Improving the production technology of drilling and blasting operations by blasting of high ledges

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Abstract. In modern economic conditions, the issue of improving the efficiency of mining enterprises is very relevant. One of the key processes is drilling and blasting operations (DBO), which determine the efficiency of the entire complex of mining operations. One of the main methods of controlling the explosion energy is the diameter of the blast wells. According to the recommendations of prof. B N Kutuzov the diameter of blast wells is correlated with the fracturing and strength of the exploding rocks. With increasing blockage and rock strength to achieve the required quality of explosive crushing preference is given to drilling equipment with a small diameter of wells. By blasting of high ledges, especially large-block rocks with a strength coefficient of more than 15 on the M M Protodyakonov scale; the use of high-performance drilling equipment for drilling small-diameter blast wells is difficult. This is due to the fact that the calculated value of the resistance line along sole (RLAS) does not pass the safety condition for drilling the first row of wells. In this regard, the paper proposes and justifies the use of extensions of the lower parts of wells using mechanical expanders.

1. Introduction
In quarries of construction, materials for drilling explosive wells with a diameter of up to 200 mm in rocks of medium and strong strength are used machines with submerged pneumatic hammers. There are mainly machines of domestic and foreign production [1, 2]:
- URB-2A with a diameter of 120–190mm blast wells;
- Sandvik (D25KS, D245S) with a diameter of blast holes 127–203 mm;
- TAMROCK (PANTERA 800, PANTERA 900, PANTERA 1100, PANTERA 1500) with the diameter of blast wells 115–152 mm;
- Atlas Copco (ROC 460 PC, ROC F7, ROC F9, ROC L6, ROC L7) with blast hole diameters of 105–165 mm;
- FURUKAWA (HCR 1000-1200-1500, PCR200) with the diameter of blast wells 65–150 mm.

This drilling equipment is used in quarries with a ledge height of 10 meters or less. By increasing the height of the ledge to 12–15 m or more, drilling the first row of wells in large-block rocks of medium and above average strength with a small diameter does not provide a condition for safe drilling, since the calculated values of the resistance line along the sole do not pass the condition for safe drilling of the first row of wells.

In this situation are the following methods and technologies for drilling and blasting operations recommended [2–4]:
- use of larger diameter wells (if this type of drilling equipment is available);
- the use of boiler charges (difficulty in creating boiler cavities, uneven crushing) or mechanical extensions along the length of the well (increased consumption of drilling the first row of wells);
- use of inclined wells drilled parallel to the slope of the ledge (presence (absence) of this type of drilling equipment at the enterprise; difficulty in ensuring the safety of inclined wells with large volumes of drilling and blasting operations; difficulty of loading and installation of the explosive network, especially in the absence of mechanization; high wear of drilling equipment);
- increase of the charge energy of explosives (type of explosives, specific consumption of explosives);
- use of paired-converged wells (increased drilling expenditure of the first row of wells).

Currently a lot of mechanical expanders are designed for blast wells, which can be installed on existing drilling equipment as well as on auxiliary equipment and allow drilling small-diameter blast wells up to 250 mm or more.

The analysis of the considered methods of explosive crushing intensification in the conditions of Krutorozhinsky field of gabbro-diabase son PAO ‘Orsk quarry management’ has shown the applicability of mechanical expansion of explosive wells to ensure the safe drilling of the first row of wells [5, 6]. Therefore, the problem emerges of substantiating the parameters of expanded well cavities.

2. Methods of research
To determine the rational parameters of the location of blast wells, we suggest using the principle of self-similarity, based on taking into account the critical displacement rates of the array in the zone of action of adjacent borehole charges [5–11]. The proposed principle of self-similarity is well established in calculating the parameters of the location of borehole charges in underground conditions [7].

3. Main part
The study of rational parameters of drilling and blasting operations was carried out in conditions of Krutorozhinsky field of gabbro-diabases on PAO ‘Orsk quarry management’. The parameters of the quarry and development system are shown in Table 1.

| Parameters                        | Value          |
|-----------------------------------|----------------|
| Design depth of the quarry, m     | 80–200         |
| Length of the quarry on top, m    | 1870           |
| Width of the quarry on top, m     | 800            |
| Design height of the ledge, m     | 15             |
| The angle of slope of the working ledge, the degree | 75            |
| The minimum width of a working platform, m | 34–60    |

At the Krutorozhinsky quarry, the following types of explosives are used in waterlogged, partially waterlogged and dry wells (Table 2).

Table 2. Characteristics of the used explosives.

| Characteristics for types explosives | Heat of explosion, kJ/kg | Volume of gaseous explosion products, l/kg | Bulk density, g/cm³ | Detonation speed, m/s |
|-------------------------------------|--------------------------|-------------------------------------------|---------------------|-----------------------|
| Grammonit 79/21                    | 4291                     | 895                                       | 0,85–0,90           | 3200–3600             |
| Grammonit 30/70                    | 3977                     | 800                                       | 0,85–0,90           | 3800–4500             |
| AS-25P                             | 3200                     | 910                                       | 1,00                | 4600–4800             |
| Arsenit ГБ-1                       | 4100–4200                | 820–850                                   | 0,75–0,85           | 4500–5100             |
| Arsenit ГБ-2                       | 4270–4750                | 850–860                                   | 0,75–0,85           | 4800–5500             |
| Arsenit ГБ-4                       | 4300–4500                | 790–820                                   | 0,75–0,80           | 5000–5200             |
| Fortis                             | 3260                     | 968                                       | 1,00                | 5100                  |
| MS-U-1                             | 5700–5800                | 710–895                                   | 0,65–0,75           | 6700                  |

For these types of explosives were the rational values of the resistance line along the sole at the height of the ledge of 15 m and the diameters of wells of 150 and 190 mm for rocks of different strength and fracturing determined (Table 3).
$$\sigma_{\text{cr}(p)} = \rho_0 C_p V_{\text{cr}(p)}$$

(1)

where $\sigma_{\text{cr}(p)}$ – acting compressive (tensile) stresses, Pa;

$\rho_0$ – specific mass of rock, kg /m$^3$;

$C_p$ – speed of spread of a longitudinal elastic wave in mountain (sample), m/s;

$V_{\text{cr}(p)}$ – the displacement rate of the mountain under the action of compressive (tensile) voltages, m/s.

Hence the critical displacement rate of the mountain is defined as: [5–7]:

$$V_{\text{cr}(p)}^{\text{kp}} = \frac{\sigma_{\text{cr}(p)}}{\rho_0 C_p} K_s$$

(2)

where $K_s$ – coefficient of dynamism.

The mountain will be destroyed if the resulting array offset rates exceed or equal the critical values:

$$V_{\text{cr}(p)} \geq V_{\text{cr}(p)}^{\text{kp}}$$

(3)

where $V_{\text{cr}(p)}$ – the displacement rate of the mountain under the action of compressive (tensile)

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The fortress of rocks on the horizon – MS-U-1 (K$\nu\nu$=0.83)

| Diameter of well, mm | Fracture category | f=8 | f=10 | f=12 | f=14 | f=16 |
|----------------------|------------------|-----|-----|-----|-----|-----|
| 150                  | II, III, IV      | 6.1 | 4.8 | 4.1 | 4.9 | 4.3 | 4.8 | 4.1 | 3.5 |
| 190                  |                  | 6.7 | 5.4 | 4.5 | 5.5 | 4.7 | 5.3 | 4.6 | 3.9 |

explosives – Arsenit GB-2(K$\nu\nu$=0.98)

| Diameter of well, mm | Fracture category | f=8 | f=10 | f=12 | f=14 | f=16 |
|----------------------|------------------|-----|-----|-----|-----|-----|
| 150                  |                  | 6.7 | 5.3 | 4.5 | 5.4 | 4.7 | 5.3 | 4.5 | 3.8 |
| 190                  |                  | 8.2 | 6.6 | 5.5 | 6.7 | 5.8 | 6.5 | 5.6 | 4.7 |

explosives – Arsenit GB-4 (K$\nu\nu$=1)

| Diameter of well, mm | Fracture category | f=8 | f=10 | f=12 | f=14 | f=16 |
|----------------------|------------------|-----|-----|-----|-----|-----|
| 150                  |                  | 6.6 | 5.3 | 4.4 | 5.4 | 4.6 | 5.2 | 4.5 | 3.8 |
| 190                  |                  | 8.2 | 6.5 | 5.5 | 6.6 | 5.7 | 6.4 | 5.6 | 4.7 |

explosives – Gramonit 79/21 (K$\nu\nu$=1)

| Diameter of well, mm | Fracture category | f=8 | f=10 | f=12 | f=14 | f=16 |
|----------------------|------------------|-----|-----|-----|-----|-----|
| 150                  |                  | 6.3 | 5.0 | 4.2 | 5.1 | 4.4 | 4.9 | 4.3 | 3.6 |
| 190                  |                  | 7.7 | 6.2 | 5.2 | 6.3 | 5.4 | 6.1 | 5.3 | 4.4 |

explosives – Arsenit GB-1 (K$\nu\nu$=1.05)

| Diameter of well, mm | Fracture category | f=8 | f=10 | f=12 | f=14 | f=16 |
|----------------------|------------------|-----|-----|-----|-----|-----|
| 150                  |                  | 6.5 | 5.2 | 4.3 | 5.2 | 4.5 | 5.1 | 4.4 | 3.7 |
| 190                  |                  | 8.0 | 6.3 | 5.3 | 6.5 | 5.6 | 6.3 | 5.4 | 4.6 |

explosives – Gramonit 30/70 (K$\nu\nu$=1.09)

| Diameter of well, mm | Fracture category | f=8 | f=10 | f=12 | f=14 | f=16 |
|----------------------|------------------|-----|-----|-----|-----|-----|
| 150                  |                  | 6.0 | 4.8 | 4.0 | 4.9 | 4.2 | 4.7 | 4.1 | 3.4 |
| 190                  |                  | 7.4 | 5.9 | 5.0 | 6.0 | 5.2 | 5.8 | 5.1 | 4.3 |

explosives – Fortis (K$\nu\nu$=1.21)

| Diameter of well, mm | Fracture category | f=8 | f=10 | f=12 | f=14 | f=16 |
|----------------------|------------------|-----|-----|-----|-----|-----|
| 150                  |                  | 6.3 | 5.0 | 4.2 | 5.1 | 4.4 | 5.0 | 4.3 | 3.6 |
| 190                  |                  | 7.8 | 6.2 | 5.2 | 6.3 | 5.5 | 6.1 | 5.3 | 4.5 |

explosives – emulsion composition AS-25P (K$\nu\nu$=1.25)

| Diameter of well, mm | Fracture category | f=8 | f=10 | f=12 | f=14 | f=16 |
|----------------------|------------------|-----|-----|-----|-----|-----|
| 150                  |                  | 7.0 | 5.6 | 4.7 | 5.7 | 4.9 | 5.5 | 4.8 | 4.0 |
| 190                  |                  | 8.6 | 6.9 | 5.8 | 7.0 | 6.1 | 6.8 | 5.9 | 5.0 |

The minimum allowable value of the resistance line along the sole under the conditions of safe placement of drilling equipment for drilling the first row of wells is 6.0 m.

According to calculations the mechanical expansion of blast wells should be used only in large-block rocks with a strength coefficient of more than 10 on the M M Protodiakonov scale.

To determine the rational parameters of mechanical expansions of blast wells, we propose the use of the principle of self-similarity [5–7, 12], which is based on the account of the critical displacement rates of the array in the zone of action of adjacent borehole charges [13, 14].

The voltages generated by the explosion of a borehole charge are determined by [5–7, 12]:

$$V_{\text{cr}(p)}^{\text{kp}} = \frac{\sigma_{\text{cr}(p)}}{\rho_0 C_p} K_s$$

(2)

where $V_{\text{cr}(p)}^{\text{kp}}$ – the displacement rate of the mountain under the action of compressive (tensile) voltages, m/s;
dynamic voltages, m/s;

\[ V_{\text{кр(р)}} \] – minimum (critical) values of the displacement rate of the mountain, when destruction occurs, due to compressive (tensile) voltages, m/s.

The resulting explosion displacement rates of the array at this point are determined by [5–7]:

\[ V_{\text{сж(р)}} = k_{\nu} \bar{r}^{-\nu} \] (4)

where \( k_{\nu} \) – seismic proportionality coefficient depending on elastic parameters of the destroyed rocks [9, 10].

\[ k_{\nu} = \sqrt{\frac{C_p}{\rho_0 \left( 1 + \mu \right)} } = \sqrt{\frac{C_p}{\rho_0 \left( 1 - \frac{4C_p^2}{3C_s^2} \right)} } \] (5)

where \( \mu \) – coefficient Poisson’s;

\( \nu = 2.25 \) – indicator of degree;

\( \bar{r} \) – equivalent reduced distance, m/kg\(^{1/3}\).

Equivalent reduced distance is determined by [6, 12]:

\[ \bar{r} = \frac{r_n}{\sqrt{Q_{\text{equiv}}}} \] (6)

where \( r_n \) – distance from the test point to the center of gravity of the equivalent charge, m;

\( Q_{\text{equiv}} \) – the equivalent charge weight, kg.

According to rock properties of Krutorozhinsky field the critical displacement rates of the mountain (m/s) are shown in Figure 1, at which the destruction of the mountain occurs.

![Figure 1](image)

**Figure 1.** The value of the critical displacement rates of the array from the rock fortress:
1 – critical speed under the action of compressive voltages;
2 – critical speed under the action of tensile voltages.

Mechanical expanders with a diameter of 250 mm were used to calculate the parameters of borehole charge extensions.

Depending on the strength of the rocks and the corresponding critical displacement rate of the array, the optimal value of the reduced resistance line along the sole (m/kg\(^3\)) is determined Figure 2.
The obtained dependencies are approximated by a polynomial equation of the form:

$$\bar{W} = \alpha f^2 - \beta f + \gamma$$  \hspace{1cm} (7)

where $\bar{W}$ – rational reduced value of the resistance line along the sole, m/kg³;

$f$ – the strength coefficient;

$\alpha$, $\beta$, $\gamma$ – empirical coefficients, the value of which is shown in Table 4.

| Type of explosives   | $\alpha$ | $\beta$ | $\gamma$ |
|----------------------|---------|---------|---------|
| Grammonit 79/21      | 0.008   | 0.26    | 3.60    |
| MS-U-1               | 0.005   | 0.17    | 2.96    |
| Arsenit G-1          | 0.003   | 0.11    | 2.30    |
| Emulsion composition AS-25P | 0.002 | 0.09    | 2.08    |

The length of mechanical expansion of borehole charges ($l_p$, m) is shown in Figure 3.

The length of mechanical expansion of borehole charges ($l_p$, m) is shown in Figure 3.

The paper defines the parameters of drilling and blasting operations using mechanical extensions of the lower parts of wells, with a ledge height of 15 m and a well diameter of 150 mm for large-block rocks of medium and high strength.

4. Conclusion

The application of a method for determining the parameters of mechanical extensions of borehole charges based on the principle of self-similarity, based on the comparison of critical displacement
rates of the array allows:

1. Increase the yield of blasted rock mass from one linear meter of wells, especially in medium and hard-to-explode rocks by 15–26%, by increasing the grid of wells, in comparison with inclined wells and wells with a diameter of 250 mm, both when exploding to a free surface, and when interacting with adjacent charges, exploding with deceleration;

2. Reduce the specific consumption of explosives by 8–23% in large-block hard rocks compared to wells with a diameter of 250 mm.

References

[1] Momeni A, Karakus M, Khanlari G R and Heidari M 2015 Effects of cyclic loading on the mechanical properties of a granite International Journal of Rock Mechanics and Mining Sciences vol 77 July pp 89–96

[2] Ugolnikov N V 2018 Management of explosion energy (Magnitogorsk: FGBOU VO ‘MGTU named of G. I. Nosov’)

[3] Belin V A, Gorbosos M G, Mangush S K and Ekvist B V 2015 New technologies for conducting explosive works GIAB Separate issue 1. Proceedings of the international scientific Symposium ‘Miner's Week-2015’ pp 87–101

[4] Gorodnichenko V I 2012 Expansion of wells for blasting of ore in underground mining operations GIAB no 7 pp 28–31

[5] Ugolnikov N V and Domozhairov D V 2019 Ensuring the safety of drilling and blasting operations by blasting paired-converged wells of high ledges in quarries News of Tula state University. Earth science no 3 pp 332–43

[6] Ugolnikov N V and Domozhairov D V 2019 Substantiation of rational parameters of a pair-of closely spaced wells in the quarries of non-metallic building materials Combined geotechnologies: Transition to a new technological structure: Collection of articles on the results of the international conference (Magnitogorsk: Magnitogorsk state technical University. G. I. Nosov University) pp 361–9

[7] Egemberdiev R I, Ugolnikov N V, Yusupov Kh A and Stolpovskikh I N 2019 Substantiation of parameters of extensions of borehole charges by breaking with fans Mining information and analytical Bulletin no 11 pp 48–58

[8] Pergament V, Melnikov Iv, Suraev V, Melnikov I, Vassiliev K, Kotik M and Shevtsov N 2014 Ensuring seismic safety of the explosive works and evaluation of the consequences related to technogenic and natural seismic events Minnodeloi Geologia (Bulgaria: 1000 Sofia) no 1–2 pp 57–63

[9] Pergament V Ch 1971 Accounting the spatial dispersion of the EXPLOSIVE charge in explosive problems Engineering methods for controlling the action of an explosion. collection of proceedings (Magnitogorsk: MGMI) issue 89 pp 3–14

[10] Pergament V Ch 1971 Critical speeds and parameters of drilling and blasting operations Engineering methods for controlling the action of an explosion. collection of proceedings (Magnitogorsk: MGMI) issue 89 pp 40–8

[11] Pergament V, Malarov I, Firstov P and Gitterman Y 1998 Experimental evaluation of near-source seismic effects of quarry blasts XXVI General Assembly of the European Seismological Commission (ESC) (TEL AVIV) p 29

[12] Belin V A, Kholidolov A N and Gospodarikov A P 2017 Methodical bases of forecasting of seismic action of mass explosions Mining journal no 2 pp 66–8

[13] Cunningham C V B 2011 Control over Blasting Parameters and Its Effect on Quarry Productivity (Rondebosch: AECI Explosives and Chemical Limited)

[14] Alenichev I A 2018 The reaction of the rock mass in the quarry space to dynamic effects in the production of blasting Mining information and analytical bulletin no 7 pp 189–95