NUMERICAL ANALYSIS ON THE ROCKBURST IN COAL ROADWAY OF DEEP SURROUNDING ROCK UNDER STRESS-WAVE DISTURBANCE

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ABSTRACT

Rockburst is a common dynamic disaster of mine in deep surrounding rock, which occurs with rock fracture and falling even casting phenomena during or after the roadway excavation. With the increase of mine depth, rockburst becomes one of the serious disasters which bothering the safety of the coal mine production. Nowadays the analyses of rockburst mostly focus on its mechanism and prediction also the prevention measures three aspects, which have achieved lots of progress. But fewer analyses pay attention on the whole procedure of rockburst which contains its occurrence and development. Analysis on the whole procedure of deep surrounding rock coal roadway responses under dynamic disturbance which based on the surrounding rock initial stress environment and the dynamic disturbance intensity and dynamic disturbance duration three related factors are constructed respectively by using the discrete element method software UDEC, moreover the transfer and dissipation rules of energy in the surrounding rock are concluded from the simulation. Those all discover a more profound and visual image of rock burst.

Key words: rockburst, deep surrounding rock, disturbance stress wave, numerical analysis.

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INTRODUCTION

Mine blasting and rock transporting and machines operating and some other form dynamic behaviors are very common in the coal mining, which would cause the stress wave occurs and affects in the whole coal mining procedure. The stress wave interacts in the rock layers for its diversity and uncertain location of its vibration source, moreover the effect of the dynamic disturbance would be shown up in the surrounding rock especially in the free surfaces. Macro fracture may not come into being under those dynamic loadings in the surrounding rock, but the condition will be changed under repeated disturbances. Quantitative changes would lead to the qualitative one as the damage in the surrounding rock in the micro-size is strengthened and also the stress increasing in partial location. Then the energy of the surrounding rock would be released in the pattern of rockburst as the cracks dynamically instantaneously expanding and also the strain energy bursting between the grains rapidly [1].

The inner rock blocks of walls in the deep roadway falls down with different angles under the dynamic loading disturbance in deep surrounding rock, but traditional rock mechanics theories have no satisfied explanation for this dynamic phenomena nowadays. On the contrary it is easy for the rock mass blocks tectonic theory, unattached blocks behave individual movements under dynamic loading so much as in the opposite direction.

UDEC can simulate the discontinuous rock masses behaviors, and also it can describe the reaction of discrete medium under static and dynamic load including the absolute deviation of blocks. The whole process of the rockburst in coal mine road surrounding rock under dynamic disturbance is simulated in this article, and the reaction of whole process is recorded from the dynamic disturbance beginning to the new balance of the roadway in the surrounding rock. The influences of the two related aspects mining depth and stress intensities are drawn from the recording data as well as the energy absorption and dissipation during the reaction. Both of all would provide a reasonable reference for the deep coal mining to avoid rockburst.

NUMERICAL ANALYSIS

Numerical Models

Rockburst usually happen at the same time the dynamic disturbance beginning or a very short period after it, which have been analyzed from the rockburst accidents in the mine. And also it usually happens in the working faces or in the roadway which have stiffness roof and floor. Mine blasting and machines vibration and blocks fracture and other dynamic loading sources are simplified as plane stress wave in this article. Coal mine rock layers numerical model is established as the figure 1 shown.

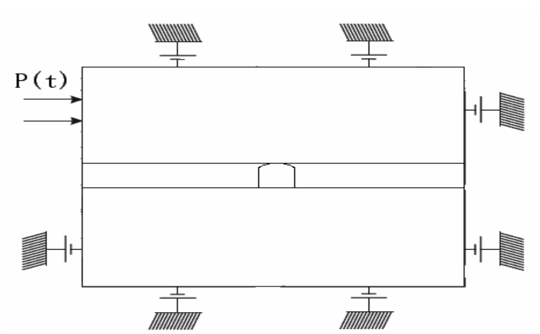

Figure 2.: Dynamic loading mechanical model.

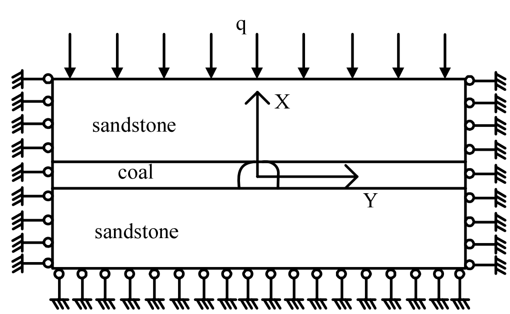

Figure 1.: Initial mechanical model of surrounding rock.

Both of the two rock layers except the coal middle rock layer are set to be sandstone in order to simulate the stiffness roof and floor , Horseshoe section tunnel located in the middle coal layer with its range 4 m×4 m and its arch radius is 2 m.

The amount of the element of the whole numerical model is 5147661 after the roadway excavation, which contains 5062127 blocks. The initial geo-stress field just considers the gravity influence and the vertical stress of upper boundary is the gravity weight of the above rock layers. Side pressure coefficient $k = \frac{\mu}{1-\mu}$, μ is Poisson Ratio.

Static loading model boundary condition is shown in the figure 1, where the horizontal direction boundary is fixed in X direction and the bottom edge is fixed in all directions, the gravity weight of the upper rock layers is applied on the upper free surface. While in the dynamic model the boundary is set to be viscous boundary in order to decrease the influence of boundary reflective wave, and the blasting loading is applied on the left boundary with the length of 4m. More specific dynamic boundary conditions are shown in the figure 2.

Physic-Mechanical Properties of Rock Material

Generally speaking the material dynamic mechanics properties of rock and joint is concerned with the velocity of strain, while the elastic modulus and poisson ratio changing range is limited in numerical value, so the concerned static parameters can replace the dynamic ones[2]. The details about the mechanics parameters of each layers is shown in the table 1. The two rock joint parameters normal stiffness and shear stiffness can use the flowing expressions to calculated [3].

$$k_n = \frac{E_e E_r}{s(E_r - E_e)}$$
$$k_s = \frac{G_e G_r}{s(G_r - G_e)} \qquad (1)$$

k_n, k_s stand for the normal and shear stiffness of rock joint (GPa); E_e, E_r is the equivalent continuum media elastic modulus and the rock material elastic modulus (GPa); G_e, G_r is the equivalent continuum media shear modulus and the rock material shear modulus (GPa); s is the average spacing of the rock joints (m).

Table 1.: Physic-mechanical properties of intact rock material.

Material	Thickness h/m	Elastic modulus E_r/GPa	Bulk modulus K_r/GPa	Shear modulus G_r/GPa	Density ρ/kg·m^{-3}	Poisson ratio μ	Compressive strength σ_c/MPa	Cohesion c / MPa	Friction angle φ/°
Sandstone	18	35	29.17	13.46	3000	0.30	20	2.5	41
Coal Rock	4	15	16.67	5.556	2500	0.35	5	1.5	30
Sandstone	18	35	29.17	13.46	3000	0.30	20	2.5	41

Table 2.: Mechanical properties of rock join.

Normal stiffness *kn*/GPa	Shear stiffness *ks*/GPa	Cohesion /MPa	Compressive strength /MPa	Friction angle
20	20	0	0	30

The natural attenuation of the movement and energy of rock mass both have hysteresis effect under dynamic loading, which is clearly concerned with the frequency. Meanwhile the actual dynamic loadings combine several different frequencies so much as the different loading patterns and loading paths, damping function should be used in order make the simulation more approximating to the truth. Rayleigh damping function in UDEC is used in the simulation with confirming critical damping ratio ξ and middle frequency of rock vibration f . The two parameters is set as ξ=0.1, f=1 with reference of other relative studies.

Dynamic Loading

Analyses show that the stress wave caused by the blasting vibration will get attenuation after certain distance propagation, and it can be simplified as pulse loading. The disturbance dynamic stress vs. time curve used in the article is shown in the figure 3[4].

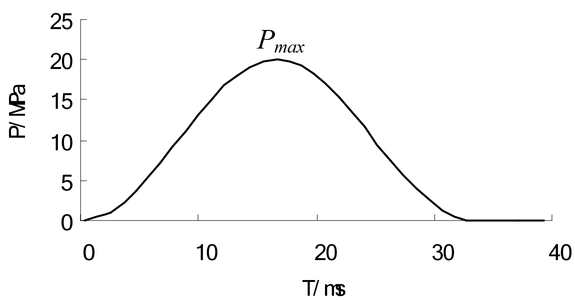

Figure 3.: Curve of disturbing stress wave vs. time

Simulation Steps and Schemes

The two aspects of mining depth and the disturbance stress intensity are focused on in the article, so relative simulations are carried out in order to confirm the relation between the two aspects and the rockburst in the deep surrounding rock under the dynamic loading.

Simulation steps:

(1) Static simulation: Initial geo-stress field in the surrounding rock model,

(2) Dynamic simulation: Analysis the stability of surrounding rock under dynamic disturbance with stress wave applied in the boundary and setting non-reflected boundary.

Simulation schemes:

(1) Analysis the influence of different mining depth for the stability of surrounding rock under dynamic loading is carried out with setting mining depth H=300m, 400m, 500m, 600m, 700m, disturbance stress intensity P_{max}=10MPa and disturbance period T=10ms.

(2) Analysis the influence of different disturbance stress intensity to the stability of surrounding rock under dynamic loading is carried out with setting stress intensities referring to the actual blasting P_{max}=1MPa,5MPa,10MPa,15MPa,20MPa, mining depth H=500m and disturbance period T=10ms.

RESULTS AND ANALYSES

Process of Rockburst

The strain energy increases at the range of stress concentration around the roadway after excavation in the deep surrounding rock. When the stress condition of surrounding rock is confirmed in the certain depth, and then the limited stored energy is also certain [5]. The minimum principal stress of the rock mass decreases as it is closer to the roadway edges, so it is with the limited stored energy of this location. The superfluous energy would be transformed if the accumulative energy is greater than its limited stored energy, part of it would be released in the form of rock deformation or other dynamic phenomena, while the rest would be transmitted into the deeper position of the surrounding rock until the current energy come to a new balance with limited stored energy. The energy released in this process is used in the surrounding rock plasticity deformation and the fracture, even some rock fragments would be cast when the released energy is strong enough.

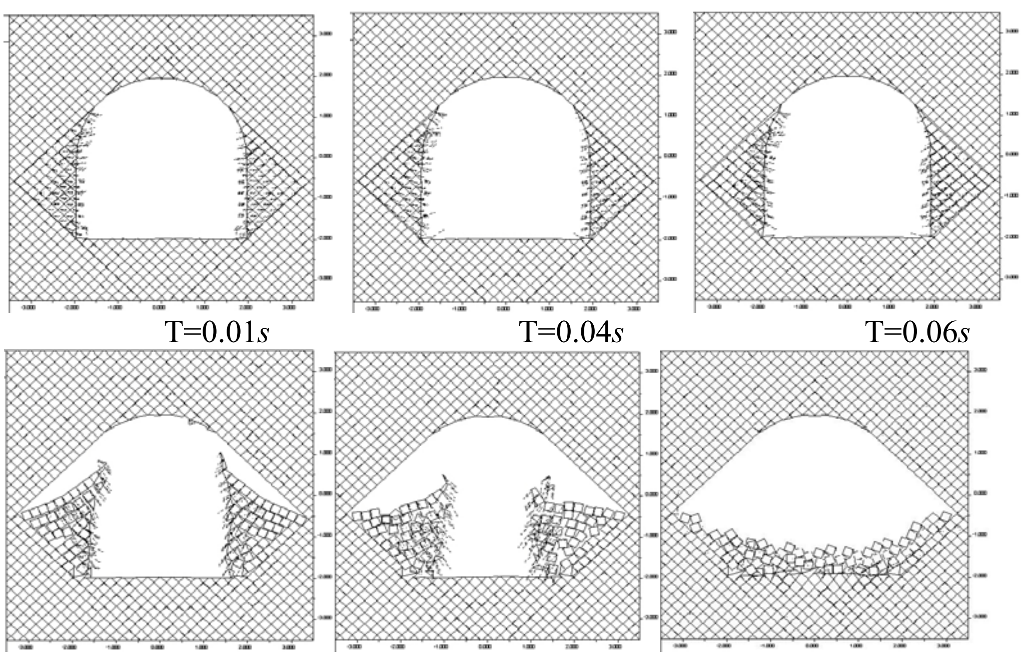

Figure 4.: The whole process of rock burst

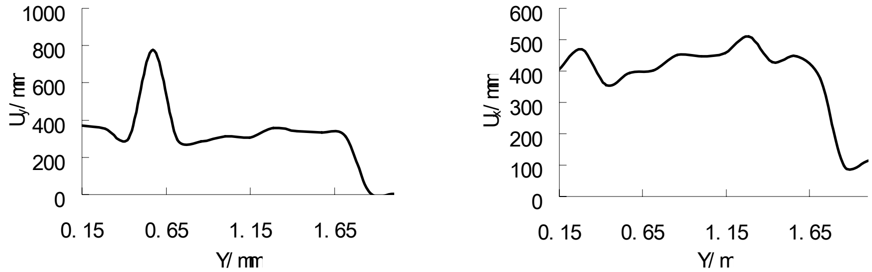

Figure 5.: The displacement curve of surrounding rock of roadway-rib

The whole process of rockburst is shown in the figure 4, which model parameters including mining depth *H*=700m, disturbance stress intensity P_{max}=10MPa and disturbance period *T*=10ms, and the arrows in the figure stand for the velocity vectors of rock blocks. The reaction of left part of roadway to the dynamic loading is greater than that of the right as the dynamic disturbance is loading on the left boundary. The maximum velocity of the rock fragments in the left part of roadway reaches 2.582m/s, while the value of the right is 2.196m/s at time *T*=0.01s. The process that the velocity value changes is also the process of the surrounding rock reaction to the stress wave. The left wall of the roadway occurs cracks at the angle of 45^0 at time *T*=0.04*s* while the right wall occurs the same cracks at time *T*=0.06*s*. After 4 seconds duration of the rockburst, the maximum velocity of the rock fragments reaches 0.009164*m/s*.

The energy of the surrounding rock increases greatly in the reaction process under the dynamic disturbance. The surrounding rock system bursts out energy when the amount is greater than the limited stored energy especially in the free face boundary. Part energy is consumed in the deformation and the fracture of surrounding rock, while the reset is transformed to the dynamic energy of the rock fragments. New balance of surrounding rock comes into being as well as the new energy balance.

The deformation curve of the roadway right wall at time T=0.3s is shown in the figure 5, in which U_X stands for the deformation displacement in the vertical direction to the walls of roadway, U_Y is the displacement in the parallel direction to the walls and Y is the distance between the lower edge of roadway. The displacement changes greatly in the left side of surrounding rock roadway walls especially the upper position 0.5m of the left wall and its deformation value is 775mm, meanwhile the displacement of X direction exceed 400mm. The lateral stiffness decreases greatly under the dynamic disturbances that leads to the rock damage of two walls, and then the rockburst takes place with the energy are released from the two walls.

Surrounding Rock Mining Depth

The damage conditions of different mining depth model is shown in the figure 6, the model parameters are set as disturbance stress intensity P_{max}=10MPa, disturbance period *T*=10ms and the mining depth *H*=300m,400m,500m,600m,700m, darker lines in the figure stand for the cracks positions. Rockburst takes place in the surrounding rock under dynamic disturbance when the mining depth reaches 700m. The fracture of rock around the roadway extends from the dynamic loading position to the both roadway walls and also the floor, cracks covered the both walls of the roadway at mining depth H=500m,600m and the range reached 1m, but the system of surrounding rock is still steady. The system will burst out catastrophe when the mining depth reached certain limited value then the balance will be broken.

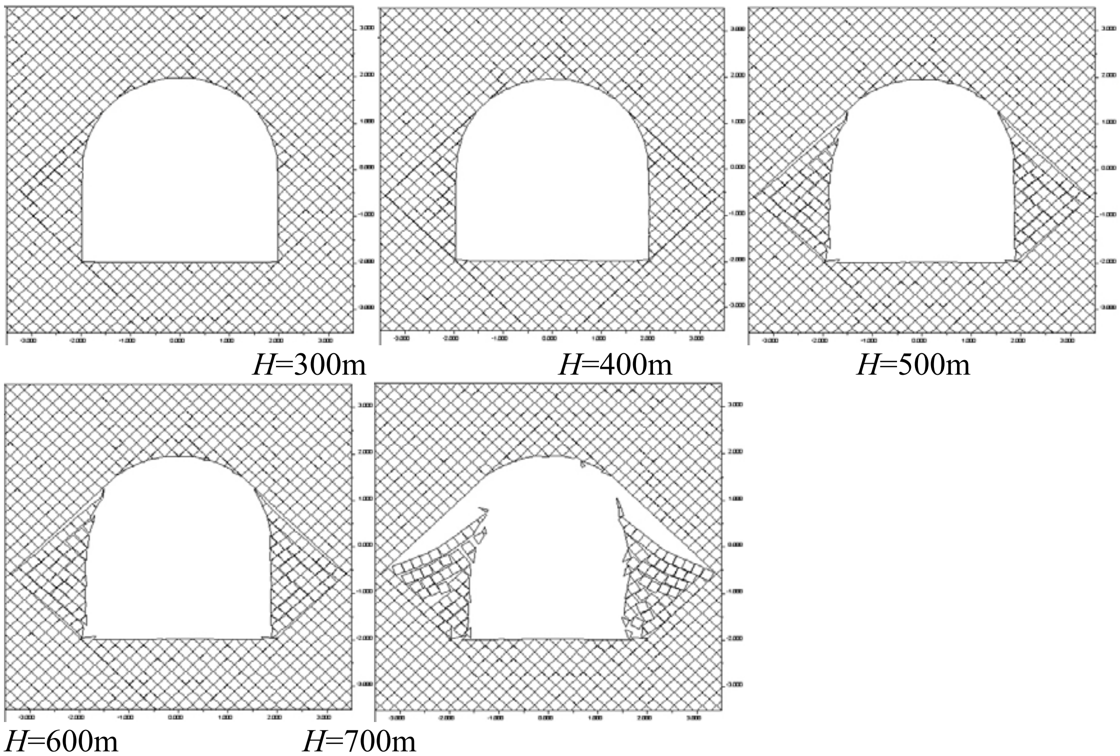

Figure 6.: The failure of the roadway under dynamic loading in different depth.

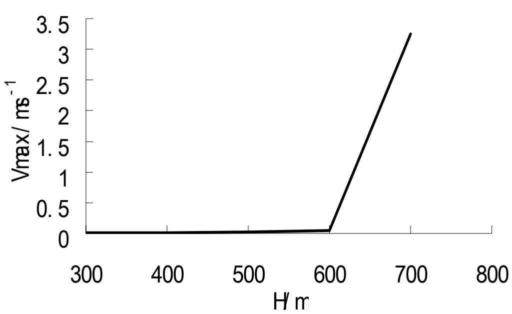

Figure 7.: Rock block maximum velocity of the surrounding rock in different depth at time t = 0.3 s

It is shown in the figure 7. that maximum velocity of rock blocks increases with the mining depth in the surrounding rock under dynamic disturbance, moreover the value changes greatly when the depth reaches 600m.

Dynamic Disturbance Intensity

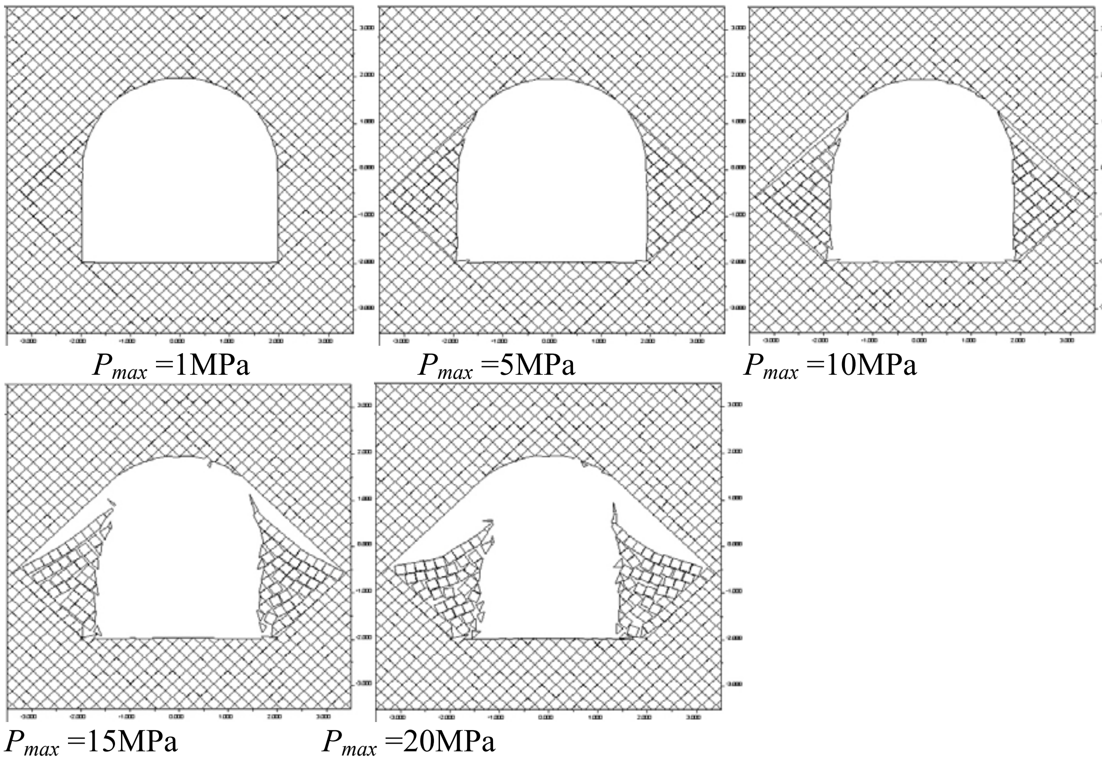

Figure 8.: The failure of the roadway surrounding rock under different stress intensities p_{max}

The damage conditions of different dynamic disturbance stress intensity model is shown in the figure 8, the model parameters are set as the mining depth H=500m, disturbance period T=10ms and disturbance stress intensity P_{max}=1MPa, 5MPa, 10MPa, 15MPa, 20MPa,. Rockburst takes place in the surrounding rock under dynamic disturbance when the dynamic stress intensity reaches 15MPa. The higher the dynamic stress intensity the more fierce the reaction it is, as the dynamic stress intensity reaches the limited intensity step by step.

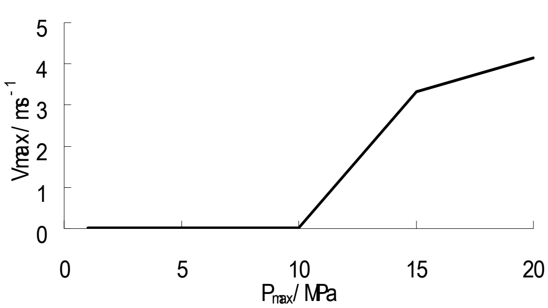

Figure 9.: Rock block maximum velocity of the surrounding rock under different stress intensities at time t = 0.3 s.

CONCLUSIONS

(1) The rock mass limited stored energy depends on the initial stress balance conditions. The initial static stress in the deep surrounding rock overlaps with the dynamic stress under the dynamic disturbance, so the energy of the surrounding rock increases. One part of the overage energy beyond the limited stored energy transmits into the deeper surrounding rock, while the reset transforms to the plasticity deformation of rock blocks and fracture so much as dynamic energy of rock fragments. Rockburst takes place in the deep surrounding rock roadway under dynamic disturbance on the condition that mining depth is 700m, dynamic stress intensity is 10MPa and the disturbance period is 10ms and rock and joint physical mechanics properties in this article. The reaction intensity of the wall of roadway near the dynamic loading is greater than the other wall and also the reaction is earlier than the other. Disturbances determine the energy of the surrounding rock system in the dynamic loading. The balance of the surrounding rock would be broken when the system reaches the limited condition, and then catastrophe comes into being.

(2) The resource mining goes deeper and deeper which brings serious high geo-stress problems. Limited mining depth is determined in the numerical simulation for certain surrounding rock condition; the possibility of rockburst will be higher if the mining depth is deeper than the limited one. The roadway of surrounding rock occur rockburst as the depth reaches 700m in the simulation in the article.

(3) The surrounding rock is influenced by the dynamic stress disturbance in the whole coal mine production, as the stress waves from different vibration sources overlay together especially the remarkable part of blasting driving roadways. The roadway in surrounding rock occur rockburst as the disturbance stress intensity reaches 15MPa in the simulation of the dynamic stress intensity influence aspect in the article. So more attention should be paid to control the blasting driving intensity in deep surrounding rock, and then should decrease the explosive charge and divide the blasting driving work into several small works to finish in order controlling the disturbance intensity below the limited stress intensity value in deep surrounding rock.

REFERENCE

[1] XU Zemin ,HUAN G Runqiu ,FAN Zhuguo ,etc. *Progress in research on rock burst hazard of long tunnel with large section* . Journal of Natural Disasters,2, 16-23(2004)(in Chinese)

[2] XIA Xiang, LI Jun-ru, LI Hai-bo ,etc. *Udec modeling of vibration characteristics of jointed rock mass under explosion* . Rock and Soil Mechanics,3,50 - 56(2005)(in Chinese)

[3] *UDEC (Universal Distinct Element Code) user's manual* . Version 3.0. Itasca Consulting Group, Inc., 1996.

[4] LEI Guang-yu, LU Ai-hong, MAO Xian-biao. *Numerical simulation on layered crack and failure of roadway under stress wave* . Rock and Soil Mechanics,3, 1477 - 1480(2005)(in Chinese).

[5] Hua Anzeng. *Energy Analysis of Surrounding Rocks in Underground Engineering*. Chinese Journal of Rock Mechanics and Engineering,7,1054□ 1059(2003)(in Chinese).

[6] ZHANG Xiao-chun, MIAO Xie-xing, YANG Ting-qing .*The layer-crack-plate model and testing study of the rock burst in mines* . Chinese Journal of Rock Mechanics and Engineering, 18,497 - 502(1999)(in Chinese).

[7] Zubelewice A, Mroz Z. *Numerical simulation of rock burst process treated as problems of dynamic instability* .Rock Mechanics and Rock Engineering,16:253 - 274 (1983).

[8] Mueller W. *Numerical simulation of rock burst* . Mining Science & Technology,12: 27 -42(1991).