Impact of blasting on pit wall rock mass

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Abstract. The paper presents the research findings obtained by the Institute of Mining in drilling and blasting in Dzhetygara open pit mass. The research was aimed at enhanced stability of stationary benches and at cost minimization of drilling and blasting. The research met two objectives. First, in terms of Dzhetygara deposit, perimeter blasting designs were developed, which ensured reduced impact of blasting on adjacent rock mass. Second, the blast-induced PPV measurement procedure was refined and introduced, and the blasting technology was improved for blasting operations at ultimate pit limit. The special technology for ultimate pit perimeter blasting includes: analysis of blast effects on pit wall rock mass; finding of mechanisms of wave processes in rock mass; interaction of perimeter blasts depending on strength characteristics of rock mass; field trial of cutback methods; determination of sequence of blasts when approaching a guarded sites; determination of efficiency criteria of drilling and blasting.

1. Introduction
Dzhetygara deposit under investigation is located in the Kostanay Region in Kazakhstan. The area features extreme continental climate with yearly average temperature of +18°C, with minimal temperature in January (to minus 40°C) and maximal temperature in July (plus 40°C). Average annual rainfall is 217.7 mm, snow cover depth can reach 260 mm and the depth of soil freezing is to 2 m.

The Dzhetygara ore province lies on the east shoulder of the South Urals and adjoins the Dzhetygara ultrabasic massif in the south. The ultramafic massif (protrusion) is elongated from the north southward and has a width of 3 km. The massif has a profile of a depthward expanding lens steeply dipping eastward in the heavily dislocated Paleozoic strata at an angle of 40–70°. The protrusion occurs in the Proterozoic formation composed of sericitic, sericitic–chloritic, siliceous and siliceous–carbonaceous shale and limestone.

The geological paperwork on Dzhetygara deposit is completely out of any information on physical and mechanical properties of rocks. It is only mentioned that this rock mass has similar properties as the Bazhenov massif. Deformation processes governed by structural features of rock mass are greatly various; for this reason, according to [1–7], we identify physical and mechanical properties of the deposit under analysis (see Table 1).

Dzhetygara deposit is developed using the truck-and-shovel system of mining with external dumping. The height of benches is 15 m, the widths of working areas in operation zones of rail transport and trucks are 45 and 35 m, respectively, the haulage and safety berms have widths of 25 and 12 m, respectively, the height of external dump layers is 30 m and their slope angle is 60–70°. Mining involves borehole blasting.
Table 1. Physical and mechanical properties of enclosing rock mass of Dzhetygara open pit mine

| Rock   | Density, t/m² | Compression strength (sample), MPa | Tension strength (sample), MPa | Shear strength (sample), MPa | Assumed structural weakening factor | Compression strength (rock mass), MPa | Tension strength (rock mass), MPa |
|--------|---------------|------------------------------------|--------------------------------|-----------------------------|-----------------------------------|---------------------------------------|-----------------------------------|
| Peridotite | 2.6 | 40.0 | 3.1 | 5.3 | 0.10 | 4.00 | 0.31 |
| Porphyrite | 2.8 | 210.0 | 9.2 | 28.0 | 0.15 | 21.00 | 0.92 |
| Porphyrite | 2.8 | 300.0 | 17.7 | 30.7 | 0.10 | 34.50 | 1.16 |
| Porphyrite | 3.3 | 250.0 | 19.2 | 33.3 | 0.15 | 37.50 | 2.88 |
| Porphyrite | 2.6 | 40.0 | 4.0 | 5.7 | 0.10 | 4.00 | 0.40 |
| Serpentinite | 2.6 | 140.0 | 14.0 | 20.0 | 0.10 | 14.00 | 1.40 |
| Shale | 2.5 | 90.0 | 11.3 | 18.0 | 0.06 | 5.40 | 0.68 |
| Shale | 2.6 | 110.0 | 13.8 | 22.0 | 0.08 | 8.80 | 1.10 |
| Shale | 2.6 | 120.0 | 15.0 | 24.0 | 0.10 | 12.00 | 1.50 |
| Shale | 2.0 | 50.0 | 4.5 | 10.0 | 0.10 | 5.00 | 0.45 |
| Shale | 2.0 | 80.0 | 7.3 | 16.0 | 0.10 | 8.00 | 0.73 |
| Porphyry | 2.3 | 100.0 | 9.1 | 20.0 | 0.10 | 10.00 | 0.91 |
| Porphyry | 2.8 | 140.0 | 12.7 | 28.0 | 0.10 | 14.00 | 1.27 |
| Porphyry | 3.0 | 200.0 | 18.2 | 40.0 | 0.10 | 20.00 | 1.82 |
| Porphyry | 2.0 | 130.0 | 11.8 | 26.0 | 0.10 | 13.00 | 1.18 |
| Porphyry | 2.0 | 150.0 | 13.6 | 30.0 | 0.10 | 15.00 | 1.36 |
| Rodingite | 2.5 | 180.0 | 16.4 | 36.0 | 0.10 | 18.00 | 1.64 |
| Rodingite | 3.0 | 200.0 | 18.2 | 40.0 | 0.10 | 20.00 | 1.82 |
| Rodingite | 3.0 | 260.0 | 23.6 | 52.0 | 0.10 | 26.00 | 2.36 |
| Rodingite | 3.4 | 180.0 | 12.0 | 30.0 | 0.20 | 36.00 | 2.40 |
| Rodingite | 3.5 | 180.0 | 12.0 | 30.0 | 0.20 | 36.00 | 2.40 |
| Rodingite | 3.6 | 190.0 | 12.7 | 31.7 | 0.20 | 38.00 | 2.53 |
| Rodingite | 3.7 | 190.0 | 12.7 | 31.7 | 0.20 | 38.00 | 2.53 |
| Rodingite | 3.8 | 200.0 | 13.3 | 33.3 | 0.20 | 40.00 | 2.67 |

Mining and blasting operations are carried out in cycles. Boreholes are drilled by roller-bit drill rig DML-LP 1200/110 with bit diameter of 215 mm. Oversizes are broken using breaker-boy Rammer and secondary blasting. Excavation involves mine excavators EKG-81, EKG-10 and EKG-6.3US. Haulage is carried out by a combination of dump trucks BelAZ models 75145 and 75131 and rail transport, traction assembly PE-2M and dump cars 2V-105. Tracks are laid using railway jibs, and electrical lines are using support carriers mounted on tractor K-701.

Specificity of the deposit is defined by its genesis, geology and geomechanics. The deposit adjoins the deep-earth north–south fault 3 km wide. Extension of the deposit in this fault is 18 km, commercial mineral reserves are proved to a depth of 500–800 m. As consistent with the deposit occurrence in the deep-earth fault, initial and secondary stress–strain behavior of rocks is governed by the modern geodynamics. The geomechanical research of Dzhetygara deposit by experts from the Geomechanics Department of the Institute of Mining, UB RAS [8] shows that the natural stress–strain behavior is moderate and nonuniform in the influence zone of the open pit mine as well as in the enclosing rock mass. The mosaic structure of natural stresses and strains conditions nonuniformity of the secondary stress–strain behavior and strains, with concentration zones of horizontal stresses and strains in pit wall rock mass, depression zones, as well as zones of predominant uplift and subsidence. Pit wall rock mass contain zones of heavy jointing which is mostly consistent with faulting. Pit wall
stability is mostly affected by cyclic short-term vibrations due to blasting, among other things. Perimeter blasting control becomes extremely important in this case, otherwise, negligence of wave processes can result in catastrophic consequences.

In 2016–2017 the Institute of Mining, UB RAS accomplished the research project aimed at drilling-and-blasting improvement at the ultimate limit of Dzhetygara open pit. The studies focused on stability enhancement of stationary benches and on cost minimization of drilling and blasting. First, it was necessary to design blasting patterns for perimeter rock blocks such that to reduce dynamic loading induced by explosions on pit wall rock mass. Second, it was intended to refine and introduce the PPV measurement procedure for seismic vibrations from blasts, as well as to improve the drilling-and-blasting technology on benches at ultimate limit. The authors wish to acknowledge participation of specialists from the Institute of Mining V.G. Shemenev, S.N. Zharikov, V.A. Kutuev, A.S. Regotunov, P.V. Menshikov, A.S. Flyagin, SS. Taranzhin, as well as experts from Kostanay Minerals M.A. Zhakeev, M.S. Sonchik, V.G. Domnyshev, A.S. Milyaev, A.A. Krivchenko and others in the research project. The fruitful teamwork of the fellows from the Institute and from Kostanay Minerals allowed reaching the two objectives specified above. The main research findings are described below.

2. Theory, materials and methods of research
First, we theoretically determined seismic stability of pit wall rock mass using the procedure from [9, 10]. Second, we carried out instrumental measurement of seismic effect generated by blasts using two stress recording and analysis facilities URAN (Avtomatika, Yekaterinburg, Russia) equipped with standard three-component seismic pickups GS-20 (working frequency range 2–250 Hz) to be installed in soil on opposite sides of a blasting block and oriented along three directions relative to explosion. All in all, we implemented 22 measurements. According to the obtained data, the minimal allowable velocities of seismic vibrations were never exceeded in the measurements, with a single exclusion in terms of serpentinite. Considering complex structure of Dzhetygara deposit and possible close-spaced location of serpentinite and peridotite layers, it is critical to select proper priming patterns to minimize adverse impact of blasting on pit wall rock mass.

Third, from the measurements, we found the P-wave velocities (Figure 1) and updated the structural weakening factors and propagation zones of deformation processes (Figure 2) in accordance with [11, 12].

Low P-wave velocities of 1000–3000 m/s (Figure 1) mean that rocks are faulted. High P-wave velocities are connected with higher number of blocks and with lower jointing. Furthermore, high velocities can be reflective of some accumulation of wave processes, which currently lacks mathematic description to be included in engineering designs.

![Figure 1. P-wave velocities determined in rock mass from seismic measurements taken during 11 large-scale blasts (2 measurements per blast).](image-url)
Figure 2. Calculated radii of impact zones of explosions from experimental data.

The bar chart in Figure 2 shows actual impact and range radii of wave processes induced by large-scale blasting deep down rock mass enclosing Dzhetygara open pit. The effects of blasting are different. However, it can be concluded that safe distances eliminating formation of residual strains range from 30 to 100 m. The significant value of possible fracturing radius of 19 m points at high risk of fracture growth in the rear of pit wall structure. Thus, it is required to arrange high-quality shielding of perimeter rock mass.

Water content of rock mass contributes to farther propagation of explosion waves and has an adverse effect on slope stability. The main source of water inflow in the open pit mine is the local faults. In such conditions, large-scale blasts impair stability of the pit wall rock mass, which agrees with the calculation. It is advisable that blasts nearby mined-out sites are carried out in maximally drained rocks as this can reduce the propagation rate of seismic waves.

Thus, in the conditions of Dzhetygara open pit, an emphasis should be laid on rock mass drainage during perimeter blasting. Furthermore, approach of drilling-and-blasting operations to the ultimate pit limit should follow special patterns aimed to reduce the effect of blasting on pit wall stability, including shielding, by means of blasting in closed-spaced boreholes in perimeter rows to create cutoff slots.

In the fourth stage of the research into seismic effect of large-scale blasts, we determined and substantiated perimeter blasting patterns for the conditions of Dzhetygara open pit, to abate the dynamic load of explosion on adjacent rock mass, as well as the perimeter blast designs depending on strength characteristics of rocks. As a result, the production procedures were developed for drilling and blasting at the ultimate limit of Dzhetygara open pit in accordance with [13, 14], which was a logical ending of this stage and the research project in whole.

3. Conclusions
The implemented research has proved the earlier findings [15] that ranges on block sliding along fractures in different rocks are different, and make from 30 to 100 m in Dzhetygara open pit, which necessitates monitoring of seismic waves in rocks mass toward appropriate drilling and blasting pattern design for perimeter blasting at ultimate limits of the open pit.

As a result of the research project implementation, the special drilling and blasting technology has been introduced at the ultimate limit of Dzhetygara open pit, which ensures minimized impact of blasting on pit wall slope stability, enhanced safety of blasting under high benches and reduced cost of marketable product. The major competitive advantage of the technology is its safety and efficiency in higher rate and intensity mining owing to regulated blasting performance at ultimate limits of open pits.
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