Experimental Study on Blasting Funnel under Cylindrical Uncoupled Charge

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Abstract. According to the Livingston blasting funnel theory, a series of single-hole blasting funnel tests were performed at the May Fourth Square Station. The relationship curve between blasting funnel volume and drug embedding depth was plotted, and the variation curves of blasting funnel depth, vibration speed and noise with burial depth were obtained. The MATLAB software was used to perform four-term regression on the test data, and the parameters such as the optimal burial depth, critical burial depth, and optimal explosive consumption of the blasting funnel were calculated.

1. Preface
Today, blasting is widely used in engineering as the main method of breaking rocks. For example, blasting is involved in mining, water conservancy, and urban construction. However, the rock has a complicated internal structure, the joints and fissures are very different, and the conditions at the site are different, so that the selection of blasting parameters cannot be completely based on experience. When an explosive explodes inside the rock, it will cause the broken rock to be thrown in the direction of the free surface, forming a blasting funnel. The blasting funnel is the main way to study the mechanism of blasting. Generally, it is necessary to test the rock before blasting. If necessary, the blastability of the rock is measured by blasting funnel tests, as well as parameters such as critical burial depth and optimal hole spacing to ensure that the blasting operation can meet the expected requirements. In order to reduce the cost of blasting equipment, guide the construction of the project, improve the blasting effect and economic benefits, control the vibration effect of blasting, and perform a funnel test on the rock at the project site\textsuperscript{[1-7]}.

2. Project Overview
Qingdao Metro Line 8 May Fourth Square Station has a starting mileage of CK60+641.478 and an end mileage of CK60+931.478. The station is an island-type underground two-story station. The length of the station body is 290m, the standard section width is 23.7m, and the height is 20.005m. The burial depth is 11.11~14.89m, and the construction method is the arch cover method. The surrounding rock grade is IV, the test site is located on the step palm surface of the Xiaoli No. 1 tunnel at May Fourth Square Station.

3. Theoretical basis
C.W. Livingston of the Colorado School of Mines in the United States conducted a large number of
blasting funnel tests in the 1950s and proposed a blasting funnel theory based on energy balance. The study found that the energy of a single blast on the rock is related to the performance, quality and characteristics of the rock. When the explosive is buried deep enough below the surface, the energy of the explosive cannot destroy the rocks on the surface. If the burial depth is reduced, the surface rocks may be damaged. The rock began to break, and the burial depth without the blasting funnel was called the critical burial depth \( H_e \), and the dose at this time was called the critical burial \( Q_e \). When the quality of the drug package is unchanged, if the burial depth continues to decrease, the volume of the funnel gradually increases. When the volume of the blasting funnel reaches the maximum, the energy utilization rate of the explosive is the highest. At this time, the burial depth of the drug pack is called the optimal burial depth \( H_o \), and the amount of the drug at the maximum blasting funnel volume is called the optimal charge \( Q_o \). When the burial depth of the drug pack exceeds the optimal burial depth, the volume of the blasting funnel decreases as the burial depth increases\(^{[8-10]}\).

Livingston's elastic deformation equation is:

\[
H_e = EQ^{1/3} \tag{1}
\]

or

\[
H_o = \Delta_o EQ^{1/3} \tag{2}
\]

Where: \( H_e \) is the critical burial depth of the drug packet, m; \( E \) is the elastic deformation coefficient; \( Q \) is the mass of the drug packet, kg; \( H_o \) is the optimal burial depth, m; \( \Delta_o \) is the best buried depth ratio \((\Delta_o = H_o/H_e)\), for a particular rock, \( \Delta_o \) is a fixed value.

When the Livingston blasting funnel theory is used to calculate the blasting parameters of an open-pit mine, the critical burial depth \( H_e \), optimal burial depth \( H_o \), optimal burial depth ratio \( \Delta_o \), the coefficient of elastic deformation \( E \) and the unit consumption of explosives at the maximum blasting funnel volume.

4. Test equipment and test plan

4.1. Test equipment

The blasting vibration monitoring instrument uses the TC-4850 blasting vibration velocity monitor developed by Chengdu Zhongke Measurement and Control. The Blasting Vibration Analysis computer software supporting the instrument is used to extract and analyze the monitoring data. The instrument has 3 channels, which can simultaneously monitor the vibration velocity in the three directions of measurement points x, y and z. The sampling time of the instrument is set to 1s, the sampling frequency is 8K, and the trigger level is 0.01 cms \(^{-1}\).

The blasting noise monitoring instrument uses the HS6288B noise spectrum analyzer. The HS6288B noise spectrum analyzer is a pocket-type intelligent noise measurement instrument. It integrates several functions such as integration, noise statistics, and noise collection. The main performance indicators meet The requirements of the IEC61672 standard and the JJG188-2002 sound level meter verification regulations for level 2 sound level meters.

Adjust the range to 80~130dB, adjust the weighting to C, and press the “Hold” key, the analyzer will be at the maximum value to maintain the measurement state. The reading will only change (rise) when a greater sound level arrives, otherwise it will To keep.

4.2. Test plan

Make a blast hole in the center of the upper step palm face of the small mileage No. 1 hole, and conduct a test once a day. The drilling machine used is an air-leg pneumatic rock drill with a blast hole diameter of 42 mm and a roll of 0.2 kg. No. 2 rock emulsion explosive, the length of the explosive is 25cm, is filled with artillery mud to the orifice, and is detonated with a detonator of a detonator. Use two TC-4850 vibrometers to monitor the blasting vibration on the corresponding surface of the palm face, and use four HS6288B noise spectrum analyzers to perform blast noise monitoring in the tunnel. The distance from the palm face is 50m, 60m, 70m, 80m. The size of the blasting funnel formed after initiation was measured, and the volume of the blasting funnel was calculated using the Simpson method\(^{[11]}\). In the test with a buried depth of 0m, a roll of 0.2kg explosive was tied to a rack welded with
steel bars, and was 1m away from the palm surface. The test plan of Wusi Square Station is shown in Figure 1. The shaded area in the figure is the unexcavated surrounding rock.

![Figure 1 Test plan](image)

### 5. Test results and analysis

A total of 7 sets of valid data were obtained at the May Fourth Square Station. The blasthole depths were 0m, 0.25m, 0.55m, 0.8m, 1.2m, 1.7m, 2.7m. The blasting funnel test data is shown in Table 1.

When the burial depth is 0.25m, 0.55m, 0.8m, 1.2m, blasting funnels have been generated. Due to the relatively developed joints, the rocks fall into blocks, and the blasting funnel formed is very uneven. Among them, the surrounding rock at a burial depth of 0.8m. The conditions are good, the blasting funnel formed after blasting is relatively uniform, and there is no crushed rock around the blasting funnel; when the burial depth is 1.7m and 2.7m, the external surrounding rock is not broken, and the blasting funnel is not formed, but the gun mud has burst out of the gun hole.

| Buried depth L/m | Noise N/dB 50m | Noise N/dB 60m | Noise N/dB 70m | Noise N/dB 80m | Vibration speed v/cm·s⁻¹ | Blasting Funnel Depth H/m | Blast Funnel Volume V/m³ |
|------------------|----------------|----------------|----------------|----------------|---------------------------|--------------------------|--------------------------|
| 0m               | 138.3          | 137.9          | 137.4          | 141.8          | 0                         | 0                        | 0                        |
| 0.25m            | 137.4          | 137.3          | 141.3          | 136.1          | 0.115                     | 0.35                     | 0.105                    |
| 0.55m            | 137.1          | 135.9          | 135.1          | 140.2          | 0.179                     | 0.6                      | 0.151                    |
| 0.8m             | 133.2          | 131.1          | 131.7          | 132.6          | 0.17                      | 0.4                      | 0.126                    |
| 1.2m             | 115.8          | 112.9          | 112.9          | 113.2          | 0.187                     | 0.35                     | 0.061                    |
| 1.7m             | 112.4          | 112.3          | 112.5          | -              | 0.246                     | 0                        | 0                        |
| 2.7m             | 121.9          | 121.5          | 121.4          | -              | 0.277                     | 0                        | 0                        |

Analysis of the blasting funnel test data in Table 1 yields Figures 2-5.
It can be seen from Figure 2 that as the burial depth increases, the overall noise at each center distance shows a downward trend. The maximum noise value monitored is 141.8 dB and the minimum noise value is 111.4 dB. The decrease is most obvious in the interval of 0.8 m to 1.2 m, which indicates that as the burial depth increases, the energy converted from blasting energy to acoustic energy is less and less, and more energy is converted into other forms. At the same burial depth, the noise gradually decreases with the increase of the burst center distance.

It can be seen from Figure 3 that as the burial depth increases, the blasting vibration speed gradually increases, indicating that shock waves and explosive gases do more and more work on the rock, and less and less energy is converted into other forms. When the burial depth is 1.7 m and 2.7 m, both blasting funnels are formed, and the vibration velocity still shows an increasing trend. This indicates that below the critical burial depth, as the burial depth increases, the energy of the explosives is dissipated outside the hole. With less and less, explosives do more and more work on rocks.

It can be seen from Figure 4 to 5 that as the burial depth increases, the depth of the blasting funnel and the volume of the blasting funnel first increase and then decrease, and the trend of the change of the depth of the blasting funnel is an "inverted V" shape. When the burial depth is 0.25 m and 0.55 m, the blasting funnel depth is 0.35 m and 0.6 m, respectively, which are larger than the burial depth. When the burial depth is 0.8 m and 1.2 m, the blasting funnel depth is 0.4 m and 0.35 m, respectively, which are less than the burial depth. It shows that at a charge of 0.2 kg, the optimal depth of the blasting funnel is 0.55 m–0.8 m, and the critical depth of the blasting funnel is 1.2 m–1.7 m, that is, when the buried depth is 0.55 m–0.8 m, 0.2 kg explosive can be obtained. The best blasting effect, when the burial depth is greater than 0.8 m, the surrounding rock is thrown less and less. When the burial depth is greater than 1.7 m, no throwing phenomenon will occur.

According to the principle of the least square method, MATLAB\textsuperscript{12-14} software is used to perform a
quadratic regression on the volume data of the blasting funnel. The polynomial expressions of the blasting funnel volume \( V \) and the drug embedding depth \( H \) are calculated as:

\[
V = -0.0148H^4 + 0.2544H^3 - 0.7436H^2 + 0.6021H - 0.0006
\]  

(3)

By solving equation (3), the optimal technical parameters of the blasting funnel are: the critical burial depth of explosive \( H_c = 1.7188m \); the optimal burial depth \( H_o = 0.5574m \); the optimal burial depth ratio \( \Delta_0 = 0.3243 \); Blasting funnel volume \( V = 0.1466m^3 \); strain energy coefficient \( E = 2.9391 \); unit explosive consumption \( q = 1.3643kg/m^3 \) at maximum blasting funnel volume.

6. Conclusions and outlook

This article mainly describes and analyzes the tests performed at the May Fourth Square Station, and draws the following conclusions:

(1) In the case of columnar uncoupled charging, the drug amount is maintained. As the burial depth increases, the blasting vibration speed gradually increases, the blasting vibration noise gradually decreases, and the blasting funnel depth increases first and then decreases, it is "inverted V" in shape. This shows that as the burial depth increases, shock waves and explosive gases do more and more work on the rocks, and they become less and less into other forms of energy such as acoustic energy.

(2) The noise decays slowly with the increase of the blast center distance. The noise value is still greater than 110dB at a distance of 80m from the palm face, because the noise is a plane wave and is not in a free field, and the energy dissipation is relatively slow. During blasting, the construction personnel should take protective measures to get as far away from the palm face as possible.

(3) The technical parameters of the optimal state of the blasting funnel were obtained: at a charge of 0.2 kg, the critical burial depth of explosive \( H_c = 1.7188m \); the optimal burial depth \( H_o = 0.5574m \); the optimal burial depth ratio \( \Delta_0 = 0.3243 \); Blasting funnel volume \( V = 0.1466m^3 \); strain energy coefficient \( E = 2.9391 \); unit explosive consumption \( q = 1.3643kg/m^3 \) at maximum blasting funnel volume.

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