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Experimental Study on the Propagation Characteristics of Blasting Vibration in Layered Rock Masses

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ABSTRACT

Blasting vibration propagates anisotropically in the layered rock mass. Combined with a typical engineering case, propagation and attenuation characteristics of blasting vibration along different propagation paths were studied based on the blasting experiment and vibration measurement result. According to the analysis result, the engineering area was classified into vibration-sensitive region, surrounding region and general region considering their different influences on the protected buildings. To comply with the vibration velocity control requirements, the blasting parameters for different regions were specifically proposed so as to ensure the safety of the neighboring building and the construction period of the project.The analysis method of blasting vibration test can provide a useful and important reference for the similar construction cases.

INTRODUCTION

For convenience and efficiency, blasting is nowadays a majorly used method for the rock excavation. But, at the same time, the stress waves induced by the blasting excavation have a negative influence on its surrounding environments. Especially there are some deficiencies on the design or protective measures, the strongly blasting vibration often result in the structure deformation, cracking or even collapse of the surrounding buildings.

The influence factors of the vibration attenuation characteristics mainly includes: damping properties of the rock masses, the reflection and transmission phenomena of waves on the rock joint surface, geological and geomorphic conditions of propagation path. Among all these factors mentioned above, the geological condition especially rock mass structural properties, which is in the exploratory research phase now, has the most complex influence mechanism on the propagation and attenuation characteristics. Therefore some researchers performed lots of related research. For

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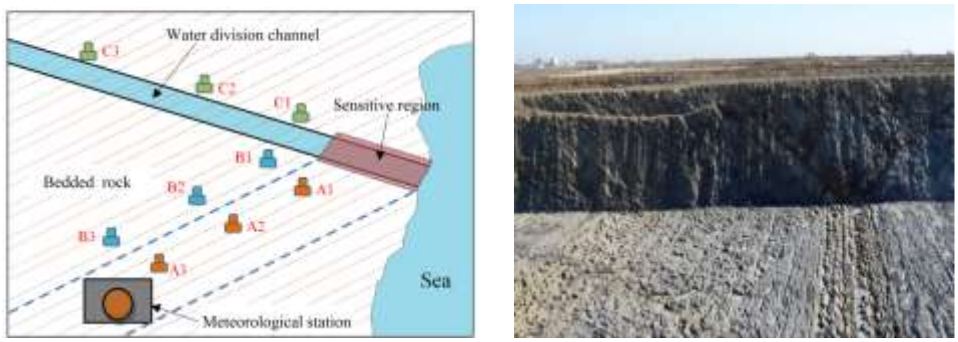
instance, in theoretical research, Wang [1], Li [2] proposed a theoretical model to describe the characteristics of stress wave pass through the linear structural plane perpendicularly and furthermore given the corresponding transmission and reflection coefficients. Zhao [3], Cai [4], Li [5] conducted a further research on the multiple reflection of stress wave in the multi-parallel linear deformation structural planes, as well as the numerical simulations with UDEC [6-8]. For the structural plane nonlinear deformation characteristics of the large amplitude blasting vibration, Zhao, Yu and Song [9-12] explored the structural plane nonlinearity effect on the traffic ability and the corresponding theoretical mechanism of stress waves. Some of their research results have been verified by the existing tests or numerical simulations results [13-15].

Current research on the influence of rock mass structural planes on stress wave propagation characteristics have been simplified, both in theory and experiment research. These conducted research ignoring the factors of structural aperture, filling condition and the matching coefficient. Besides, only the conditions that the structural planes are parallel or perpendicular to the rock strata are taken into consideration, which are far from the complex cutting of the engineering rocks. Hence, those research results cannot be used to make a precise evaluation of blasting vibration hazard in the engineering practice.

This paper combines the blasting excavation of the water diversion channel for a coastal power station, the transmission and attenuation characteristics of the vibration along or crossing typical layered rocks is achieved by the in-situ blasting vibration measuring. Based on the test result, the transmission characteristics of vibration along different propagation paths were analyzed, and the improvement measures on the blasting design and construction were put forward also. The measuring method and the analysis results will be of great referential significance for the similar excavation engineering and studies.

PROJECT OVERVIEW

The water diversion channel of a coastal power station is designed as the concrete lining trapezoid channel, with bottom width of 18 m, top width of 32 m and a length of 2.6 km. The construction site is composed mainly of the moderately weathered thin-layer and medium thick-bedded dolomite limestone with a strike direction of NE 25 °~30 °，dip direction of SE and with angle of 50 °~55 °. There exists a national basic meteorological station which is 180 m from the blasting excavation region of the water dispersion channel (seen in **Fig. 1**). Hence the blasting vibration induced by the blasting excavation should be controlled in case of any damages to the instruments and structure of the meteorological station.



(a) Layout schematic at the construction site (b) Stratification photo after the excavation

Figure 1. Schematic of the project overview.

During the monitoring of the blasting vibration, it is finds that although the blasting parameters are the same, there exists a vibration-sensitive excavation region which with the same formation with meteorological station, where the vibration velocity at meteorological station is obvious larger than other regions. The blasting vibration propagation demonstrates obvious anisotropically.

TEST SCHEME

In order to proposed suitable blasting parameters for the vibration-sensitive region mentioned above, the blasting test and vibration velocity measuring was conducted at the construction site so as to achieve the propagation characteristics of the blasting vibration along different paths. The detailed test scheme is as below, as shown in **Fig.1**:

① In the vibration-sensitive region, several blasting tests were carried out with different explosives shot per delay charges: increased from 15 kg to 45 kg, with each test 5 kg added. ② Three vibration velocity transducers, numbered A1, A2 and A3, were laid along the rock formations that blast hole and meteorological station shared. ③ The vibration velocity transducers B1, B2, B3 were laid parallel to A1, A2 and A3 on the rock formations that has no blasting hole or the meteorological station. ④ The vibration velocity transducers C1, C2, C3 were laid along the strike direction of the water diversion channel. ⑤ According to the position of the blasting source, three dimensional vibration velocity transducers with horizontal-radial direction, horizontal-tangential direction and vertical direction, were mounted at each monitoring point. The vibration attenuation along different propagation paths were achieved based on the results of the velocity monitoring, thus providing reference data for the future vibration control analysis and blasting design adjustment.

TEST RESULTS AND ANALYSIS

The Sadov's formula is normally adopted to conduct the regression analysis of the blasting vibration velocity data collected from the in-situ monitoring points. The Sadov's formula is as below:

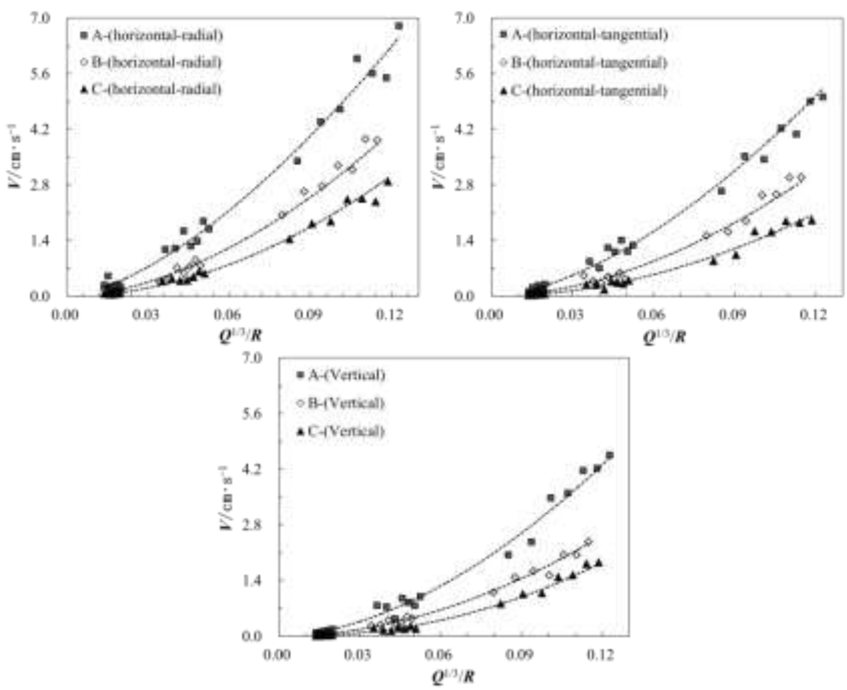
$$V=k\cdot(Q^{1/3}/R)^{\alpha} . \quad (1)$$

Where V represents the particle vibration velocity induced by blasting (units: cm/s); Q represents the charge amount per delay interval for blasting (units: kg), R represent the distance from the explosive source (units: m); $\boldsymbol{k}$ and $\boldsymbol{\alpha}$ represent the coefficient and attenuation index respectively which have a close relationship with the lithology, topography and geology.

TABLE 1. REGRESSION PARAMETER FOR VIBRATIONS OF DIFFERENT DIRECTIONS.

Propagation paths	Vibration Direction	k	α	Correlation coefficient **r**
Path A	Horizontal-radial	165.19	1.5410	0.9617
	Horizontal-tangential	158.34	1.6258	0.9778
	Vertical	183.31	1.7679	0.9858
Path B	Horizontal-radial	174.38	1.7630	0.9674
	Horizontal-tangential	150.00	1.8248	0.9866
	Vertical	152.09	1.9297	0.9733
Path C	Horizontal-radial	179.31	1.9232	0.9881
	Horizontal-tangential	124.09	1.9265	0.9872
	Vertical	203.16	2.2107	0.9912

The vibration velocity of the horizontal-radial direction through different propagation paths and the corresponding curves are shown in **Fig. 2a**. While **Fig 2b** and **2c** are the monitoring results of the horizontal-tangential and vertical direction respectively and the corresponding regression curves. Conduct the regression fitting of the data results by the formula (1), the attenuation law of vibration velocities along different propagation paths was achieved. The regression parameters of the vibration attenuation formula of different propagation paths are listed in **Table 1**.



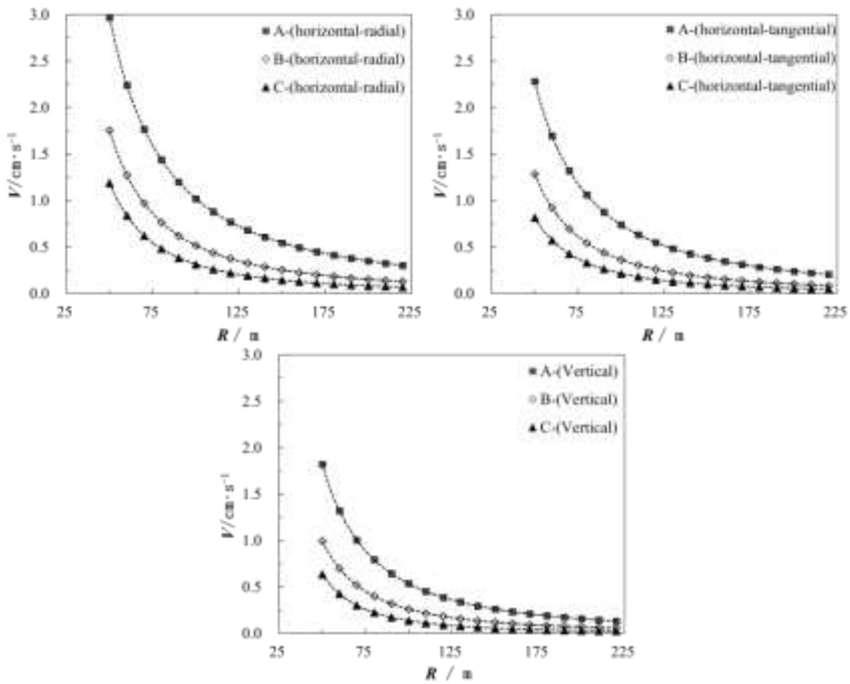
（a）Horizontal-radial direction （b） Horizontal-tangential direction （c）Vertical direction

Figure 2. The vibration velocity and its regression curve of different propagation paths.

Vibration velocity results show that, the vibration monitoring data along three propagation paths all demonstrate good regularity. And the corresponding correlation coefficients of the parameters in fitting calculation are relatively high value, indicating that the results of the in-situ blasting tests are of high reliability and availability.

According to the parameters k, α and Formula (1), the blasting vibration velocity along different directions and propagation paths can be calculated, as shown in **Fig. 3**. The calculating result shows the various attenuation characteristics of blasting vibration along different propagation paths.

The experimental results revealed that, by comprising with the same explosives charge and distance, all the vertical, horizontal and horizontal tangential vibration velocities of path A demonstrates the maximal velocity. The vibration propagating along path C demonstrates a minimum velocity while the vibration propagating along path B demonstrates a medium velocity.



（a）Horizontal-radial direction （b）Horizontal-tangential direction （c）Vertical direction

Figure 3. The calculated value of the vibration velocity of different propagation paths.

The rock stratification has significant impact on the deflection and transmission of stress wave propagation due to the dispersion and attenuation effect. The dispersion and attenuation effect will be much more obvious with higher surface roughness, larger opening width and less filling degree. As blasting vibration transmissions in path A, due to the least crosses of stratification planes, the stress wave suffered least attenuation during the same propagation distance thus resulting in a largest blasting vibration velocity. On the contrary, as the path C intersects with the stratification strike, the corresponding vibration passed through the most stratification planes within the same propagation distance, thus suffered the most serious of attenuation and resulting in a smallest blasting vibration velocity. The propagation path B is kind between path A and path C, and with corresponding vibration velocity in between.

Besides, for all the propagation paths, the horizontal-radial vibration velocity ranks as the largest, then the horizontal-tangential vibration velocity, and the vertical vibration velocity ranks as the last. To be different from common practical experience, the horizontal-tangential velocity is larger than the vertical velocity in geologic site conditions of this paper. The reason must been that the rock stratifications with large dip angle (50 °~ 55 °) played an obvious attenuation effect on the vertical vibration.

CONTROLLING METHOD AND EFFECTS

As required by the meteorological station, the particle vibration velocity should be firmly controlled so as to guarantee normal operation and monitoring accuracy of the meteorological station. The particle vibration velocity at meteorological station induced by the blasting excavation shall be less than 0.5 cm/s. It is necessary to find the maxim charge amount per delay interval, which could be calculated by the blasting vibration attenuation formula, thus providing the basis for the blasting design and implementation.

Meanwhile, in order to minimize the influence on the construction period, the vibration-sensitive region, surrounding region and general region shall be divided into several partitions and for each partition, different blasting design parameter is applied. As shown in **Fig. 4**, the blasting region which the rock formations that blast hole and meteorological station shared (propagation path A) is in corresponding to the vibration-sensitive region. According to the test result, a surrounding region (propagation path B) with length of 30 m was set nearby the vibration-sensitive region. Other blasting regions can be considered as the general region (propagation path C).

According to the attenuation law of blasting vibration for different propagation paths, the relation between the vibration velocity and the allowed blasting charge of different propagation paths can be obtained, as shown in **Fig. 5**. When the blasting vibration velocity of the meteorological station is 0.5 cm/s, the allowed blasting charges for vibration-sensitive region, surrounding region and general region are 52 kg, 195 kg and 420 kg respectively.

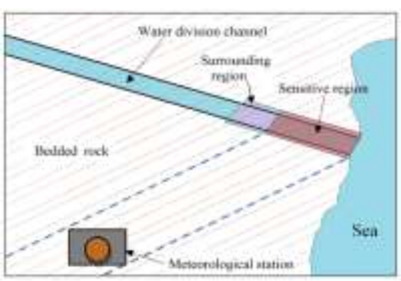


Figure 4. Schematic of the partition control for the blasting excavation.

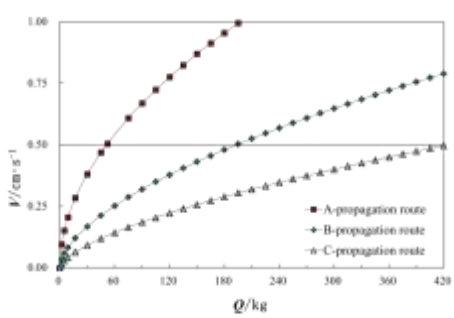


Figure 5. Relationship between the vibration velocities of different paths with variety explosive charges.

As the millisecond short-delay blasting method is adopted herein this excavation, the maximum charge restriction for the surrounding region and general region was indeed have no influence on the blasting design and construction. For the blasting in the vibration-sensitive region, the rock mass was excavated in layers and with millisecond short-delay method so as to decrease the explosive charge for each blasting (the actual value is less than 45 kg) and the blasting vibration velocities.

The result of the tracing monitoring result shows that the particle vibration velocities of meteorological station induced by the blasting in vibration-sensitive region are less than 0.5 cm/s, which effectively guaranteed the normal operation of the meteorological station. The regional control method, maximize the vibration restriction influences on the construction period and guaranteed the timely completion of this project.

CONCLUSIONS

Based on the blasting test and vibration measurement result of a water diversion channel project, the blasting vibration propagation characteristics in layered rocks of different propagation paths were studied in this article. In order to guarantee the safety of the surrounding buildings and the project construction period, the explosive region was divided into several partitions and the blasting parameters were put forward for each partition respectively. The major conclusions are as below:

(1) Under the geological conditions of bedded structure, there is smallest vibration attenuation along the strike of the rock formation. Besides, the attenuation of vibration velocity would increase with the increasing of the formation dip angle (≤90 °).

(2) In this layered formation with large dip angle, the vertical vibration demonstrates an obvious attenuation after passing through the stratification. The measure value of the vertical vibration velocity is less than that of the horizontal-tangential direction.

(3) For the excavation site with layered rock masses, blasting experiment and vibration velocity test should be conducted to obtain vibration attenuation laws of different propagation paths and divide the excavation region. And basis on, the blasting parameters and allowable amounts of charges per delay should be proposed specifically for different regions, thus to maximize the vibration restriction influences on the construction period.

REFERENCES

[1] M.Y. Wang, & Q.H. Qian, Attenuation law of explosive wave propagation in cracks, Chinese journal of geotechnical engineering. 17(1995):42-46.
[2] X.B. Li, Influence of the structural weakness planes in rock mass on the propagation of stress waves, Explosion and Shock Waves. 13(1993):334-342.
[3] J. Zhao, Y.X. Zhou, Rock dynamic research related to cavern development for ammunition storage, Tunneling and Underground Space Technology. 14(1999): 513-526.
[4] J.G. Cai, J. Zhao, Effects of multiple parallel fractures on apparent attenuation of stress waves in rock masses, International Journal of Rock Mechanics and Mining Sciences. 37(2000):661-682.
[5] J.C. Li, G.W. Ma, Analysis of blast wave interaction with a rock joint, Rock Mechanics and Rock Engineering. 43(2010):777-787.
[6] J.G. Cai, J. Zhao, A study of UDEC modeling on effects of nonlinear deformational behavior of a fracture on P-Wave attenuation, International Conference on Geotechnical & Geological Engineering. Melbourne, Australia, 2000.
[7] J. Zhao, S.G. Chen, J.G. Cai, Simulation of Blast Wave Propagation in Jointed Rock Mass Using UDEC, Journal of China University of Mining& Technology. 32(2002):111-115.
[8] S.G. Chen, J.G. Cai, J. Zhao, Discrete element modeling of an underground explosion in a jointed rock mass, Geotechnical and Geological Engineering. 18(2000):59-78.
[9] J. Zhao, J.G. Cai, Transmission of elastic P-waves across single fractures with a nonlinear normal deformational behavior, Rock Mechanics and Rock Engineering. 34(2001): 3-22.

[10] J. Zhao, J.G. Cai, X.B. Zhao, et al., Dynamic model of fracture normal behavior and application to prediction of stress wave attenuation across fractures, Rock Mechanics and Rock Engineering. 41 (2008): 671-693.
[11] J. Yu, Q.H. Qian, C.M. Lin, et al., Transmission of elastic P-wave across one fracture with improved nonlinear normal deformation behaviors, Chinese Journal of Geotechnical Engineering. 31(2009):1156-1164.
[12] L. Song, Y.Z. Yan, B.X. Han, et al., Theoretical research into the wave propagation of P-wave across rock joint with nonlinear deformation. Chinese Journal of Applied Mechanics. 29(2012): 133-140.
[13] N.N Li, J.C. Li, H.B. Li, et al., SHPB experiment on influence of contact area of joints on propagation of stress wave. Chinese Journal of Rock Mechanics and Engineering. 30(2015): 1994-2000.
[14] J.F. Liu, S.J. Qu, Experimental study of influence of joint angle of strike on explosive stress wave propagation, Blasting. 32(2014): 57-62.
[15] B. Sun, S.S. Guo, S. Zeng, Transmission and reflection and the attenuation law of stress wave, Journal of Disaster Prevention and Mitigation Engineering. 35(2015): 828-832.