The Elevation Effect of Vibration Induced by Pneumatic Rock Breaking with Carbon Dioxide Ice Powder

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Abstract. In traditional explosive blasting, the elevation amplification effect is an important aspect that cannot be ignored in the study of vibration disasters. Compared with this type of vibration, the elevation amplification effect of vibration induced by pneumatic rock breaking with carbon dioxide ice pow-der was explored through on-site vibration monitoring experiments. The results showed peak particle velocity increased when the sensor was higher than the vibration source, indicating that vibration induced by pneumatic rock breaking with carbon dioxide ice powder, like explosive blasting, has an elevation amplification effect. However, the elevation effect of vibration induced by pneumatic rock breaking with carbon dioxide ice powder mainly manifests as an amplification of the low-frequency vibration component, suppressing and weakening the high-frequency vibration. Others, the elevation amplification effect is only reflected within a certain distance. As the distance to the vibration source increases, peak particle velocity returns to its standard value and follows the existing attenuation rule. The elevation factor no longer affects the propagation and attenuation of vibration within the rock mass.

Keywords: vibration; elevation amplification effect; carbon dioxide ice powder; pneumatic rock breaking.

1. Introduction

China's modernization process is rapidly developing in today's century, and re-source extraction and infrastructure construction are constantly underway. Ex-plosive blasting, as an economical and efficient operation method in geotechnical engineering construction, has been widely used in fields such as ore mining, municipal transportation, and water conservancy facilities. However, various safety accidents and civil disputes caused by blasting also emerge, among which blasting vibration ranks first among the harmful effects of blasting.

Engineers are also constantly trying various non blasting excavation techniques, such as static expansion fracturing technology [1], hydraulic fracturing technology [2], carbon dioxide blasting technology [3,4,5], etc., to reduce the negative impact of engineering construction on the surrounding environment. In 2019, Hu Shaobin and others first proposed pneumatic rock breaking with carbon dioxide ice powder technology, which was successfully applied to the slope reduction treatment of the Qingshan Lake underwater tunnel and extension road project in Lin'an, Hangzhou. During this period, the vibration induced by pneumatic rock breaking with carbon dioxide ice powder was preliminarily analyzed, and it was pointed out that the downward slope will accelerate the attenuation of the peak particle velocity, and the larger the slope, the faster the attenuation [6,7,8].

Based on previous research, this article will further explore the elevation effect of vibration induced by pneumatic rock breaking with carbon dioxide ice powder under open-pit bench conditions through on-site experiments to guide the design and construction of engineering rock breaking in complex and sensitive environments.

2. Field Vibration Tests

The on-site vibration test site is located in the circular foundation pit of a pump-ing station in Chongqing, China, with a maximum excavation circumference of about 274m and a maximum depth of 27.6m. Due to the proximity of the pumping station to the Jialing River and the existence of existing power stations nearby, following the requirements of local environmental protection and power station protection, the graded slope excavation of the pumping station uses hydraulic fracturing hammers and other rock-breaking machinery, and traditional explo-sives cannot be used for blasting.

Fig.1 Real scene of pumping station

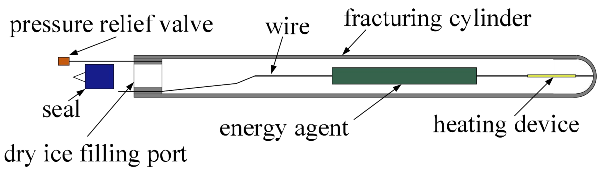


Fig.2 Dry ice fracturing cylinder

To improve on-site construction efficiency, pneumatic rock-breaking tests with carbon dioxide ice powder were conducted on the excavation slope bench of the pumping station. The experimental equipment selected is the dry ice fracturing cylinder developed by Jiangsu Zhongkong Energy Science and Technology [6], as shown in Figure 2. The specific model is ZLQ- Φ 89 × 600, preset rupture pressure 60MPa. According to the calculation method of explosion energy for pressure vessels, as shown in equation (1), The explosion energy of ZLQ-Φ89×600 dry ice fracturing cylinder is about 581.9 kJ, and the corresponding emulsion explosive equivalent is about 0.2 kg (the explosion energy per kg of emulsion explosive is about 3009 kJ) [9].

$$E = \frac{P_1 V}{K-1}\left[1-\left(\frac{P_2}{P_1}\right)^{\frac{K-1}{K}}\right] \tag{1}$$

Where, E is the explosive energy of the fracturing cylinder, J; P1 is the absolute pressure of the gas inside the fracturing cylinder, Pa; P2 is the standard atmospheric pressure, taken as 101 325 Pa; V is the volume of the fracturing cylinder, m3; K is the heat capacity ratio of carbon dioxide, taken as 1.295.

During the experiment, vibration monitoring sensors were installed on the excavation benches of the pumping station foundation. Since the vertical vibration component has the most significant elevation effect, this experiment only recorded the vibration data in that direction. The arrangement of on-site boreholes and vibration sensors is shown in Figure 3, with two cracking holes and five vibration sensors.

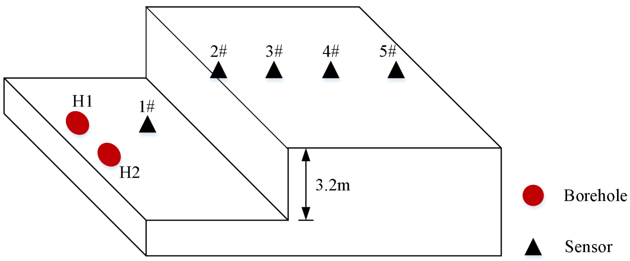


Fig.3 Schematic diagram of on-site borehole and vibration sensor layout

Figure 4, Table 1, and Table 2, respectively, show the separated blasting vibration monitoring system and its technical indicators, composed of TC-4850N wireless network vibration meter and TCS-B3 vibration sensor provided by the Zhongke (Chengdu) instruments Co., Ltd.

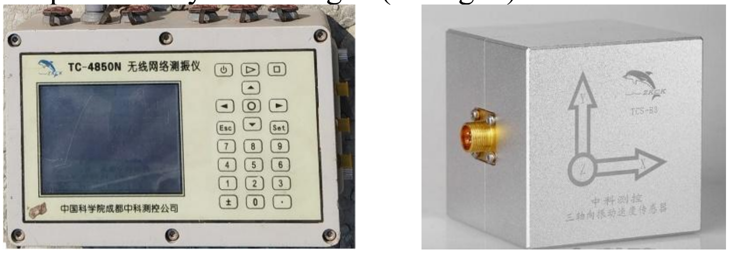


Fig.4 Wireless network vibration meter TC-4850N and TCS-B3 sensor

Table 1. Technical index of wireless network vibration meter TC-4850N

Technology index	Parameter value	Technology index	Parameter value
Channel number	4	Sampling rate	100~100kHz
A/D resolution	16Bit	Frequency range	0~10kHz
Record duration	1~5000s	Trigger mode	Internal triggering
Range	±10V	Storage capacity	256MB
Recording accuracy	0.01cm/s	Reading accuracy	1‰

Table 2. Main technical indexes of TCS-B3 sensor

Frequency range	Sensitivity	Damping coefficient	Output impedance	Harmonic distortion	Working temperature	Maximum displacement
5~300Hz	28V/m/s	0.6	380Ω	≤0.2%	-20~75℃	4mm

3. Vibration statistical analysis

After the on-site test, the peak particle velocity at each vibration sensor as shown in Table 3.

Table 3. Peak particle velocity of ground vibration

Borehole	Sensor	Horizontal distance/m	Relative elevation/m	PPV/(cm•s^{-1})
H1	1#	12.8	0	1.25
	2#	17.4	3.2	1.44
	3#	21.6	3.2	0.46
	4#	24.9	3.2	0.57
	5#	32.9	3.2	0.25
H2	1#	12.0	0	1.57
	2#	16.5	3.2	2.00
	3#	20.8	3.2	0.71
	4#	23.4	3.2	0.93
	5#	31.2	3.2	0.38

According to the engineering geological survey report, the rock mass of the pumping station foundation pit is sandstone interbedded in the Jurassic Xintiangou Formation, with an average uniaxial strength of 55.76 MPa, belonging to hard rock. According to the "Safety Regulations for Blasting" (GB6722-2014), it can be seen that under hard rock conditions, K and α, the range of values is 50-150 and 1.3-1.5, respectively. Take the median value within the above range (i.e., K=100、α= 1.4), draw the vibration attenuation curve at 0.2 kg emulsion explosive equivalent, and compare it with the measured data in Table 3, as shown in Figure 5. It can be seen that (1) most of the data points conform to the attenuation law of flat ground vibration velocity under hard rock conditions in K=100、α=1.4 indicates that the method of calculating the equivalent of dry ice fracturing cylinder based on the explosion energy of pressure vessels is appropriate; (2) The two peak particle velocities at sensor 2# are both higher than the attenuation curve and deviate significantly, indicating that the vibration induced by pneumatic rock breaking with carbon dioxide ice powder, like explosive blasting, has an elevation amplification effect; (3) Except for sensor 2#, the peak particle velocity at sensors 3#, 4#, and 5# did not reflect the elevation amplification effect, indicating that the elevation amplification effect is only reflected within a certain distance. After exceeding a certain distance, the elevation factor will no longer affect the propagation and attenuation of vibration inside the rock mass.

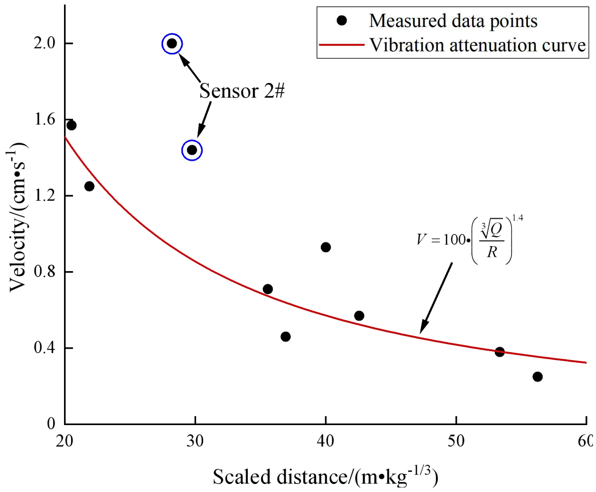
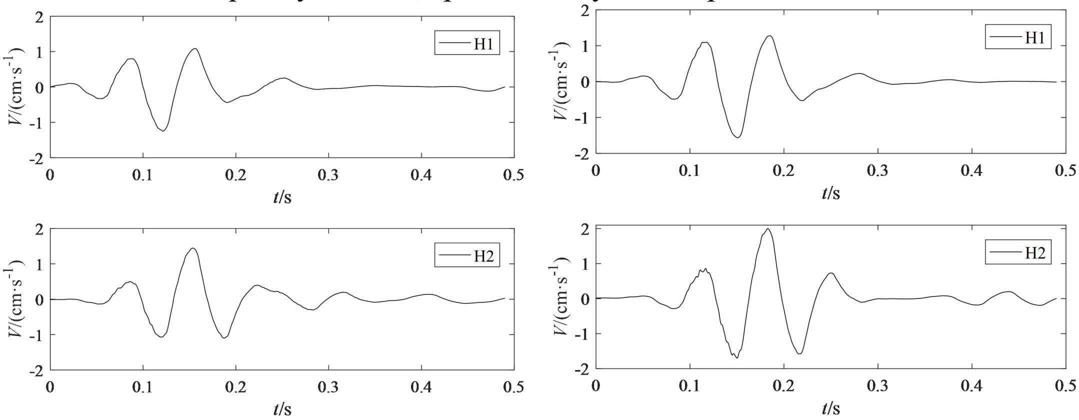


Fig.5 Scatter diagram of PPV

4. Vibration Signal Analysis

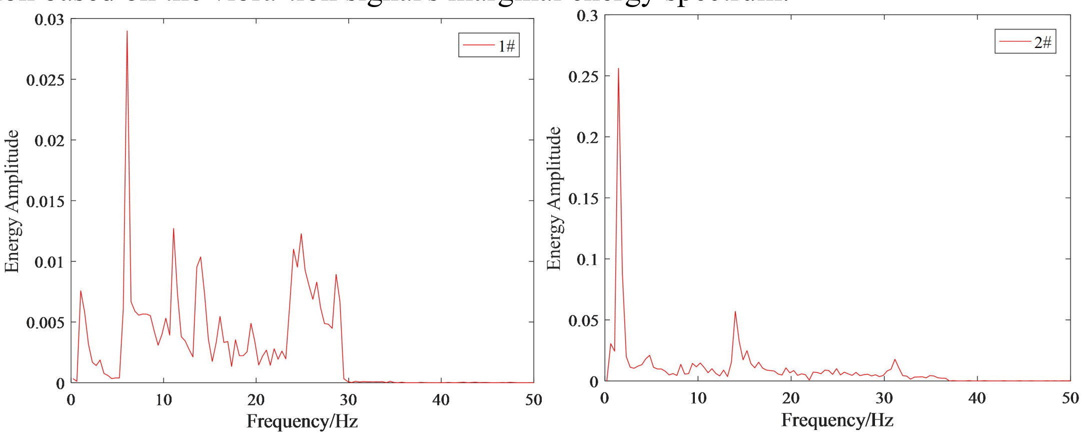
Figure 6 shows the vibration signals recorded by sensors 1 # and 2 #. To reveal the impact of elevation on vibration frequency content, spectral analysis was performed on the waveforms.



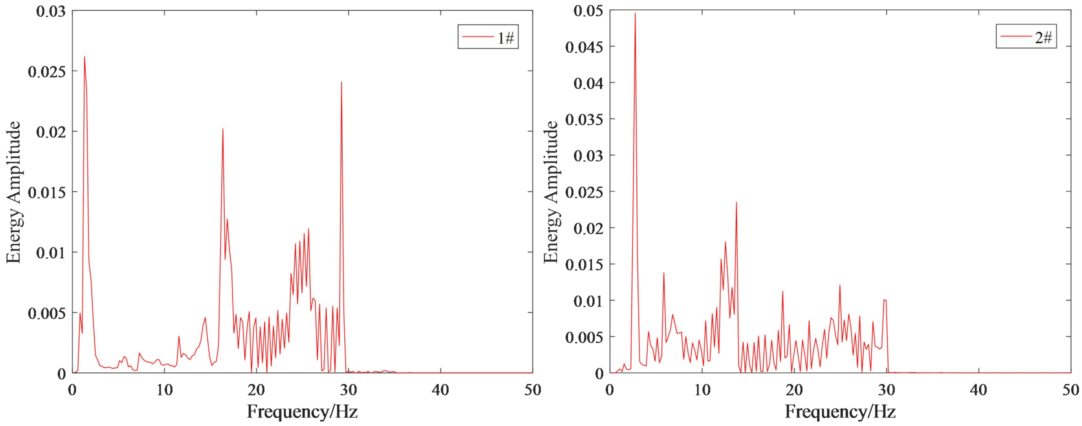
(a) Vibration waveform at sensor 1# (b) Vibration waveform at sensor 2#

Fig.6 Vibration induced by H1and H2 in ground surface

MEEMD (Multivariate Ensemble Empirical Mode Decomposition) was used to decompose the recorded vibration signals, and the corresponding marginal ener-gy spectrum was calculated using the Hilbert transform [10], as shown in Figure 7. Table 4 calculates each frequency band's energy proportion based on the vibra-tion signal's marginal energy spectrum.



(a) Vibration velocity waveform at sensor 1#



(b) Vibration velocity waveform at sensor 2#

Fig.7 Marginal energy spectrum of vibration signals

Table.4 The proportion of each frequency band

Frequency band \ Type	H1		H2	
	1#	2#	1#	2#
0~10Hz	30.9%	53%	23.2%	34.4%
10~20Hz	32%	27.4%	33.4%	34.6%
20~30Hz	36.6%	12.1%	43%	30.9
>30Hz	0.5%	7.5%	0.4%	0.1%

From Figure 7 and Table 4, it can be seen that compared to sensor 1#, the high-frequency vibration content at sensor 2# has significantly decreased in both vibration events, indicating that as the elevation increases, vibration induced by pneumatic rock breaking with carbon dioxide ice powder, mainly manifests as an amplification of the low-frequency vibration component, which in turn sup-presses and weakens the high-frequency vibration. This situation is more likely to cause resonance in the building (structure) and should be taken seriously in the scheme's design.

5. Conclusion

The article explores the elevation effect of vibration induced by pneumatic rock breaking with carbon dioxide ice powder under open-pit bench conditions through on-site experiments and data analysis. The results show that (1) most of the data points conform to the attenuation law of flat ground vibration velocity under corresponding hard rock conditions indicates that the method of calculating the equivalent of dry ice fracturing cylinder based on the explosion energy of pressure vessels is appropriate. (2) The vibration induced by pneumatic rock breaking with carbon dioxide ice powder, like explosive blasting, has an elevation amplification effect, but it mainly manifests as the amplification of low-frequency vibration components. The elevation increase will have a suppressive and weakening effect on high-frequency vibration components, which should be carefully considered in safety protection. (3) The elevation amplification effect is only reflected within a certain distance. After exceeding a certain distance, peak particle velocity returns to its standard value and follows the existing attenuation rule. The elevation factor no longer affects the propagation and attenuation of vibration within the rock mass.

Acknowledgements

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References

[1] XIE Xionggang, LIU Jinwei, WANG Lei, et al. Testing study of expanding and cracking outburst coal seam by the static expansion agent. Journal of the China Coal Society, 2016(41): 2620-2625.

[2] De Graaf, W.W., Spliteri W. A preliminary qualitative evaluation of a hydraulic splitting cylinder for breaking rock in deep-level mining. Journal of the Southern African Institute of Mining and Metallurgy, 2018(118):891-897.

[3] LI Wen, CHEN Yong, WANG Fuyun, et al. Feasibility study of developing one new type of seismic source via carbon dioxide phase transition. Chinese Journal of Geophysics, 2020, 63(7):2605-2616.

[4] SUN Xiaoming. Experimental study on cutting and rock breaking by liquid CO2 phase transition fracturing technology. Coal Science and Technology, 2021, 49(8):81-87.

[5] XIA Xiang, LI Haibo, WANG Xiaowei, et al. Comparison analysis of ground vibrations induced by CO_2 gas fracturing and explosive blasting. Chinese Journal of Rock Mechanics and Engineering, 2021, 40(07):1350-1356.

[6] HU Shaobin, PANG Shuogang, YAN Zhengyong. A new dynamic fracturing method: deflagration fracturing technology with carbon dioxide. International Journal of Fracture, 2019(220): 99-111.

[7] LI Baolin, WANG Enyuan, HU Shaobin, et al. A Study of Vibration Velocity Attenuation Induced by Pneumatic Rock Breaking with Carbon Dioxide Ice Powder for Safety Assessment. Rock Mechanics and Rock Engineering, 2021, 54(12):6481-6493.

[8] YE Wu, LU Yong, XI Lingzhi, et al. Vibration effect induced by rock breaking technology based on dry ice and energy-gathered agent in trench excavation. Journal of Physics: Conference Series, 2022, 2148(1):1-11.

[9] WANG Jie, ZHANG Yunpeng, GE Xiaodong, et al. Study on rock breaking parameters and numerical simulation of phase transition of liquid CO2. Explosive Materials, 2022, 51(04):16-22.

[10] LI Chen, LIANG Shufeng, LIU Chuanpeng, et al. Trend Removing Method of Blasting Vibration Signals Based on MEEMD. Transaction of Beijing Institute of Technology, 2021, 41(6):636-641.