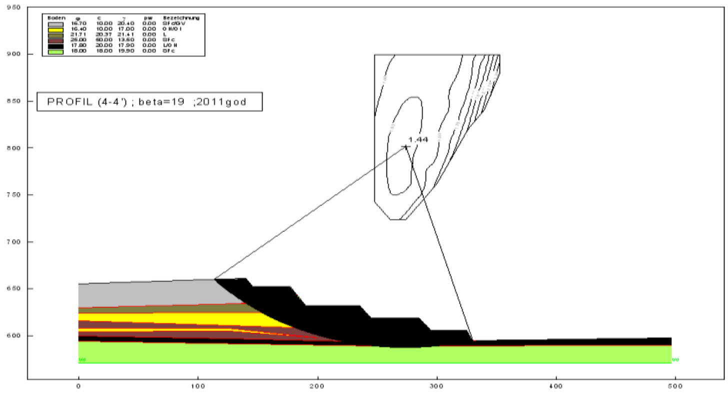

Figure.4.2. Profile 4-4`, Bishop; Sliding surface; 4. Fs=1.44, ru=0.00

Table 4.2 β=19°, Stability analysis for profile 4-4'

4-4' 2011	ru=0		ru=0,20		ru=0,30	
	Bishop	Janbu	Bishop	Janbu	Bishop	Janbu
1	0,97	0,99	0,8	0,8	0,71	0,71
2	1,22	1,22	0,98	0,99	0,87	0,88
3	1,34	1,42	1,13	1,24	1,02	1,15
4	1,44	1,46	1,36	1,33	1,31	1,26

ru=0	**ru=0,20**	**ru=0,30**
J/B	J/B	J/B
1,020619	1	1
1	1,010204	1,011494
1,059701	1,097345	1,127451
1,013889	0,977941	0,961832

Table 4.3 Difference between achieved Fs for sliding surfaces according to Bishop and Yanbu depending on ru for profile 4-4

$B_{0,2}-B_{0,3}$	$B_0-B_{0,3}$	$B_0-B_{0,2}$
0.09	0.26	0.17
0.11	0.35	0.24
0.11	0.32	0.21
0.05	0.13	0.08
$J_{0,2}-J_{0,3}$	$J_0-J_{0,3}$	$J_0-J_{0,2}$
0.09	0.28	0.19
0.11	0.34	0.23
0.09	0.27	0.18
0.07	0.20	0.13

Table 4.4 Relationship between achieved Fs for defined sliding surfaces according to Bishop and Yanbu depending on ru for profile 4-4'

$B_{0,3}/B_{0,2}$	$B_{0,3}/B_0$	$B_{0,2}/B_0$
0.89	0.73	0.82
0.89	0.71	0.80
0.90	0.76	0.84
0.96	0.90	0.94
$J_{0,3}/J_{0,2}$	$J_{0,3}/J_0$	$J_{0,2}/J_0$
0.89	0.71	0.80
0.89	0.72	0.81
0.92	0.80	0.87
0.94	0.86	0.91

From Table 4.2 it can be concluded that in profile 4-4`, for sliding surface 2 no noticeable difference is observed in the results according to the two methods. In sliding plane 3, however, the difference becomes more pronounced, especially with an increase in ru. Also, the values of Fs for the four sliding surfaces fulfill the stability condition (Fs=1.15) only for ru=0.00 and for sliding surface no. 3 and 4 for the case ru=0.20 and ru=0.30.

Comment on the results obtained

The stability analyses were performed for working slopes of the mine and required Fs=1.15, with variation of ru for different presence of groundwater, whereby ru=0.0 was taken as the relevant one, which should be achieved with the foreseen drainage measures.

The analysis was simulated at ru=0.2 and ru=0.3 in order to show the negative impact of increased presence of water, but by applying drainage measures it should be avoided. The verification of the slopes was performed by years, whereby all represented lithological members were entered with their representative physical and mechanical characteristics.

From the attached analyses for profile 4-4', it can be concluded that stability for an angle of 19o is not always satisfied, i.e. it is necessary to mitigate the angle in order to obtain a stable slope in completely dry conditions on the terrain.

As a conclusion from the analyses performed in this way, the fact that the influence of pore pressure for certain slip surfaces is drastic is imposed. Namely, if we consider very deep slip surfaces analyzed according to the Bishop method, it can be observed that in the 4-4` profile there is a decrease in Fs of up to 30% in conditions of ru=0.3 compared to Fs at ru=0. 0

In a similar format as above, the following provides a review and commentary on the results of the analyses and the achieved safety coefficients as a function of changes in the geomechanical parameters obtained by applying the SLIDE software.

It is concluded that the Fs values obtained from the SLIDE calculations are 10-15% lower than the Fs values obtained from the GGU software package calculations for the same Bishop method. This represents a linear decrease in the safety coefficient and this trend can be observed in the other analyzed sliding surfaces, but with a changed intensity.

It can also be concluded that the stability analysis with FEM (PLAXIS) yields values for the safety factor that are close to those achieved with MGR (SLIDE and GGU), although there are also certain differences in the procedures, which further partially affect the amount of Fs:

Recommendatins and guidelines

A complex task is to select the right physical models and parameters that are most important in the process of interaction of the environment with the engineering intervention. The selection of the right parameters can be made only through the optimal setting of the research methods and procedures, in relation to a given design phase. The economic and environmental effects of the construction of any facility largely depend on this choice.

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