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Numerical simulation of charge blasting without coupling to air media

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Abstract: Blasting technology is one of the means commonly used in the excavation process of stone tunnels, in the blasting technology, it is mainly divided into glossy blasting and pre-cracking blasting. In the process of blasting, in order to prevent the excessive damage caused by explosive blasting, it is often used to blast by means of uncoupled charges. In this study, LS-DYNA was used to establish a three-dimensional model for numerical simulation of blasting, and the whole process of blasting of uncoupled charge was reproduced. By simulating the damage cloud map, the pressure on the pore wall and the vibration speed of the pore wall are analyzed and compared with the non-coupling coefficients k=1.5, 2, 2.5, and 3, which provides a theoretical basis for the calculation of the parameters of glossy blasting and pre-cracking blasting.

Keywords: Uncoupling coefficient; Uncoupled charge; Blasting; LS-DYNA.

1. Introduction

Uncoupled charge is a special way to control blasting, through the uncoupled charge structure, that is, to maintain an appropriate distance between the explosive and the hole wall, thereby reducing the harm of the shock wave generated by the explosive explosion during the blasting process to the hole wall, eliminating the crushing area to achieve the effect of protecting the hole wall, making the glossy surface or pre-crack smoother.

Uncoupled charges are mainly used in glossy blasting and pre-cracking blasting. Holmes, the American, first applied uncoupled charging technology, and in the 1950s, he applied this technology to the construction of large hydropower stations, and the blasting effect exceeded expectations, and there was almost no hyper-explosion. Subsequently, the uncomplemented technology continued to evolve and improve. Through experimental research, Tengshan Bangjiu [1] found that the blasting effect is closely related to the distance between the charge hole and the space hole; Matsumoto. S et al. [2-3] analyze the stress wave propagation after blasting of an uncoupled charge by numerical simulation. In the early 1970s, uncomplemented charging technology was first applied in China. By the mid-1970s, uncoupled charge blasting technology was widely used in China's surface mining industry and achieved good results.

In this paper, four uncoupling charge coefficients of k=1.5, k=2, k=2.5 and k=3 are considered, and the effects of blasting of different Uncoupling coefficients on rocks are explored by numerical simulation, which provides a theoretical basis for the calculation of glossy blasting and pre-cracking blasting parameters.

2. Establishment of numerical model of blasting

2.1. Model establishment

Using ANSYS/LS-DYNA numerical simulation software to build a model, as shown in Figure 1, in order to study the impact of blasting with different coupling degrees on the surrounding rock, this paper considers four working conditions: condition 1 k=1.5, working condition 2 k=2, working condition 3 k=2.5, and condition 4 k=3. As shown in Figure 1, a quarter finite element model is established to improve computational efficiency. Cylindrical rock radius of 1m, height of 0.1m, charge length of 0.5m, charging radius of 0.045m, considering the interaction of rock, explosives and air 3 kinds of materials, the use of fluid-structure coupling algorithm, that is, rock using LaGrange algorithm, explosives and air using ALE algorithm, with the keyword * CONSTRAINED_LAGRANGE_IN_SOLID coupling the solid domain and fluid domain, the surrounding of the rock mass using non-reflective boundary condition to simulate the infinite rock area.

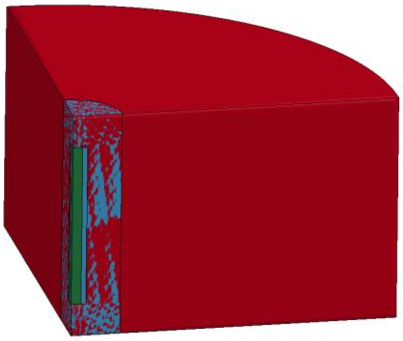


Figure 1. Model diagram

2.2. Material models and equations of state

2.2.1. Explosive material model and equation of state parameters

For explosive materials: The explosive constitutive *MAT_HIGH_EXPLOSIVE_BURN (material type 8) provided by the ANSYS/LS-DYNA software material library was used to simulate rock emulsified explosives No. 2, and the Jones-Wilkins-Lee equation of state (*EOS_JWL) was used to simulate the functional relationship between the pressure volume and energy of the detonation products during the explosion process, which has the following function equation:

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

Where P is the explosion pressure; V is the relative volume; AJ, BJ, R1, R2 are equation of state parameters. The specific parameters are shown in Table 5:

Table 1. Explosives material model and equation of state parameters

ρ_0 Kg·m^{-3}	D_J m·s^{-1}	A_J GPa	B_J GPa	R_1	R_2	ω	E_0 J·m^{-3}
1050	4000	540.9	9.4	4.5	1.1	0.35	8×10^9

2.2.2. Air material model and equation of state parameters

For air materials: In LS-DYNA, air materials are typically defined by the keyword *MAT_NULL with * EOS_LINEAR_POLYNOMIAL equation of state, which is:

$$P=C_0+C_1\mu+C_2\mu^2+C_3\mu^3+\left(C_4+C_5\mu+C_6\mu^2\right)E$$

Where: μ is the specific volume, which is the volume parameter used for calculation, μ=ρa/ρ0-1; ρa is the current moment density of the air; ρ0 is the initial moment density of air; E is the internal energy density. For specific parameters, see Table 2

Table 2. Air material model and equation of state parameters

ρ_0 Kg·m^{-3}	C_0	C_1	C_2	C_3	C_4	C_5	C_6	E KJ·m^{-3}	V
1.293	0	0	0	0	0	0	0	235	1

2.2.3. Model of rock materials

At present, in dyna software, there are Mohr-Coulomb models and Drucker-Prager models for constitutive models of rock materials in geotechnical engineering. However, for rock materials, it is necessary to consider both strain rate effect and damage on rock strength and failure strain, and the JOHNSON_HOLMQUIST_CONCRETE damage constitutive model used in this paper is an ANSYS/LS-DYNA software, which is numbered 111. Proposed by Holmquist et al. [4] in 1993, the model takes into account simulations of concrete and rock at high strain rates and large deformations, model evolution equations and parameter references.

(1) Strength model, which is described in terms of equal effect forces, considers the effects of strain, strength, strain rate, etc., and its expression is:

$$\sigma^*=\left[A(1-D)+BP^{*N}\right]\left[1+C\ln\left(\dot{\varepsilon}^*\right)\right]$$

(2) Damage model, which describes the degree of damage to the model, and its expression is:

$$D=\sum\frac{\Delta\varepsilon_P+\Delta\mu_P}{D_1\left(P^*+T^*\right)^{D_2}}$$

(3) Equation of state, the equation of state of the HJC model is used to describe the relationship between hydrostatic pressure and volumetric strain, and the whole process can be divided into three stages: elasticity, plasticity and compaction.

Elastic Phase:

$$P=k_e\mu$$

Plastic stage:

$$P=P_{crush}+K_{crush}\left(\mu-\mu_{crush}\right)$$

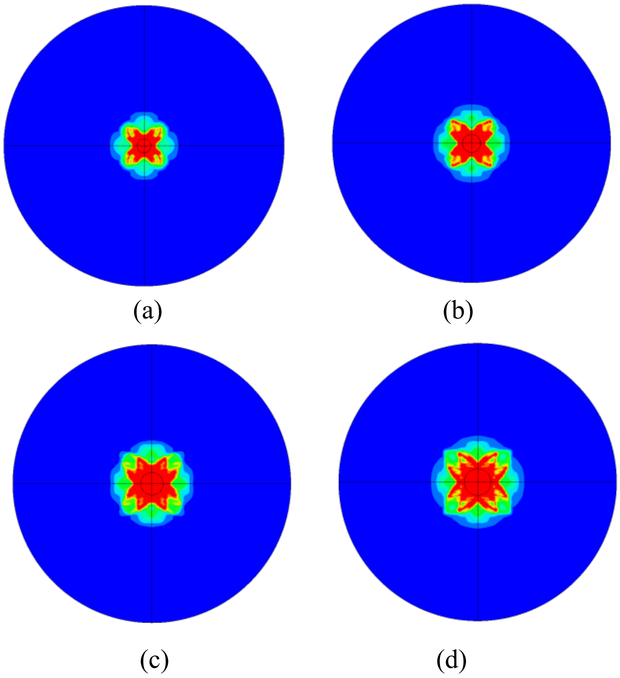
Compaction Phase:

$$P=K_1\mu+K_2\mu^2+K_3\mu^3$$

3. Simulation result analysis

3.1. Injury

As shown in Figure 2, a has a hole radius of 4.5cm, a explosive radius of 3cm, and a coupling coefficient k=1.5; b has a gunhole radius of 6cm, an explosive radius of 3cm, and a coupling coefficient k=2.0; c gunhole radius is 7.5cm, an explosive radius of 3cm, and a coupling coefficient of k=2.5; d gunhole radius is 9cm, an explosive radius is 3cm, and a coupling coefficient k=3.0; as can be seen from the figure, after blasting, the damage radius caused by working conditions a is the smallest; The maximum radius of damage caused by the rocks under working conditions d; It can be seen from this that, all other things being equal, the greater the coupling coefficient, the greater the damage to the rock after the explosives are blasted.



(a) (b)

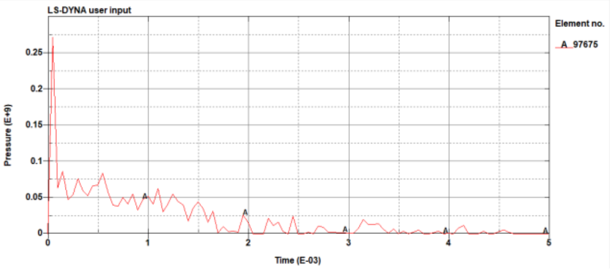
(c) (d)

Figure 2. Model of rock damage after blasting

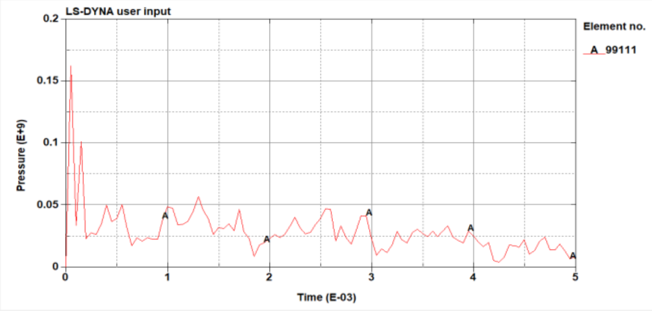
3.2. Hole wall pressure

In order to study the effect of blasting with different coupling coefficients on the pressure caused, the monitoring point is selected at the same location and the pressure on the point under four different working conditions is analyzed, as shown in Figure 3.

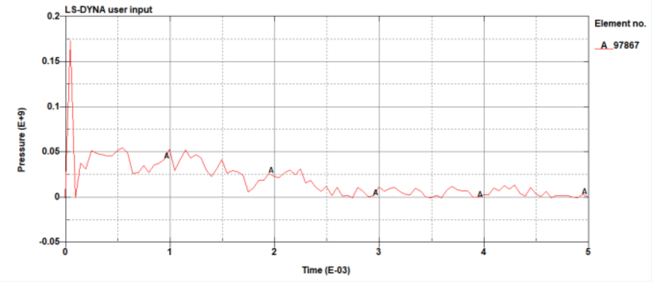
Figure a is the Uncoupling coefficient k= 1.5, the hole wall pressure after blasting, it can be seen from the figure that the maximum value is 0.245×109Pa; Figure b is the pressure of the hole wall after blasting when the Uncoupling coefficient k=2.0 is shown, and it can be seen from the figure that the maximum value is 0.154×109Pa; Figure c is the uncoupling coefficient k= 2.5, the hole wall pressure after blasting, it can be seen from the figure that the maximum value is 0.154×109Pa; Figure d is the Uncoupling coefficient k= 3.0, the hole wall pressure after blasting, it can be seen from the figure that the maximum value is 0.152×109Pa; It can be seen that the larger the non-coupling coefficient, the smaller the pore wall pressure.



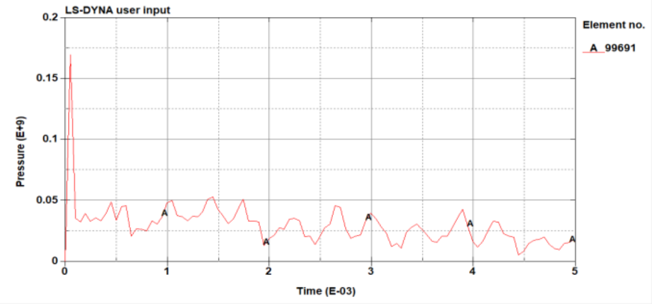
(a) K=1.5



(b) K=2.0



(c) K=2.5



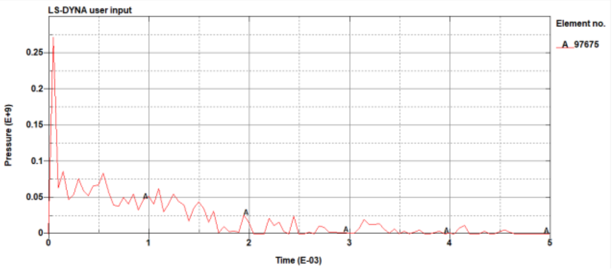
(d) K=3.0

Figure 3. Pressure-time plot

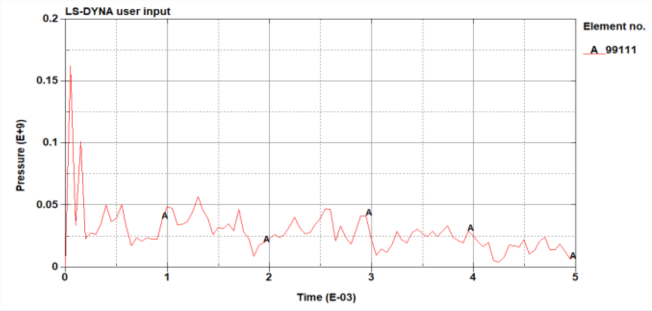
3.3. The vibration speed of the hole wall

In order to study the impact of blasting with different coupling coefficients on the pressure caused, the vibration speed data of the monitoring points obtained in the limit of 3.2 are extracted and sorted out, and the vibration speed of the measured points under four different working conditions is analyzed, as shown in Figure 4.

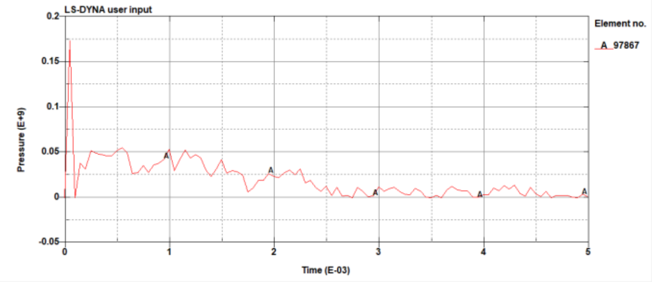
Figure a is the Uncoupling coefficient k= 1.5, the vibration rate of the hole wall after blasting, it can be seen from the figure that the maximum value is 82m/s; Fig. b is the vibration speed of the hole wall after blasting when the uncoupling coefficient k=2.0 is shown, and it can be seen from the figure that the maximum value is 65 m/s; Figure c is the Uncoupling coefficient k= 2.5, the vibration speed of the hole wall after blasting, it can be seen from the figure that the maximum value is 57m/s; Figure d is the Uncoupling coefficient k= 3.0, the blast wall vibration speed after the blast, it can be seen from the figure that the maximum value is 53m/s; It can be seen that the larger the non-coupling coefficient, the smaller the vibration rate of the pore wall.



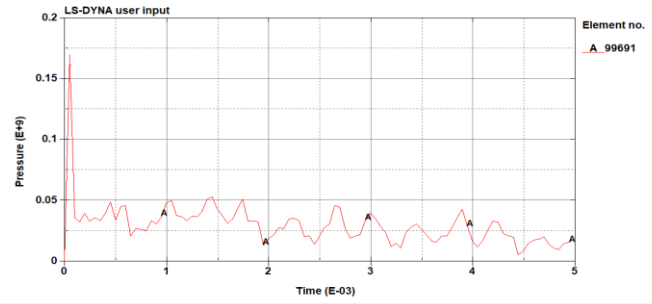
(a) K=1.5



(b) K=2.0



(c) K=2.5



(d) K=3.0

Figure 4. Velocity-time plot

4. Conclusion

LS-DYNA was used to establish a three-dimensional numerical model with an Uncoupling coefficient of k=1.5, k=2, k=2.5, and k=3, and the numerical simulation was carried out, and the whole process of blasting was reproduced: under the same conditions, the greater the coupling coefficient, the greater the damage to the rock after the blasting of the explosives; The greater the coefficient of non-coupling, the less pressure the pore wall is subjected to. The larger the non-coupling coefficient, the smaller the aperture wall vibration rate. It can be seen that the larger the non-coupling coefficient, the less harmful the shock wave generated by the explosive explosion to the hole wall, so the selection of a suitable non-coupling coefficient in blasting can not only produce a smoother surface, but also control the degree of damage to the hole wall.

References

[1] Tengshan bangjiu, Sasa Hongyi, itoichiro. On the role of guide holes in smooth blasting [a]. See: Fuxin mining science movement, translation. Smooth blasting: a collection of translations of coal mining tunneling technology [C]. Beijing: Coal Industry Press, 1979

[2] Smith, P.D.(Cranfield Univ): Vismeg, P., Teo, LC.: Tingey, L. Blast wave transmission along rough-walled tunnels[J]. International Jourmal of Impact Engineemg,v21, n6, Jul,1998, 419-432.

[3] Matsumoto, S.(Shock Wave/Condensed Matter Res.C., Kumamoto University): Nakamura, Y. Itoh, S. Dynamic behavior of stress waves in blasting process. Materials Science Formn,v465-466, Explosion, Shock Wave and Hypervelocity Phenomena in Materials, 2004, 55-60.

[4] Johnson H G R . A Computational Constitutive Model for Glass Subjected to Large Strains, High Strain Rates and High Pressures[J]. Journal of Applied Mechanics, 2011, 78(5):051003.