on the shaft support and reinforcement at depths greater than 700 zm.

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GEOMECHANICAL SUBSTANTIATION OF THE NORTHEASTERN PIT WALL STABILITY IN KURZHUNKUL MINE

Kurzhunkul magnetite deposit is located in the Kostanai Region of Kazakhstan and is an open pit mining project of Sokolovsko–Sarbay Mining and Production Association (SSGPO) since 1983. The current depth of the open pit is 240 m (Level -28 m). It is expected that Kurzhunkul pit reaches the depth of 290 m. The deformation determinant in Kurzhunkul mine is its geological structure represented by complex faulting. Special care and attention should be paid to the northeastern pit wall which is a zone of large and closely spaced tectonic faults essentially extended along the strike and dip of the deposit, and depthward the pit. Unfavorable bedding conditions in combination with weak physical and mechanical properties of fracture fillers can induce movement of rock blocks during extraction of mineral reserves from the weak zone of the northeastern pit wall. This study offers the geomechanical substantiation of stability of NE Kurzhunkul pit wall which is most heavily intersected by tectonic faults and has low strength characteristics.

Keywords: *open pit mine, tectonic faults, stability, physical and mechanical properties, stability factor.*
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Introduction

Structural heterogeneity, extensional tectonics, jointing and broken bedding are the critical factors of higher concern in mineral mining safety. All other geological and geophysical processes are controllable and are governed by the extensional tectonics [1, 2].

From the engineering geology data, the Kurzhunkul open pit mine field is intersected by premineral NE-striking faults with NW dips at 80–85° and by NW-striking faults with SW dips at the same angles, and represents a small- and medium-size blocky rock mass. Tectonic faults are oriented ether north–southward, or west–eastward, north–eastward and north-westward, and represent either normal faults, or shifty faults and overthrusts, which condition the broken blocky structure of the region.

The premineral NE-striking faulting is synvolcanic normal faults in docite and quartz porphyry, with zones of fragmented and heavily jointed rocks in contact zones. These faults feature disintegration together with consolidation of rocks mass with joints healed by strong minerals. The NW-striking faulting regenerated after orogenesis represents fragmentation zones and sandy–clayey residuum; it considerably complicates the rock mass structure and promotes its disintegration.

Research results

Based on the lab-scale strength tests, Kurzhunkul rocks are assumed as medium strong to very strong. Depthward the rock mass, the strength of rocks varies from 39.0 MPa to 89.1 MPa. The footwall (eastern pit wall) is heavier faulted as against the hanging wall. Strong jointing and low strength of rocks in the footwall are connected with the local tectonic faults. For example, metasomatic rocks in the southeast of the open pit have half as high strength as in the southwest.

The main part in formation of unstable blocks in enclosing rocks of Kurzhunkul open pit is taken by the combination of differently oriented faults. **Figure 1** offers 3D visualization of the positions of main NW-striking faults 1 to 6 as well as NE-striking faults (in the horizontal plane) relative to each other and to Kurzhunkul pit walls from the mapped boring data.

The faulting governs the block hierarchical structure of Kurzhunkul rock mass. The faults split the rock mass into blocks from ten to hundred meters in size [3–6].

Tectonic stresses and blasting can induce displacements of structural blocks along fractures both in the line of the pit wall and towards the pit. The highest danger is constituted by faults in the northern pit wall as they dip towards the mined-out void, and in case of instability, the structural blocks will move along weak surfaces to the pit (**Figs. 1 and 2**).

The northeastern pit wall is cut with a series of faults 1–6 with the northwestward strike at azimuth of 295–320° and with the southwestward dip (to the pit) at angles of 80–85°. These faults are long and are traceable to the full length. A large anticlinal fold is well detected in the longitudinal faults here. The surfaces of lithogenetic vertical joints have a dip towards the work face. Weakening of the rock mass will take place in the line of the faults. In the zones of large faults, Paleozoic rocks of Kurzhunkul open pit are weathered, heavily jointed and fractured. The strength of the rock mass in shearing in parallel to the faults is governed by the shear strength of the faults. This area is susceptible to deformation in the form of subsidence, rockslide and rock falls along tectonic fractures.

Considering occurrence of layers at the angles 15–25° towards the pit, the rock mass structure will also be the decisive factor in estimating possible failure mechanisms. The prevailing system of flat-lying joints (system 1) in adjacent rock mass of Kurzhunkul pit will cause rockslides in the areas of developed flat-dipping bedding, while steep joints (system 2) can induce failure of benches during undercutting of rock blocks lying on the weak surface. The triggers will be seismic effects produced by blasts, water intrusions and loads generated by mining machinery.

Generally, the northern and northeastern pit walls are most susceptible to deformation and represent a weak zone. The weak zone in NE pit wall, alongside with the unfavorably

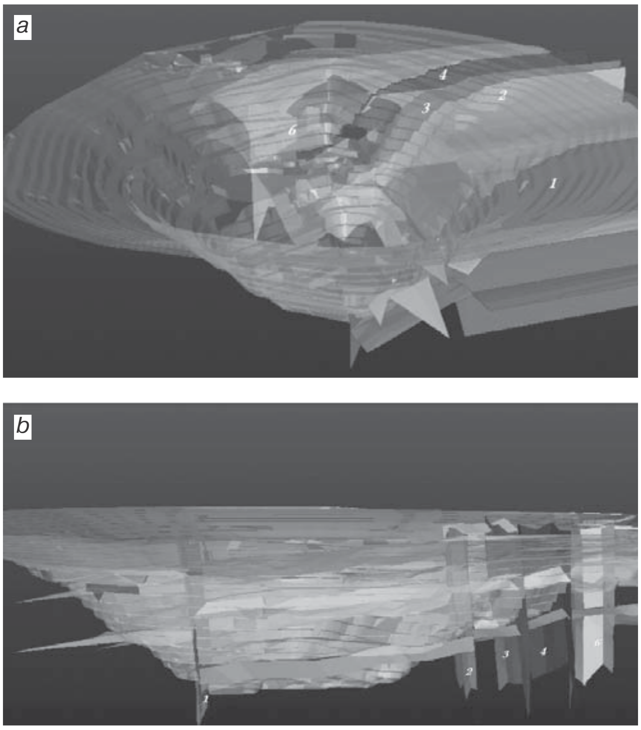

Fig. 1. Main faults intersecting ultimate pit limits in Kurzhunkul mine:
(*a*) view from the south; (*b*) view from the east

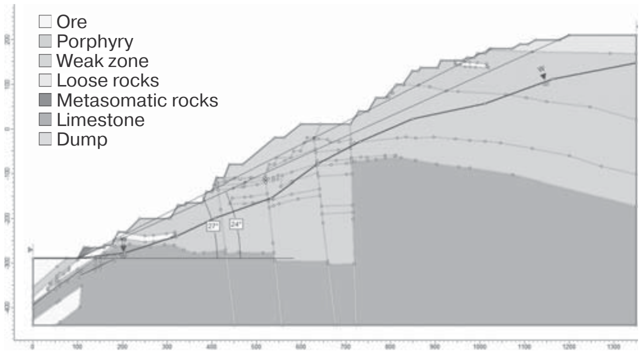

Fig. 2. Elevation view along profile 6 (weak zone in NE pit wall)

oriented faults, have low strength characteristics of weak surfaces. This fact is proved by the data obtained in borehole 11i drilled in this pit wall: rock mass to Level +105 m is composed of heavily jointed porphyry of medium strength (39 MPa on the average), core is 75% crushed rocks, the average size of particles is 2–7 cm. The joints will have the highest impact on NE pit wall stability.

Mining safety can be ensured owing to comprehensive analysis of geological structure and geotechnical features of the deposit. The determinant of the pit wall stability is the structural geology as differently oriented tensile fractures form potential sliding triangles in the pit walls. Potentially unstable walls and benches are detected by analyzing parameters of structural faults identified in the pit wall rock mass [7–9].

The stress–strain behavior of enclosing rock mass surrounding the pit in the current conditions is characterized by low stresses according to the data of borehole slotting and numerical modeling.

Stability estimation of NE Kurzhunkul pit wall is carried out with Rocscience Slide using the methods of limiting equilibrium by comparing the external (shearing) and internal (retaining) forces in line with the procedure developed by VNIMI [10].

For the stability calculation of the weak zone in NE pit wall, profile 6 was plotted by the data from certified boreholes (see Fig. 2). The slope of the pit wall is 27° in strong rocks and is 24° at the ultimate pit limit. The location and orientation of the profile are chosen from the criterion of the highest hazard (pit wall failure).

The initial strength characteristics of pit wall rock mass are added with the stability factor n = 1.3 [11]. The slope stability calculations for Kurzhunkul open pit mine included such determinants of stability as:

Table 1. Estimated strength characteristics of loose rocks in the northeastern pit wall of Kurzhunkul mine (EEG – element of engineering geology)

EEG no.	EEG	Density γ, kg/m³·10³	Cohesion *C*, MPa	Internal friction angle φ, deg	Estimated data	
					C, t/m²	φ
1	Loam edQIV	2.01	0.03	15	2.35	11.6
5	Clay P_{2cg}	1.67	0,08	11.5	6.27	8.9
6	Sandstone-banded clay P_{2ts}	1.56	0.13	21.0	10.2	16.4

Table 2. Estimated strength characteristics of strong rocks in the northeastern pit wall of Kurzhunkul mine (EEG – element of engineering geology)

EEG no.	Rock	Density g, kg/m³·10³	Core test data		Structural weakening coefficient λ	Estimated data		
			Cohesion C_o, MPa	Internal friction angle φ, deg		Cohesion C_m, MPa	Cohesion C_m, t/m²	Internal friction angle φ
9	Porphyry	2.61	11.33	31.67	0.0474	0.41	41.6/36	25.4
10	Metasomatic rocks	2.73	16.74	34.24	0.0352	0.45	46.23	27.6

Table 3. Strength characteristics of weak surfaces and contacts

no.	Weak surfaces	Core test data		Structural weakening coefficient λ	Estimated data		Density γ, kg/m³·10³
		Cohesion C_o, MPa	Cohesion C_o, MPa		C', t/m²	φ', deg	
1	Internal dump				0	34	2.07
2	Weak zone in NE pit wall	8.9	29	0.02	13.3	23	2.67

– physical and mechanical properties of rocks and weak surfaces (**Tables 1–3**);

– water content including groundwater;

– impact induced by mining operations (7 points as per survey results).

The source data for the strength calculation of weak NE pit wall rock mass (area of tectonic faults and weak contacts) (Table 3) were assumed to be the most probable values of strength of a crack filler from the core tests [12–15].

The stability calculations for the design pit boundary along profile 6 (weak zone in NE pit wall) included some variants, namely (**Table 4**):

– design pit boundary without a dump and without regard to impact from blasting;

– design pit boundary with a dump and without regard to impact from blasting;

– design pit boundary with a dump and with regard to impact from blasting (minimal seismicity coefficient μ = 0.25 as per Construction Regulations SP RK 2.03–30–2017) (**Fig. 3**).

Conclusions

The calculations show that additional load exerted on the weak zone of NE pit wall by the internal dump improves the pit wall stability. The weak zone of NE pit wall at its ultimate limit in the calculation variant without regard to impact from blasting has the minimal stability factor SF = (1.00÷1.10) and, thus, the pit wall is unstable (See Table 4). The broken bedding

Table 4. Stability calculations for weak NE pit wall in case of increasing depth of Kurzhunkul mine to (–290) m

Profile no.	Pit wall	Calculation variant	Boundaries of minimal triangle of failure, m	Pit wall height, m	Pit wall slope, deg	Min SF	Pit wall condition
6	Weak zone in NE pit wall	Design boundary with regard to ground water (no dump, blasting effect excluded)	(–110)÷(160)	370	30	1.008	nearly limiting
		Design boundary with regard to ground water (dump, blasting effect excluded)	(–200)÷(160)	360	28	1.10	stable
		Design boundary with regard to ground water (dump, blasting effect included)	(–200)÷(160)	360	28	0.892	unstable

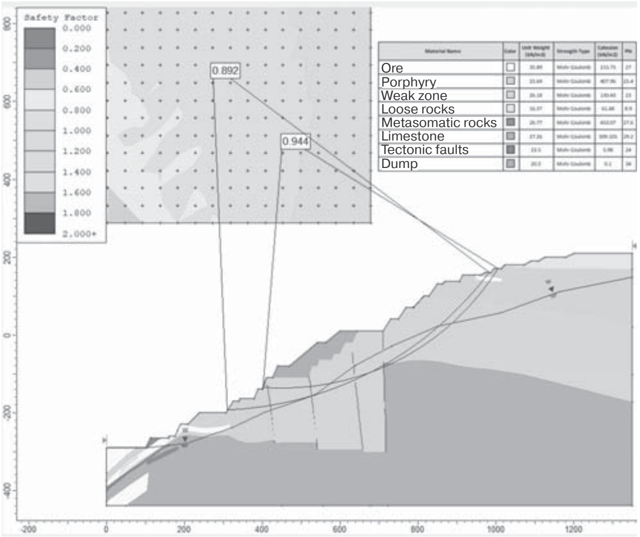

Fig. 3. Stability calculation results for weak zone in NE pit wall at design limits (with regard to influence of groundwater, blasting and internal dump)

conditions in combination with weak physical and mechanical properties of crack fillers will promote displacement of rock mass during mining of middle levels of NE pit wall. The anthropogenic effect and watering of rock mass will contribute to deformation of the pit wall areas adjacent to the zones of fractures and faults. This fact is proved by the stability calculations (See Table 4).

For the stability maintenance in the northeastern area of the pit, the operating sites on Levels (–110)–(+10) m at the ultimate pit limits are additionally loaded by an internal dump. The internal dump will act as a counterforce to prevent development of shearing along the faults in the northern and northeastern pit walls. The extension of the counterforce is governed by the girtwise length of the weak zone in the pit wall rock mass.

On the whole, the northeastern area of the pit requires monitoring of deformation, applying of low-impact technology of blasting at the ultimate pit limit, efficient drainage of the pit wall rock mass as disintegrated rocks within the weak zone will favor enhanced permeability of water, and special slope reinforcement measures. Within the boundaries of the faulted zones in NE pit wall, it is prohibited to undercut layers with continuous fractures and faults oriented towards the mined-out void.

The research results and recommendations made can ensure safety of mining at the ultimate pit limit with beneficial effect on mining performance. The slope stability of pit wall and benches provides reduction in the volume of striping at the sustained stability of the pit wall at the maximal allowable slope. The geomechanical research data and calculations make it possible to eliminate possible losses due to landsliding, violation of mining schedule, damage of transportation roads, loss of useful minerals and downtime of mining machines.

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