The Blasting Funnel Parameters Design and Simulation Study of Shizishan Mine Deep Mining

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ABSTRACT

Based on the mine of Shizishan deep mining blasting parameters experiment and numerical calculation, with using the finite element software ANSYS/ls-dyna to model, recursively analysis the best spacing of multi-hole hole, using ANSYS/Ls-dyna to simulate the action of multihole hole blasting stress distribution and transmission mechanism. Obtained the stress distribution of different time and the typical unit of stress - time history curve, analyzing the Broken degree of surrounding rock affected by the action of explosion stress wave and discussing the related factors of blasting funnel forming. Research shows that the numerical simulation results are basically consistent with the experiment, and reveal the process of stress wave propagation when explosive funnel form.

KEYWORDS: Blast funnel; Deep mining; Numerical simulation; Blasting parameters

INTRODUCTION

In the development of blasting theory, blasting funnel parameters theory and experimental study has been occupied an important position, because it not only can be used as the basis of selecing reasonable blasting parameters and improving blasting efficiency. With basing on blasting funnel test and comparison analysis of different explosive, it provide the basis for choosing explosives. In recent years, the scientific research person to do a lot of work in the blasting parameter theory and in the combination of theory and practice aspects. The optimization of blasting parameters is good for improving the blasting efficiency, reducing construction cost and improving the level of enterprise technology has practical significance [1]. Wang Xinmin and others use of BP neural network or through blasting testing in order to get the optimal blasting parameters; with blasting vibration velocity test and borehole acoustic test, verify the rationality of the blasting parameters.Studying of deep rock tunnel smooth blasting parameters, then they put forward the calculation method of deep rock tunnel smooth blasting parameters [2 ~ 4].Gong min, Meng Zhuochao etc, using the method of numerical simulation combined with field experiment, research the Influence degree of blasting parameters influence on the driving speed in hard rock tunnel excavation.For blasting funnel test object, base on the dynamic finite element model constructed, study the formation process of blasting funnel, analysis dynamic damage characteristics of rock, and compared it with the measured data [5 ~ 6].Wei Mingyao etc, using of numerical simulation, analyze the unloading stress distribution and transfer rule of surrounding rock before and after blasting.Put damage in the process of surrounding rock damage characteristics reflected in load incremental iterative calculation, formed the elastic-plastic dynamic damage constitutive model, damage stresses iterative calculation method was deduced in detail[7 ~ 8]. Zhang Junbing, etc studied ice and frozen soil through blasting funnel test and blasting test method in the tuotuo river on tibet plateau [9]. Wang Peng , using ANSYS/ls-dyna nonlinear three-dimensional dynamic finite element software, simulation the action of the rocks with blasting stress distribution and transmission mechanism of Multiple hole blasting at the same time.Obtained the stress distribution nephogram of different time and stress - time history curve of typical unit, probes into the related factors affecting the formation of explosive funnel [10].Jianguo Wang in Final Highwall Governance apply Pre-splitting Blasting to achive a better effect[11].Combining with Shizishan mine production conditions and environment, using the finite element analysis software ANSYS/ls-dyna dynamic, by the method of embedding explosive in rock do multihole hole blast, field test and simulate the Multiple hole blasting at the same time and then discuss stress wave propagation mechanism and blasting funnel formation.

ENGINEERING BACKGROUND

Shizishan mine of Yunnan yuxi is located in the east of lvzhijiang, which located in the yungui plateau, zhongshan landscape. Mountains in the area is the north-west and north-south terrain slope generally between 30 ~ 40 °, ridge and the top of the mountain area is flat, general 10 ~ 20 °.Mining area topography looks like saddle, middle is high and both sides are low, the highest point in Shizishan is 2103.632 meters, the lowest point is 1720 meters, the relative elevation is 383 meters. The study of this text is located in the middle "west wind" ore, belong to the deep mining of the ore body.

THE THEORY BASIS

$$\sigma_\gamma = \left[1 + \left(\frac{\varepsilon}{C}\right)^{\frac{1}{P}}\right]\left(\sigma_0 + \beta E_P \varepsilon_P^{eff}\right) \qquad (1)$$

Type: σ_0 - the initial yield stress, MPa; ε - strain rate, S^{-1};

ε_P^{eff} - effective plastic strain; E_P - the plastic hardening modulus.

High explosive adopts the JWL state equation describes the relationship of the detonation pressure P , per unit volume internal energy E and the relative volume V [12] :

$$p = A\left(1 - \frac{\omega}{R_1 V}\right)e^{-R_1 V} + B\left(1 - \frac{\omega}{R_2 V}\right)e^{-R_2 V} + \frac{\omega E}{V} \qquad (2)$$

Type: P - explosion pressure, Pa; ω - g parameters, namely under the condition of constant volume, the rate of pressure relative to the internal energy; A, B - material constant; R1, R2 – dimensionless constant; V - relative volume of detonation product;E_0 - initial internal energy. using 2 # rock emulsion explosive in Field test, the parameters are shown in Table 1.

Table 1: 2 # rock emulsion explosive parameters

Density （kg/m^3）	Detonation velocity （m/s）	$P_{C\text{-}J}$	V_0	A (Gpa)	B (Gpa)	R_1	R_2	ω	E_0 (Gpa)
1.18×10^3	4.0×10^3	5.15	1.0	293.9	21.73	6.366	2.152	0.207	3.14

THE BLASTING FUNNEL TEST ANALYSIS OF VARIABLE BLAST HOLE DISTANCE

When variable Hole distance, the depth of hole is 1.45m and blast hole spacing are designed by 2.4 m, 2.8 m, 3.2 m and 3.6 m, a total of five hole, each hole is filled with same explosive. It Use the electric detonator to blast at the same time when variable distance Hole blast , the layout diagram of variable hole distance blasting funnel hole as shown in figure 3-1.

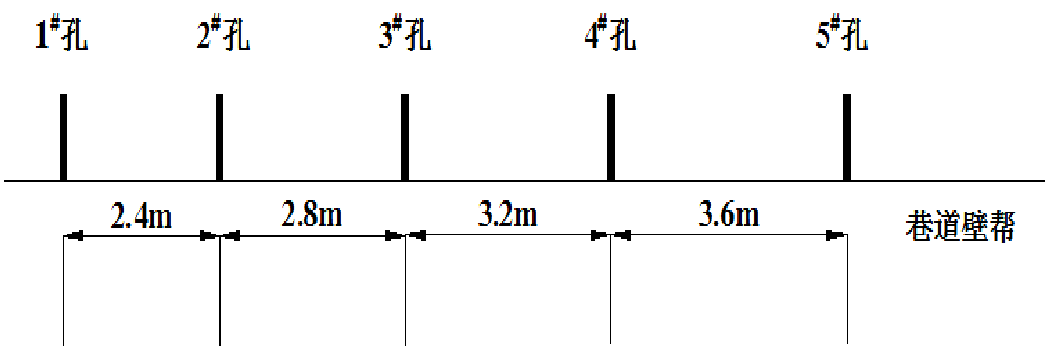


Figure 1: the layout diagram of variable hole distance blasting funnel hole

By observing the joint action strength of different distance hole which blasted, contrast and analysis block size and the broken situation of Trigonometric spine after blasting, make table 3-4 data statistics of variable hole distance blasting funnel hole.

Table 2: data statistics of variable hole distance blasting funnel hole

Serial number	*Explosive Dose /kg*	*Buried depth /m*	*Hole spacing /m*	*Blasting volume /m3*	*Specific charge /(kg·m-3)*	*Blasting effect description*
1#～2#	6	1.25	2.40	3.92	1.53	Trigonometric spine broke good, fragmentation rock uniform and small
2#～3#	6	1.23	2.80	4.66	1.28	Trigonometric spine broke good, fragmentation rock uniform
3#～4#	6	1.25	3.20	4.27	1.40	spine is not completely broken，a few Fragmentation rock
4#～5#	6	1.26	3.60	3.85	1.56	exist spine，Uneven blocks，Large Fragmentation rock

Analysis From the chart in charge 6 kg, Buried depth 1.25m, hole spacing of 2.4 m - 2.8 m broken lumpiness of surrounding rock by uniform does not need to secondary broken, for loading out of the blocks;In the hole spacing of 3.2 m to 3.6 m, broken is not completely, is not conducive to load and transport, some need a second broken rock.

THE PROCESS OF STRESS WAVE MODEL WHEN BLAST FUNNEL FORMED

4.1 ANSYS/ls-dyna is used to do numerically simulate [13 ~ 18], do the following assumptions:
1) Rock material is considered as the ideal elastic-plastic body, regardless the initial damage of Rock such as joint, crack;
2) Assuming that the expansion of the detonation product is adiabatic process, irrespective the seepage effect of detonation gas;
3) Explosive shape is cylinder evenly distributed, The explosion stress is evenly distributed in The hole wall;
4) Gravity is very small relatively to the explosion stress, do not consider the effect of gravity on charging.

Establishing the model

The numerical simulation using the 3 d solid164 unit type. Material model and the parameters of rock and explosive are described below.

Table 3: the physical and mechanical parameters of rock material

name	Density/ kg·m^{-3}	Modulus of elasticity/ E /10^{10} Pa	Poisson's ratio /λ	static Tensile strength /MPa	dynamic Tensile strength	Cohesive forcec/(MPa)	Angle of internal frictionφ/（°）
dolomite	2.83	20.01	0.269	2.956	29.56	2.611	41.99

Numerical simulation and field test using 2 # rock emulsion explosive, the parameters of explosive are shown in table 4.

Table 4: of 2 # rock emulsion explosive parameters

Density（kg/m3）	Detonation velocity（m/s）	PC-J (GPa)	V0	A (GPa)	B (GPa)	R1	R2	ω	E0 (GPa)
1.18×103	4.0×103	5.15	1.0	293.9	21.73	6.366	2.152	0.207	3.14

Set up five hole in the Mode, hole at the top of the free surface to the bottom of the material are: hole depth of 1.65 m, fill of 0.85 m, explosive column of 0.8 m and 1.35 m reserved rock, interval between adjacent holes are 2.4 m, 2.8 m, 3.2 m and 3.6 m, Starting from the orifice detonation. Model shape, size and hole arrangement as shown in figure 4-2 and table 5. in order to acquire complete unit Effective stress in numerical simulation, the solved time sets to 200 ms, calculation step length sets 0.1 ms, it output 1 results after model calculation 1step everytime. Use mm - kg –us to model, in order to ensure that the unit of harmonious and unified.

Table 5: model size

hole diameter /mm	*h*/m	*L*/m	*L1*/m	Explosive height*h1*/m	Filling height*h2*/m
100	3	15	3	0.8	0.85

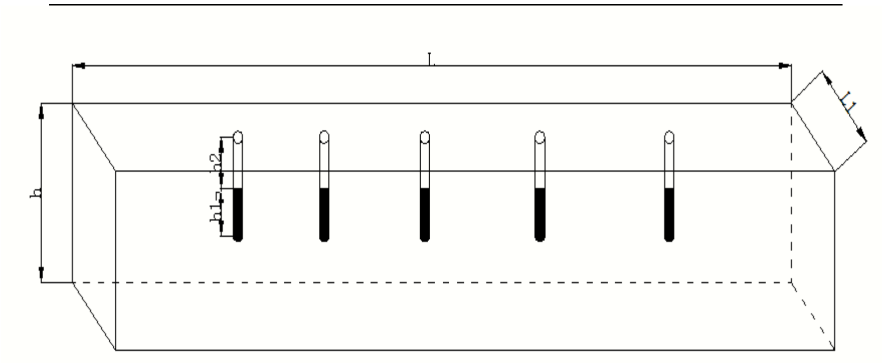


Figure 4: 1 model and hole arrangement

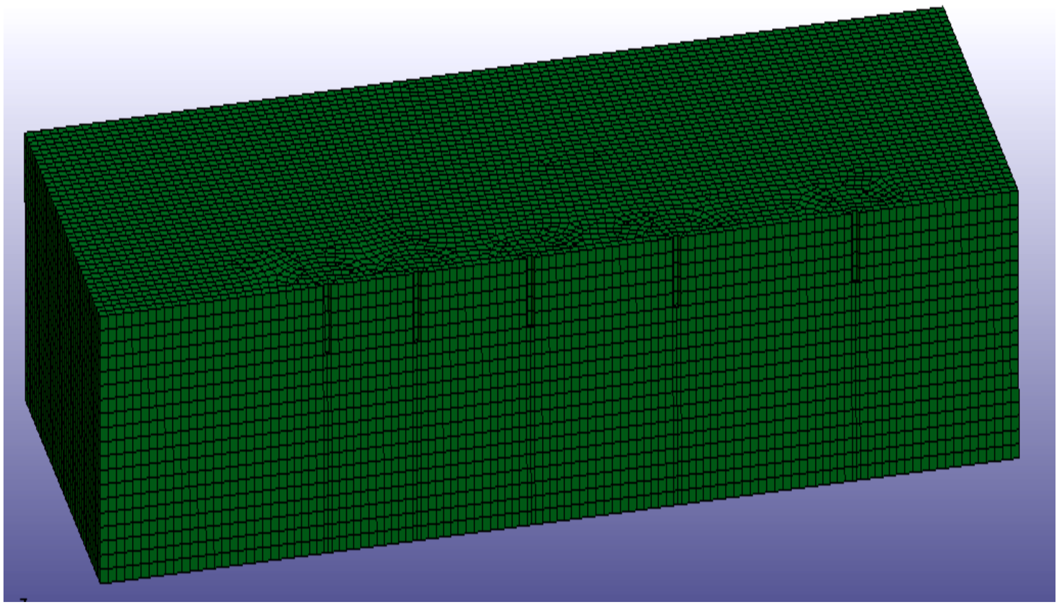


Figure 5: the figure of model mesh

The results of blasting funnel stress wave numerical simulation

In order to conveniently research The Adjacent two charge superposition of Stress wave, Choose seven typical unit in the model and set the stress - time course records.Choose typical unit as shown in figure 4-3, 4-5, stress time history curve as shown in figure 4-4, 4-6.

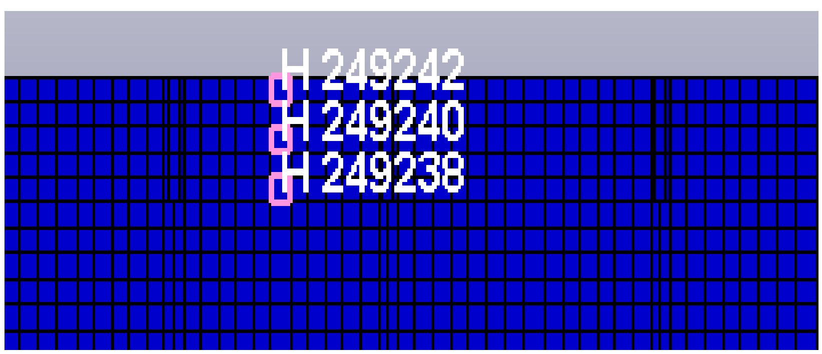


Figure 6: selected unit location

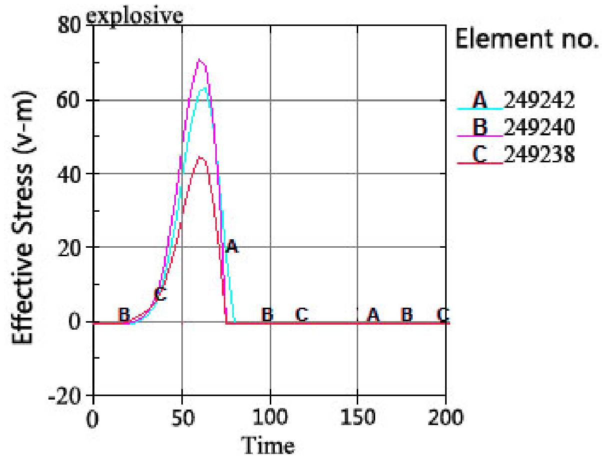


Figure 7: selected unit effective stress time curves

When the unit of the peak stress is greater than the mine deep rock dynamic tensile strength of 26.56 MPa, said the rock unit can be damaged; Conversely said the rock unit is not damaged. Realise from Figure 7, the superimposed stress of each selected unit at 60 ms is to maximum, the maximum effective stress of three selected units in a same center is about 69 mPa, and its maximum at the top of Pthe units is about 62 mPa, the maximum effective stress at the bottom of the units is about 42 mpa. So in blasting funnel test of variable blast Hole distance, because of the stress wave superposition, the strengthening area of effective stress is on the hole center selected unit, and the weaken effective stress area is near the left or right of the center hole.

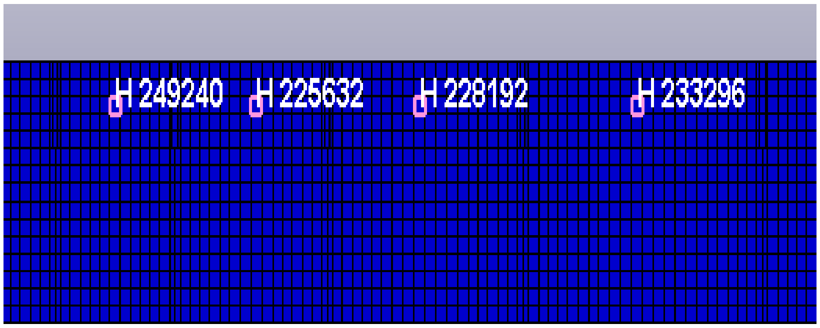


Figure 8: The position of typical unit

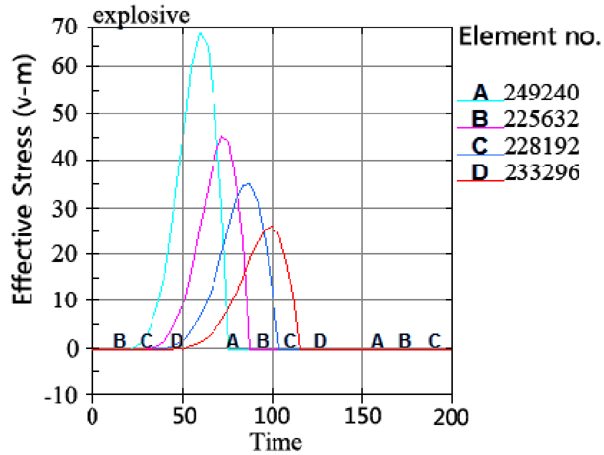
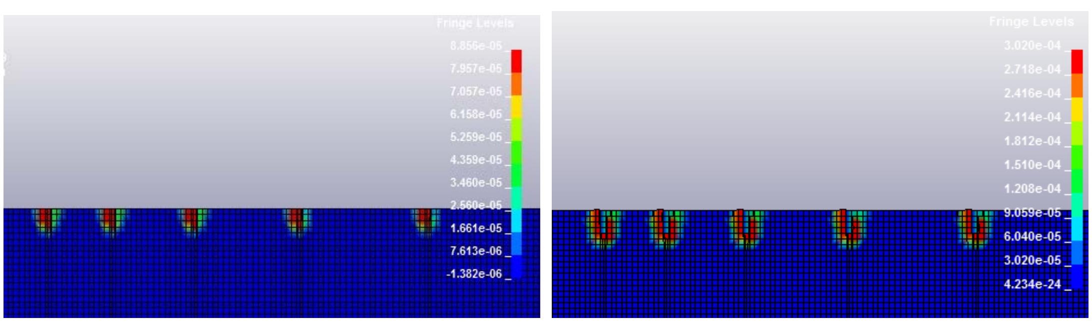


Figure 9: typical unit effective stress curve

When two adjacent charge detonation of wavefront of stress wave encounters and generate overlap together, stress wave on the surface of the matrix in the two tangent to generate synthetic tensile stress.If the distance between the two hole, the dynamic tensile strength of the rock under tensile stress of the composite values, then along the hole center will produce radial fractures, penetration throughout each other until the adjacent two gun perforation, formation of the funnel. Obtained from figure 8 and figure 9, the maximum effective stress of A and B units are significantly higher than the dynamic tensile strength of rock, from figure 6 can be obtained, hole spacing area of 2.4 m and 2.8 m will eventually connect, and the maximum effective stress of C units slightly larger than the dynamic tensile strength. Coupling with figure 7, it can be seen that the hole spacing of 3.2 m can't completely through. The maximum effective stress of unit D is less than the dynamic tensile strength, eventually cannot be well through, only to form independent blasting funnel. The adjacent blast hole spacing is one of the factors which influence the funnel connecting. In the actual blasting production, the choice of a reasonable hole spacing can be beneficial to improve the blasting effect.Figure 4-7 for the diagram of variable hole blasting funnel stress transmission schematic .



t=8ms t=20ms

Figure 10: *Continues*

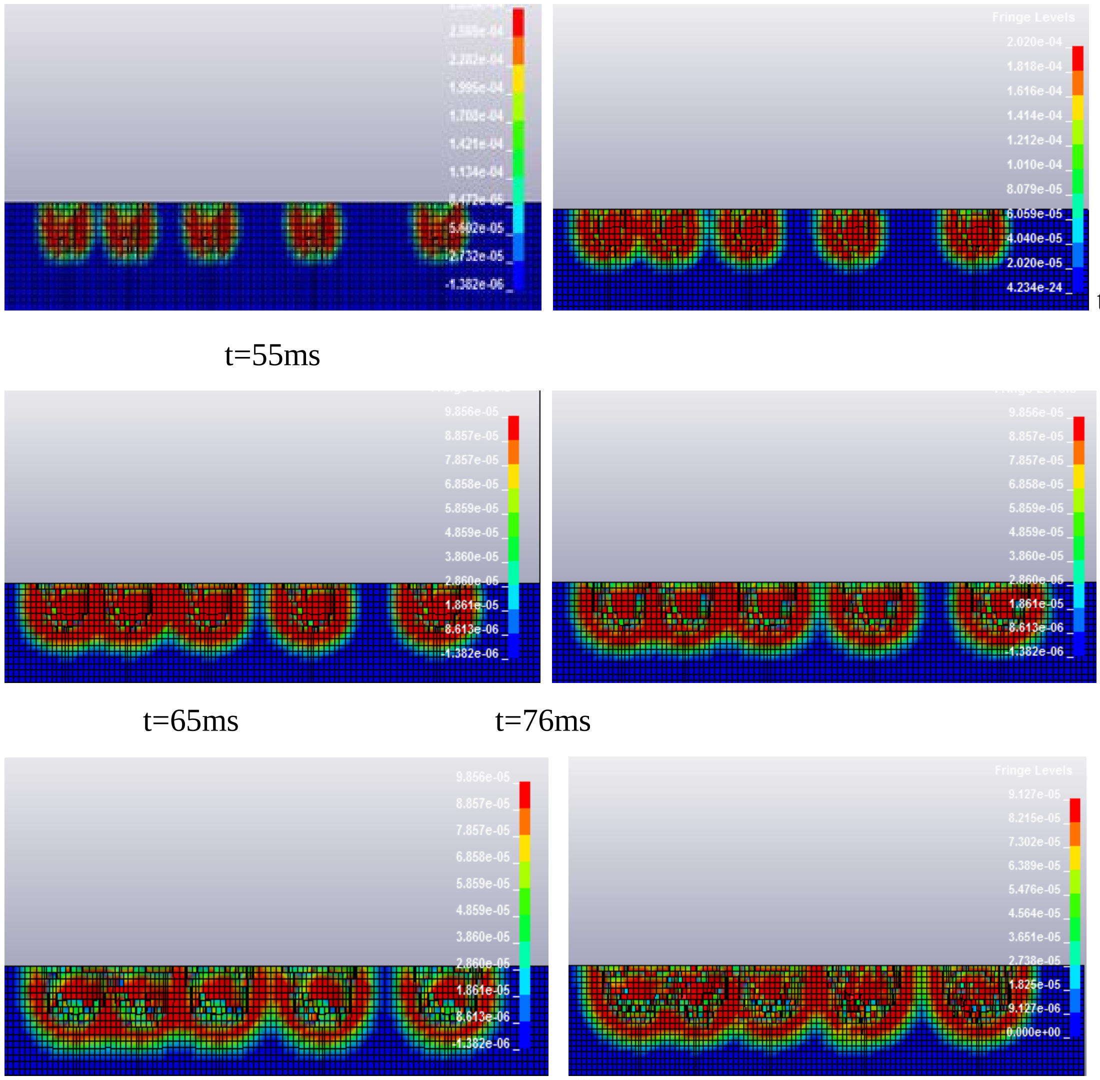


Figure 10: the diagram of variable hole blasting funnel stress transmission schematic

Figure 10 reflects the process of variable hole blasting funnel stress wave transmission.When 65 ms, The blasting stress wave broke rock and form similar with the destruction of the "funnel" for rock. when 88 ms, the compression damage zone and tensile damage zone of the blasting hole has evident boundary; when 95 ms, Funnel linking between Suitable adjacent hole spacing, and the rocks of adjacent hole are completely broken, forming a relatively large funnel.

Seen from the numerical simulation, funnel volume of different hole spacing is not the same size, blasting effect between each two hole is also different. When the hole spacing is 2.4 m, two holes groove in the Joint action of explosive blasting along the center line. When the hole spacing is 2.4 m, two holes formed connected, while Joint action is relatively less, still can form groove, the spine between two adjacent hole does not exist;When the hole spacing is 3.2 m , two holes connected but do not form groove;When the hole spacing is 3.6 m, the two hole do not form a groove well, blasting funnel formed is independent. Analysis from the above results is not hard to see that, when the distance between two hole is relatively small, the mutual superposition of explosive is larger, blasting effect for rock is stronger and the spine between hole is not exist. The numerical simulation results of different hole spacing blast funnel show that hole spacing is equal to or a little less than 2.8 m, the adjacent blasting funnel are connect well, the bottom ore of the hole achieve well broken.The numerical simulation results are same with blasting funnel test results.

CONCLUSION

By using the method of embedding explosive in rock mass this experiment do the variable blast Hole distance experiment and simulation multi-hole blasting funnel. Using ANSYS/ls-dyna dynamic finite element analysis software and then discuss the stress distribution of blasting funnel stress wave and The formation of blasting funnel. Draw the following conclusions:

The simulation results of the variable hole blasting funnel experiment show that when hole spacing is equal to or less than 2.8 m, two adjacent blasting funnel link better, the bottom of hole can achieve better broken. The better hole spacing is 2.8 m. The numerical simulation results is same with the Field test results. From the finite element numerical simulation it find that when the distance between the two hole is relatively small, the mutual superposition effect of explosive energy in the blast process is larger, blasting effect for rock is stronger and the blast hole have no spine.

REFERENCES

1. Liu Ze, Zhu Chuanqu, Xie Donghai, Chen Caixian, Hu Lei small hard rock blasting parameters optimization design and practice [J]. Journal of rock mechanics and engineering, 2007, 24 (1) : 0070 ~ 0073
2. Wang Xinmin, Zhao Bin, Wang xianlai, Zhang qinli drilling and blasting parameter optimization based on BP neural network [J]. Journal of central south university (natural science edition), 2009, 40 (5) : 1411 ~ 1416
3. Chen Junhua, Li Xinping, Zhang Jiasheng protection layer excavation blasting parameters based on the blasting damage of rock Taiwan study [J]. Journal of rock mechanics and engineering, 2016, 35 (1) : 0098 ~ 0108
4. Fu Yuhua, Li Xibing, Dong Longjun damage of deep rock mass tunnel smooth blasting parameters under the condition of study [J]. Journal of rock mechanics and engineering, 2010, 31 (5) : 1420 ~ 1424
5. Gong Min, Wang canhua, Liang Lixun, wang hua, Wen Bin, Wu Haojun the determination of the main blasting parameters in hard rock drivage Wu Haojun and function [J]. Journal of rock mechanics and engineering, 2015, 40 (7) : 1526 ~ 1233
6. Meng Zhuo, Zhou Keping damage model based on the pull - pressure dynamic response analysis of the blasting funnel [J]. Journal of central south university (natural science edition), 2012 lancet (7) : 2717 ~ 2722
7. Wei Mingyao, WangEnyuan, Liu xiaofei, Wang Chao deep coal seam pressure relief effect of prevention and control of blasting shock pressure numerical simulation research [J]. Rock and soil mechanics, 2011, 32 (8) : 2539 ~ 2544
8. Shuang-Ying Zuo, xiao Ming, Xu Jianke, Shi Wenbing tunnel blasting excavation surrounding rock dynamic damage effects numerical simulation [J]. Rock and soil mechanics, 2011, 32 (10) : 3171 ~ 3177
9. Zhang Junbing, Pan weidong, Fu hongxian. The qinghai-tibet railway permafrost years high ice content of blasting funnel test study [J]. Journal of rock mechanics and engineering, 2005, 24 (6) : 1077 ~ 1081
10. Wang peng; Zhou Chuanbo;Geng XueFeng;Jia Jiangong porous with the numerical simulation research on the formation mechanism of blasting funnel [J]. Rock and soil mechanics, 2010, 31 (3) : 0993 ~ 0997
11. Jianguo Wang, Longfa Luan, and Haohao Wang: "Application of Pre-splitting Blasting in Final Highwall Governance" *Electronic Journal of Geotechnical Engineering*, 2016 (21.03) pp 1331-1340. Available at ejge.com.
12. Zhang Sherong.Kong Yuan;Wang Gaohui underwater and air explosion shock wave propagation analysis [J]. Journal of vibration and shock, 2014 (13);0148-0153.
13. Li Wangxing coal blasting numerical simulation study [D] Henan university of technology, master thesis, 2010
14. Wang Qingguo tunnel rock blasting theory research and numerical simulation [D] the southwest jiaotong university, master thesis, 2008

15. Frédéric Victor Donzé and Pascal Bernasconi: “Simulation of the Blasting Patterns in Shaft Sinking Using a Discrete Element Method” *Electronic Journal of Geotechnical Engineering*, 2004: pp 1-44. Available at ejge.com.

16. Rui Song, Jianjun Liu, and Meng Li: “New Method for Structured Finite Elements Modeling of Porous Media Reconstruction” *Electronic Journal of Geotechnical Engineering*, 2014 (19.M), pp 2909-2915. Available at ejge.com

17. Murad Abu-Farsakh, Jie Gu, George Voyiadjis, and Qiming Chen: “Finite Element Parametric Study on the Performance of Strip Footings on Reinforced Crushed Limestone over Embankment Soil” *Electronic Journal of Geotechnical Engineering*, 2012 (17.F), pp 723-742. Available at ejge.com

18. Ramy Saadeldin, Manal A. Salem, and Mani A. Lotfi: “Experimental Investigation and Finite Element Analysis of Highway Embankment on Soft Clay” *Electronic Journal of Geotechnical Engineering*, 2012 (17.D), pp 402-417. Available at ejge.com

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