

Numerical Study on Impact Characteristics of Filling Body with Deep Hole Blasting in Underground Stope

Nan Jia

School of Resources and Safety Engineering Central
Central South University.CSU
Changsha, China
Jianan1989@csu.edu.cn

Dongping Shi

School of Resources and Safety Engineering Central
Central South University.CSU
Changsha, China
shidongping@csu.edu.cn

Chao Wu

School of Resources and Safety Engineering Central
Central South University.CSU
Changsha, China
wuchao@mail.csu.edu.cn

Chengyu Xie

School of Resources and Safety Engineering Central
Central South University.CSU
Changsha, China
Xiechengyu87@csu.edu.cn

Abstract—To explore the impact characteristics of filling body on the both sides of stope under the dynamic loads in a deep underground metal mines, based on trock mechanical parameters experiment, dynamic was loaded by measured and de-noised blasting vibration monitoring-curve, response parameters development regularity of filling body were achieved and the dynamic characteristics was revealed by FLAC3D: filling body which first excavated show have relatively large dynamic stress and displacement, plastic zone and shear strain increment of the eastern increases with the time and then tended to be stable; plastic zone is more obvious in the root and floor of the first excavated filling body under dynamic impact effect. This is because of disturbance accumulation effect and filling technology. It shows that, surrounding rocks stability affected by mining sequence to a certain extent and blasting design after adjusting parameters based on impact characteristics analysis controls blasting boundary effectively and improve the stope stability.

Keywords-Explosion Mechanics; Deep-hole Blasting; Backfill; Dynamic Characteristics; Numerical Analysis

I. INTRODUCTION

With the improvement of mechanization in underground metal mines as well as the rapid development of blasting technology, the large scale blasting mining mode was used frequently in slowly inclined large and thick ore body[1-2]. However, as the

deep blast hole and big quantity of one-time explosive, in order to prevent deleterious effects on filling body and stope caused by blasting, it is necessary to control the blasthole boundary line and blasting vibration effect effectively [3-4].

An underground lead-zinc mine adopts large diameter deep hole stopping and subsequent filling method, the mining sequence is from room to pillar. The goaf formed from mining rooms on both sides was filled before mining the pillars. The resulting problems are that when pillar was mined, over break or under break phenomenon can be easily formed if blast hole border was not controlled well and ore dilution rate increased with waste mixed in. Therefore, felting out the nonlinear characteristics of filling body under the blasting dynamic disturbance when pillar was being mined, the blasting boundaries can be better controlled and improve blasting efficiency. Meanwhile, dynamic disturbances generated by room stope blasting and cumulative damage left in mining activity affecting the stability of roof, floor and filling body, which most likely cause goaf collapse. Thus, study of nonlinear dynamic disturbance characteristics of filling body, roof and floor under blasting loads has the practical significance to improve blasting effect and discriminate the stability of goaf[5-7]. In order to get reasonable analysis and forecast about dynamic response of filling body on both sides of the goaf and provide technical support to goaf stability analysis and mining blasting design, dynamic response problem of the goaf under blasting loads and nonlinear response characteristics of the filling body of the goaf were analyzed through rock

mechanics experiment, LS-DYNA and FLAC3D in a lead zinc mine. The measured goaf model and blasting design model are compared and analyzed to verify the reasonable of nonlinear blasting dynamic response characteristics finally.

II. NUMERICAL MODEL

A. Model construction

Three-dimensional dynamic finite difference model was constructed in order to reflect the dynamic response characteristics of goaf filling body objectively, see Fig. 1. Goaf was buried -600 ~-650m in depth, 40m in length, 8m in spans and 40m in height[8]. Strike value was 180m, trend value was 90m and vertical value was 120m along goaf which located in the middle of the numerical model, bottom edge of the model is below the goaf for 41m. Mining sequence: Mining room 1 first and filled promptly, then room 2 and filled, goaf 3 was formed finally. Dynamic analysis was done after static analysis, bottom and around are fixed as boundary condition and then made dynamic disturbance numerical calculation[9]. Free field boundary conditions[10] was adopted and use local damping as the damping coefficient (formula 1). As the critical damping ratio d valued as 5% generally, damping ratio got a value of 0.1571.

$$\partial_1 = \pi d \quad (1)$$

Where d is the critical damping ratio.

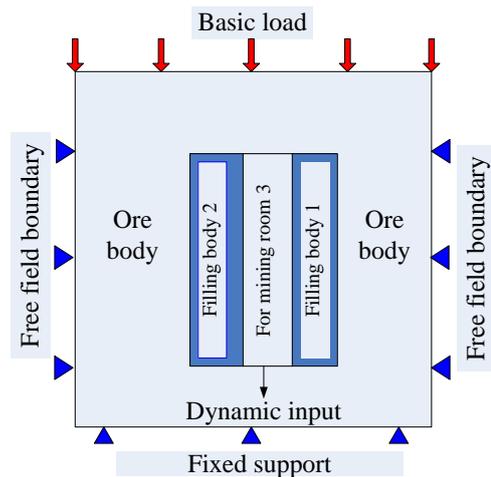


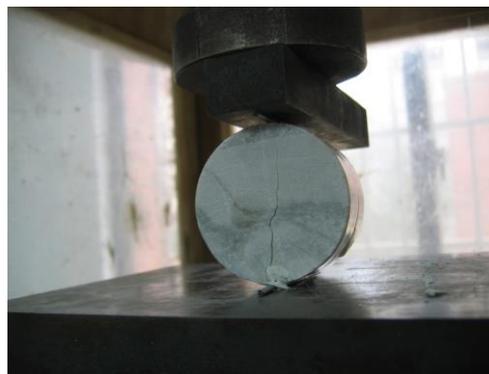
Figure 1. Model of numerical analysis

B. physical and mechanical parameters rock

As shear failure is one of the main rock destruction forms, Mohr-Coulomb yield criterion and mineral rock elastic-plastic constitutive relation were adopted[12]. In order to make numerical calculation and analysis more accurately, physical and mechanical parameters indexes of standard-sized rocks and filling body were measured (as is shown in Fig. 2) and made necessary reduction computing[13]. Rock physical and mechanical parameters after reduction is shown in table I. In addition, initial situ stress field generated after inversion of the results ((1) $\sigma_1=21.9\text{MPa}$; (2) $\sigma_2=28.5\text{MPa}$; (3) $\sigma_3=17.9\text{MPa}$) which were measured according to the ore blocks (-680.4m) situ stress.



(a) Uniaxial compression test



(b) Tensile strength test

Figure 2. Rock mechanical parameters experiment

TABLE I. THE PHYSICAL AND MECHANICAL PARAMETERS ROCK IN DEEP MINE

Rock name	Weight $\gamma/(g \cdot cm^{-3})$	Elasticity modulus E/Gpa	Poisson ratio ν	Compressive strength σ_c/Mpa	Tensile strength σ_t/Mpa	Cohesion c/Mpa	Internal friction angle ($^\circ$)
Surrounding rock	3.1	9.18	0.24	12.9	2.11	3.56	39.6
Ore body	3.46	17.4	0.25	14.3	2.37	3.05	36.3
Filling body	3.23	5.7	0.23	0.35	0.12	0.35	38.1

C. 1.3 LS-DYNA model

Field test on blasting vibration velocity is difficult as the underground stope space is limited[14]. Therefore, the numerical model was built by LS-DYNA. Constitutive model and parameter of explosives can be seen from formula 2 and Tab.II[15]. air-separated charging structure which used at mine were adopt (radial spacing ratio is 0.588). The blasting vibration

velocity and blasting vibration velocity time-history curve of monitorings can be seen from Fig. 3 and Fig. 4. Waveform was smoothed and filtered by Origin software. Three-dimensional dynamic loading model was built through vertical and horizontal vibration time-history curves incidenced along the goaf surround rocks normally and tangentially(see Fig. 4)[16].

$$P_0 = A_c \left(1 - \frac{\omega}{R_1 V_x}\right) e^{-R_1 V_x} + B_c \left(1 - \frac{\omega}{R_2 V_x}\right) e^{-R_2 V_x} + \frac{\omega E_c}{V_x} \quad (2)$$

Where P_0 , V_x and E_c are pressure, relative volume and initial specific internal energy respectively; A_c , B_c , R_1 , R_2 and ω are material constants. Explosive state equation can be obtained by determining these

several correlated coefficients. And detonation pressure P_b , detonation velocity D_b and chemical energy E_b can be determined by CJ conditions.

TABLE II. PHYSICAL AND MECHANICAL PARAMETERS OF EXPLOSIVE

material	density $/(kg \cdot m^{-3})$	D_b $/(m \cdot s^{-1})$	P_b /GPa	A_c /GPa	B_c /GPa	R_1	R_2	ω
explosive	1050	3750	9.5	200	0.21	4.6	1.05	0.32

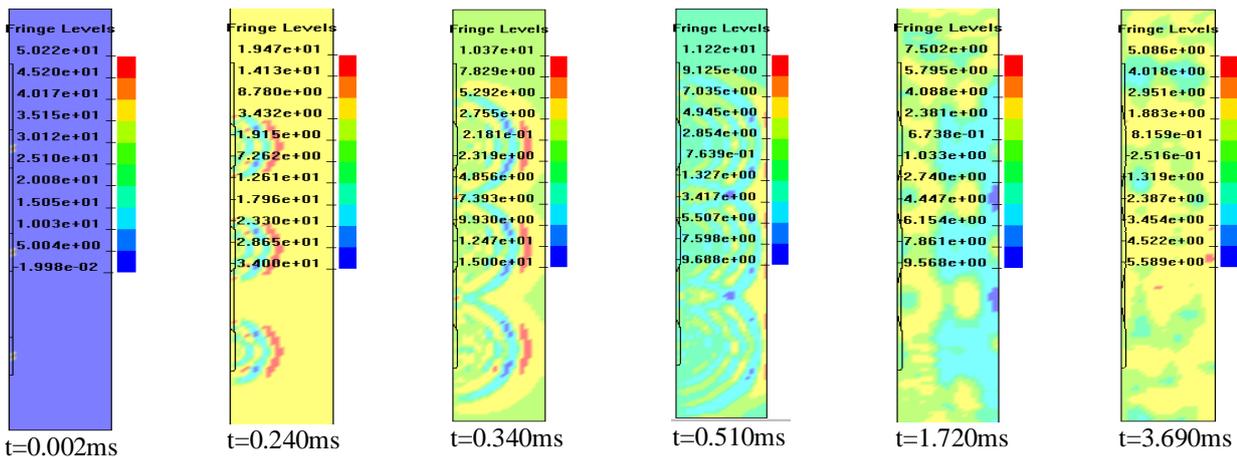


Figure 3. Distribution map of velocity blasting vibration each time in horizontal direction

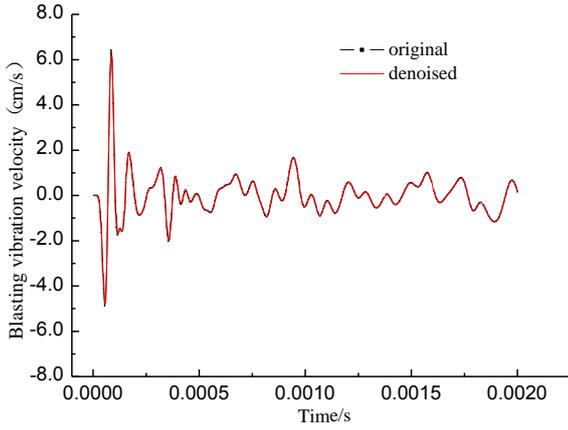


Figure 4. Velocity time-history curve of blasting vibration

III. ANALYSIS ON NUMERICAL RESULTS

Three-dimensional graphs of filling body were enmeshed from central axis and processed by Tecplot and Origin software after blasting dynamic excavation

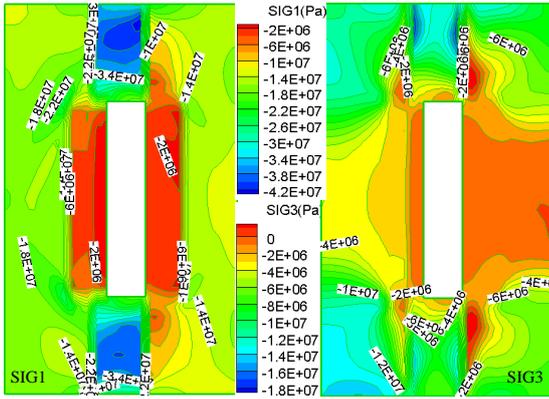


Figure 5. Distribution law of principal stress

B. Dynamic displacement and velocity vector

Fig. 6 shows dynamic displacement nephogram of goaf surrounding rocks. Amplitude of vertical dynamic displacement was 0 ~ 80mm after blasting dynamics excavation, while the horizontal dynamic displacement amplitude was 0 ~ 55mm. The maximum horizontal dynamic displacement appeared in the roof and floor of west filling body and the maximum vertical dynamic displacement exits in the roof. Dynamic disturbance have little influence on goaf stability in general as dynamic displacements on wall rocks are small. Arrows in Fig. 6 indicate the velocity vector of surrounding rock and backfill. Dynamic wave propagation in the model can be fully reflected by velocity vector distribution: surrounding rock and backfill are moving to the interior goaf with impact loading; filling body on both sides of goaf have small dynamic displacement which have little effect on the mined-out area stability.

C. plastic zone and shear strain increment

As is shown in Fig. 7, plastic zone was produced in filling body under the influence of nonlinear dynamic

numerical analysis. And nonlinear dynamic response characteristics under blasting loads were analyzed through dynamic stress, dynamic displacement, velocity vector, plastic zone and the distribution of shear strain increment of the filling body.

A. Dynamic stress

Principal stress distribution in medial axis profile under dynamic disturbance is shown in Fig. 5. The influence scope of blasting excavation on goaf surrounding rocks is much larger than static unloading. The maximum principal stress value exits at roof and floor meanwhile there is no stress concentration phenomenon. On the other hand, study from the minimum principal stress, tensile stress generates at partial surrounding rocks. The maximum range of tensile stress is in the eastern surrounding rocks and the maximum value is 0.11MPa which smaller than the minimum tensile strength value of wall rocks. Therefore, tensile failure under blasting loads would not appeared in filling body on both sides of goaf and keep stable generally.

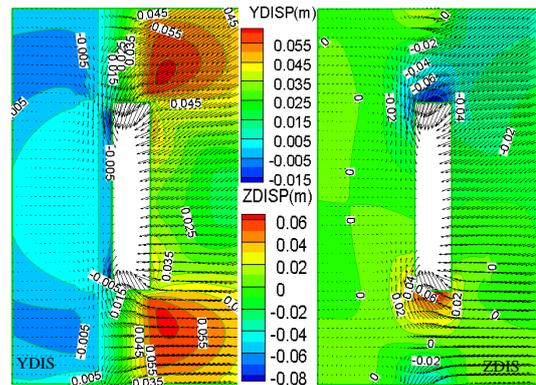


Figure 6. Change law of displacement

disturbance. Due to the difference of blasting dynamic excavation order and the quality of the filling body, plastic zone produced in filling body on the east side of goaf was significantly large, while filling body on the west side of goaf especially the central part show little plastic zone. Collapse destruction could happen easily because parts of filling body on the east side was still in shear failure state after excavation, and blasting cumulative effect made the expansion of plastic zone. Damage degree of filling body under dynamic disturbance can be reflected by shear strain increment. Shear strain is the ratio of shear stress and shear modulus, see formula (3).

$$\gamma = \frac{\tau_0}{G} \quad (3)$$

Where γ is shear strain; τ_0 is shear stress; G is shear modulus.

Damage extent of goaf surrounding rocks under dynamic disturbance can be reflected through shear strain increment. Fig. 11 shows contour of shear strain

increment. Changing trends of shear strain increment can be summarized as from increasing progressively to stable finally. Shear strain increment of goaf is small on the whole. Shear strain increment on the east side of wall rocks is large relatively and the maximum value is only 5.5×10^{-3} which cannot generate shear rupture surface. Failure would occur first from here with the influence of blasting loads disturbances continuing enhance and cumulate.

At the same time, based on the comprehensive analysis on the response parameters, nonlinear response of filling body is obtained under blasting, meanwhile the influence of mining sequence on stope stability under the engineering background of this paper can be

summarized: Filling body on the firstly mining and filling side have low stability condition than the later side. The main reasons are that, the first excavated side disturbed more on times and lasting period due to blasting accumulate effects, so the first excavated side filling body shows reduced stability and more damaging possibility with same charge weight. Secondly, the first excavated side as room, slag mixed in room when filling in order to save cost that lead strength decreased when recovery the pillar. On the second excavation, slag did not filled as there has been palled, so filling body strength increased significantly and pillar stability improved.

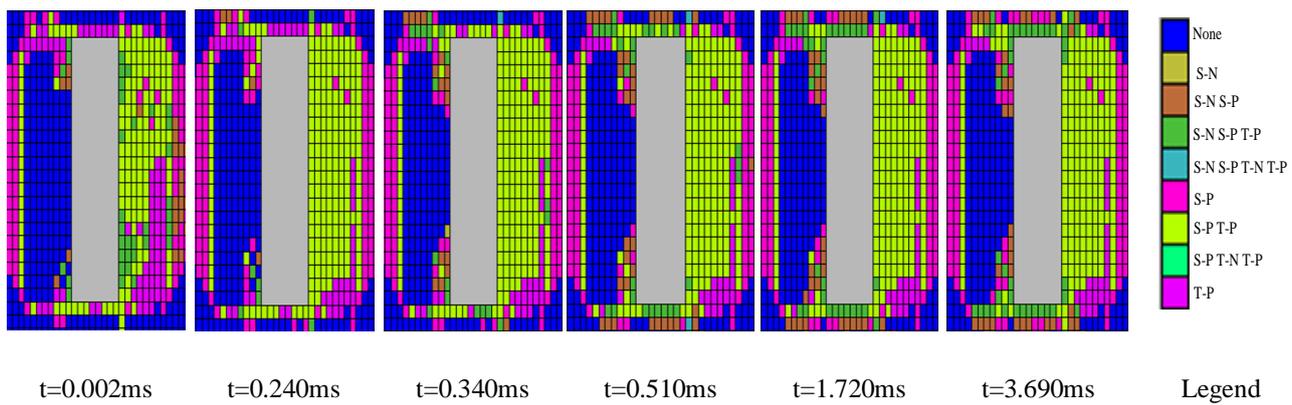


Figure 7. Contour of block state

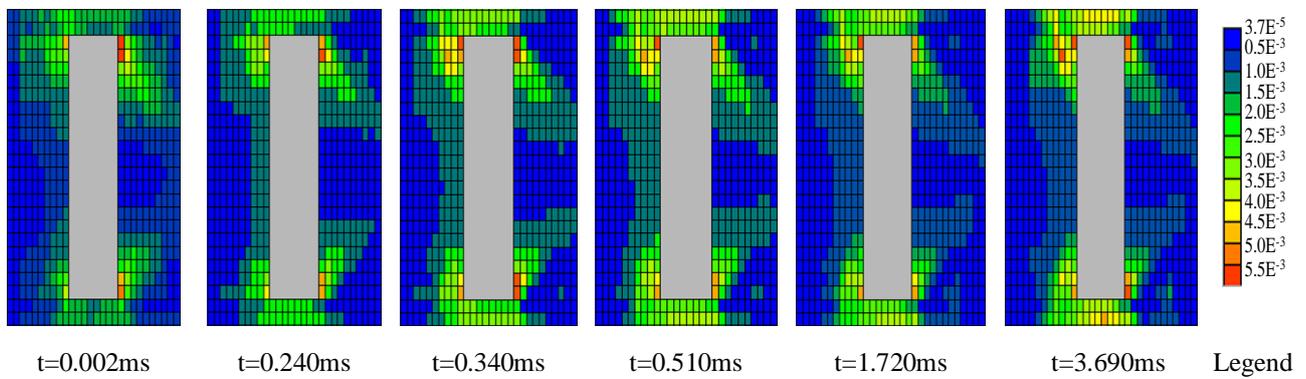


Figure 8. Contour of shear strain increment

IV. VERIFICATION BY CMS MEASUREMENT

Damage extent of the east filling body was significantly greater according to the nonlinear dynamic response characteristics analysis result. Therefore, some measures must be taken in mining blasting design to reduce the impact of blasting on the east filling body when pillar was being mined, such as reduce hole charge in the near filling body appropriately and increase initiation segment number. The measured model of goaf which was formed after pillar mined through blasting parameters adjustment is shown in Fig. 9. Measured model was detected by CMS and

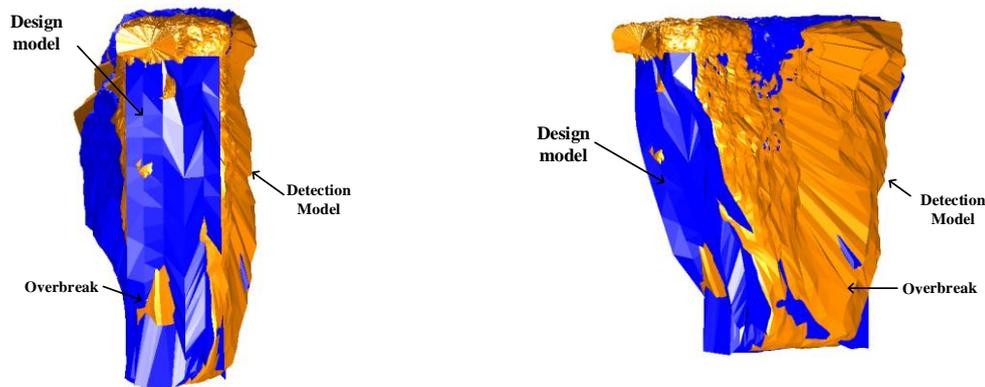


Figure 9. The detection model of goaf by CMS

V. CONCLUSION

To reconstruct the response model of deep goaf with deep hole blasting objectively, three-dimensional dynamic finite difference was used and dynamic was loaded by the measured and de-noised blasting vibration monitoring-curve. Nonlinear response evolution characteristics of filling body were revealed and the influence of mining sequence on stope stability was discussed.

Dynamic characteristics was revealed by FLAC3D: filling body which first excavated show have relatively large dynamic stress and displacement; plastic zone and shear strain increment of the later excavated side increased gradually and then tended to be stable within a period time.

Influence of mining sequence on stope stability under the engineering background of this paper was summarized: filling body on the firstly mining and filling side have low stability condition than the later side. And reasons were analysed from two aspects (disturbance accumulation effect and filling technology).

Blasting parameters were optimized through impact characteristics numerical analysis of filling body, and CMS measured model validated that, adjusting blasting parameters based on nonlinear response of backfill can control blasting boundary effectively reducing mining dilution rate and loss rate and improve the stope stability.

ACKNOWLEDGMENT

The authors wish to acknowledge the editors and the anonymous reviewers for insightful suggestions on this

processed through Surpac software. Blasting effect could be judged intuitively by measured model. As the figure shown, blasting design model basically tallied with the measured model. Over break phenomenon still existed in a small part of the filling body lower half but it was within the allowable range in addition to errors caused by probe. Therefore, study on dynamic response characteristics of filling body under blasting loads could make blasting borders better controlled and exploitation dilution rate reduced.

work. The projects (51274250) supported by National Natural Science Foundation of China; projects (No. 2012BAK09B02-05) supported by the National Science & Technology Pillar Program during the Twelfth Five-year Plan Period; projects(CX2013B080) supported by Hunan Provincial Innovation For Past graduate.

REFERENCES

- [1] D.R. Tesarik, J.B. Seymour and T.R. Yanske, "Post-failure behavior of two mine pillars confined with backfill," *International Journal of Rock Mechanics & Mining Sciences*, vol. 40, Dec. 2003, pp. 221-232, doi: 10.1016/S1365-1609(02)00139-9.
- [2] TAO Ming, LI Xi-bing and WU Cheng-qing, "3D numerical model for dynamic loading-induced multiple fracture zones around underground cavity faces," *Computers and Geotechnics*, vol. 54, Dec. 2013, pp. 33-45, doi: 10.1016/j.compgeo.2013.06.002.
- [3] Melih Genis, "Assessment of the dynamic stability of the portals of the Dorukhan tunnel using numerical analysis," *International Journal of Rock Mechanics and Mining Sciences*, vol. 47, Dec. 2010, pp. 1231-1241, doi: 10.1016/j.ijrmmms.2010.09.013.
- [4] YU Yang, BAI Jian-biao, CHEN Ke, WANG Xiang-yu, XIAO Tong-qiang, et al, "Failure mechanism and stability control technology of rock surrounding a roadway in complex stress conditions," *Mining Science and Technology*, vol. 21, Dec. 2011, pp. 301-306, doi: 10.1016/j.mstc.2011.05.024.
- [5] ZHANG Yao-hua and Hani S, "Mitri. Elastoplastic stability analysis of mine haulage drift in the vicinity of mined stopes," *International Journal of Rock Mechanics & Mining Sciences*, 2008, 45: 574-593. vol.45, Dec. 2008, pp. 574-593, doi: 10.1016/j.ijrmmms.2007.07.020.
- [6] HAO Zhi-yong, ZHOU Chao, LIN Bai-quan, PANG Yuan and LI Zi-wen, "Pressure-relief and permeability-increase technology of high liquid-solid coupling blast and its application," *International Journal of Mining Science and*

- Technology, vol. 24, Dec. 2014, pp. 45-49, doi: 10.1016/j.ijmst.2013.12.008.
- [7] XIE Cheng-Yu, LUO Zhou-Quan, JIA Nan, YANG Biao and CHENG Gui-hai, "Safety roof cutting thickness in mining gently inclined and extremely thick ore body," *Journal of Mining & Safety Engineering*, vol. 30, Dec. 2013, pp. 278-284, doi: 1673-3363-(2013)02-0278-07.
- [8] G. Exadaktylos and M. Stavropoulou. A specific upscaling theory of rock mass parameters exhibiting spatial variability: Analytical relations and computational scheme [J]. *International Journal of Rock Mechanics & Mining Sciences*, 2008, 45 (7) : 1102-1125.
- [9] JIANG Wei, WANG Yan-hai and FENG Qiang, "Study of the influence of blasting load on fresh concrete at adjacent chambers based on DDA," *Proc. IEEE Symp. 2012 International Workshop on Information and Electronics Engineering (IWIEE)*, IEEE Press, Dec. 2012, pp. 563 - 567, doi: 10.1016/j.proeng.2012.01.004.
- [10] John Coggan, Fuqiang Gao , Doug Stead and Davide Elmo, "Numerical modelling of the effects of weak immediate roof lithology on coal mine roadway stability," *International Journal of Coal Geology*, vol. 90, Dec. 2012, pp. 100-109, doi: 10.1016/j.coal.2011.11.003.
- [11] ZHAO Xing-dong, LI Lian-chong, TANG Chun-an and ZHANG Hong-xun, "Stability of boundary pillars in transition from open pit to underground mining," *Journal of Central South University*, vol. 19, Dec. 2012, pp. 3256-3265, doi: 10.1007/s11771-012-1402-x.
- [12] M.R. Karim, "Behaviour of piles subjected to passive subsoil movement due to embankment construction—A simplified 3D analysis," *Computers and Geotechnics*, vol. 53, Dec. 2013, pp. 1-8, doi: 10.1016/j.compgeo.2013.04.004.
- [13] SHEN Chun-ming, LIN Bai-quan, MENG Fan-wei, Zhang Qi-zhi, and Zhai Cheng, "Application of pressure relief and permeability increased by slotting a coal seam with a rotary type cutter working across rock layers," *International Journal of Mining Science and Technology*, 2012, 22 (4) : 533-538. , vol. 22, Dec. 2012, pp. 533-538, doi: 10.1016/j.ijmst.2012.01.016.
- [14] LUO Zhou-quan, XIE Cheng-yu, JIA Nan, YANG Biao and CHENG Gui-hai, "Safe roof thickness and span of stope under complex filling body," *Journal of Central South University*, vol. 20, Dec. 2013, pp. 3641-3647, doi: 10.1007/s11771-013-1891-2.
- [15] YANG Shan-yuan, *Basis of rock blasting kinetic*, China coal industry publishing house, 1993.
- [16] Jafar Khademi Hamidi , Kourosh Shahriar , Bahram Rezai, and Jamal Rostami, "Performance prediction of hard rock TBM using Rock Mass Rating (RMR) system," *Tunnelling and Underground Space Technology*, vol. 25, Dec. 2010, pp. 333-345, doi: 10.1016/j.tust.2010.01.008.