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Blasting Crater Test and Application Based on Digital Section Measurement Method

Tianfeng HOU[1], Zhiming JIANG
School of Civil Engineering, Changsha University of Science and Technology, Changsha, Hunan Province 410014

Abstract. In order to reduce the labor intensity and human subjective error of the artificial scale of the Simpson method to measure the distance between each section of the blasting funnel and the distance between the pre-explosion and post-explosion measurement points, in the series blasting funnel test of the Jinchanghe mine, based on the characteristic of the tunnel laser profiler on the basis of measuring the current section, the pre-explosion (post) data of each measurement section was measured, and then it was imported into the 3Dmine software three-dimensional model to calculate the blasting funnel volume, and the relationship curve diagram and fitting analysis were drawn using Origin. Reasonable rock drilling and blasting parameters for large-diameter deep hole mining in underground mines are proposed, which lays a solid technical foundation for the production of mines. The recommended drilling and blasting parameters are: the spacing between the middle hole and the side hole is 2.6 m; The row spacing between the middle hole and the side hole is 2.8 m and 2.6 m, respectively; layered collapse height height 2.6 m; The unit consumption of explosives is 0.46 to 0.51 kg/t.

Keywords. Blasting Crater Test; Tunnel Laser Profiler; Digital Volume Measurements; Underground Large-Diameter Long Hole Mining; Optimization of Blasting Parameters

1. Introduction

When mining and blasting large-diameter deep holes in underground mines, it is of great practical significance to select the best rock drilling blasting parameters to optimize the blasting effect and reduce mining costs. The determination of rock drilling blasting parameters is mainly based on Livingston blasting theory, according to the dimensional derivation equation of the small blasting funnel test into the required actual production of rock drilling blasting parameters, many domestic scholars have carried out a lot of research on the measurement method of blasting funnel volume in blasting funnel test and the analysis method of measurement data. The accuracy of blasting funnel volume measurement is directly related to whether the recommended rock drilling blasting parameters are adapted to the rock mass change characteristics of the mining area, and the common methods of blasting funnel volume measurement are parabolic method (i.e. Simpson method)[1], weight method, three-point reference positioning method[2], with the rise of Matlab, Origin and other software, measurement

[1] Corresponding Author: Tianfeng HOU, Author to whom any correspondence; School of Civil Engineering, Changsha University of Science and Technology; e-mail: houtianfeng777@qq.com

data processing and analysis methods are not the same. Q L Zhang[3] et al. obtained the best burial depth and best resistance line in the test by single-hole blasting funnel in a pyrite experimental mining area, and then controlled the hole spacing and row spacing through the orthogonal test, and used the BP neural network to predict and optimize the test results, and obtained the minimum total unit consumption of explosives. C P Wu[4] et al. carried out a single-hole blasting funnel test in a lead mine, used a 100 mm×100 mm grid to measure the distance between the plane after the explosion and the grid plane, used the simplified vertical section method and 3Dmine modeling to obtain the volume of the blasting funnel, and fitted the data obtained to obtain the technical parameters of deep mining of a lead mine.F l Jiang[5] et al. carried out a single-hole series blasting funnel test in a mine and screened the blasted rock block, and then used Matlab software to process the test data to make the blasting funnel characteristic curve, etc, and then regression calculation of the test data according to the least squares method, and finally the parameters were inverted to obtain the blasting parameters suitable for production. T Q Ye[6] et al. carried out a single-hole series blasting funnel test in a pyrite mine, took the plane perpendicular to the axis of the gun hole as the reference plane, manually measured the distance between the pre-(post) contour and the reference plane with a network of 20 cm×20 cm, measured the volume of the blasting funnel by parabolic method, and then used Matlab software to regression calculation of the obtained data to analyze the optimal burial depth of the blasting funnel, unit explosive consumption and other parameters.

In summary, the blasting funnel test and theory is the basis for selecting reasonable rock drilling blasting parameters, there are many means to measure the volume of the blasting funnel and analyze the test data, but the parabolic method (i.e. Simbsen method) affected by human factors for blasting funnel volume measurement is widely used, to obtain more accurate and actual production of blasting production parameters, should be carried out when the blasting funnel measurement should be carried out to ensure that the obtained data is accurate and less affected by human factors. When calculating the volume of the blasting funnel, the parabolic method is used to measure the distance from the reference plane to the rock face before blasting and the contour line of the funnel after blasting to calculate the funnel depth corresponding to each measurement point, and the volume of the blasting funnel is calculated by Simpson's formula. The determination of the position of each pair of corresponding points between the datum plane and the funnel surface depends on the surveyor's determination, and it is time-consuming and laborious to require the connection of each pair of measurement points parallel to the datum plane[7]. Moreover, human factors have a great influence on the distance between the measured measurement point and the corresponding point of the reference plane on each section, resulting in poor accuracy and inaccurate calculation of blasting funnel volume[8].

C Deng[9] et al. used the tunnel section instrument to measure the section of the roadway before the explosion and the section of the blasting funnel after the explosion, and after finding the area difference before (after) the corresponding section, the volume of the blasting funnel was obtained according to the Simpson formula, and the reference plane method (parabolic method based on the tunnel section meter measuring the cross-section), the Simpson method and the weight method were compared to obtain that the percentage difference of the reference plane method was less than 5%, and the data obtained by the test met the accuracy requirements of the underground blasting funnel test. Referring to the above blasting funnel volume measurement method, this paper carried out an in-situ blasting funnel test based on digital volume measurement of the tunnel section meter in Jinchanghe Mine and used the tunnel section meter to measure the difference before (after) section, and then used 3DMine modeling to obtain the blasting funnel volume and the data measured by Origin analysis and processing test to obtain the rock drilling blasting parameters suitable for on-site production, which has reference significance for the determination of blasting parameters of large-diameter deep hole rock drilling in underground mines.

2 Theoretical Basis of Blasting Funnel Test

Livingston Blasting Funnel Theory believes that from the perspective of energy transfer, the quality of the drug bag remains unchanged and changes the drug bag embedding depth, which has the same blasting effect as changing the drug bag quality without changing the drug bag depth, then the Livingston Blasting Funnel elastic deformation formula is[10,13]:

$$l_e = EQ^{1/3} \tag{1}$$

$$l_e = \Delta_j EQ^{1/3} \tag{2}$$

Formula: l_e is the critical burial depth of the drug package, m; E is the elastic strain energy coefficient, for specific explosives and rocks, E is constant; Q is the quality of the medicine pack, kg; Δ_j is the best-buried depth ratio ($\Delta_j = l_i/l_e$, l_j is the best-buried depth of the medicine bag, m).

According to the evolution of Livingston's elastic strain equation, when the same explosive is used in the same rock mass, the small blasting funnel test satisfies the following (cube root) similarity law with the blasting funnel parameters of large-diameter deep holes:

$$L_{j1} / L_{j0} = (Q_1 / Q_0)^{1/3} \tag{3}$$

The subscripts 0 and 1 correspond to the technical parameters related to the small blasting funnel test and large-diameter deep hole blasting, respectively.

3 Field Test of Single-Hole Series Blasting Funnel

3.1 Overview of Single-Hole Series Blasting Funnel Test

A single-hole series blasting funnel test was carried out in the surrounding rock of the hard section of the 1750m exit level $15^{\#}$ mining area exit road of the Jinchanghe mine. Using $2^{\#}$ rock emulsion explosive with specifications of Φ32 mm×200 mm and a single medicine roll weighing 200 g, it was unpacked and replaced with a self-made test medicine bag with a diameter of Φ90 mm~95 mm and a kraft paper outer packaging, the length of the medicine bag was 520 mm~500 mm, the single-hole drug volume was 4.6 kg, and the corresponding length-diameter ratio was 5.78~5.26 , respectively.

During the test, the gun mud was filled and pounded to make it consistent with the recovery blasting. The depth of the test gun hole is between 1.2~2.8 m, and the gun hole is located on the right side of the mining area exit road. The height of the center of the hole is 1.3 m from the roadway floor and the distance between the test gun holes is 3.5 m, ensuring that there is no mutual interference between the formed blasting funnels (Figure 1). The YGZ-90 drilling rig is used to drill rock by transferring the short brazing with Φ100 mm column tooth drill bit, and the diameter of the gun hole is about Φ105 mm. The drilling should be required to be horizontal of the drill pipe, and the depth of the gun hole should be measured immediately after the drilling is completed, and the design hole depth requirements should be ensured.The comparison of the test hole before and after the explosion is shown in Figure 2.

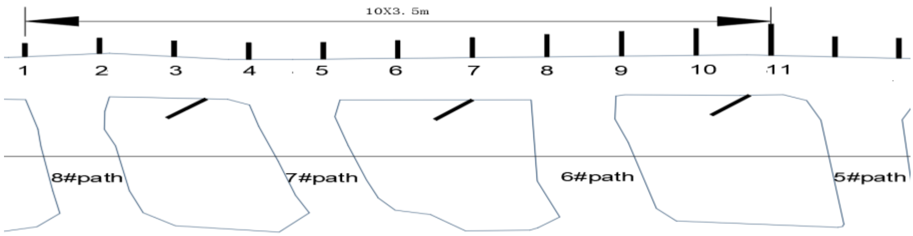


Figure 1. Arrangement of single-hole blasting crater test

a) 1# hole before the explosion | b) 1# hole after the explosion | c) 2# hole before the explosion | d) 2# hole after the explosion

Figure 2. Comparison of pictures of test blast hole before and after the explosion (example)

3.2 Blasting Funnel Test Section and Radius Measurement

When the BJSD-3 tunnel section meter (Figure 3) is used for the volume measurement of the blasting funnel, it is necessary to adjust the measurement method to adapt to the measurement of the blasting funnel volume by the vertical section method of the reference plane and measure the difference between the section area before and after the explosion by fixed-point pre-test and post-explosion respectively, according to the section spacing of 20 cm.

To accurately measure the volume of the blasting funnel, the center position of the instrument is first erected, leveled, and positioned with the fixed datum point of the midline of the roadway roof, and the surface formed by the adjacent fixed datum point is used as the midline datum, and the tunnel section meter measures the current section perpendicular to the midline of the roadway. After setting the starting parameters of the measurement section on the handheld computer, the probe automatically completes the measurement of the current section. Then set the spacing of the front section, and the instrument automatically measures the front section (Figure 4). Considering the height difference of the camera, the two-dimensional analysis software of the tunnel section meter was used to coincide the sections before and after the explosion, and the files were converted into CAD temporary files and imported into 3DMine to build a three-dimensional model. The radius of the blasting funnel is converted into an AutoCAD file by using the envelope evaluation method, connecting the vertices of each section, and then converting it into a two-dimensional envelope diagram, and 8 different azimuth radii (4 different azimuth diameters) are made through the center of the gun hole, and the radius length is obtained by linear length annotation, and the arithmetic average is the radius of the blast funnel.

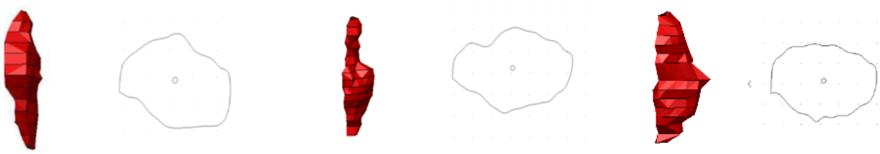
a) Instrument host b) PDA

Figure 3. Main components of BJSD-3 tunnel laser profiler

Figure4. Automatic cross-sectional measurement

3.3 Data Processing and Result Analysis of Single-Hole Series Blasting Funnel Test

The post-processing software of the tunnel section meter can display the shape and measurement data of the measured section in real time, import the data into 3D-Mine to establish the blasting funnel model, determine the volume of the blasting funnel, and convert it into a two-dimensional graph to obtain the blasting funnel envelope, and the use of 3D-Mine software modeling to calculate the blasting funnel volume is still the Simbsen method in principle, but its modeling of the adjacent measurement profile is coupled with a continuous and smooth surface, and its calculation accuracy is also more accurate. (Figure 5)



$1^{\#}$ hole $2^{\#}$ hole $3^{\#}$ hole

Figure 5. 3D model and envelope diagram of 1～$3^{\#}$ hole blasting crater(example)

After measuring the buried depth L of the center of the blasting funnel with a steel tape measure, and obtaining the data such as the funnel radius r through the two-dimensional envelope diagram, the parameters such as the volume V of the blasting funnel, the buried depth ratio △, and the blasting volume per unit explosive amount were obtained (Table 1). Plot the blasting funnel characteristic curve with Origin based on Table 1 data (Figure 6).

Table 1. Basic parameter table of single-hole series blasting crater test

Hole number	The center of the explosives is buried deeply	Funnel depth/m	Funnel radius/m	Funnel volume /m^3	Buried depth ratio/△	Unit explosive blasting volume/m^3•kg^{-1}	Blasting action index
1	1	0.46	0.98	0.82	0.43	0.1789	0.98
2	1.05	1.05	1.13	1.88	0.45	0.4081	1.08
3	1.15	1.03	1.1	1.84	0.5	0.3997	0.96
4	1.35	0.72	0.97	0.86	0.58	0.1878	0.72
5	1.2	0.82	1.04	1.16	0.52	0.2525	0.87
6	1.32	0.56	0.84	0.88	0.57	0.1906	0.64
7	1.45	0.42	1.01	0.68	0.63	0.1478	0.7
8	1.82	0.68	0.85	0.56	0.79	0.1219	0.47
10	2.12	0.19	0.476	0.12	0.92	0.0260	0.22

It can be seen from Table 1 that the embedding depth in the center of the $2^{\#}$ and $3^{\#}$ hole packs are located near the optimal burial depth value, and its blasting effect index n=0.96~1.08 is similar to that of standard throwing blasting n=1, and the blasting effect is the best. For tight hard ore rocks with no joint fracture development, it is recommended to take an n value slightly greater than 1, while for loose and soft ore rocks with joint fracture development, it is recommended to take an n value slightly less than 1.

The test data are fitted using the principle of least squares, and the multiple expressions of the unit explosive volume (V/Q) and the proportional burial depth b (L_j/Q) are as follows:

$$V/Q = -1.36461 + 5.74648b - 6.32663b^2 + 2.08551b^3 \tag{4}$$

After the experimental data were fitted according to equation (4), the sum of squared residuals was 0.44864, the standard deviation of the constant term was 1.30503, the standard deviation of the primary term coefficient was 4.46457, the standard deviation of the quadratic term coefficient was 4.85554, and the standard deviation of the cubic term coefficient was 1.6766.

The test data are fitted using the principle of least squares, and the relationship curve between the scale radius br(R_j/Q) and the proportional burial depth b can be plotted by Origin (Figure 7), and its multiple expressions are as follows:

$$b_r = 0.31662 + 0.97598b - 0.76912b^2 \tag{5}$$

After the experimental data were fitted according to equation (5), the sum of squared residuals was 0.76661, the standard deviation of the constant term was 0.39704, the standard deviation of the primary term coefficient was 0.89162, and the standard deviation of the quadratic term coefficient was 0.474.

From equations (4) and (5), we can obtain that the critical buried depth L_e is 2.31 m and the strain energy coefficient E is 1.39. The optimal burial depth L_j was 1.18 m,

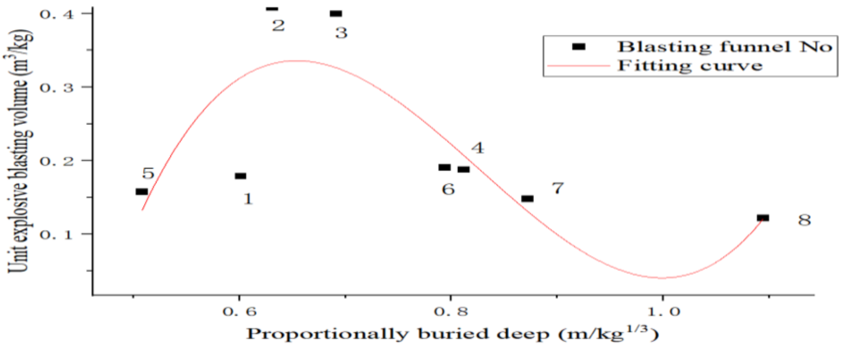


Figure 6. The characteristic curve of single-hole blasting crater

the optimal blasting funnel volume V_j was 1.26 m^3, the optimal funnel radius R_j was 1.03 m, the blasting action index n was 0.87, and the unit explosive consumption was 1.07 kg/t. The results of the blasting funnel test are shown in Table 2.

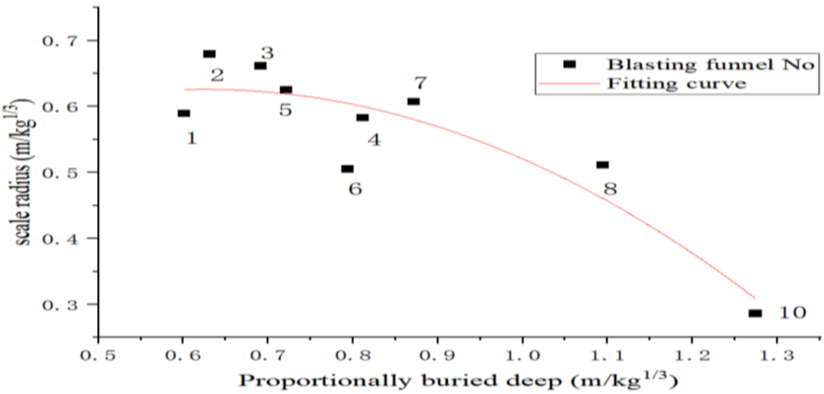


Figure 7. Relationship between the proportional radius and proportional burial depth

Table 2. Explosive properties and blasting crater test results

Name of the explosive	explosive density ρ(g · cm-3)	Optimal proportional volume V/Q(m^3 · kg-1)	Optimal scale radius b_{rj}(m · $kg^{-1/3}$)	The optimal ratio of burial depth b_j(m · $kg^{-1/3}$)
2# Rock emulsion explosive	1.10~1.25	0.273	0.622	0.712

4 Determination of Blasting Parameters for Large-Diameter Deep-Hole Mining Drilling

The time required to determine the spacing between the blast holes and the explosive list produced in the test stope cannot be simply cited by the relevant parameters obtained from the single-hole blasting funnel test. Considering that there are many types of ore in Jinchanghe and the geological conditions of ore rock, the explosiveness of various types of ore rock has not been fully grasped. Therefore, for the first mining stop of Jinchanghe Mine 15#, the hole spacing was determined to be 1.6~1.8 times the optimal funnel radius, and gradually optimized in combination with the improvement of blasting process technology during the test.

For the Jinchanghe mine with a large diameter deep hole aperture of Φ165 mm, the current use of 2# rock emulsion explosive, the diameter of the medicine package is Φ15 cm, the length is 1.0~1.2 m, according to the calculation of the spherical medicine package, the length-diameter ratio is 6.67~8.0, and the single-layer charge is 25~30 kg.

1) hole spacing a

When the single-layer charge is 25 kg: $a_1=(1.6\sim1.8)\times b_{rj}\times Q^{1/3}=2.91\sim3.27$ m; When the single-layer charge is 30 kg: $a_2=(1.6\sim1.8)\times b_{rj}\times Q^{1/3}=3.09\sim3.48$ m.Considering the width of the 15# experimental stope of Jinchanghe Mine is 15 m, combined with the blasting practice similar to the large hole distance and small resistance line in mines, the groove area is used as the direction of the minimum resistance line pointed by the lateral collapse blasting action, and the gun hole row is arranged along the width of the mining area, and the middle hole distance of each row is 3.2 m, and the distance between the side hole and the middle hole is 2.6 m.

2) Row spacing (first-row minimum resistance line) b

According to the mining and blasting experience of large hole spacing and small resistance line in Anqing copper mine and other similar mines and the results of single-hole series blasting funnel test, the middle gun hole row spacing B = 2.8m, and the encrypted side hole row spacing B = 2.6 m. to optimize blasting effects and control harmful effects.

3) Stratified collapse height h

When the stratified charge is 25 kg:$h_1=0.5+b_j\times Q^{1/3}=2.58$ m≈2.6 m; when the stratified charge is 30 kg: $h_2=0.5+b_j\times Q^{1/3}=2.71$ m≈2.7 m. Therefore, according to different charges, the stratified collapse height h is 2.6 m.

4) Explosive single consumption q

According to the width of the stope of 15 m, 6 holes are arranged in each row along the width of the stope, and 6 holes in one row are taken as the calculation unit, and the blasting volume V of the unit body is $V=15\times b\times h=109.2$ m^3. The average weight of ore is calculated as 3.42 t/m^3, and the unit collapse volume is 373.46 t.

5 Conclusions and Recommendations

1) The vertical section measurement method of the blasting funnel reference plane with BJSD-3 tunnel section meter as the main body is efficient and accurate; The data post-processing using 3DMine 3D mining engineering software and Origin software is concise and intuitive, forming a systematic and scientific blasting funnel test method.

2) According to the results of the single-hole series blasting funnel test, the design parameters of large-diameter deep-hole rock drilling using 2# rock emulsion explosives in the industrial test stope were determined.

3) When drilling in a large-diameter deep hole mining area, the deflection of the borehole will lead to an increase in the hole spacing at the bottom of the mining area and affect the blasting effect. The principle of rock drilling and hole repair in the recommended mining area is: when the hole spacing is greater than 2.5~3.0 times the radius of the optimal blasting funnel, or when the ore control area of a single gun hole is greater than 15~18m^2, the hole filling is required.

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