An Experimental Study on Model Test of Blasting Vibration of Open Pit Slope

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ABSTRACT

In this study, based on the dimensional analysis and similarity theory, the small-scale model is established to analysis the influence of charge structure and elevation on blasting vibration. And the results show that the vibration intensity caused by concentrated charge is generally higher than that of column charge, and the dominant frequency is higher than the column charge also. Blasting vibration has elevation amplification effect, and its degree can be expressed by the power exponent function of the charge quantity and the elevation. Compared with the results of model and field test, it is found that both the vibration waveform, frequency spectrum and the attenuation law of particle vibration velocity are similar. And the research results provide reference for the analysis of blasting vibration in the engineering and the design of disaster prevention or mitigation.

KEYWORDS: Blasting vibration; model test; dimensional analysis; charge structure; elevation

INTRODUCTION

Engineering blasting is widely used in mining, railway, transportation, water conservancy, harbor and other infrastructure construction. Blasting is an efficient way to break rock, but it also brings some negative effects, such as blasting vibration, blasting flying rocks, air shock wave, noise, dust etc. Due to the influence of geological conditions and other factors, the repeatability of the site blasting vibration test is poor. In addition, the study and exploration of new blasting technology and blasting vibration rule also requires a large number of test data. However, it is difficult to carry out large-scale experiments on site and sometimes it can’t get accurate rules. Therefore, it is necessary to carry out the corresponding model test research.

Li et al [1] optimized the ratio of model material in cast blasting by the single hole blasting funnel. Shan et al [2] studied the influence of cutting parameters on blasting effect by the model test method. Li et al [3] analyzed the failure process of cement mortar model by the application of high speed camera and super dynamic strain gauge, and the influence of concentrating coefficient of blasting holes on crack coalescence time in cast blasting was obtained. Bian et al [4] used the blasting model test to deduce the similarity problem of throwing distance. Ma et al [5] studied the influence of millisecond time on shaft blasting vibration. At present, the research of blasting model test is mainly focused on the rock blasting mechanism, the blasting effect and distribution law of rock, and there is little research on the effect of blasting vibration. On this basis, this paper makes an exploratory study on the blasting vibration by the model test method.

ESTABLISHMENT OF SIMILARITY CRITERIA FOR MODEL TEST

It is very complicated to the effect factors of blasting vibration, in order to detailed analyze the blasting vibration, the influence parameters of blasting model test are divided into four kinds of geometric parameters, medium parameters, explosive performance parameters and time parameters. The geometric parameters include the size parameters of blast hole and the geometric parameters of the drug, such as cartridge diameter, borehole diameter, hole depth, minimum burden, step height and seismic wave propagation distance etc. Medium parameters include the medium density, the strength of the medium, elastic modulus, the longitudinal wave velocity of the medium, the wave impedance etc. Explosive performance parameters include the density of explosives, the detonation velocity and the explosive charge. Time parameters include millisecond time in the hole and millisecond time outside the hole. Before the model test, the relation between each independent physical parameter should be established.

According to the above analysis, the relationship between blasting vibration velocity and its influence parameters is expressed as follows:

$$V = f(E, W, \sigma, \rho_m, t, R, e, l, \rho_0, D, H, a, b) \qquad (1)$$

The dimensions of the above mentioned parameters are expressed in terms of length, mass and velocity, as shown in Table 1. According to the π theorem, three parameters of ρ_m, R and D are used to realize the non dimensional treatment. The results are as follows:

$$\frac{V}{D} = f\left(\frac{E}{\rho_m D^2}, \frac{W}{R}, \frac{\sigma}{\rho_m D^2}, \frac{t}{RD}, \frac{e}{\rho D^2 R^2}, \frac{l}{R}, \frac{\rho_0}{\rho_m}, \frac{H}{R}, \frac{a}{R}, \frac{b}{R}\right) \qquad (2)$$

Table 1: Similar parameters of blasting vibration model test

Name	Symbol	Dimension	Name	Symbol	Dimension
medium elastic modulus	E	$ML^{-1}T^{-2}$	explosive energy per unit length	e	MLT^{-2}
minimum burden	W	L	charge length	l	L
medium intensity	σ	$ML^{-1}T^{-2}$	explosive density	ρ_0	ML^{-3}
medium density	ρ_m	ML^{-3}	detonation velocity	D	LT^{-1}
time	t	T	step height	H	L
propagation distance	R	L	Hole spacing	a	L
particle vibration velocity	V	LT^{-1}	row spacing	b	L

The above analysis shows that there are ten dimensional combinations which influence the blasting vibration velocity. The parameters of the prototype are expressed by the superscript “ y ”, and the model parameters are expressed by the superscript "m", each of the non dimensional combination in formula (2) can be explained as follows:

(1) The relationships of W/R, l/R, H/R, a/R and b/R reflect the similar ratio of the model to be followed by the size of charge and cloth, that is $W^y/W^m = l^y/l^m = H^y/H^m = a^y/a^m = b^y/b^m = r$ (r is the similar ratio of the model), the corresponding model parameters are scaled down or enlarged in the same proportion. In blasting vibration model, due to the refraction and reflection of the seismic wave in the model boundary, the distortion of the test waveform is easy to be caused, so there are two ways can be used to this end. The first is to increase the size of the model, the charge from the minimum size of non blasting boundary is far away from the minimum burden. The second is to enhance the constraints of boundary, the model is embedded in material with similar wave impedance to enhance the transmission of elastic wave. This experiment adopts the combination of the two methods, the concrete model is set up in the pit and the boundary is filled with clay.

(2) The relationship of $e/(\rho D^2 R^2)$ reflects the performance of explosives. The critical diameter of industrial explosives is relatively large and the pore size of the model is very small, which can't meet the requirements of the detonation of industrial explosives. Therefore, high power explosive is used in model test as blasting source and the ratio of explosive energy is proportional to the square of the detonation velocity.

(3) The relationships of $E/(\rho_m D^2)$ and $\sigma/(\rho_m D^2)$ reflect the matching relationship between explosive and rock. High power explosive has high detonation velocity, in order to satisfy the second relationship, the model material should be selected with lower strength. At present, model materials are often used in cement mortar and its density is slightly lower than that of the original rock, so this condition is difficult to meet. In order to meet the above conditions, reducing the material strength and charge density of the model are two feasible methods.

(4) The relationship of ρ_0/ρ_m reflects the matching relationship between charge density and medium density. The charge density of the model is similar to 2# rock explosive and the concrete density is close to the rock's density, so this condition is easy to meet.

(5) The relationship of t/RD reflects the delay time that should be followed in model test and prototype test. Because the propagation distance in prototype is much larger than that of model, the delay time of the model test is usually very small, so the high precision electronic cap is needed.

DESIGN AND MANUFACTURE OF TEST MODEL

The test model is poured by 400# Portland cement and coarse sand, and its mechanical parameters are shown in Table 2.

Table 2: Basic mechanical parameters of the test model

density (g/cm^3)	longitudinal wave velocity (m/s)	elastic modulus (GPa)	compressive strength (MPa)
2.49	2740	15.91	28.97

The borehole diameter is designed by the minimum permissible size of existing detonators, other parameters such as hole spacing, row spacing, minimum burden, slope height, slope angle are designed by geometric similar principle. According to the actual situation of a mine and its blasting parameters, the model size is shown in Table 3 (the geometric similar ratio is 1:50).

Table 3: Prototype and model geometry parameters

	slope height	borehole diameter	block length	hole spacing	row spacing	slope angle	super deep
prototype size(m)	10	0.2	4～5	8	4	70°	2
model size(m)	0.2	0.008	0.08～0.1	0.16	0.08	70°	0.04

The test model is divided into four zones with 90 holes, its geometric size is shown in Figure 1 (unit: cm), the actual model is shown in Figure 2.

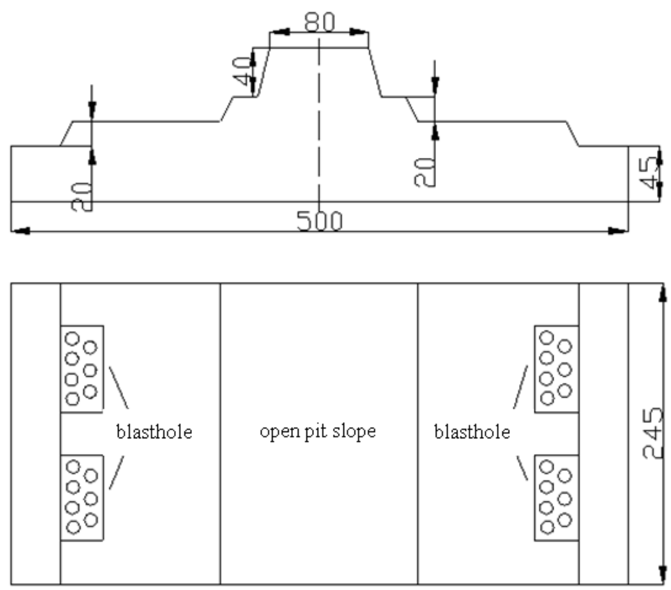

Figure 1: Model size of blasting vibration experiment

Figure 2: Concrete model and sensor installation

MODEL TEST RESULTS AND ANALYSIS

Analysis of Vibration Characteristics of Single Hole Blasting

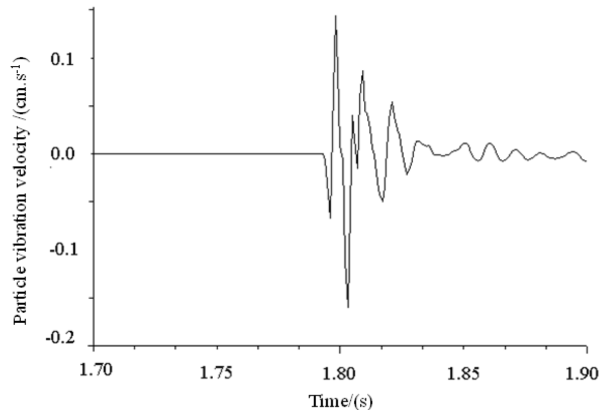

Figure 3: Particle vibration velocity of single hole blasting in model test

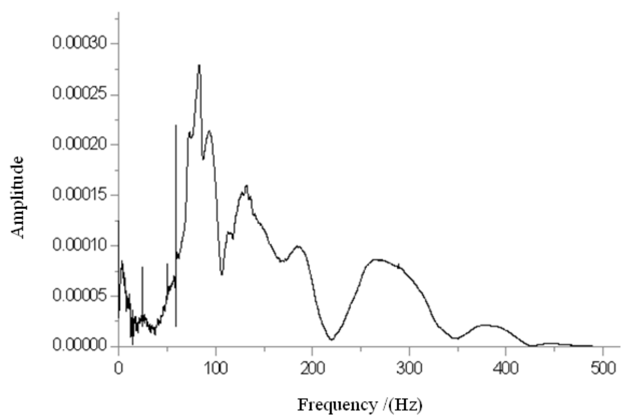

Figure 4: Frequency spectrum of particle vibration velocity in single hole blasting (test model)

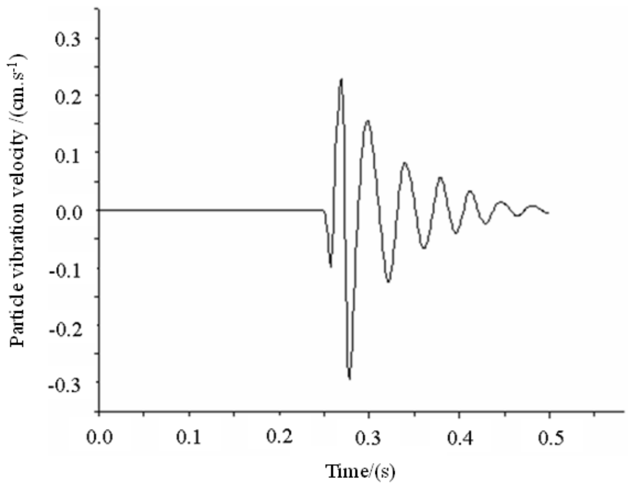

Figure 5: Particle vibration velocity of single hole blasting in site

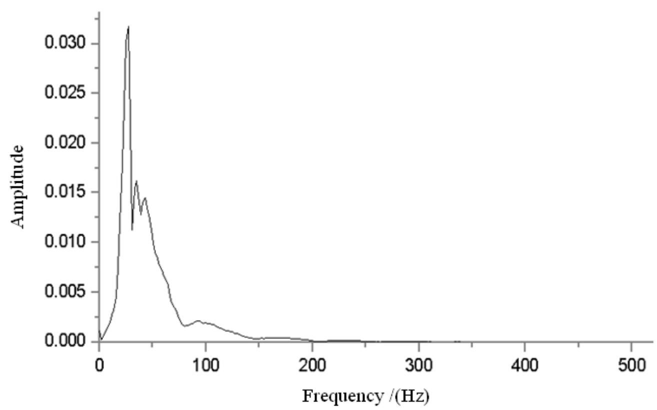

Figure 6: Frequency spectrum of particle vibration velocity in single hole blasting (in site)

Figure 3~ Figure 6 are the single hole blasting particle vibration velocity and its frequency spectrum. Comparison model and prototype test, we can see that the vibration characteristics of the two cases have a certain similarity. But there are some subtle differences: the waveform of the model test is relatively steep, the high frequency component is relatively abundant, and the dominant frequency is higher than the field test results. From the vibration duration, the vibration duration of single hole blasting in model tests are between 20ms ~ 40ms, but the vibration duration in prototype is between 100ms ~ 200ms. There are several reasons for those differences.

(1) Explosive charge in model test is relatively small, and it is easy to arouse high frequency elastic wave.

(2)The reflection of model boundary has a certain influence on the test waveform and its frequency spectrum.

(3) In the model, the distance between the hole and the measuring point is very small, although the amplitude of the vibration velocity and the measured results are not quite different from the

similar distance, but the shape of the model test is more steep and the vibration duration is relatively short.

Effect of Charge Structure on Blasting Vibration

Concentrated charge and column charge are two methods of commonly used in Engineering blasting. The early blasting engineering often used concentrated charge, the study of blasting technology for concentrated charge is relatively deepened and the related theories are relatively mature. In recent years, column charge is widely used in the domestic and foreign large-scale engineering blasting. Comparing with concentrated charge, the column charge has advantages on blasting pile concentration, small vibration effect, more blasting volume, broken uniformity and a series of advantages [6]. At present, there is a lot of research on rock breaking, throwing, accumulation and other aspects, but the research on the effect of blasting vibration is relatively short. Through the model test, this paper analyzes the vibration characteristics of blasting seismic wave under two kinds of charge structure. Table 4~6 shows the comparison of blasting vibration parameters of centralized charge and column charge, Figure 7~8 are the typical vibration velocity and its frequency spectrum.

Table 4: Vibration parameters of concentrated charge and column charge (charge 1.73g)

charge structure	measuring point distance(cm)	minimum burden(cm)	peak vibration velocity(cm/s)	dominant frequency(Hz)
cylindrical charge	87.0	8	0.373	26.6
	115	8	0.311	39.8
	144	8	0.263	26.2
	194	8	0.188	39.8
concentrated charge	87.0	8	0.404	39.8
	115	8	0.382	42.3
	144	8	0.365	/
	194	8	0.176	42.3

Table 5: Vibration parameters of concentrated charge and column charge (charge 2.01g)

charge structure	measuring point distance(cm)	minimum burden(cm)	peak vibration velocity(cm/s)	dominant frequency(Hz)
cylindrical charge	81.0	8	0.471	41.3
	107	8	0.264	41.3
	171	8	0.201	30.7
	204	8	0.194	30.7
concentrated charge	81.0	8	0.537	45.7
	107	8	0.268	40.1
	171	8	0.246	50.0
	204	8	0.260	50.0

Table 6: Vibration parameters of concentrated charge and column charge (charge 2.63g)

charge structure	measuring point distance(cm)	minimum burden(cm)	peak vibration velocity(cm/s)	dominant frequency(Hz)
cylindrical charge	92.0	12	0.480	54.5
	123	12	0.518	50.3
	173	12	0.210	50.2
	200	12	0.131	50.2
concentrated charge	92.0	12	0.670	/
	123	12	0.560	58.9
	173	12	0.346	79.2
	200	12	0.186	61.9

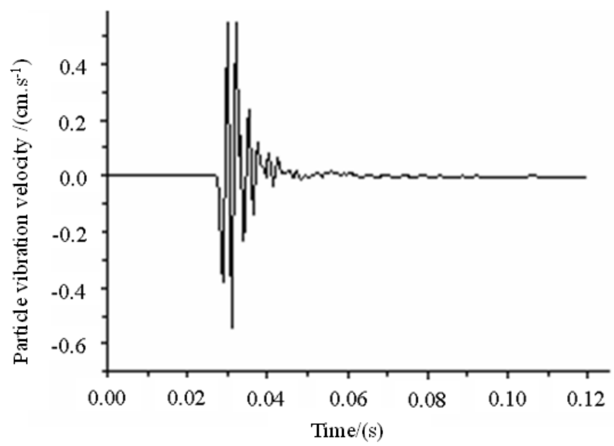

Figure 7: Vibration velocity of concentrated charge

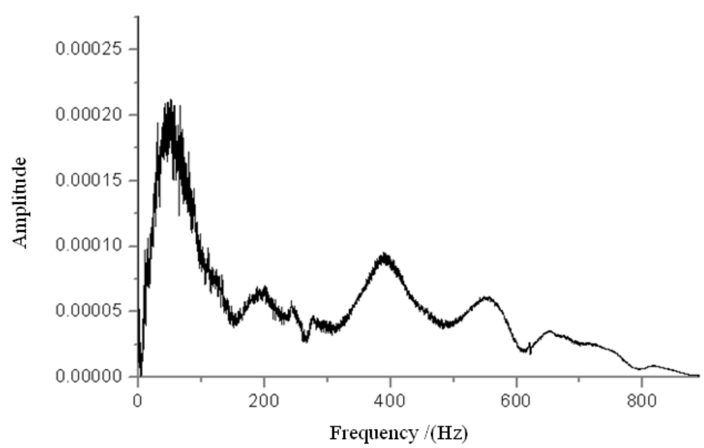

Figure 8: Frequency spectrum of the vibration velocity in concentrated charge

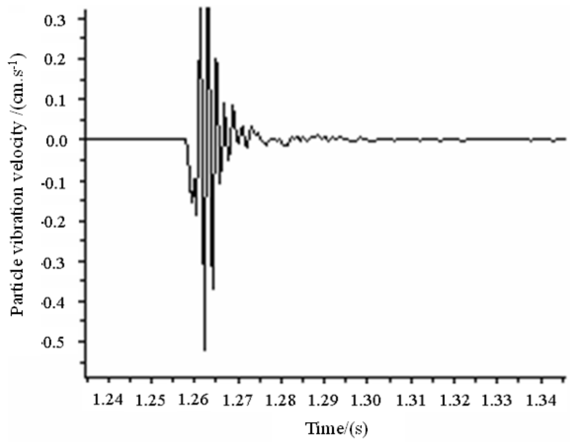

Figure 9: Vibration velocity of column charge

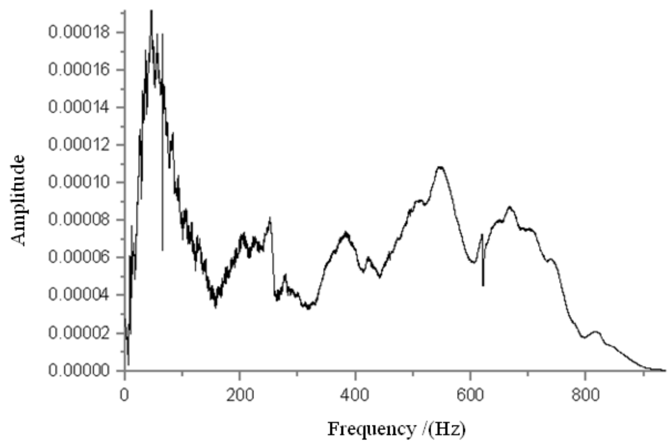

Figure 10: Frequency spectrum of the vibration velocity in column charge

Form the above monitoring data, the Sodev's empirical formula is used for regression analysis:

$$V = K\ (Q^{1/3}/R)^{\alpha} \qquad (3)$$

In the formula (3), V is the peak velocity of the particle, Q is the maximum initiation charge, R is the horizontal distance from the point to the explosion source, K and α are the coefficient related to the condition of the site.

column charge $V = 52(Q^{1/3}/R)^{1.13}$

concentrated charge $V = 40.8(Q^{1/3}/R)^{1.03}$

The research result shows that the vibration intensity of centralized charge is higher than that of column charge and the dominant frequency is higher than that of column charge also. Regression analysis of the test data reveals that K and α value of the test model are small, which shows that the actual rock medium is quite hard. The energy utilization ratio of column charge is relatively higher in rock breaking and throwing, so the energy into seismic waves is relatively small. The vibration intensity of column charge is less than the concentrated charges, this conclusion is consistent with the results obtained from Yang's research [7]. Because of the different mechanism of seismic wave generation on column charge and concentrated charge, the calculation approach of vibration parameters for column charge blasting with concentrated charge formula has some defects.

Effect of Elevation on Blasting Vibration

A large number of studies have indicated that the slope has elevation amplification effect in blasting vibration, namely the blasting vibration velocity increases with the increasing of the elevation. In order to analyze the vibration with different elevations, two kinds of slope height are designed in model test.

Table 7: Blasting vibration velocity of slope at different elevation

charge quantity (g)	measuring point distance (cm)	elevation (cm)	vibration velocity (cm/s)	charge quantity (g)	measuring point distance (cm)	elevation (cm)	vibration velocity (cm/s)
1.73	147	20	0.295	2.63	204	60	0.425
1.73	181	20	0.265	2.63	207	60	0.227
1.73	190	20	0.215	2.63	214	60	0.194
2.01	122	20	0.518	2.63	154	60	0.687
2.01	145	20	0.383	2.63	184	60	0.568
2.01	156	20	0.215	2.63	199	60	0.381

For the elevation amplification effect of blasting vibration, Chen [8] insists that elevation has a major effect on the value of K and the analysis of amplification effect can be realized by the formula $V = KH^{\beta}(Q^{\frac{1}{3}}/R)^{\alpha}$, but this formula does not carry out the non dimensional treatment and it does not consider the change of other parameters caused by elevation. Using the dimensional analysis method, the prediction formula of blasting vibration velocity is established.

$$V = K(Q^{\frac{1}{3}}/R)^{\alpha}(Q^{\frac{1}{3}}/H)^{\beta} \tag{4}$$

Through the regression analysis of test data in Table 7, the follow result is obtained:

$$V = 62(Q^{\frac{1}{3}}/R)^{2}(Q^{\frac{1}{3}}/H)^{-0.48}$$

The further analysis shows that the particle vibration velocity occurs elevation amplification effect except in a few measuring points. From the regression parameter $\beta = -0.48$, it can be known that the blasting vibration velocity increases with the increasing of elevation, that is to say, there is a significant nonlinear relationship between blasting vibration velocity and elevation. Shu [9] pointed out that the blasting vibration associates with slope angle, when the slope angle is greater than 1:2, the amplification effect of the slope will appear. On the contrary, the amplification effect disappears. The analysis shows that the distance from the source to the measuring point is increased with the increasing of slope height, so when the slope angle is relatively small, there is a possibility reducing of the blasting vibration velocity. In addition, the different of the medium of seismic wave propagation will also affect the velocity of blasting vibration.

CONCLUSIONS

Based on the dimensional analysis and similarity theory, the similarity criterion of blasting vibration model test is established. The influence of charge structure and elevation on blasting seismic is studied by concrete model experiment. The following conclusions are obtained:

(1) Single hole blasting tests of the model show that wave waveform of blasting seismic, frequency spectrum and attenuation law of particle vibration velocity have good similarity with field measured seismic wave. There are small differences in the dominant frequency and duration, but it does not affect the accuracy of the model test.

(2) The analysis of blasting seismic model test show that the vibration intensity of concentrated charge is higher than that of column charge, and its dominant frequency has the similar disciplinarian. Regression analysis of vibration test data show that the blasting vibration velocity has elevation amplification effect and its degree can be expressed by the power exponent function of the quantity and the height. When the slope angle is small, there is a possibility that the elevation amplification effect is not obvious or decreased due to the increase of the measuring point to the explosion source.

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