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The analysis of computer aided methods applied for pit wall stability rating

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Abstract. A comparative analysis of the results of the pit slope stability rating carried out under normative technique and Scad Office Slope application is presented. The possibility of combination of normative technique and computerized calculations to gain integrity and computation operability is suggested.

1. Introduction

The problem of pit wall and slope stability is of current importance in mining, civil engineering and other branches of human activity. Theoretical development and improvement of calculation methods for pit slope and dump stability under real mining and geological conditions were developed based on well-established calculation methods (V. Fellenius, V. V. Sokolovskiy, S. S. Golushkevitch, G. T. Shakhunyantz) and research data on slope deformation in field or laboratory conditions [1, 2, 3, 4]. Advanced methods for calculating slope stability are based on the limit equilibrium theory for loose medium together with the limit equilibrium of cohesive soil medium such as rock massif.

2. Methods and materials

Methods of algebraic force addition and force polygon (vector addition) are two known and widely used basic calculation methods currently being used for pit slope and wall stability rating.

The method of algebraic force addition is characterized by sufficient simplicity of graphic construction and subsequent calculations. The method is applied in isotropic (homogeneous) slope stability rating the length (L) of which is 2-3 times more than their height (H) and potential sliding surface has the form of fair curve. The method assumes that the prism of a possible collapse is deformed as a whole and reactions between blocks are not taken into account. This results in the underestimation of design ratio of holding and shear forces (underestimation of determined stability coefficient) by 3-20 % relative to the actual one. However, this method gives acceptable results [5, 6] when the slope height is low (up to 100 m) in loose rocks and internal friction angle values are small ($\varphi < 20^\circ$).

The most reliable and universal method for calculating slope stability in real mining and geological conditions is the method of force polygon (vector addition) advanced by All-Russian Research Institute of Mining Geomechanics and Survey (VNIMI). The method takes into consideration both internal and external forces acting on the limits of possible block mining marked in the prism [7]. The method in question allows for an accurate evaluation of the pit slopes stability or their sites especially



in difficult mining and geological conditions, namely the presence of differently oriented contacts of rocks and tectonic deformations in the array; the layered array structure at pit walls; dump (mounds) formation on the sloped or weak base.

To determine the maximum stable parameters of pit walls and quarry faces in homogeneous rock mass, VNIMI developed and constructed graphs of the relationship between the height of the flat slope H and its angle α for different physical and mechanical characteristics of rock mass (density γ , internal friction angle φ and cohesion C_m) based on the force polygon method. According to the graphs, it is possible to evaluate the slope stability with the given parameters or to determine the maximum stability parameters at a given safety margin [8]. It is worth noting that this method allows to achieve the results quickly without special training. However, the reverse side of simplicity is the need to average the characteristics of an array, which matters with a complex structure of a pit wall.

Recently, computer-aided methods for pit wall and slope stability calculations have been spreading; the best known are Rocscience (Slide), Geo (Slope), Fine Soft (Geo 5) and others. The apparent advantage of these methods is the possibility of carrying out on-line multivariate calculations (the search for the weakest surface formed in the array at pit walls; the detection of the weakest parts in the slope height). A traditional method, on the other hand, requires much more effort and time of a specialist. However, software application employed for stability rating requires from a specialist theoretical and practical training since the result of computerized analysis heavily depends on the experience of a specialist and may differ from the reality as one cannot describe the natural environment based on typical up-to-date mathematical tools.

The set of forces acting in the slope array (holding and shear) is a complex geomechanical process depending on the set of independent factors the correct accounting of which directly determines the accuracy of stability rating results. Among the main factors affecting the stability rating are the choice of initial physical and mechanical characteristics of mine rock; the shift from the characteristics of rocks in the sample to those in the array; the accuracy of array geomodelling; the provision for the most likely sliding surface; the consideration of the effect of array characteristics (tectonics), hydrogeological conditions, external loads, etc. Therefore, the quality of the initial geomechanical condition modelling, regardless of the applied calculation method, is of great importance for rating the stability of the quarry slopes, pits, dumps or mounds.

Though software packages currently used for slope stability rating fail to meet the requirements of current regulatory documents; they can serve as a powerful auxiliary tool for on-line multivariate calculations thus increasing research data representativeness.

3. Results

To evaluate the possibility of using computer-aided systems for pit slope and slope stability rating, the results of computer calculation in the software Scad Office Slope were compared through research with those of manual calculations of the force polygon method (vector addition) recommended in regulatory documentation.

The force polygon method used as a reference in the comparative analysis is specified in the relevant regulatory documentation on issues relating to pit wall stability rating [9, 10, 11, 12, 13].

The computational methods used in the software Scad Office Slope apply the mathematic tools specified both in open sources and in the programme user manual [14, 15, 16, 17]:

- Fedorovskiy – Kurillo;
- Fellenius;
- Bishop simplified;
- Corps of engineers №1;
- Louw and Karafight;
- Janbu simplified;
- Janbu corrected;
- Spencer.

Laboratory of pit wall stability and rock movement has considerable experience in evaluating the stability of pit wall and striping soil bank where the software Scad Office Slope was repeatedly employed to perform calculations as a supplement to traditional methods regulated by reference documents.

Research covered two copper-ore quarries: Yubileiny (LLC Bashkirskaia med) and Novo-Shemurskiy (JSC Svyatogor). To conduct research two specific strip pits (Fig. 1, 2) oriented along the normal to pit wall extension were employed. Pit wall stability was evaluated at maximum quarry depth for each strip pit. Table 1 shows the findings of pit wall stability rating on the Yubileiny quarry and Table 2 provides data on the Novo-Shemurskiy quarry.

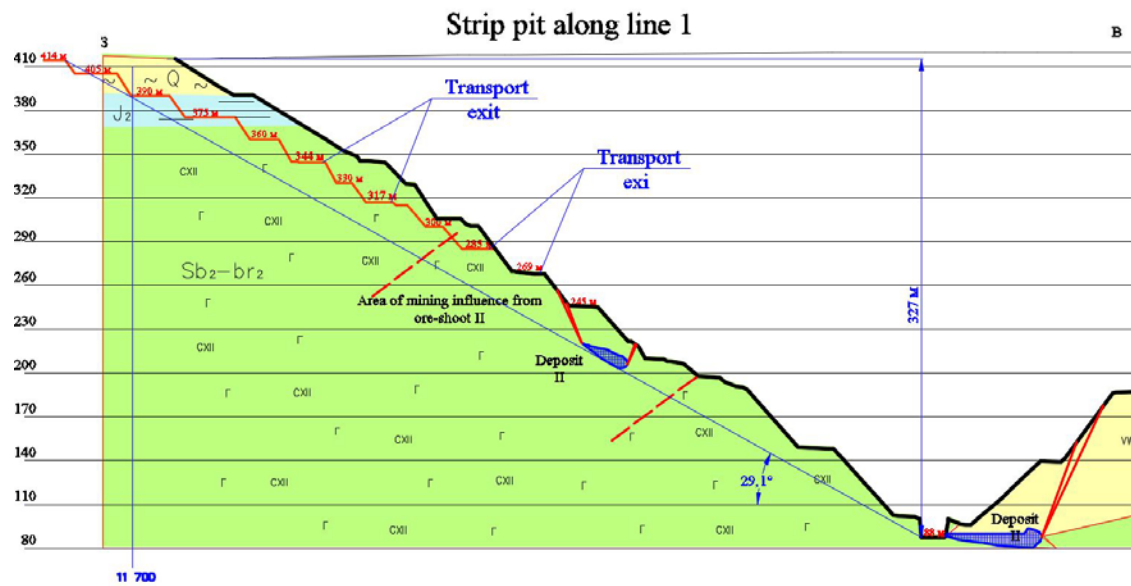


Figure 1. Yubileiny quarry. Calculated strip pit taken along line 1.

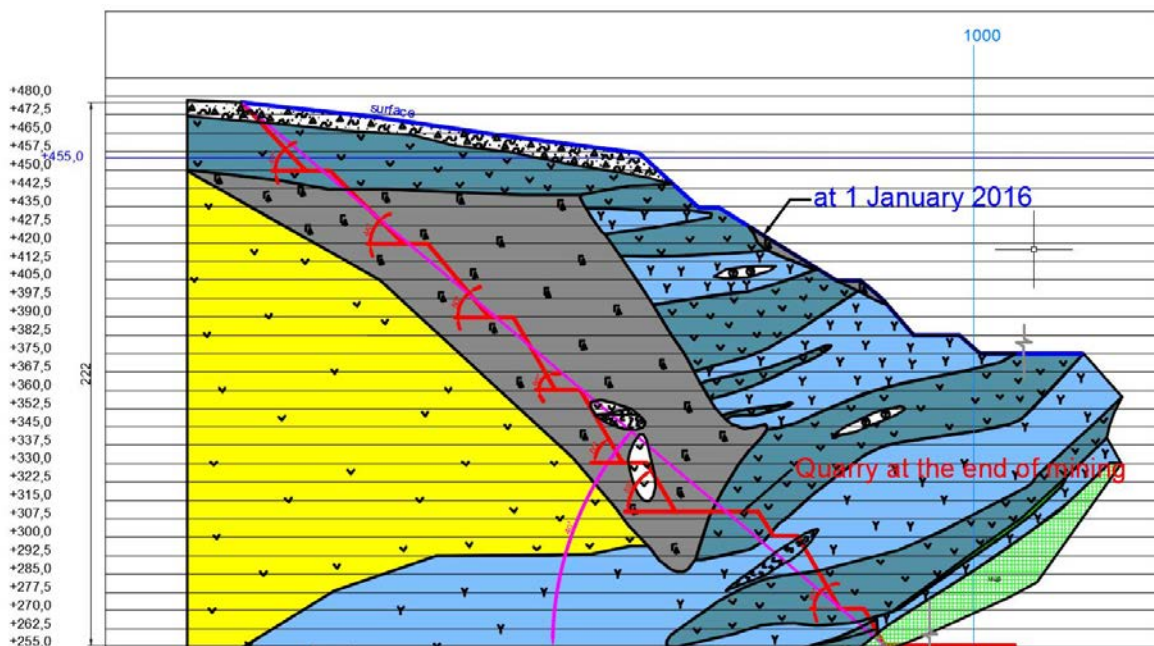


Figure 2. Novo-Shemurskiy quarry. Calculated strip pit taken along line 2.

Table 1. Calculation data on the Yubileiny quarry.

Calculation method	Stability coefficient	
	Strip pit along line 1	Strip pit along line 2
Janbu simplified	1.68	1.65
Spencer	1.81	1.77
Fedorovskiy – Kurillo	1.74	1.70
Polygon of forces (reference)	2.20	2.10

Table 2. Calculation data on the Novo-Shemurski quarry.

Calculation method	Stability coefficient	
	Strip pit along line 1	Strip pit along line 2
Fedorovskiy – Kurillo	1.95	1.30
Fellenius	1.92	1.30
Bishop simplified	2.02	1.32
Janbu corrected	1.95	1.32
Spencer	2.00	1.32
Polygon of forces (reference)	1.96	1.37

4. Discussion

Research shows that in general the results of computer calculations are consistent with those of stability rating performed with force polygon method. In this respect, the utmost convergence with classical technologies for quarry mining conditions under study is achieved through the following methods:

- Fedorovskiy – Kurillo;
- Fellenius;
- Bishop simplified;
- Janbu corrected;
- Janbu simplified;
- Spencer.

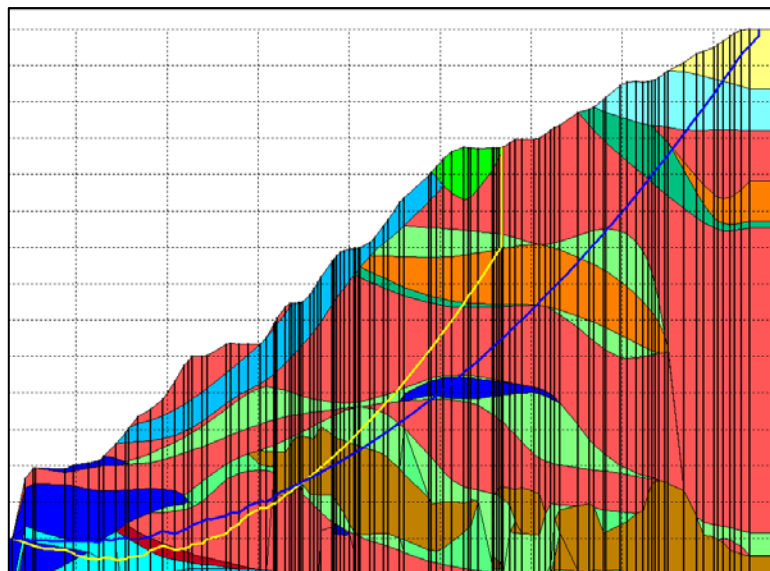


Figure 3. Pit wall modelling and calculation of pit wall stability coefficient in the software Scad Office Slope based on Fedorovskiy - Kurillo method.

Based on computer calculations the stability coefficient values are generally found to be slightly less than those of polygon of forces that is a positive factor as it gives an additional safety margin.

Figures 3 and 4 show the examples of pit wall modelling and computer-aided slide surface modelling on which calculations are made.

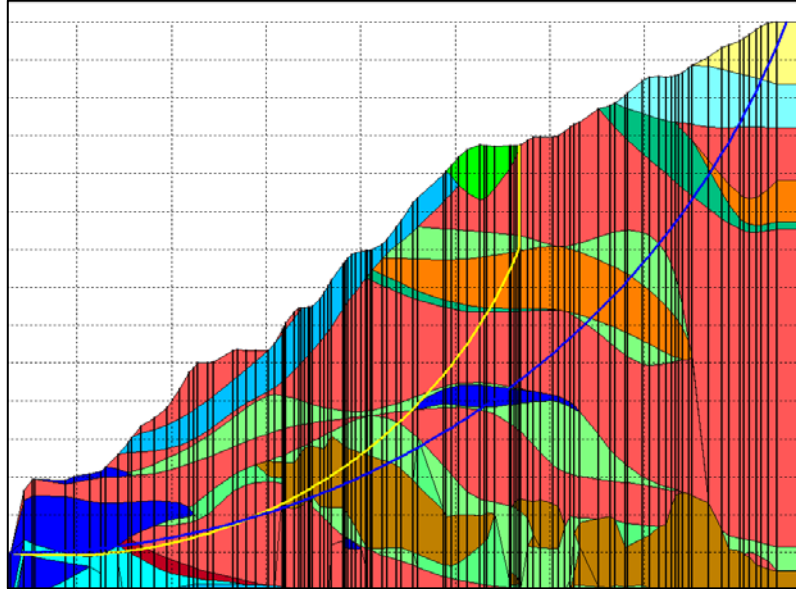


Figure 4. Pit wall modelling and calculation of pit wall stability coefficient in the software Scad Office Slope based on Fellenius method.

In particular, the Novo-Shemurskiy quarry deviations in stability coefficient values did not exceed 0.01-0.07 which is comparable to the accuracy of its determination. Several large deviations reaching 0.33-0.52 were recorded in the Yubileiny quarry. Here the computer calculations and those of polygon of forces performed by different researchers explain the difference in the approach to reference geochemical condition modelling directly affecting the results of calculations. Even when outside experts were involved in checking calculations, the software package introduced an additional coefficient to the stability margin enhancing safety of further operation of a hazardous production facility. This is particularly important when obtaining safety margin coefficients close to the ultimate ones (1.3 – 1.5) where an error as low as one-tenth reclassifies the pit wall from unstable to safe for operation. Moreover, if deformations at the initial stage may be insignificant for non-working pit banks placed in the limit position, the incorrect justification of the pit wall stability with a main exit to the quarry can potentially result in emergencies and the interruption or complete stop in the enterprise operation [18].

5. Conclusions

Close examination reveals that the software package Scad Office Slope having offered acceptable results of the calculations is likely to be applied in the pit wall and slope stability ranking. The application of computer calculations allows:

- enhancing performance effectiveness of slope stability study since the software facilitates completing a great number of calculations with less specialist's effort and time;
- increasing the degree of calculation details including rating the stability of a sufficiently large number of local areas in the height of pit walls or slopes;
- defining accurately the position of the most likely sliding surface that is of great importance for rating the stability of the quarry slopes or mounds where the surface is based on trial method;
- varying quickly enough initial physical and mechanical characteristics observing the dynamics of safety margin changing under initial geomechanical condition changes (in particular, the

decrease in the rock strength with its watering increasing or underworking of a pit wall by underground mining).

However, the application of software packages for pit wall or slope stability rating within the limits of research works does not preclude the need for the implementation of traditional methods (force polygon method or method for algebraic force addition) regulated by normative documents. Gaining reference values, the methods are employed for checking calculations on the most specific strip pits. Furthermore, the modelling of reference geomechanical conditions – geological and structural modelling of pit wall or slope under study, provision of calculated physical and mechanical characteristics of the rock, allowance for loads of different kinds – is significant to ensure calculation results regardless a calculation method applied.

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