Dynamic Damage Effect on Soft Rock Roadway Excavated by Blasting

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ABSTRACT

Aiming at providing a theoretical basis for safety construction measures, reasonable supporting techniques and water prevention and control methods, numerical simulation and in-situ ultrasonic test have been applied to investigate the dynamic damage effect on the surrounding rock of the driving face for deep rock roadway excavated by blasting. Numerical simulation adopted Mohr-Coulomb model and dynamic damage constitutive model developed secondary based on the user-defined constitutive modules of FLAC3D to calculate dynamically respectively. And the in-situ rock mass ultrasonic tests have obtained the features of velocity distribution of the surrounding rock of the ultrasonic test hole. The experiment results indicate that the error between the plastic failure zone of the simulation using Mohr-Coulomb model and the in-situ ultrasonic test is large, which imply Mohr-Coulomb model is improper for simulating the dynamic damage effect on the surrounding rock, while the result of simulation using the dynamic damage constitutive model match that of the in-situ ultrasonic test closely ,which show the dynamic damage constitutive model founded through secondary development is available.

KEYWORDS: Numerical simulation; dynamic damage effect; deep rock roadway; secondary development

INTRODUCTION

Tunneling and stopping are the two key parts of coal mining, safe and fast roadway excavation and support technique are necessary conditions for the safe and efficient production of mine[1]. In view of complex current conditions of deep rock laneway, its underground pressure presents some following obvious characteristic safe excavation: larger initial amount of deformation of surrounding rock, longer duration of the deformation is long and the high-stress fracturing [2]. When suffering from external disturbance, roof fall or water inrush accidents in deep rock laneway often happen, causing the construction difficulties and delays, even casualties and mining flooding. Thus the research on safe and fast roadway excavation of deep rock laneway is necessary in the field of mine construction. Currently, a large number of literatures deeply research deformation rule and support theory of roadway surrounding rock from the angle of "quasi static", and the main method of rock drivage is drilling and blasting method at present[3]. Although periphery hole with smooth blasting technology can greatly reduce the damage of blasting load to the surrounding rock, the damage of blasting dynamic stress to surrounding rock damage is unavoidable. Thus it presents the necessity of research on damage effect of surrounding rock of deep well digging and blasting working face.

In order to study the damage of rock of blasting excavation, Ming Xiaohas carried on the three-dimension elastic-plastic damage finite element analysis and calculation for surrounding rock loose circle of underground cavern by excavation blasting [4]. They are consistent with the results of numerical calculation. Yoshinaka R, Sakayuchi S, Shimizu T, etc.,[5] established fracture-damage constitutive model of compression-shear and tensile-shear state of anchoring joint rock, and program the corresponding three-dimensional damage finite element procedure and studied stress and deformation characteristics and the damage evolvement process of surrounding rock of underground cavern of power station in the process of the excavation and support. EGGER P [6] studied damage distribution zone of blasting excavation of kam screen secondary auxiliary hole by numerical calculation and field wave velocity test, and divided the excavation damage into inside damage zone and outside, and thought that. In-situ stress transient unloading effect in the blasting process is one of the direct causes of the damage zone formation. ABUOV M G, AITALIEV S M, ERMEKOV T M, et al.,[7] indicated the exponential distribution relationship between nuclear magnetic resonance (NMR) porosity and the uniaxial compressive strength is exponential distribution, based on rock porosity parameters and the transverse relaxation time T2 spectrum parameters by quantitatively determining the scope of the damage of rock blasting using nuclear magnetic resonance (NMR) imaging technology. The above researches mainly aimed at traffic tunnel and underground cavern. However, surrounding rock loose circle theory is mature in researching the deformation and damage scope of coal mine roadway surrounding rock [8]. MARTINO J B, and CHANDLER N A[9] obtained the correlative relations between average loose thickness of roadway roof and cross-section size, buried depth, surrounding rock intensity of roadway by field measurement of surrounding rock loose circle of main roadways in four mines based on method combining deep basis points multipoint displacement and drillings peep. On the basis of Haizi coal mining area's gyrus wind rise entry, Hualei Zhang[10] established the elastic-plastic mechanics model under the un-isostatic state, deduced a formula about width of plastic zone of surrounding rock of floor and put forward the corresponding schemes of reinforce. Xuxu Yang [11] measured in-situ stress state of shaft station in deep coal mine by hollow xenoliths method and also measured the ruptured scope of surrounding rock in different roadway working slope parts through sonic wave testing technique. Jianqing Xiao[12] researched variation rule of acoustic velocity along hole and effect of blasting working on loose circle, and concluded that the interaction of longitudinal wave and transverse wave caused its damage when the weakening zone of surrounding rock lies in crack area, while strengthening belt lies in area of stress concentration due to the vibration effect of blasting and the extrusion of bulking force CAI M, KAISER P K, TASAKAY, et al., and CAI M, KAISER P K, MARTIN C D[13-14] summarized the common method of surrounding rock loose circle test of coal mine roadway.

Based on blasting excavation of rock drift in Guan di Coal Mine, this paper research the damage effect of surrounding rock of working face in rock drift blasting tunneling by the combinative method between numerical simulation and field test. This paper establishes the constitutive model developed secondary based on user-defined module of finite difference program FLAC3D to analyze the damage effect of surrounding rock of rock drift and display wave velocity test hole of elastic wave on the working plane of rock drift tunneling to measure the distribution depth range of the damage zone of surrounding rock and provide references to evaluate the damage characteristics of surrounding rock of deep buried rock drift.

THE NUMERICAL SIMULATION SCHEME

The mechanical model of rock drivage working face

With the surrounding rock near the drivage working face regarded as the research object, the mechanical model is shown in Fig.1 including the gravity of the overlying strata σ_v, horizontal stress σ_h and blasting dynamic stress σ_d .

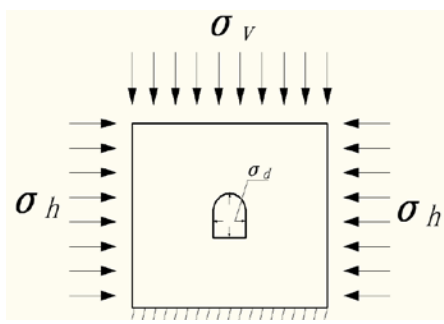


Figure 1: Mechanical model of the deep rock roadway

The establishment of the numerical analysis model

Simulation and simplification of blasting stress wave

(1) The initial value of blasting stress wave equals the initial pressure on the rock interface determined by the theory of elastic wave [15-24].

In the borehole and caving stage, the engineering uses columnar coupling charge widely used in engineering, the pressure P_0 produced in blasting on the hole and put the data in Table.1 substitute the parameters in the eq.1:

$$P_0=\frac{1}{4}\rho_0 D^2\frac{2}{1+\frac{\rho_0 D}{\rho C}}=\frac{1}{4}\times 1.13\times 10^3\times 3900^2\times\frac{2}{1+\frac{1.13\times 10^3\times 3900}{2.67\times 10^3\times 4200}}=21.3GPa \quad (1)$$

Columnar decoupling charge is widely used for the smooth blasting holes, as the detonation products have impact on the hole. The pressure P_0 is increasing obviously. The pressure value is often gained through an increment coefficient n in engineering. Put the data in table.1 substitute the parameters in the eq.2.

$$\lambda_1=\frac{d_c}{d_b}=0.64\ ;\ \lambda_2=\frac{l_c}{l_b}=0.45 \quad (2)$$

$$P_0=\frac{1}{8}1.13\times 10^3\times 3900^2\times 0.64^6\times 0.45^3\times(8\sim 10)=38.7\sim 48.4GPa \quad (3)$$

where: ρ_0 represents the density of explosive(Kg/m3); D represents the detonation velocity(m/s); ρ represents the rock density (Kg/m3); C represents the rock mass wave velocity (m/s); λ_1 represents the ratio of charge diameter d_c and hole diameter d_b; λ_2 represents the ratio of charge length l_c and the length of hole l_b; n represents the increment coefficient ranging from 8 to 10.

(2) The attenuation law of blasting wave in rock mass [25].

$$P_r=P_0\left(\frac{r_0}{r}\right)^a \quad (4)$$

Where: r_0 represents the radius of the charge (m); r represents the distance between the site of investigation and the center of charge; a represents the attenuation coefficient.

(3) The equivalent stress time curves of blasting wave

The initial pressure of blasting wave can be derived by Eq.1, the blasting wave in smooth blasting segment can be derived by Eq.2. The calculating parameters can be found in table.1, the equivalent stress peak value on the plane determined by hole defined line and the borehole axis at the same row can be derived with Eq.4.

Table 1: Parameters for blasting wave calculation section [29]

ρ_0(g/cm^3)	D(m/s)	ρ(g/cm^3)	C (m/s)	λ_1	λ_2	α
1.13	3900	2.67	4200	0.64	0.45	2.2

The program implementation of dynamic damage criterion

At present, many studies on second development of constitutive model based on FLAC^{3D} have been launched. Shao J F, Zhu Q Z, Su K et al.[26] have developed many models such as viscoelastic model of rock, viscoelastic-plastic rheological model of rock, constitutive model of joint rock mass damage due to mining. And then many researchers studied a second development and engineering application of and improved Burgers creep damage constitutive model of rock based on FLAC^{3D}[27]. This article referred to the research of MURAKAMI S, OHNO N. A et al. [28], introduced a second development of dynamic damage constitutive model based on FLAC^{3D}. Firstly, import the written header file and source file into project file in VC++, after compiling, interlinkage and shaping the dynamic-link library file. Copy this file to installation directory. And then load it to the master program in $FLAC^{3D}$, call it and after post-processing by the built-in language (fish) in $FLAC^{3D}$, the result can be produced.

APPLICATION IN PRACTICAL ENGINEERING EXAMPLE

Introduction of Engineering background and establishment of analytical model

(1) Engineering geological and hydrogeology conditions of rock roadway

Guan Di Coal Mine is mining the No.8 coal of lower Taiyuan group coal, which is nearly horizontal coal seam. Return airway in No.2 Mining Area lies in the sandrock of floor. Threats by water during driving mainly come from water stored in gob of upper group coal, sandstone fissure, karst-fissure under the floor and thin layer of limestone in Taiyuan group.

(2) Rock roadway parameters and blasting operation methods

Rapid mechanized drivage construction scheme is adopted: drillings blasting hole by air-rider jack hammer, ϕ 42mm and 2.8m in depth, 3.0m of depth for cutting hole, parallel cut, whole section smooth surfaces millisecond blasting.

Blasting material is 2# water-resistant coal mining AN-TNT Explosive, periphery hole need to use ϕ 32 mm, 0.1kg per cartridge, cutting hole and bottom hole use ϕ 32 mm, 0.2kg per cartridge, ϕ 32 mm, 0.15kg per cartridge for other blasting drillings.

Blasting parameters of the driving face are given in table 2. Layout of the blasting drillings in the driving face is shown on Fig.2.

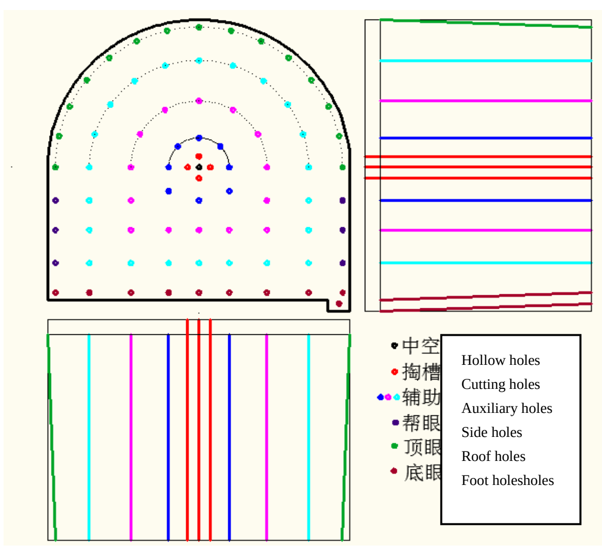


Figure.2: Layout of the blast holes in the driving face

Table 2: Blasting parameters of the driving face [29]

The name of the holes	The number of holes	The depth of holes/m	explosive payload				Priming sequences	Connection mode	Charging structure
			Per hole		Sum				
			Cartridges	Weight/ kg	Cartri-dges	Weight kg			
Empty holes	1	3.0						Serial , parallel	Reverse
Cutting holes	4	3.0	9	1.8	36	7.2	Ⅰ		
The Inside perimeter auxiliary holes	8	2.8	6	0.9	48	7.2	Ⅱ		
The perimeter auxiliary holes in middle	14	2.8	7	1.05	84	14.7	Ⅲ		
The outside perimeter auxiliary holes	22	2.8	5	0.75	154	16.5	Ⅳ		
Side holes	6	2.8	3	0.3	18	1.8	Ⅴ		
Roof holes	15	2.8	3	0.3	45	4.5	Ⅴ		
Foot holes	10	2.8	7	1.4	70	14	Ⅵ		
Sum	80				455	65.9			

Solving Process for numerical analysis

This paper establishes a mesh model for numerical calculation, as shown in Fig.3.Mechanical parameters of strata for numerical computation can be seen in Table 3. Primary stress field distribution of analysis model could be obtained after placing stress and displacement boundary conditions

Table 3: Mechanical parameters of rock mass for numerical computation [29]

Lithology	Thickness /m	Density (g/cm^3)	Elastic Modulus (GPa)	Poisson ' s ratio	Cohesion (MPa)	The internal friction angle (°)
Fine Sandstone	22.7	2.66	3.96	0.25	5.15	56
Mudstone	8.3	2.37	2.74	0.36	1.63	44
Fine Sandstone	14.0	2.66	5.67	0.32	3.34	58
Siltystone	11.0	2.53	4.08	0.28	2.48	49

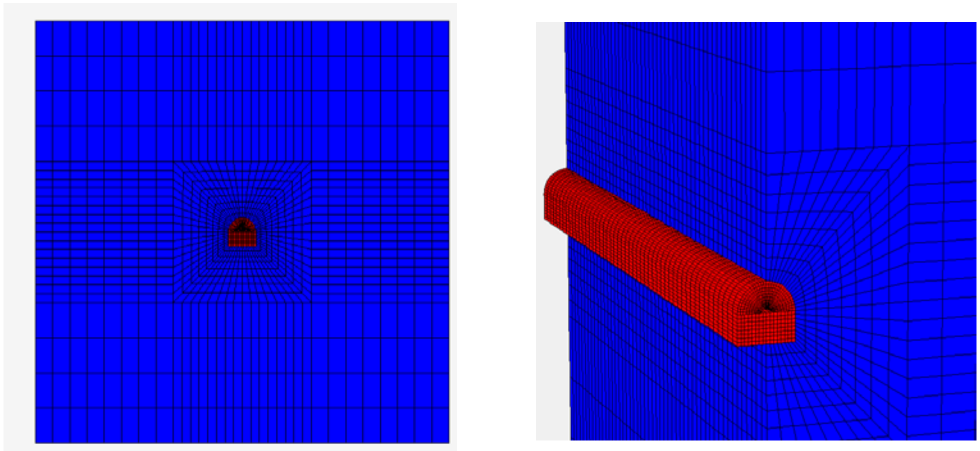


Figure 3: Numerical calculation model of the rock roadway

Mohr-Coulomb model and secondary developed dynamic damage model are respectively used for dynamic calculation. This article sets perimeter as viscous wave absorption boundary and chooses proper form of damping and parameters, simulating impact of blasting dynamic load on surrounding rock through excavating a footage of rock mass and applying simulant blasting stress time-history curve on it.

Mathematical expression of blasting approximately equal stress in each stage is shown in Eq.(5). each section of blasting approximately equal stress time-history. stress time-history paragraphs are obtained by fish language programming simulation blasting approximate equivalent shown in Fig. 4, 5, and 6.

$$P_{ri} = \begin{cases} K_i \exp(\mathrm{m}^{-\beta_1} - \mathrm{m}^{-\beta_2}), \mathrm{t} > \mathrm{t}_i \\ 0, \mathrm{t} \leq \mathrm{t}_i \end{cases} \quad (5)$$

where P_{ri} represents approximate equivalent stress time-history of number i Segment, K_i is amplitude control parameters determined by peak stress of each Segment. m、β_1、β_2 are Shape Parameters which is respectively 2.718,76.1,119.7.

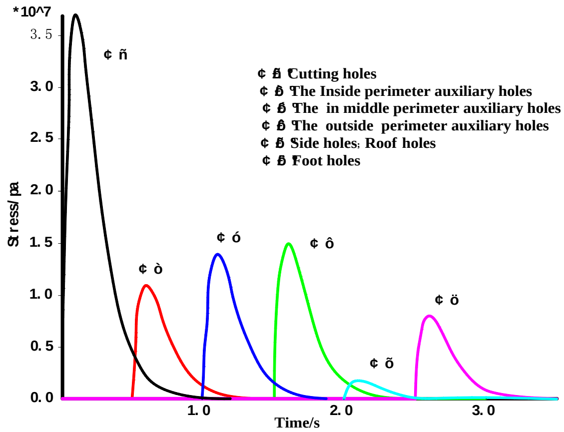


Figure 4: Approximately equivalent dynamic load versus time applied to surrounding rock of heading face

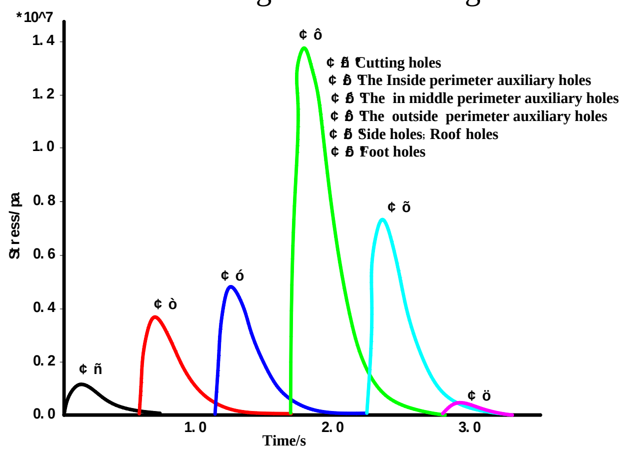


Figure 5: Approximately equivalent dynamic load versus time applied to surrounding rock of tunnel roof and wall

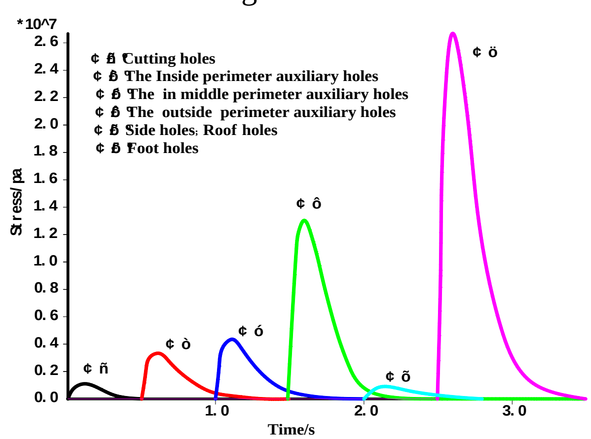


Figure 6: Approximately equivalent dynamic load versus time applied to surrounding rock of the driving face floor

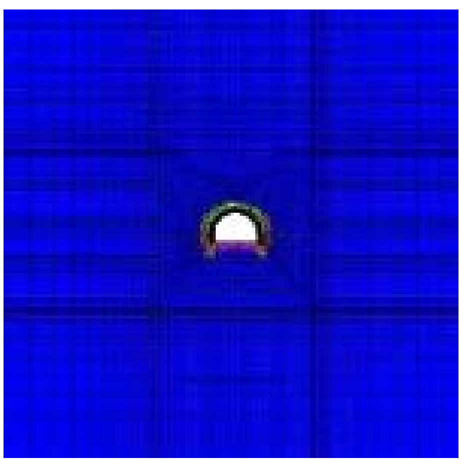
Considering that a footage is accomplished by six steps of millisecond-delay blasting. because of many blasting drillings (totally come to 80) on driving face, it would be a heavy and complex workload calculation of regular showing all the blasting drillings grid is heavy and complex.

Surrounding rock of sidewall can be processed by imposing equivalent load on cylindrical plane determined by center line of holes in same row and axis of blasting drillings.

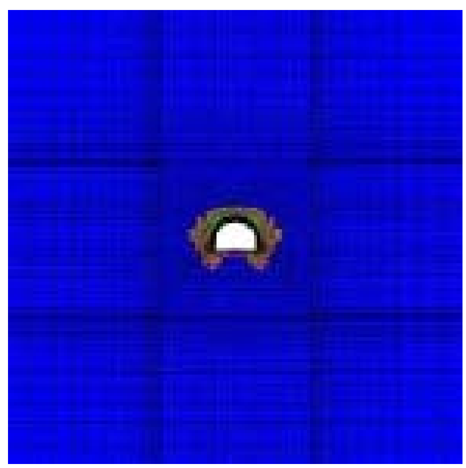
For front section of surrounding rock, the method of applying equivalent load to circular ring plane determined by bottom plane of blasting drillings and caving rock in same section could be adopted.

COMPARATIVE ANALYSIS OF TEST RESULTS

Mohr-Coulomb criterion and Dynamic damage mode are utilized to evaluate the damage region and plastic failure, as shown in Fig.7 : (a) for Mohr- Coulomb model and (b) for the Dynamic damage mode of second development. According to the contrast of two figures, the results show the damage region gained using Mohr-Coulomb model is less than the plastic failure scope by dynamic damage mode of second development, and the maximum destruction position of surrounding rock is located near the apex angle and basic angle.



(a) Mohr-coulomb model



(b) Secondary developed model

Figure 7: Results of the numerical solution

Compared the maximum depth of the plastic zone that is calculated by $FLAC^{3D}$ own Mohr-Coulomb model and the maximum depth of damaging area by the rock damage model of the secondary development with the average depth of in-situ test of surrounding rock damage. it can be found that the error between the plastic failure zones of surrounding rock calculated by the Mohr-Coulomb model and the field measured results is larger, about 10%,and the maximum error may reach 16.6%, which shows that the Mohr-Coulomb model is not suitable for the evaluation of surrounding rock blasting wave dynamic damage characteristics. But the results of the dynamic damage model of the secondary development are consistent with the measured results. The calculation error is around 3% showing that effect is acceptable, but it is still less than the measured results. Analysis result indicates that this is because the degradation of the rock blasting vibration effect is neglected although the damage model is adopted and the evolution of micro-cracks is taken into consideration.

CONCLUSIONS

(1) Simulation acquired the time-history curve of equivalent stress of the dynamic load of millisecond blasting in the full cross-sectional rock and considered the accumulative damage effect of surrounding rock blasting stress wave has in every blasting excavation paragraphs.

(2) This paper secondary developed rock dynamic damage constitutive model based on $FLAC^{3D}$, and applied it to forecast the damage area in deep rock drivage of surrounding rock. Moreover, the field acoustic observation results verify the effectiveness of the dynamic damage constitutive model of rock mass.

(3) Compared with the field measurement, the rock damage error using the Mohr-Coulomb model to calculate the plastic zone of surrounding rock is larger. But the dynamic damage model results was coincident with the measured results, the effect is ideal.

(4) The damage depth of surrounding rock roof is larger, next comes the floor damage depth and the minimum is laneway side. The damage depth near apex angle and base angle peaked, the measured results are 2.7m and 2.6 m respectively.

(5) The damage depth is larger in the apex angle and base angle of roadway and these parts should be supported intensively.

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