Design the Blast in Low Benches and some Practical Applications in Vietnam

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ABSTRACT
The blasts in low benches appear more often at the mining and especially at the construction sites in Vietnam such as: blasting for road construction, trench blasting, ground levelling; blasting for digging foundation of the hydraulic power plant,... The paper presents the influence of bench height/charge length on the value of burden based on the experimental study of many series of full scale single hole test blasts. The results show that with the ratio of bench height to charge diameter H/d < 60 or the ratio of charge length to charge diameter l/d < 40, the blasts are classified into low bench blasting and the values of burden in these cases should be decreased to get better blasting results.

KEY WORDS: Blasting of rock/Burden/Low bench blasting/Charge length/Bench height

1. INTRODUCTION
Drilling and blasting is the most basic method of rock breaking used in mining operations and civil engineering in Vietnam for the purposes such as: breaking of rock for mining; blasting for road construction; ground levelling; trench blasting; digging foundation in hard rocks,... In many cases, the blasting work in Vietnam, especially blasting in civil engineering, blasting engineers usually deal with the blasting works which carry out in low benches. When applying parameters for normal bench blasting into these cases, they soon realized that this calculation method did not bring satisfactorily blasting results in these conditions. For the case of low benches, it is better if smaller borehole diameters were used in order to rationally distribute explosive energy in the blasted rock mass. However, in most cases, there are not enough borehole diameter for each changing of bench height at the in-situ conditions. Therefore, in this case, the value of bench height usually close to the value of the burden, and the charge length must be reduced to maintain a distance of collar big enough for stemming. If the value of burden was kept as in the normal bench blasting, the explosive energy has the trend to break the rock at the collar zone due to bigger fixation of the rock at the floor (Fig. 1).

Besides, the tendency to use bigger borehole diameters also leads to the decrease of charge length if the bench height remains unchanged or decreases. To solve this problem, the blasting engineers must adjust the value of burden when blasting in low bench blasting conditions.

Fig. 1 Illustration of the decrease of charge length with the same charge diameter when reducing the bench height.

With the purpose to improve the blasting results when blasting in low benches, this paper presents the application of new calculation method for low bench blasting and its practical application in Vietnam.

2. BASIC THEORY AND RESEARCH METHOD
The influence of the bench height on the calculation of blasting parameters has been mentioned by many researchers such as Langefors & Kihlström [1], Ash [2], Konya & Walter [3], Olofsson [4]... Some research results by other researchers such as Sukhanov & Kutuzov [5], Harries [6], Belin & D.T. Thang [7] have shown that the radius of fracture zone by the cylindrical elongated charge increase respectively with the elongation of the charge to a critical value, and after this critical value the radius of fracture zone remains unchanged.

Figure 2 shows the relation between radius of fracture zone with the ratio of bench height to charge diameter H/d and charge diameter d (the ratio l/d is named relative charge length) [5].
Radius of fracture zone vs. $l/d$ [5].

Besides, bench height is also a parameter influencing on the blastability of the rock mass at the burden. The researchs by Ash [2], Konya & Walter [3], Hagan [8] have shown that the bench stiffness increases when decreasing the bench height, especially in low bench blasting. For normal bench blasting, the rock is easier to break by flexural rupture, in contrariwise, with low bench height, it is difficult for the explosive energy to break the rock at the burden due to the increase of bench stiffness, therefore, the rock at the burden can not be broken by the bending. Figure 3 shows the breakage of the rock at the burden by flexural rupture of a single hole blast.

Fig. 3 Breakage of burden rock by flexural rupture [8].

Based on the requirements in practice, the calculation method of blasting parameters for low bench blasting was developed by serries of full scale single hole test blast (Figure 4). The experimental works are described as follow: For a constant charge diameter, a series of single hole test blasts are fired with different values of burden to determine the optimal burden, the burden at which the breakage volume was maximum. Many variables influence on blasting results such as: burden, bench height, charge length, charge diameter, explosive strength, explosive density, detonation velocity, rock and rock mass properties and so on. Therefore, it is necessary to reduce the number of variables to determine experimentally the relation between charge length and burden. The variables can be classified into two groups: the controlled variables and the independent variables. For one experimental blast series of single test blasts, the controlled variables are bench height, charge length, charge diameter, explosive factors and rock factors. The independent variables in one experimental blast series was burden. The values of burden are changed in one experimental blast series in order to determine the maximal burden corresponding with maximal broken volume which was defined indirectly through the breakage angle. For studying the relation between charge length and burden, several experimental blast series were carried out and in the next experimental blast series, the parameters: bench height and charge length were increased. Similar experimental procedures were carried out to determine the optimal burden corresponding with the change in bench height and charge length. By that way, the relation between charge length and optimal burden were studied through several experimental blast series of single hole test blasts.

From the experimental results, the calculation method of blasting parameters for low bench blasting was established. More information can be referenced in our papers [9-13]. The calculation method of blasting parameters for low bench blasting introduces in section 3.

Fig. 4 The illustration of a single hole blast on the bench

3. CALCULATION OF BLASTING PARAMETERS FOR LOW BENCH BLASTING

3.1 The classification of low bench blasting

The classification of low bench blasting is based on two parameters: the bench height $H$ and the charge diameter $d$. A low bench blast may change into a normal bench blast when keeping the bench height unchanged and reducing the charge diameter. Contrariwise, a normal bench blast may change into low bench blast when keeping the bench height unchanged and increasing the charge diameter. Our research results [9] shown that, a blast is classified into low bench blasting when the ratio of bench height to charge diameter $H/d$ is smaller than 60. In the range of $H/d < 60$, the bench stiffness increases when reducing the ratio $H/d$ and the blasting parameters need to be adjusted to bring better blasting result in this condition.

3.2 Determining the value of burden

Burden is an important blasting parameter determined in each blast design. In low bench blasting, one of factors is taken into account is the influence of low bench height on the value of burden. The value of burden calculated for low bench blasting is determined by the following equation [9]:
\[ B = B_m \left[ 1 - K_s K_r \left( \frac{H}{J} \right)^2 \right] ; \text{m} \]  

where \( B_m \) is the maximum burden, the burden at which its values remains unchanged even with further increase of bench height/charge length. The values of \( B_m \) when blasting in limestone shown in Table 1. \( K_s \) is the factor referring to the influence of rock mass, \( K_r \) is the factor referring to the influence of explosive energy. \( K_s \) can be determined by the method suggested by Azarkovich & Shuifer [14]:

\[ K_s = \frac{\rho_s E_s D_e}{\rho_e E_e D_s}; \]  

\( \rho_s \) and \( \rho_e \) are the densities of the comparison and standard explosive, \( E_s \) and \( E_e \) are the unit potential energy of comparison and standard explosive; \( D_e \) and \( D_s \) are the detonation velocity of comparison and standard explosives, respectively. With the popular use of explosive ANFO in the surface mining today, so ANFO with the density of 845 kg/m\(^3\) is chosen as the standard explosive in this calculation and the energy characteristics of some industrial explosive using in Vietnam are presented in Table 2.

Table 1: Values of maximum burden \( B_m \), factor \( K_s \), \( K_r \) for the experimental blast in limestone.

<table>
<thead>
<tr>
<th>Charge diameter</th>
<th>Explosive</th>
<th>( B_m ) m</th>
<th>( K_s )</th>
<th>( K_r )</th>
</tr>
</thead>
<tbody>
<tr>
<td>32 mm</td>
<td>AD-1</td>
<td>1.40</td>
<td>1.47</td>
<td>191.57</td>
</tr>
<tr>
<td>76 mm</td>
<td>ANFO</td>
<td>2.53</td>
<td>1.00</td>
<td>172.85</td>
</tr>
</tbody>
</table>

Table 2: The value of factor \( K_s \) for some industrial explosives using in Vietnam.

<table>
<thead>
<tr>
<th>Explosive</th>
<th>( E_e ) MJ/kg</th>
<th>( \rho_e ) kg/m(^3)</th>
<th>( D_e ) m/s</th>
<th>( K_s )</th>
</tr>
</thead>
<tbody>
<tr>
<td>ANFO</td>
<td>3.72</td>
<td>845</td>
<td>3700</td>
<td>1.00</td>
</tr>
<tr>
<td>Zernogranulit 79/21</td>
<td>4.19</td>
<td>900</td>
<td>3800</td>
<td>1.23</td>
</tr>
<tr>
<td>AD-1</td>
<td>4.08</td>
<td>1025</td>
<td>4100</td>
<td>1.47</td>
</tr>
<tr>
<td>EE-31 (Emulsion)</td>
<td>3.84</td>
<td>1200</td>
<td>3600</td>
<td>1.43</td>
</tr>
<tr>
<td>P-113L (Emulsion)</td>
<td>3.66</td>
<td>1200</td>
<td>4300</td>
<td>1.65</td>
</tr>
</tbody>
</table>

3.3 The calculation of the charge length \( l \)

The charge length \( l \) is the parameter having close geometry relation with the bench height. It can be easily realised that when the bench height decreases, the stemming length must remain the value close to the value of burden, and therefore the charge length in this case must be decreased. The charge length calculated for low bench blasting is determined by equation 3 [9]:

\[ l = 0.467 H^{0.27} ; \text{m} \]  

where \( l \) is the charge length, \( H \) is the bench height.

3.4 The calculation of Spacing \( S \)

The value of spacing in low bench blasting should take into account the influence of bench height or charge length. In this calculation method, the value of spacing for low bench blasting is determined by equation introduced by Konya [3]. Equation 4 and 5 has been considered and analyzed and it shows the suitability in the calculation range of low bench blasting.

Immediate initiation: \( S = \frac{1.15(H + 2B)}{3} \)  

Delayed initiation: \( S = \frac{1.15(H + 7B)}{8} \)

where \( S \) is the spacing, \( H \) is the bench height, \( B \) is the burden.

3.5 The calculation of subdrilling, borehole length and stemming length

Between subdrilling, borehole length and stemming length exist the geometrical relation. The value of subdrilling is calculated based on the blastability of the rock mass. For low bench blasting, subdrilling is determined by the following equation:

\[ J = 0.3B ; \text{m} \]  

where \( J \) is the subdrilling, \( B \) is the burden.

Borehole length is the parameter depending on the bench height, subdrilling and borehole inclination. In case of vertical borehole, the borehole length is determined by equation:

\[ L_K = H + J \; \text{m} \]  

The stemming length is determined through the relation with charge length, borehole length. In low bench blasting, the stemming length is calculated to ensure no premature escape of explosive gases and the value of stemming length is (0.75 – 1.0) time the burden. The stemming length is determined by the following equation:

\[ T = L_K - l \]  

where \( L_K \) is the borehole length, \( l \) is the charge length

3.6 Determination of the charge weight

The charge weight for each blasthole is determined by following equation:

\[ Q = LP \; \text{kg} \]  

where \( P \) is the charge concentration:

\[ P = \frac{\pi d^2}{4} \rho_e \; \text{kg/m}^3 \]  

where \( d \) is the charge diameter, \( \rho_e \) is the density of explosive, kg/m\(^3\).

4. DESIGN AND CARRY OUT A EXPERIMENTAL LOW BENCH BLASTS

In order to estimate the calculation method of low bench blasting in practice. Two experimental blasts were carried out in a limestone quarry. The rock masses were classified by blastability index BI
by Lilly [15], the blastability index BI is 60.4. The rock has the dark-grey colour, bedding structure, and the compressive rock strength of 93.2 Mpa, the tensile strength of 7.3 Mpa, the rock density of 2.7 g/cm³.

The bench height is 1.2 m, the explosive with the trademark Amonit AD1 with the cartridge diameter of 32 mm and the charge concentration of 0.825 kg/m was used. The blasts were classified into low bench blasting due to the ratio H/d = 37.5. The first blast EB1 was applied the blasting parameters of the normal bench blasting at the limestone quarry. The second blast EB2 was designed based the calculation method for low bench blasting introduced in section 3. The blasting parameters for the two blasts are presented in Table 3.

Table 3: The blasting parameters designing for the blasts with the charge diameter of 32 mm.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blast EB1</td>
<td>Blast EB2</td>
</tr>
<tr>
<td>Bench height H, m</td>
<td>1.2</td>
</tr>
<tr>
<td>Borehole inclination, degree</td>
<td>90°</td>
</tr>
<tr>
<td>Burden B, m</td>
<td>1.3</td>
</tr>
<tr>
<td>Subdrilling J, m</td>
<td>0.26</td>
</tr>
<tr>
<td>Stemming length T, m</td>
<td>0.9</td>
</tr>
<tr>
<td>Charge length L, m</td>
<td>0.56</td>
</tr>
<tr>
<td>Borehole length Lb, m</td>
<td>1.46</td>
</tr>
<tr>
<td>Number of blasthole</td>
<td>15</td>
</tr>
<tr>
<td>Charge weight Q, kg/hole</td>
<td>0.46</td>
</tr>
</tbody>
</table>

The blasts used the delayed-electric detonators; the delay time between rows was 25ms. After blasting, some blasting results were estimated.

- **The fragmentation and the displacement of the muckpile**

From the qualitative visualization, it could be seen that the boulder appeared more in the blast EB1, the displacement of this blast was also small (Fig. 3). At the second blast EB2, the rock fragments were uniformly broken (Fig. 4). In order to more accurately estimate, the photograpic method was used to analyze the degree of fragmentation. The representative images were selected to analyze by the Split-Desktop software (Fig. 5, 6). The average fragmentation F₅₀ for the blast EB1 was 36.42 cm and for the blast EB2 was 17.27 cm, the maximum fragment size (99.95% passing) for the blast EB1 was 108.85 cm and for the blast EB2 was 7.82. The fragment sizes of the blast EB2 completely satisfy the fragmentation at the limestone mine and there was no boulder in the blast EB2.

- **State of the remaining rock and bench floor:**

For the blast EB1, after removing the rocks, it could be realized that the bench floor was higher than designed floor of about 0.25 to 0.3 m. Toe also appeared in front of holes. These problems may be caused by both reasons: too big burden or short subdrilling. The backbreak from 0.9 to 1.0 could be seen at the sides of the blast. For the blast EB1, the bench floor was blasted to the designed level. Therefore, the actual breakage height for the blast EB1 is of 0.9 m and for the blast EB2 is of 1.2 m, exacts the designed level. The bench floor is without mounds.

5. CONCLUSIONS

The paper presents the calculation method for low bench blasting, especially for limestone. This method helps the blasting engineers in designing the blasts with low benches more effective. The research results also shown that it is better if the normal bench
blasting is applied (ratio H/d > 60). In case the low bench blasting must be applied, it is necessary to adjust the blasting parameter to reduce the bench stiffness and blasting efficiency.

ACKNOWLEDGEMENTS
The authors would like to thank the staffs at Hoa Nam Company for supporting us in doing the experimental blasts.

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