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ABSTRACT: This work focused on the stability analysis of Vasilkovskoye open pit north wall slope. The current height of the north wall is about 270 m and within the north wall area there are several critical areas that have the potential for instability at the scale of two to three benches. These areas are characterized by significant jointing and form a blocky rock mass. Because the main haulage ramp goes through this location, any wall failure would jeopardize the operational safety and productivity of the pit. Stability analysis of the wall was conducted to assess the wall stability and determine the wall failure mode as well as shape and depth of probable failure plane. Knowledge of failure plane geometry and depth is a key parameter in selecting the stabilization method. A complete rock mass characterization of north wall aiming at determining design parameters was carried out and a comprehensive numerical analysis of the wall critical areas was conducted. Moreover, with regard to the calculated shape and depth of probable failure plane at wall critical areas, recommendations for appropriate support system were suggested. Thus, slope stability analysis of this area will significantly contribute to maintaining safety and productivity of the mine. The results of the study will provide the Vasilkovskoye with valuable information on stability for safe and sustainable operations on the north wall of the mine.

1 INTRODUCTION

In the developing stages of deposits in an open-pit mine, it is very important to ensure the stability of both individual benches and the whole pit walls. To prevent their deformation and collapse during the entire period of operation of the pit, stability analysis of all mine walls is essential. The stability of the pit walls depends on different factors, for instance: structural and geological features of the deposit (including fracturing), physical and mechanical properties of the rocks, stress-strain state, pit wall design, hydrogeology, blasting technology, weathering, seismicity, etc. The stability of the pit walls is associated with issues of safety and technology of work in mines, as well as determining the ultimate pit angle, the maximum depth of the pit and the possibility of drainage of the deposit. The aims of this project are to evaluate the stability of the critical pit walls of Vasilkovskoye open-pit gold mine, based on numerical simulations in RS3 environment.

2 GEOLOGY OF VASILKOVSKOYE OPEN PIT

The Vasilkovskoye gold deposit is located in the Akmola region of Kazakhstan, nearly 20 km northwest of Kokshetau town. The ore deposit was discovered in 1963, and mining activities began in 1980 and were carried out by open pit mining.
The main observed rock types are as follow:

- Megacrystic granodiorite with abundant K-feldspar megacrysts. This is the main host rock for the mineralization.

• Quartz diorite and gabbro-diorite. These rock types contribute to a lesser extent to the mineralization.

Mineralization is hosted mainly by megacrystic granodiorite and it is associated with hydrothermal quartz and quartz-arsenopyrite veins.

3 ROCK MASS CHARACTERIZATION

The rock mass characterization is a major step to determine rock mass design parameters to assess the stability of a north wall slope at its current state. With regard to the previous investigations of Vasilkovskoye mine, the laboratory data provided by Golder Associates Consulting Company, SRK Consulting and AMC Consultants Companies were analyzed. Furthermore, rock mass characterization was performed and rock mass design data, as input for 3D modelling, were obtained.

Accordingly, rock mass data were collected for the main geotechnical domains and critical areas of the pit. In general, the uniaxial compression strength of the main lithological units in different pit sections exceeds 150 MPa. However, the top portion of the pit is consists of weak weathered rocks that can be visually distinguished from the base rocks. The thickness of these rocks varies and encompasses several benches at higher elevations. The compressive strength of the weak rocks is less than 50 MPa. The following types of laboratory tests were performed: Uniaxial Compression Test, Triaxial Compression Test, Tensile Strength Test, Shear Box Tests, Residual Joint Strength tests. A much less weathered rock mass underlies the above described weathered rock mass. Based on field observations, a GSI index greater than 70 was attributed to the deeper rock mass of the open pit (approximately below 150m). Borehole camera analysis confirmed these observations and indicated a general GSI index improvement with depth down to -395 m. This level is equivalent to the geotechnical domains named 2-7 in northeast and 2-12 in south-west sectors (AMC Consulting, 2008).

The following three main rock types are identified at Vasilkovskoye:

- Granite and granodiorite;
- Quartz diorite / mix-diorite;
- Gabbrodiorite;

The rock type distribution map observed in the open pit is based on data provided by Vasilkovskoye: gabbrodiorite and quartz-diorite outcrop in the northern side of the open pit and they represent approximately 30% of the total rock mass. Granites and granodiorites outcrop in the central and southern parts of the open pit, and represent approximately the 70% of the north wall rock mass.

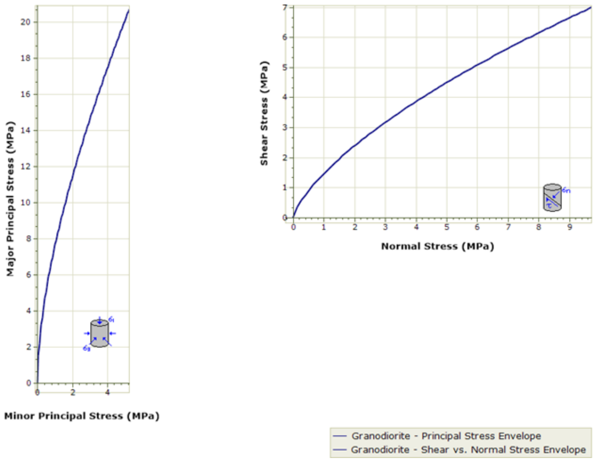
For the rock mass characterization, samples were collected from several boreholes that were located in the north-east side of the pit. Boreholes were oriented toward N171° with an inclination to the horizontal of 60° (at starting point). In the south-west side of the pit the boreholes were oriented toward N26° with an inclination to the horizontal of 60° (at starting point) to conduct a laboratory tests. Consequently, to determine the rock mass rating (RMR) and geological strength index (GSI), various elevations within the north wall were taken as representative locations to assess rock mass design parameters of the main geotechnical domains. The recorded rock mass parameters were calculated for each geotechnical units using the laboratory test results. Table 1 illustrates a prepared designed data of rock mass for 3D modelling.

Table 1. Summarized Intact Rock mass parameters.

Rock Type	Unit Weight (t/m3)	Young's Modulus (GPa)	Pois. Ratio	UCS (MPa)	Cohesion (MPa)	GSI	Friction°	RMR	mi	mb	s
Granodiorite	2.6	58.9	0.24	92.9	8.18	70	40.6	62/72	8.39	2.875	0.035
Quartz Diorite	2.68	86.7	0.28	114.9	13.57	70	38.9	76	8.75	2.99	0.0357
Gabbro Diorite	2.9	86.7	0.28	100	13.57	70	36.9	76	8.5	2.9	0.035

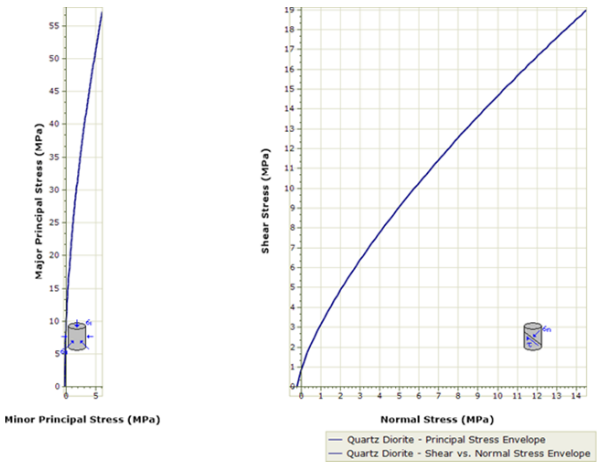
4 ROCK MASS DESIGN PARAMETERS

After completing the data analysis, it is necessary to transfer the laboratory data to the in-situ values for the modeling. In order to determine the rock mass design data the RocLab software was used.



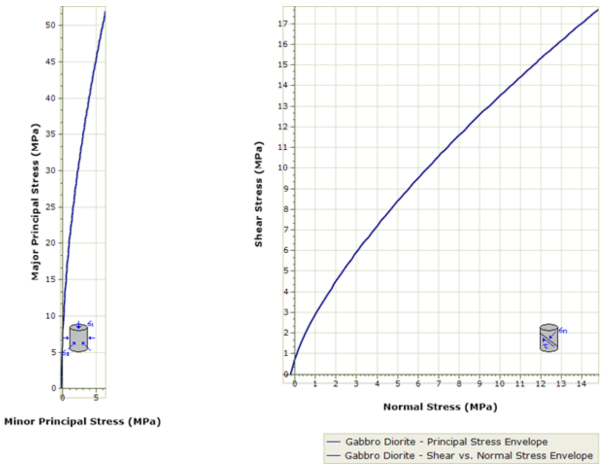
Granodiorite	
Hoek Brown Classification	
intact uniaxial compressive strength	84 MPa
GSI	45
mi	29
disturbance factor	1
intact modulus	58900 MPa
Hoek Brown Criterion	
mb	0.57
s	1.045e-004
a	0.508
Failure Envelope Range	
application	slopes
sig3max	5.122 MPa
unit weight	0.026 MN/m3
slope height	270 m
Mohr Coulomb Fit	
cohesion	1.088 MPa
friction angle	33.024 deg
Rock Mass Parameters	
tensile strength	-0.015 MPa
uniaxial compressive strength	0.797 MPa
global strength	8.144 MPa
modulus of deformation	2985.733 MPa

Figure 1. Rock mass designed data determined for Granodiorite geotechnical unit.



Quartz Diorite	
Hoek Brown Classification	
intact uniaxial compressive strength	114.9 MPa
GSI	70
mi	31
disturbance factor	1
intact modulus	86700 MPa
Hoek Brown Criterion	
mb	3.637
s	0.007
a	0.501
Failure Envelope Range	
application	slopes
sig3max	5.919 MPa
unit weight	0.027 MN/m3
slope height	270 m
Mohr Coulomb Fit	
cohesion	2.688 MPa
friction angle	50.12 deg
Rock Mass Parameters	
tensile strength	-0.213 MPa
uniaxial compressive strength	9.368 MPa
global strength	29.847 MPa
modulus of deformation	18565.964 MPa

Figure 2. Rock mass designed data determined for Quartz Diorite geotechnical unit.



Gabbro Diorite	
Hoek Brown Classification	
intact uniaxial compressive strength	100 MPa
GSI	70
mi	27
disturbance factor	1
intact modulus	86700 MPa
Hoek Brown Criterion	
mb	3.168
s	0.007
a	0.501
Failure Envelope Range	
application	slopes
sig3max	6.243 MPa
unit weight	0.029 MN/m3
slope height	270 m
Mohr Coulomb Fit	
cohesion	2.564 MPa
friction angle	47.459 deg
Rock Mass Parameters	
tensile strength	-0.213 MPa
uniaxial compressive strength	8.153 MPa
global strength	24.329 MPa
modulus of deformation	18565.964 MPa

Figure 3. Rock mass designed data determined for Gabbro Diorite geotechnical unit.

RocLab results for granodiorate, quartz diorite and gabbro-diorite are presented in Figure 1, 2 and 3.

Table 2. Determined Designed Data of the rock mass as input for numerical analysis.

Rock Type	Unit Weight (t/m3)	Tensile strength (MPa)	UCS (MPa)	Global strength (MPa)	Modulus of deform. (GPa)	Cohesion (MPa)	Friction angle◦	mb	s	a
Granodiorite	2.6	0.015	0.797	8.144	2.986	1.088	33	0.57	0.0011	0.508
Quartz Diorite	2.68	0.213	9.368	29.847	18.566	2.688	50	3.64	0.007	0.501
Gabbro Diorite	2.9	0.213	8.153	24.329	18.566	2.564	47	3.17	0.007	0.501

The parameters which have the strongest influence on the slope reliability were summarized and presented in Table 2.

5 3D NUMERICAL SIMULATION OF VASILKOVSKOE NORTH WALL

With regard to limitations in computational capabilities, the model dimensions were selected as illustrated in Figure 6. Since this work in progress, for future publications, the model boundaries will be extended to minimize the probable errors associated with boundaries. Having prepared the data (Table 2) for the modelling, 3D model of the north wall of Vasilkovskoe open-pit was constructed within the RS3 environment. The north wall region was employing an average mesh size of 1m. Key geological materials were assigned as appropriate, RS3 software has a different approach for restraining the model. This model was restrained with auto surface restrain tool. Figure 4 and Figure 5 illustrates the determined maximum and minimum principal stress distribution within the simulated pit region.

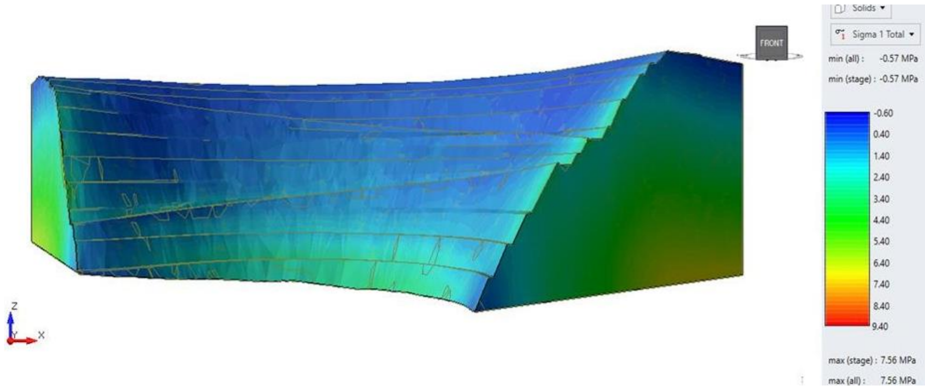


Figure 4. The calculated maximum principle stress distribution within north wall (front view).

Thus, the maximum principal stress (sigma 1) and the minimum principal stress (sigma 3) were obtained from the simulation results using RS3. The calculated maximum principal stress was 7.56 MPa (Figure 4) and the minimum principal stress was found to be 7.14 MPa (Figure 5). Both stresses pose the greatest compressive stress on the basement of the north wall indicating lithostatic load, because of the mass of the overlying layers in rocks, and gravity that increases pressure on each layer of rock that increases with increasing depth.

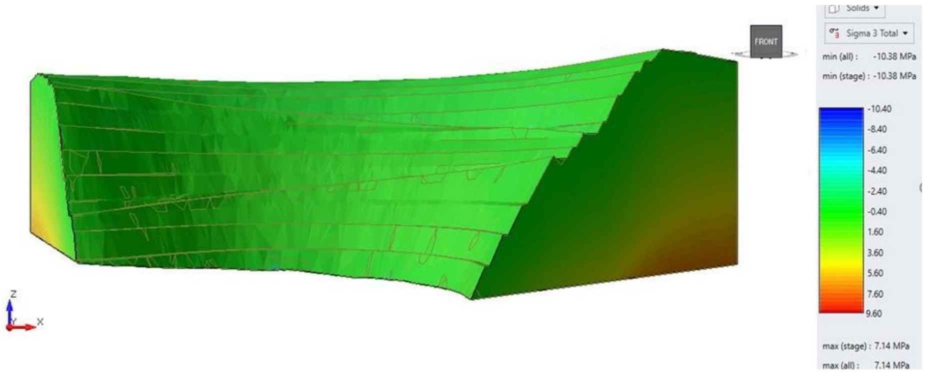


Figure 5. The calculated minimum principle stress distribution within north wall (front view).

Distribution of total displacements within the North wall is shown in Figure 6. The contour of total displacement presented for a representative section of the wall in Figure 7. The results of the overall rock mass stability analyses indicated that the proposed design for pit walls are expected to have instability with respect to potential failure mechanisms that could involve multiple benches.

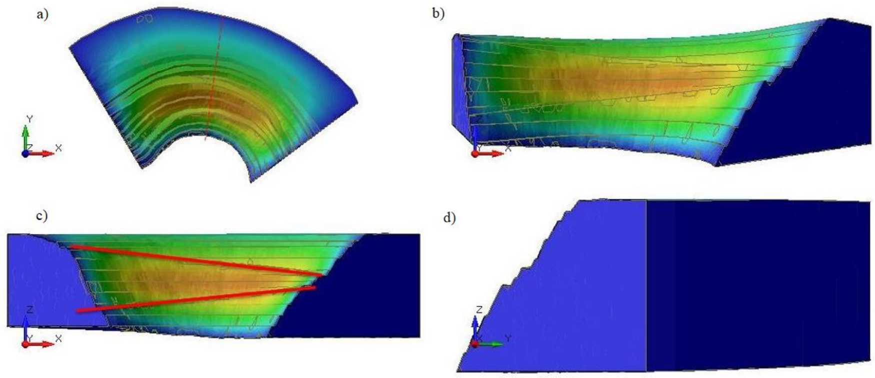


Figure 6. The calculated total displacement of the north wall (from four different perspectives: a) top view, b) isometric view, c) front view and d) side view).

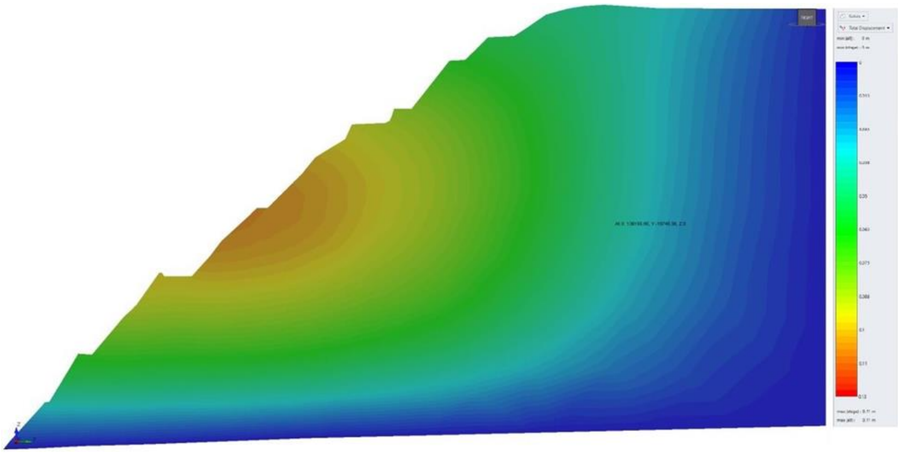


Figure 7. Total displacement contours on the north-south cross section.

As illustrated in Figure 6, the central section of the north wall possesses the highest instability potential within the whole structure. The overall size of the most unstable area corresponds to about 120 meters in length, 50 meters in height and 10 meters in depth and the probability of the maximum displacement is about 0.11 meters.

With the help of RS3 feature of displaying displacement vectors Figure 8 was obtained.

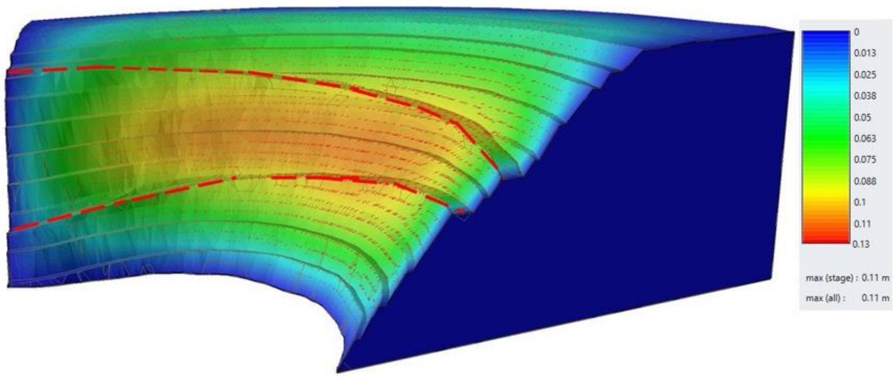


Figure 8. Displacement vectors direction.

This model simulation allows us to predict possible direction of the rock movement. As vectors point to forward direction towards the center of the pit, it can be stated that there is a risk of several benches' failure. We have shown within 3D numerical modelling results that the north wall has the potential to fail, due to the wall is destressing potential at the middle portion. With regard to the jointed nature of the wall as the potential to fail at those areas, we recommend stabilization to the pit.

6 DISCUSSION

Stability analyses were conducted for the overall pit walls considering the potential failure mechanisms. The finite element program RS3, was used to confirm that the proposed pit walls are comparatively stable with instability potential in central part. Numerical modelling approach allowed a better method to evaluate the stability of the slope than the conventional methods, it also takes into account complex geometry and non-linear behavior.

The conducted 3D modelling of the north wall, that was constructed using RS3, allowed us to determine the induced wall stress field and its influence on slope stability (in dry wall condition). These values indicate that the effect of these stress directly contribute to potential slope instability in the central region of the north wall. As it is stated in the 3D numerical simulation of Vasilkovskoe north wall section both stresses pose the greatest strain on the basement of the north wall indicating the maximum principle stress as 7.56 MPa and the minimum principal stress as 7.14 MPa lithostatic load. Because of the mass of the overlying layers in rocks, and gravity, as being an increasing pressure on each layer of rock section, Figures 4 and 5 illustrate the base of the pit as the most stressed portion of the wall.

As illustrated in Figure 6, the central section of the north wall possesses the highest instability among the whole structure. The main source of wall center instability is the distressing of wall and weak rock mass properties. The size of the predicted unstable area was found to be about 120 meters × 50 meters × 10 meters with an average displacement of 0.11 meters. Other simulation model predicts possible direction of the rock movement towards the center of the pit which poses a risk of several benches' failure. This indicates the risk for further operations on those benches. Bench, inter-ramp and overall slope geometries were studied by means of numerical simulation. It is suggested to follow the specific design criteria that will support the stability of the slope such as rock inter-ramp should comprise no more than about three benches and should have a vertical height of no more than 90 meters. These bench stacks should be separated by a 25-meter ramp or geotechnical berms.

7 CONCLUSION

Pit wall stability analysis is of great interest to the Vasilkovskoye open pit due to the fact that the safety and profitability of the mine directly depends on the stability of the pit walls. The results of this work provided advantages for Vasilkovskoye, for example: determination of critical wall (the north wall) stability, rock characterization and 3D modeling. The results of the work are of a great significance as the safety and stability of the north wall is vital. The scope of this paper is to evaluate the stability of critical areas in the north wall. Through numerical modeling, it was possible to examine the north wall in detail and determine possible scenarios of deformations and failures, and propose remedial support.

REFERENCES

AMC Consulting, 2008. Open pit mining sustainability JSC Vasilkovskoe zoloto. West Perth.

Golder Associates, 2016. Steeper Slope Angle Evaluation at Vasilkovsky Open Pit. Atyrau: Golder Associates Kazakhstan LLP

Karaganda State Technical University, 2009. Substantiation of stable parameters of open-pit bench slopes and walls at Vasilkovsky GOK. Karaganda.

SRK Consulting, 2019. Justification of the stability of benches and berms of the Vasilkovskoye open pit. Moscow.