

Vibration effect of tunnel surrounding rock under cyclic blasting excavation

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Abstract: Model test studies based on the similarity theory was conducted to solve the problem of vibration effect of tunnel surrounding rock under push-type cyclic blasting excavation. The model was constructed with a ratio of 1:15. By simulating the tunnel excavation of push-type cyclic blasting, the influence of the change of blasting parameter on vibration effect was explored. The relationship between the damage evolution of surrounding rock and blasting times was established. The following test results can be obtained: When the maximum section dose was roughly same, the influence of the initiation section number on the dielectric coefficient (K) of Sodev formula was very small, and on the contrary to the attenuation coefficient of Sodev formula.

Introduction

Drilling blasting is a common and efficient construction method for excavation, tunnel excavation, underground chamber construction and other engineering rock mass excavation. During the excavation of rock mass engineering, it is inevitable to have a negative impact on the surrounding rock mass. The vibration effect caused by the circulating blasting, which leads to the rapid release of the stress in the surrounding rock, inevitably damages the surrounding rock, and makes the mechanical parameters of the surface rock mass decrease greatly. Blasting vibration may cause rock to retain the local crack and destabilization, and blasting relaxation zone formation may also aggravate rock subsequent unloading charge relaxation effect. There are hidden dangers to the safety construction and normal operation of the project.

Many scholars at home and abroad have studied the problem of surrounding rock damage caused by blasting operation, and have carried out fruitful research work [1,2]. However, the above researches of rock mass damage caused by blasting loading were put forward and realized mostly in the case of single hole charge blasting or repeated blasting under single hole charge, so it is not consistent with the actual blasting operation in rock mass engineering. Actual rock engineering excavation, such as mining, tunnel excavation, underground chamber construction, is a push-type reciprocating multi delay blasting operation. Therefore, it is necessary to study in depth and systematic the vibration effect of surrounding rock.

Similar material model test plan

Model scale and similar material model design

According to the actual size of the copper mine roadway excavation section, and the indoor test site space, the test model scale was finally determined as 1:15. The test model scale is in full compliance with the requirements of the similar theory (1:20~1:4) [3]. Therefore, according to the test model scale, the model size was determined as 3000mm×3000mm×2500mm. Natural quartz sand and gravel of particle size 2-4cm were chosen as the aggregate of the similar material model. Reference to China's current concrete mix design procedures [4], the similar materials with compressive strength 31.1MPa and elastic modulus 29.3GPa were made from the portland cement with compressive strength 32.5MPa, and it was used to simulate the surrounding rock of limestone.

Scheme design of blasting operation

According to the similarity theory [3], the blasting damage test of similar material model should be in accordance with the way of the push-type cyclic blasting excavation of the tunnel. Each cycle of blasting operation all includes the blasting form of the cutting hole, caving hole and periphery hole in this model test. The length of one cycle of blasting excavation is about 300mm. Four cycles of blasting excavation are carried out, so there are twelve blasting operations. In this test, the total length of the tunnel blasting excavation is about 1200mm.

The section size of the simulating tunnel excavation is determined by the test model scale. The blasting holes arrangement of the tunnel excavation section is as follows: the inside ring, middle ring, and outer ring are the cutting hole, caving hole, and periphery hole, respectively. The blasting order is the first cutting hole, then caving hole, the last periphery hole, and the blasting is delayed initiation mode, shown in Fig.1. After four cycles of blasting excavation, that is, a total of twelve blasting operations, the photograph of the tunnel blasting excavation for model test is shown in Fig.2.

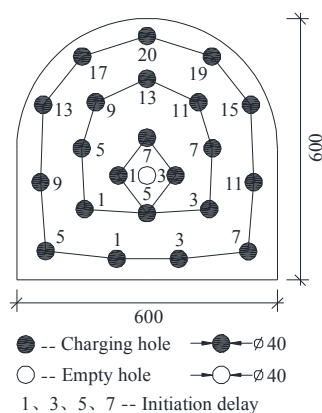


Fig.1 Tunnel section size and blasting hole layout



Fig.2 Tunnel blasting excavation for model test

Emulsion explosive is used in the test. In order to improve the blasting effect, the charge mode is a coupled charge. When charging the explosive, the explosive is pressed into the bottom of the hole, and pressed close to the hole wall. The clay is used to block the hole, and the blockage length is about 150~200mm. The blasting of the cutting hole, caving hole, and periphery hole is used to delay initiation in the model test. According to the similar theory and the tunnel excavation section size, the numbers of the millisecond delay initiation for the cyclic blasting operation can be determined, and the specific blasting parameters are shown in Table 1.

Table 1 The blasting parameters of circulation blasting operation of tunnel model

Blasting hole name	Excavation length /mm	Initiation delay time	Initiation charge /g	Total charge /g	Charge mode
Cutting hole	300	1,3,5,7	50,50,55,55	210	Coupling
Caving hole	300	1,3,5,7, 9,11,13	50,50,50, 50,55,55,60	370	Coupling
Periphery hole	300	1,3,5,7,9,11, 13,15,17,19,20	55,55,60,60,55, 55,60,60,55,55,60	630	Coupling

Scheme design of test measuring

The blasting vibration testing of the model test is carried out by the BlastmateIII blasting vibration recorder, produced in Canada. The instrument has the characteristics of wide detection frequency band, large measurement range and high precision, and its speed sensor is the three-direction earthquake detector. During the testing, the speed sensor is arranged in the center of each acoustic wave testing section, and there is a total of 6 units, as shown in Fig.3. In order to improve the effect of blasting

vibration monitoring, the speed sensor is fixed firmly on the model by the expansion bolt. The photograph of blasting vibration testing of test site is shown in Fig.4.

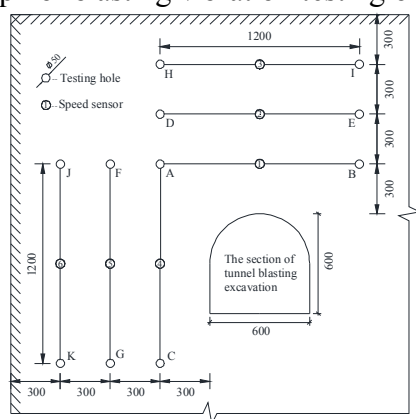


Fig.3 Layout of measuring points of the model test



Fig.4 Blasting vibration testing of model test

Testing results and analysis

According to the relevant research shows that [5]: the particle vibration in the medium caused by the explosive explosion has vertical, radial and tangential velocity components; In the case of the smaller altitude difference and close distance, the vertical velocity component plays a controlling role in the blasting vibration. Therefore, the vertical particle vibration velocity is chosen as the monitoring physical quantity in this essay.

The tunnel blasting excavation adopts the cutting hole, caving hole, and periphery hole blasting operation sequence in the model test, and vibration monitoring is carried out for each blasting operation. Typical blasting vibration time-history curves are generated by three kinds of blasting operation, as shown in Fig.5.

There are respectively 4, 7 and 11 peaks in the blasting vibration time-history curves of the cutting hole, caving hole, and periphery hole, as seen from Fig.5. The delay blasting effect is very obvious, which is completely corresponding with the initiation detonator delay distribution listed in Table 1.

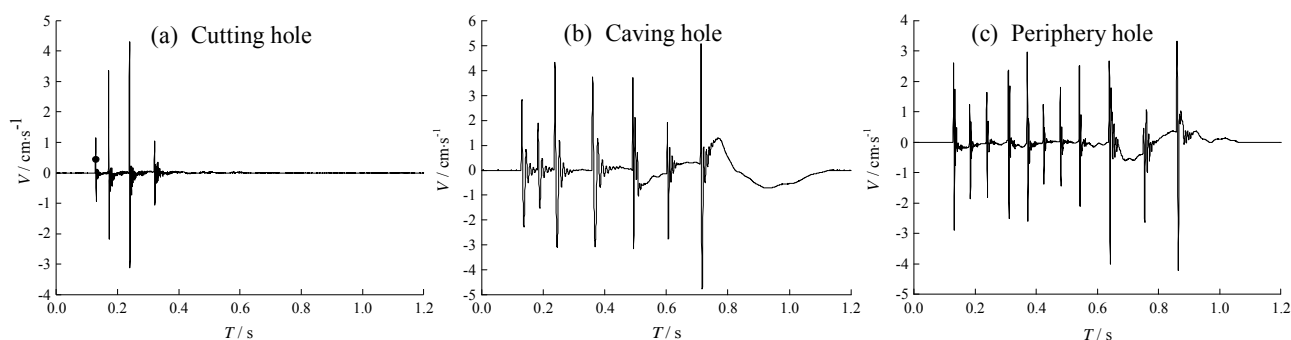


Fig.5 Blasting vibration curve of cyclic blasting excavation

Table 2 The related data of blasting vibration monitoring

Measuring point	Distance from blast center / m	Blasting type	Number of delay / n	Main vibration frequency / Hz	PPV / $\text{cm}\cdot\text{s}^{-1}$
①,④	0.6	Cutting blasting	4	137~162	6.14~7.62
		Caving blasting	7	153~192	6.07~7.51
		Periphery blasting	11	201~258	6.02~7.78
②,⑤	0.9	Cutting blasting	4	105~141	4.03~5.21
		Caving blasting	7	117~149	4.38~5.62
		Periphery blasting	11	161~201	4.17~5.55
③,⑥	1.2	Cutting blasting	4	41~85	1.82~3.29

Caving blasting	7	68~111	2.08~3.62
Periphery blasting	11	85~143	2.22~3.56

The related data of blasting vibration monitoring of the cutting hole, caving hole, and periphery hole blasting operations under push-type cyclic blasting excavation are shown in Table 2.

The analysis from Table 2 shows that: In the same geological environment and distance from blast center, the number of delay initiation is more, the higher the main vibration frequency of blasting seismic wave; In the same delay blasting, the distance from blast center is longer, the lower the main vibration frequency of blasting seismic wave. The peak particle vibration velocity depends on the maximal delay dose and the distance from blast center, and is in conformity with Sodev formula, as shown in Formula (1).

$$V = K \left(\frac{\sqrt[3]{Q}}{R} \right)^{\alpha} \quad (1)$$

Where V is the peak particle vibration velocity ($\text{cm}\cdot\text{s}^{-1}$); K is the dielectric coefficient; Q is the maximal delay dose (kg); R is the distance from blast center (m); α is the attenuation coefficient.

According to the relevant research shows that [6]: Because the delay blasting method is adopted in the tunnel blasting excavation, the distance between the initiation point and the measuring point should be replaced by the equivalent distance. The calculation formula of the equivalent distance and the maximal equivalent delay dose can be expressed as:

$$R' = \frac{\sum_{i=1}^n (\sqrt[3]{q_i} r_i)}{\sum_{i=1}^n \sqrt[3]{q_i}} \quad (2)$$

$$Q' = \sum_{i=1}^n q_i \left(\frac{R'}{r_i} \right)^3 \quad (3)$$

Where R' is the equivalent distance (m); Q' is the maximal equivalent delay dose (kg); q_i is the charge dose of the i hole (kg); r_i is the distance between the i hole and the measuring point (m).

According to the monitoring data of blasting vibration, the equivalent distance and the maximal equivalent delay dose of all measuring points under each blasting are respectively calculated by the Formula (2) and (3). Using Formula (1), the linear regression analysis of the monitoring data of different number of delay is carried out by the least square method, and the dielectric coefficient K and attenuation coefficient α of Sodev formula and the correlation coefficient γ of linear regression analysis can be determined, shown in Table 3. With blasting monitoring data of four initiation delays as an example, the linear regression analysis is shown in Fig.6.

From the analysis of Table 3, it is known that the influence of number of delay on the attenuation coefficient α of Sodev formula is very large, on the contrary to the dielectric coefficient K of Sodev formula. The main reason is that: In the same geological environment, the number of delay initiation is more, the main vibration frequency of blasting seismic wave is higher, and the attenuation of high frequency signal in the rock and soil is faster. In addition, the blasting vibration effect analysis is carried out according to the blasting monitoring data of the same number of delay, and the correlation is better. Therefore, the influence of number of delay on blasting vibration effect can not be ignored.

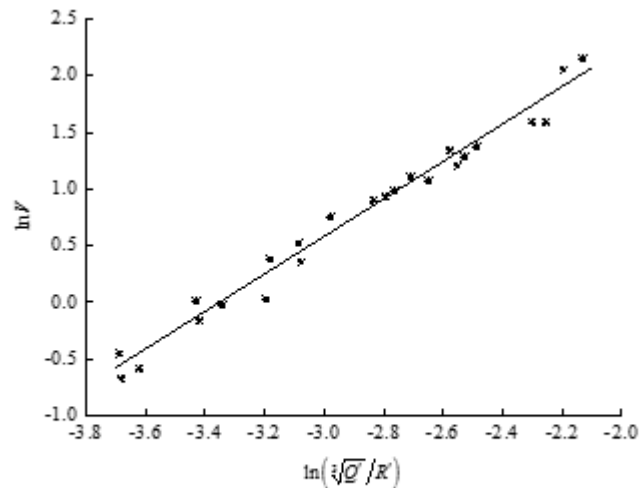


Fig.6 Linear regression analysis of blasting vibration data of four initiation delays

Table 3 The parameters of linear regression analysis of blasting vibration monitoring data

Number of delay / n	Dielectric coefficient / K	Attenuation coefficient / α	Correlation coefficient / γ^2
4	108.42	1.2539	0.9435
7	109.25	1.3673	0.9541
11	106.63	1.6145	0.9369
4,7,11	107.86	1.3841	0.8523

Fig.6 Linear regression analysis of blasting vibration data of four initiation delays

Conclusion

In the cyclic blasting operation of tunnel excavation, the blasting parameters design not only controls the maximal delay dose, but also pay attention to the influence of the number of initiation delay on blasting vibration effect. When the maximum section dose was roughly same, the influence of the initiation section number on the dielectric coefficient (K) of Sodev formula was very small, and on the contrary to the attenuation coefficient (α) of Sodev formula. The reasonable initiation delay can gain better rock mass breaking effect, and to control the stability of surrounding rock. When analyzing the influence of blasting vibration on surrounding rock damage, the influence of number of delay on blasting vibration effect can not be ignored.

Acknowledgements

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