Optimal Design of Presplit Blasting Network of Deep Concave Open-Pit Mine Slope with Heterogeneous Complex Rock Mass

Yajun Chen¹, Juanjuan Zhao¹ and De Cao²
¹ College of Mining Engineering and Geology, Xinjiang Institute of Engineering, Urumqi 830091, China
² Beishan Open-Pit Coal Mine, Qitai County, Changji Prefecture, Xinjiang 831800, China
Email: 2583703964@qq.com

Abstract. To ensure that the mining steps of deep concave open-pit coal mines with heterogeneous complex rock masses in arid areas are safely bounded by the design requirements and form a fixed side wall, to avoid the occurrence of instability and disaster caused by blasting vibration, based on non-homogeneous rock mass structure, lithology characteristics, fracture surface composition, morphology and joints, analysis of fissure development trend, and case studies of wedge-shaped landslide accident caused by blasting vibration, we proposed: (1) The pre-split instantaneous denotation charge is the dosage used for the segment unit charge of the primary blast hole and buffer hole, and it’s used for calculating . Based on this, the time intervals of segmented detonating cord and fuse are calculated and the actual detonating unit charge is decided. (2) Leave lateral free surface on the fixed side boundary and drill inclined blast holes along the slope of the steps, connect detonating cords to the blasting network, multi-point instantaneous detonate uncoupled segmented charge holes, use the pre-crack and fracture surface to reduce the damage caused by the explosion shock wave of the primary and buffer blasting holes. (3) The main blast hole and buffer hole are connected by non-conductive detonating cord and “four-way” blasting network, couple continuous concentrated charge using non-conductive detonating cord and fuse plus or detonator plus segmented ammonium dynamite initiator and expanded ammonium oil charge for millisecond interval detonation. Control the number of blasting holes and unit detonating charge over equal segments of fuse and detonating cord, reduce the impact of close-range blasting vibration of vertical deep holes on fixed side wall and step slope. Results of the blasting experiment show that using the technology of detonating cord in combination with non-conductive detonator’s pre-split hole millisecond differential blasting network plus reserved free face and segmented unit charge detonation, provide 1-2 blasting lateral free face or positive free face, making the blasting effect dispersed around the blasting hole. It has better solved the major safety problem of instability and disaster caused by the blasting effect on the fixed border-to-boundary steps of deep concave open-pit mine in arid region.

Keywords. Arid region; non-homogenous complex rock mass; open-pit mine slope; pre-split blasting network; safe and stable.

1. Introduction
Xinjiang is rich in mineral resources and excellent mineralization conditions and huge resource reserve. It is an important energy base for the construction of China’s “One Belt One Road” energy
base, especially the mining of its open-pit coal mines, which has made great contributions to Xinjiang’s economic growth. However, because most of the open-pit coal mines in Xinjiang are located in the inland sub-arid desert climate zone, the mining area is arid, with frequent wind, and scarce rain. It’s characterized by prominent non-structural fissure rock mass and pronounced weathering effect of non-structural fissures [1], which is not only seriously affects the mining efficiency, but also poses great harm to the safety and stability of open slopes when carrying out blasting operations with a short distance [2].

The explosive products of heterogeneous rock mass are random in pressure distribution, expansion direction, and loading rate, etc. [3]. In recent years, research on the evolution mechanism and fracture patterns of blasting fracture damage of non-structural joints and fissured rock masses has touched the areas of reflection and transmission pattern of blasting stress wave in layered composite rock mass and the general rules of micro-fissure propagation and damage evolution process [4-6]. Affected by the disturbances of blasting, stripping and transportation in open pit mines, the development and distribution of joint cracks in space will change. Therefore, traditional rock damage and fracture criteria have certain limitations. Based many years’ analyses of the effects of joints and fissures of heterogeneous rock masses on blasting, the research believes that optimal design and key technologies of the pre-splitting blasting network of heterogeneous rock slopes need to be further studied and explored in conjunction with specific cases in the experimental target area. Therefore, taking Beishan open-pit coal mine in Xinjiang as a pilot research target area, through field tests and analysis, key technology of open-pit slope blasting of heterogeneous rock mass was proposed, which combined the application of open-pit coal mine blasting site technology, ensured the safety and stability of slopes under short-range blasting operations. This has helped solving the technical problems of pre-splitting blasting in deep concave open-pit mines in arid regions.

Xinjiang Beishan open-pit coal mine is a deep concave open-pit mine, located within Qitai County. The area has large day and night temperature difference, severe weathering and erosion, complex rock mass structural plane, rich joint fissures, which affect the shallow bedrock layer of 20-30 m below the surface. The inclination direction is from north to south, and the inclination angle of the rock layer is 16-19º. The stepped mining method is adopted from north to south along the inclination direction of the coal seam for zonal vertical mining, with the initial mining area starts from the bottom floor of the coal mine following process of lowering down. For the southern sidewall, fix each step up to the boundary to form a stable sidewall. Based on surveying and analyzing the rock structure and lithology changes from the +680 and +670 level to the boundary of stripping steps of the south sidewall, it revealed that the crack distribution is scattered without order, and the rocks’ continuity and integrity have been damaged (figures 1 and 2). The surface of the step slope caused by the pre-splitting control blasting is uneven, and small wedge-shaped landslide accidents often occur during the sidewall cleaning, mining and loading process.

**Figure 1.** +680 horizontal complex rock mass structure.

**Figure 2.** +670 horizontal heterogeneous rock mass.
2. Rock Mass Structure and Blasting Effect

The deeper the mining depth of the deep concave open pit mine, the greater the slope hanging surface, and the possibility of landslide is greatly increased. In many examples of landslides, blasting vibration and close-range blasting cause cracks in the slope. Under the influence of weak layers, joints and fissures of non-homogeneous rock mass, improper selection of final slope angle and other design parameters is one of the main causes of slope landslide. At present, the mining depth of the mine has reached 90m, with 9-10m steps. When evaluating the risks of blasting vibration, the correlation between lithological conditions and explosive performance and relationship between detonating charge and charge structure should be fully considered [7].

(1) For the boundary step where the joints and fissures are developed, the explosive explosion adds additional pressure to the potential failure surface of the rock mass, which can further expand the non-structural fissures and produce secondary explosion cracks. The rock structural surface increases and the rock mass structure is damaged. Under instantaneous detonation of deep hole blasting, blasting vibration can have a destructive effect on the safety and stability of the non-homogeneous rock mass fixed slope, increasing the possibility of landslides.

(2) The use of low-explosion industrial explosives and uncoupled segmented charge can reduce the impact of blasting on slope safety. Due to the existence of a large number of joints and fissures in the heterogeneous rock mass, the peak value of the compressive stress wave decreases sharply with the distance from the surface of the charge to the wall of the blast hole when the explosive explodes, hence, reduces the blasting effect. Selecting low-explosion industrial explosives can enhance the breakage and action time of the explosive gas on the joints and fissures of heterogeneous rock masses. Uncoupled segmented charge loading can reduce the excessive breakage of the rock wall by stress waves.

(3) The millisecond differential time interval of the blasting rock mass should be greater than the duration of elastic vibration of the rock mass and less than or equal to the time when the rock starts to move obviously. The realization of pre-splitting blasting in heterogeneous rock mass with joints and fissures depends largely on the choice of pre-splitting hole blasting parameters, the optimal design of the main blasting hole and buffer hole, and the blasting network. If the millisecond differential time interval is too short, the blasting differential vibration damping effect will not be evident, and the seismic waves generated by the sequential deep-hole detonations cannot interfere with each other, thereby aggravate the blasting vibration damage.

(4) Heterogeneous rock mass blasting needs to increase the blasting effect of lateral free surface so that part of the energy from the detonation wave is used to break the rocks or release laterally along the free surface, and the other part of the energy is converted into a radial tensile stress and used to crush the rock at the bottom of the step, avoiding the large clamping effect due to fewer free surfaces, making the explosion stress waves being superimposed on each other, resulting in an extremely high stress state and intensifying the blasting vibration [8], this can cause damage to the formation of the step slope and the stability of the slope.

3. Optimal Blasting Design Scheme

3.1. Selection of Blasting Parameters

Using pre-splitting control blasting, the design determines a step slope angle of 70°, select 90 mm down-the-hole drill rig along the step slope to make the inclined pre-splitting holes, the line charge density is 1.1 kg/m, the drug packing density is 960 kg/m³, the package length is 0.3 m, charge pack weight is 1.2 kg, and the uncoupling coefficient is 1.25. For the main blast hole and the buffer hole, the 150mm down-the-hole drill rig was used to drill vertical deep holes. The explosive unit consumption is 0.36 kg/m³. Detailed blasting parameters are listed in table 1.
Table 1. Blasting parameters.

| Category             | Unit | Pre-splitting hole | Buffer hole | Main blasting hole |
|----------------------|------|---------------------|-------------|--------------------|
| Hole spacing         | m    | 2.0                 | 4.5         | 5.0                |
| Row spacing          | m    |                     | 4.0         | 4.0                |
| Hole depth           | m    |                     | 7.6         | 11.5               |
| Hole length          | m    | 10.6                |             |                    |
| Ultra-deep           | m    |                     |             | 1.5                |
| The amount of explosive charge | kg  | 11.7                | 48.0        | 72.0               |
| Charge interval      | m    | 0.45                |             |                    |
| Upper filling height | m    | 3.5                 | 2.5         | 2.5                |

3.2. Blasting Technical Requirements

(1) The designed length of the blast area is 40-50m, along the mining operation slope surface place inwardly three parallel rows of main blasting, buffer and pre-splitting holes. The order of detonation follows the sequence of pre-splitting hole → main blasting hole → buffer hole.

(2) The amount of explosive used for the segmented main blasting hole and buffer hole is the same as the detonating charge of the pre-splitting hole, and the number of detonating holes, the segmented time interval, and actual detonating charge are calculated accordingly.

(3) Due to the effects of joints and fissures, the rock mass cracks first from the lowest weak surface. Because of the continuation of the post-blast stress and the uneven time interval of the detonator delay, in blasting network design, the time interval of each detonator is fixed at 25 ms.

(4) To avoid the blasting effect concentrated on the step slope with throughout pre-split, the design requires the blasting step has at least one positive free face and a lateral free face, and the detonating point should be located on the lateral free face of the pre-splitting hole in the blasting area.

(5) As the onsite operation method is end face flat-loading truck whole layer carving, the excavating working face of the excavator can be regarded as the designed positive or lateral free face.

(6) After the excavation, the unevenness of the pre-splitting surface be no greater than 15 cm. The large clump from the main and buffer blasting holes must meet the requirement of the 5 m³ hydraulic backhoe: the size of the large block is less than 1.36 m³, the blasting pile does not extend beyond 2-3 m, and the blasting pile settlement is not more than 1-2 m.

3.3. Blasting Network Design

The design selects detonator cord plus un-conductive detonator millisecond differential blasting network.

(1) The pre-splitting hole adopts a detonating cord parallel initiation network, and the pre-splitting hole is arranged along the top line of the step slope. The initiation detonating charge is instantaneous detonating charge with no more than 258kg, and is not coupled with the staged charge, so as to achieve multiple charge packages in the hole instantaneously detonate directly.

(2) The main blast hole and the buffer hole are coupled with continuous centralized charge, the detonating cord is connected to the non-conductive detonator and the “four-way” blasting network connection [9-10], the non-conductive detonator plus ammonium denotation charge and expanded ammonium oil explosive staged unit charge millisecond differential interval detonation [11-12]. Among them:

The main blasting hole selects 3 sections of detonators, using the charge of 3 holes as and the detonating charge, and the detonator is detonated three times at 50 ms interval. The charge of 5 buffer holes is used as the amount of detonation charge, and the detonation is divided into two times with a time interval of 75 ms. The millisecond time can be seen in table 2.
Table 2. Millisecond difference interval time.

| Category                      | Unit     | Pre-splitting hole | Main blasting hole | Buffer hole |
|-------------------------------|----------|--------------------|--------------------|-------------|
| Hole numbers                  |          | 22                 | 9                  | 10          |
| Explosive charge per unit     | kg       | 258                | 216                | 240         |
| Hole numbers for one explosive|          | 22                 | 3                  | 5           |
| Time interval of explosive charge per unit | ms | Instant            | 50                 | 75          |
| Time interval between rows    | ms       |                    |                    | 75          |

(3) The +680 horizontal blasting design has a lateral free face and a positive free face formed by excavation, and the +670 horizontal blasting design has a positive free face and a lateral free face formed by excavation. The blasting network can be seen in figures 3 and 4.

4. Key Blasting Techniques and Effect Analysis

4.1. Pre-splitting Blasting Key Techniques and Effect Analysis
The inclination direction of the rock in this mine is inversely inclined to the southern slope. Affected by the structural plane, after blasting the slopes have rocks with varying sizes which can cause potential danger to wall cleaning operation. Therefore the design selects small down-the-hole drill rig to drill inclined holes along the step slope to protect the step slope. The thickness of the edge protection layer of the pre-splitting hole from the top line of the step slope is no thicker than 30 cm, to reduce post-blasting under-excitation or over-excitation, keep the excavated step slope maintain a flat surface.

(1) Choose relatively small pre-splitting hole spacing, after blasting the non-structural fissures within the rock mass develop into throughout pre-splitting cracks along the blasting hole line, causing stress superposition along the director of the connection line of the blasting holes. The pre-splitting zone can reflect or absorb the stress wave of the subsequently detonated main and buffer blasting hole, control the resultant blasting vibration, hence maximally reduce the damage to the rock wall and the workload of wall cleaning.

(2) The uncoupling coefficient should be no smaller than 1.25, the distance between explosive packages within the hole should be no longer than 1.5 times of the explosive package length. Design adopts 10 small explosive packages with uncoupling segmented charging, leaving ring-shaped space around each of the explosive packages, hence reduce the peak stress of the shockwave caused by the wall of the hole. The spacing between the explosive charge package is 0.45m, leave space between explosive charge along the direction of the axis of the blasting hole, make the explosive charge more evenly distributed along the length direction of the blasting hole, reduce the damage of the blasting vibration to the step slope.

(3) Operation quality analysis from +680 level to boundary step pre-splitting post-blasting wall cleaning, step slope formed at 70°, no obvious large lumps appear on top of the step, position of the...
top line of the slope was well in place, the step slope face was relatively even. The blasting effect can be seen in figure 5.

![Figure 5. +680 horizontal pre-hole blasting face of cleaning steps.](image)

### 4.2. Main Blasting Hole and Buffer Hole Key Blasting Technique and Effect Analysis

Because the main blasting hole and buffer hole are close to the step slope face, the throughout presplit from the pre-splitting blasting hole along the topline of the step slope will be affected by the blasting gas from the main blasting hole and buffer hole and cause shake damage to the step slope face, meanwhile the large blasted rock make the wall cleaning operation more difficult.

1. Selecting segmented unit detonating charge millisecond differential detonation, segmented unit detonation charge is smaller than or equal to the pre-splitting hole instantaneous detonating explosive charge, ensure blasting extent without increasing the blasting vibration strength at the same time, and make the released energy from the blasting of the explosive converting into elastic wave that can induce shallow surface vibration, relatively reduce the vibration due to the reduced amount of detonating charge.

2. Buffer hole is close to the pre-splitting blast hole, detonating effect is concentrated, unit detonating charge millisecond differential interval should be larger than the main blasting hole, make the detonation disperse around the blasting hole along the positive and lateral faces, the vibration wave is absorbed by the rock structural face, reaching the goal of reduced detonation effect on the step slope face of the pre-splitting hole.

3. The pre-splitting hole and main lasting hole is detonated sequentially a few milliseconds ahead of the buffer hole, providing 1-2 lateral blasting free faces for the buffer hole (table 3), so that both the minimum resistance line of the buffer hole and the direction of the blasting effect will change, alter and expand the propagation direction of the vertical waves, making the energy disperse around, weakening the excessive fragmentation of deep slope blasting on the slope rock mass. According to the blasting data statistics, for each additional lateral blasting free face, the rate of large rock mass is reduced by 5-8%, making the mining, loading and the cleaning operation easier (figure 6).

| Category                              | Unit 225 ms buffer hole | 300 ms buffer hole |
|---------------------------------------|-------------------------|--------------------|
| Instantaneous blasting of pre-splitting hole | 1                       | 1                  |
| Explosive charge per unit of main blasting hole | 1-2                     | 1-2                |
| 225 ms buffer hole blasting           | 1                       |                    |
| Design of lateral free surface       | 1                       |                    |
Figure 6. +670 horizontal work step slope.

5. Conclusion
In arid regions, heterogeneous complex rock mass structural face dictates the deformation, occurrence of damage and development of the slope rock mass. The inclination of the rock mass of the mine is from north to south, and the south slope is inversely inclined, hence enhanced the potential occurrence of wedge-shaped small-scale landslide. Using optimized pre-splitting blasting network design with vibration damping and velocity reduction techniques can ensure blasting operation quality (table 4) and the slope’s safety and stability.

Table 4. Blasting construction quality.

| Category        | Unit | +680 horizontal pre-splitting hole to boundary slope | +670 horizontal main blasting hole slope |
|-----------------|------|-----------------------------------------------------|----------------------------------------|
| Large blasted rock | cm   | <20                                                 | 50-110                                  |
| Hard wall       | /m   | 0.3-0.8                                             | 1.0-2.0                                 |
| Umbrella rock   | cm   | 0.3-0.6                                             | 0.8-1.1                                 |
| Undercut        | /m   | 0.1-0.2                                             | 0.3-0.5                                 |

(1) Open-pit mine close-range blasting vibration has a short duration, usually in the range of 0.1-1.5s, with high vibration frequency and fast attenuation, which can be regarded as pulsating or instantaneous vibration. According to the field blasting experiment, the impact of blasting vibration on the slope is directly related to the number of blast holes and the amount of explosive charge.

(2) Through pre-splitting detonator cord network design, using uncoupled segmented charge, the blasting rupture face formed by multi-point instantaneous blasting of the charge in the hole, can reduce the influence of the blasting effect of the main blast hole and buffer hole on the step slope.

(3) Through the main blast hole and the buffer hole non-conductive detonator blasting network design, segmented unit charge is detonated at millisecond interval, control the equal-number detonator cord unit detonating charge and the number of detonation holes, can disperse the blasting energy, and reduce the influence of blasting vibration on the slope.

Acknowledgement
This paper was funded by Science and Technology Department of Xinjiang Uygur Autonomous Region (2018D01A42).

References
[1] Chen Y, Chang Z and Mao J 2015 Blasting effect analysis of hole-by-hole millisecond minute difference initiation network along V-Shaped oblique line Electronic Journal of Geotechnical Engineering 20 (13) 2533-2538.
[2] Ren Y, Cai Q, Shu J, et al. 2014 Influence of blasting vibration and structural plane progressive failure on slope stability Journal of Mining & Safety Engineering (03) 435-440.
[3] Chu H, Yang X, Liang W, et al. 2011 Experimental study on the blast damage law of the
simulated coal *Journal of Mining & Safety Engineering* (03) 488-492.

[4] Yang J, Jin Q, Gao W, et al. 1999 Some problems in the research of rock damage model by blasting *Chinese Journal of Rock Mechanics and Engineering* (03) 255-258.

[5] Ding X, Yuan W and Xie Z 2019 Classification and identification of explosibility of rock mass in open-pit mine based on comprehensive weighted cloud model *Coal Science and Technology* (10) 88-95.

[6] Yang H, Yang T and Tang R 2016 Application of pre-split blasting technique for retaining roadway along the hole in steeply inclined coal seams *Mining Safety and Environmental Protection* 43 (04) 87-89+108.

[7] Lei Z, Yang R and Tao T 2015 Comprehensive evaluation of bench blasting effect based on uncertainty measurement theory *Journal of China Coal Society* 40 (2) 353-359.

[8] Chen Y, Cang Z and Zhao F 2017 Non-structural fracture blasting technique and case study of open pit coal mine in arid area *Journal of Mining & Safety Engineering* 34 (6) 1162-1168.

[9] Chen Y, Chang Z and Zhao F 2019 Theory and practice of blasting action line in open pit mine in arid area *Journal of Mining and Safety Engineering* (03) 435-440.

[10] Yu J and Song Z 2015 Application of hole-by-hole initiation technology in deep-hole blasting in open-pit coal mine *Journal of Liaoning University of Engineering and Technology (Natural Science Edition)* 34 (4) 438-441.

[11] Lou X and Zhou W 2015 Selection of delayed time in millisecond blasting of open-pit mining *Nonferrous Metals (Mining Section)* 67 (4) 82-88.

[12] Zhong D, He L, Cao P, et al. 2016 Time-holding analysis of blasting vibration and optimization of delay time of differential blasting *Explosion and Impact* 36 (05) 703-709.