Blasting methods for heterogeneous rocks in hillside open-pit mines with high and steep slopes

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Abstract. In the arid desert areas in Xinjiang, most limestone quarries are hillside open-pit mines (OPMs) where the limestone is hard, heterogeneous, and fractured, and can be easily broken into large blocks by blasting. This study tried to find effective technical methods for blasting heterogeneous rocks in such quarries based on an investigation into existing problems encountered in actual mining at Hongshun Limestone Quarry in Xinjiang. This study provided blasting schemes for hillside OPMs with different heights and slopes. These schemes involve the use of vertical deep holes, oblique shallow holes, and downslope hole-by-hole sublevel or simultaneous detonation techniques. In each bench, the detonations of holes in a detonation unit occur at intervals of 25-50 milliseconds. The research findings can offer technical guidance on how to blast heterogeneous rocks in hillside limestone quarries.

1. Background

Hongshun Limestone Quarry is a hillside quarry in Dabancheng District, Urumqi City. This hill has an average height of 58 m and a slope of approximately 45°. This quarry is situated in a windy, rainless desert region in inland China, where the highest temperature in summer can reach above 40 °C. Due to the influence of structural planes, the surface 6-9 m limestone in this hill is heavily weathered and eroded, contains a lot of joints and fissures, and can be easily broken into large blocks by blasting. It is feasible to characterize the structure of the heterogeneous rock mass by studying the rock surfaces exposed by blasting and the current status of this quarry.

2. Analysis of factors affecting the effectiveness of blasting

The hillside limestone quarries in Dabancheng District are mostly small quarries. Field survey and analysis of these quarries show that limestone is locally exposed at the surface of hills and the surface limestone can be easily broken into large blocks by blasting, which are a potential safety hazard.

2.1. A subsection

Small-scale millisecond delay blasting with blast holes arranged in lines is commonly used in hillside OPMs. The effect of blasting between rows is apparently directional. When the fracture orientations are parallel to the directions of blasting between rows, the blast wave and gases generated by blasting can cause further dislocation and expansion of primary fractures along the free surfaces of bench [1]. Consequently, the rock mass is split into several large blocks.

2.2. Effect of inclined bedding planes
Previous experiences in blasting demonstrate that during blasting of rock masses with non-structural fractures, the fractures created by the dynamic stress resulting from blasting vary in density, orientations, and length. The stratiform structural planes in this quarry are dominated by inclined bedding planes [2]. The non-structural fractures mostly extend along the dip direction of the hill. The presence of these structural planes reduces the rock’s fracture strength. The superhigh pressure gases produced by blasting can enter the joints and fissures in rock masses and pull fracture surfaces apart. The surrounding rock masses, squeezed by the fracture surfaces, tend to break into large blocks and be thrown towards the inclined free surface [3]. The inclined bedding planes contribute to the widely scattered distribution of the rock blocks all over the inclined free surface.

3. Blasting methods

The study suggests that blasting methods should be determined based on hill slope and the mode and parameters of blasting operation. In order to ensure safe blasting, downslope bench mining from hill top to bottom is recommended.

3.1. A blasting scheme for a hillside OPM with a height greater than 50 m and a dip larger than 45°

For high and steeply sloping hillside OPMs, millisecond delay blasting or chamber blasting with concentrated charge is adoptable. The fracture and deformation of rock masses are controlled by the strength and orientations of weak structural planes. As rock blocks are cast towards the free surfaces of the hill, the blasting can hardly produce desirable results [4]. To prevent cast of rock blocks towards the free surfaces, a hole-by-hole millisecond-delay detonation network was designed. It consists of nonels arranged in V-shaped oblique lines and deep blast holes in a triangular layout. In this blasting scheme, the deep holes are loaded with uncoupled cylindrical deck charge. After initiation, the detonation propagates along the V-shaped oblique lines from the outside in. The blasting process can create three lateral free surfaces inside the rock mass blasted. The vertical holes are drilled to proper depths based on bench heights and the three rows of holes are detonated by one-shot initiation at the hole in the middle of the first row. The explosives in each row are detonated hole by hole at intervals of 25 ms and the detonations along each oblique line occur at intervals of 100 ms. The rock is quarried by downslope sublevel mining. Figure 1 shows the schematic of this blasting scheme.

![Figure 1](image.png)

Figure 1. A blasting scheme for a hillside OPM with a height greater than 50m and a dip larger than 45°.

3.2. A blasting scheme for a hillside OPM with a height of 35-50 m and a dip of 30-45°

For an OPM with a relatively gentle hill slope, rock blocks are thrown towards the free surfaces on a smaller scale. Using vertical deep holes and one-shot initiation will increase the bench bottom burden, weaken the explosive effect at hole bottoms, and cause hole bottom undercut and formation of large rock blocks. This can reduce the effectiveness of blasting. A multistage millisecond-delay simultaneous detonation network was designed for such OPMs. It consists of nonels arranged in V-
shaped oblique lines and blast holes in a triangular layout [5]. A group of shallow vertical holes are drilled in two adjacent benches and loaded with concentrated and coupled column charge. Along the strike of the working face, the benches are divided into sections by the V-shaped oblique lines. Three lateral free surfaces can be formed in a blasted rock mass. The initiation points are located at the rightmost holes in the second rows in the two benches. Detonations occur at intervals of 50 ms along each row (blasting line) and at intervals of 25 ms along each V-shaped oblique line. Figure 2 shows the schematic of this design.

**Figure 2.** A blasting scheme for a hillside OPM with a height of 35-50 m and a dip of 30-45°.

3.3. A blasting scheme for a hillside OPM with a height less than 35 m and a dip smaller than 30°
Small hillside OPMs are normally lower than 35 m and slope at angles smaller than 30°. Given the relatively gentle hill slopes, the blasting scheme designed for such OPMs uses a group of shallow oblique holes drilled in two adjacent benches. These holes are arranged in a triangular layout and loaded with concentrated and coupled column charge [6]. Six adjacent holes in three rows constitute a detonation unit. Adjacent detonation units are connected by dominant detonating cords through one interval hole. These dominant detonating cords are connected perpendicular to the nonels in detonation units. Sublevel detonation can be achieved using nonel detonators, and 2 or 4 lateral free surfaces can be formed at the interval holes [7]. The initiation point is located at the leftmost hole of the first row in the lower bench, and the holes in the upper and lower benches are detonated simultaneously. In each detonation unit, detonations occur at intervals of 25 ms. This blasting scheme is illustrated in Figure 3. The blasting parameters are presented in Table 1.

**Figure 3.** A blasting scheme for a hillside OPM with a height less than 35 m and a slope smaller than 30°.
The blasting parameters are presented in Table 1.

**Table 1.** Design parameters for these blasting schemes.

| Drilling and blasting parameters | Hill height: >50 m (Hill dip: >45°) | Hill height: 35-50 m (Hill dip: 30-45°) | Hill height: <35 m (Hill dip: <30°) |
|----------------------------------|-------------------------------------|----------------------------------------|------------------------------------|
| Bench height (m)                | 8                                   | 4                                      | 4                                  |
| Hole spacing (m)                | 4                                   | 2.5                                    | 2.5                                |
| Row spacing (m)                 | 3                                   | 2                                      | 2                                  |
| Unit explosive consumption (km/m³) | 0.38                               | 0.42                                   | 0.4                                |
| Explosive charge (kg)           | 90                                  | 90                                     | 90                                 |

4. Analysis of results

Higher hillside OPMs are more easily weathered and eroded and thus more likely to break into large rock blocks during blasting. In heterogenous rock masses, non-structural fractures are not the results of extension of pre-existing fractures, but are induced by the radial tensile stress exerted by the tensile waves reflected from the free surfaces created by blasting. An analysis of the rock surfaces blasted reveals that the blast holes along blasting lines can produce stronger explosive effect and break the rock more effectively due to the existence of the free surfaces. Therefore, hole-by-hole, millisecond-delay detonation networks that allow early detonations to create free surfaces for subsequent holes were designed for hills with different heights and slopes. The results of field experiments and statistical analysis of the experimental data suggest that an increase of one free surface in a rock mass can lead to a 4-6% decrease in block rate, as shown in Table 2.

**Table 2.** Analysis of block rate measurements.

| Blasting scheme | Percentages of blocks of different sizes in rock masses (%) |
|-----------------|-------------------------------------------------------------|
|                 | Rock mass with two lateral free surfaces | Rock mass with three lateral free surfaces | Rock mass with four lateral free surfaces |
|                 | >30cm >70cm >110cm | >30cm >70cm >110cm | >30cm >70cm >110cm |
| Hill height: >50m | 48 | 23 | 11 |
| Hill height: 35-50m | 29 | 17 | 7 |
| Hill height: <35m   | 26 | 17 | 11 |

5. Conclusions

Hillside OPMs in the arid desert areas of Xinjiang are characterized by heterogeneous rock masses with non-structural fractures and poor structural integrity, due to the presence of structural planes. These rock masses can be easily broken into large blocks by blasting. It is necessary to design proper blasting schemes for such OPMs based on the distribution of structural planes, development of joints and fissures, and the morphology of hill. This study provided different blasting schemes for different hill conditions and the effectiveness of blasting experiments using these schemes were assessed in terms of block rate (percentage of large blocks in rock mass). The study found that using hole-by-hole, millisecond-delay detonation networks can effectively reduce block rate.

For hillside OPMs that are higher than 50 m and have a slope larger than 45°, a hole-by-hole millisecond-delay detonation network consisting of nonels arranged in V-shaped oblique lines and vertical deep holes was designed. This scheme uses one-shot initiation and downslope small-bench excavation.
For hillside OPMs with a height of 35-50m and a slope of 30-45°, a multistage and millisecond-delay simultaneous detonation network was designed. This design consisting of nonels arranged in V-shaped oblique lines and vertical shallow holes distributed in two benches.

In the blasting scheme designed for hillside OPMs with a height less than 35 m and a slope smaller than 30°, a group of shallow oblique holes are drilled in two adjacent benches. The detonations in each detonation unit occurred at intervals of 25 ms.

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