Vibration Response of Brick Concrete Building under Shaft Blasting

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Abstract. During the blasting construction, the problem of building vibration caused by blasting cannot be ignored. Therefore, this paper uses the measured blasting seismic wave of a shaft in Qingdao Metro as the input parameter to conduct numerical simulation to research the influence of blasting vibration of shaft on brick concrete buildings. The results show that the Z-direction vibration velocity has obvious local amplification on the roof, and the amplification factor is 1.4-1.9 relative to the top floor. The magnification factor on the backward side is smaller than the magnification factor on the frontward side, and the elevation magnification effect gradually weakens as the elevation difference increases. HHT (Hilbert-Huang Transform) method is used to analyze blasting seismic wave signals, when the blasting seismic wave propagates from the first floor of the brick concrete building to the roof, the energy is reduced by about 67%-80%. The frequency band of 0-30 Hz is the main range of blasting energy distribution in brick concrete buildings, and attention should be paid to resonance phenomenon.

1. Introduction

In metro blasting construction, blasting seismic waves have the greatest impact on surrounding buildings. For brick concrete building with large numbers, low strength, and poor seismic resistance, frequent blasting construction can easily cause damage and pose a serious threat to the safety of residents[1-2]. Past studies have shown that the dynamic response of buildings under blasting loads is inseparable from the three elements of blasting seismic waves, and is also related to the building’s material strength, structural characteristics, damping and natural frequencies[3-4].

Vibration velocity and frequency are the main basis for judging the damage of building structure. The application of time-frequency localization analysis methods such as wavelet transform and HHT in the analysis of blasting seismic signals has made the research on the time-frequency characteristics and energy distribution characteristics of blasting seismic wave signals more comprehensive, and structural failure criteria considering frequency characteristics have also begun to gain attention[5-8]. In the blasting frequency domain close to the natural frequency of the building structure, the building will show varying degrees of vibration amplification effects. The magnitude of the amplification factor is related to the blasting source, geological conditions, building structure, elevation difference and other factors[9-11].

This paper takes the blasting construction of the shaft at Xizhen Station of Qingdao Metro Line 1 as the background, and uses ANSYS/LS-DYNA software to establish a numerical model to explore the vibration velocity response law of brick concrete building under shaft blasting loads. Using the
HHT method to analyze the spectral characteristics and energy distribution of the blasting seismic wave signal is of great significance and engineering application value for evaluating the safety of buildings under blasting loads.

2. Engineering overview
The shaft is located at the intersection of Yuncheng Road and Feixian Road, Qingdao. The design depth of the shaft is 38m, upside-down well wall method is adopted for construction. The excavation area of the shaft is 56.76 m², and the surrounding rock is mainly grade III. The two-stage wedge cut blasting is used, the cycle footage is 1.0 m, and the maximum single-section detonating charge is 9 kg. Millisecond delay blasting is adopted at the blasting site, and No.2 rock emulsion explosive is used.

Select a 7-story brick concrete residential building on the west side of the shaft as the monitoring building. The monitoring building is at a horizontal distance of 27.5 m from the shaft. The TC-4850 blasting vibrometer is used for real-time monitoring of shaft blasting excavation. The monitoring point is located on the ground of facing the blasting side of the monitoring building. The explosive zone environment is shown in figure 1.

3. Numerical simulation calculation

3.1. Numerical model
The numerical calculation model is established by ANSYS/LS-DYNA software, the model is shown in figure 2. The total size of the rock and soil layer is 60 m×20 m×20 m, the thickness of the soil layer is 1 m. The size of the building is 20 m×11 m×20 m, with a total of 7 floors. The rock mass and soil material parameters are measured by in-situ test data, and the rock, soil, wall, column and floorslab are simulated by the MAT_PLASTIC_KINEMATIC. The material parameters are shown in table 1.

![Figure 1. Explosive zone environment (unit: m).](image1)

![Figure 2. Numerical model.](image2)

Table 1. Material parameters of rock, soil, wall, column and floorslab.

| Material          | $\rho$ (g/cm$^3$) | E (GPa) | PR | SIGY (GPa) | ETAN (GPa) | BETA |
|-------------------|-------------------|---------|----|------------|------------|------|
| Rock              | 2.6               | 22      | 0.2| 1.2E-1     | 0          | 0.5  |
| Soil              | 2.12              | 4.768   | 0.2| 2.98E-3    | 0          | 1.0  |
| Wall              | 2.12              | 4.768   | 0.2| 2.98E-3    | 0          | 1.0  |
| Column and floorslab | 2.4              | 30      | 0.2| 1.67E-2    | 6.1        | 0.6  |

3.2. Benchmark input parameters of blasting seismic wave
In order to study the dynamic response of brick-concrete buildings under shaft blasting load, the blasting seismic waves measured at the monitoring points when the shaft is excavated to 4 m and 28 m are used as the reference input parameters. The vibration velocity time history curve of blasting seismic waves is shown in figure 3.
4. Structural dynamic response analysis

Nodes are selected on each floor of the building's frontward side and backward side. The peak particle velocity of the X, Y, Z and vector sum of the nodes when the shaft is excavated to 4 m and 28 m are presented in table 2. Figure 4 is obtained by analyzing the blasting vibration data in table 2.

Table 2. Numerical simulation of blasting vibration data.

| Depth (m) | Floor  | Facing the blasting side | Back blasting side |
|-----------|--------|--------------------------|--------------------|
|           |        | Three dimensional vibration velocity (cm/s) | Vector sum (cm/s) | Three dimensional vibration velocity (cm/s) | Vector sum (cm/s) |
|           |        | X    | Y    | Z    | X    | Y    | Z    | X    | Y    | Z    | X    | Y    | Z    |
| 4         | 1      | 2.69 | 1.20 | 1.95 | 2.88 | 1.06 | 0.58 | 1.19 | 1.54 | 0.86 | 0.42 | 0.58 |
|           | 2      | 1.01 | 0.49 | 1.47 | 1.52 | 0.79 | 0.42 | 0.86 | 1.18 |        |        |        |
|           | 3      | 0.56 | 0.27 | 0.99 | 1.01 | 0.41 | 0.14 | 0.62 | 0.66 |        |        |        |
|           | 4      | 0.35 | 0.25 | 1.06 | 1.07 | 0.77 | 0.21 | 0.14 | 0.67 |        |        |        |
|           | 5      | 0.31 | 0.19 | 0.76 | 0.65 | 0.46 | 0.24 | 0.08 | 0.37 |        |        |        |
|           | 6      | 0.26 | 0.11 | 0.46 | 0.26 | 0.21 | 0.10 | 0.28 | 0.36 |        |        |        |
|           | 7      | 0.31 | 0.13 | 0.39 | 0.39 | 0.26 | 0.13 | 0.53 | 0.54 |        |        |        |
| Roof      |        | 0.35 | 0.18 | 0.76 | 0.76 | 0.26 | 0.13 | 0.53 | 0.54 |        |        |        |
| 28        | 1      | 2.24 | 1.07 | 1.77 | 2.64 | 0.99 | 0.48 | 0.90 | 1.26 |        |        |        |
|           | 2      | 0.98 | 0.53 | 1.29 | 1.29 | 0.64 | 0.30 | 0.70 | 0.77 |        |        |        |
|           | 3      | 0.30 | 0.34 | 0.80 | 0.81 | 0.26 | 0.18 | 0.62 | 0.65 |        |        |        |
|           | 4      | 0.24 | 0.20 | 0.80 | 0.84 | 0.21 | 0.15 | 0.45 | 0.48 |        |        |        |
|           | 5      | 0.19 | 0.18 | 0.65 | 0.64 | 0.14 | 0.11 | 0.35 | 0.39 |        |        |        |
|           | 6      | 0.21 | 0.13 | 0.35 | 0.35 | 0.16 | 0.07 | 0.24 | 0.24 |        |        |        |
|           | 7      | 0.20 | 0.08 | 0.26 | 0.26 | 0.18 | 0.08 | 0.24 | 0.26 |        |        |        |
| Roof      |        | 0.25 | 0.10 | 0.42 | 0.42 | 0.20 | 0.08 | 0.35 | 0.37 |        |        |        |

The first floor is directly incident by the blasting seismic wave, the blasting vibration response is the strongest, so the vibration velocity is the largest. The peak particle velocity of the first floor of the building presents the law of X-direction>Z-direction>Y-direction, and other floors all present the law of Z-direction>X-direction>Y-direction. The peak particle velocity of the bottom floor of the building is maximum due to the maximum constraint. The Z-direction vibration velocity has obvious high-level amplification on the roof, and the amplification factor is 1.4-1.9 relative to the top floor, and the amplification factor on facing the blasting side is smaller than that on the back blasting side. The magnification factor decreases with the increase of the shaft excavation depth. The reason is that the elevation magnification effect gradually weakens with the increase of the elevation difference. When the elevation difference exceeds a certain range, the magnification phenomenon will no longer occur.
When the shaft is excavated to 28 m, the vector combined vibration velocity of the first floor is reduced by 15%-18%, and the vector combined vibration velocity of the roof is reduced by 36%-41% compared with that when the shaft is excavated to 4 m. This shows that the depth of the shaft excavation has a more significant impact on the attenuation of the vibration of the brick concrete building roof. Because the blasting seismic wave needs to be diffracted to reach the back blasting side, the energy is attenuated in the process of propagation, and the peak particle velocity of three-dimensional particles is smaller. Therefore, it is more reasonable to use the ground blasting vibration velocity on facing the blasting side of the building as a reference when performing shaft blasting design and vertical shaft blasting adjacent to brick concrete building vibration monitoring.

![Variation curve of vibration velocity with floor](image)

Figure 4. Variation curve of vibration velocity with floor.

5. HHT analysis of blasting seismic wave signal

The HHT method is currently recognized as one of the latest time-frequency localization analysis methods. The HHT method is based on the local mean characteristics and time scale of the original signal, and extracts the IMF (Intrinsic mode function) components of the blasting seismic wave signal through EMD (Empirical mode decomposition) decomposition. After Hilbert transforms the IMF components, the frequency is integrated to obtain the blasting instantaneous energy spectrum to obtain the energy amplitude of each sampling point[12-13].

In order to further study the distribution and change characteristics of frequency and energy, facing the blasting side with greater peak particle velocity is selected for research. The HHT analysis was performed on the blasting seismic wave signals of the first floor and roof of the building when the...
shaft was excavated to 4 m and 28 m. The Hilbert three-dimensional energy spectrum is shown in figure 5. Comparing the time when the vibration velocity waveform peak appears in figure 3, the multiple energy peaks at different time sampling points are caused by the difference in initiation time of different blastholes in the millisecond delay blasting. The peak energy time corresponds to the blasting time of the cutting hole, which indicates that the cutting hole blasting is greatly used by the rock clamp, and the blasting energy is large, which leads to the high blasting vibration velocity. The damping cutting blasting technology is adopted, such as arranging the damping hole, improving the structural form of the cutting hole, and increasing the large diameter hollow hole.

When the shaft is excavated to 4 m, the blasting energy amplitude of the first floor is concentrated between 0.5-0.8 cm²/s², and the energy amplitude of the roof is between 0.1-0.2 cm²/s². When the shaft is excavated to 28 m, the blasting energy amplitude of the first floor is concentrated between 0.3-0.5 cm²/s², and the energy amplitude of the roof is between 0.1-0.15 cm²/s². From the first floor to the roof, the energy of the seismic wave propagates is reduced by about 67%-80%. 0-30 Hz is the main frequency band of blasting energy distribution. With the increase of floor and excavation depth, the proportion of energy in low-frequency band has a gradually increasing trend. The natural frequency of brick-concrete building is 1-10 Hz, which is in the main frequency band of blasting energy and prone to cause resonance. Since the frequency at the roof is closer to the natural frequency of the building, it is necessary to take measures to increase the main frequency of blasting vibration, reduce the speed of blasting vibration and strengthen the monitoring and protection of the roof.

![Hilbert three-dimensional energy spectrum](image)

6. Conclusion
A numerical model was established by ANSYS/LS-DYNA finite element software to study the vibration velocity change of the brick concrete building under the blasting load of the subway shaft. The HHT method is used to analyze the building blasting seismic wave signals, and the distribution and changes of energy and frequency at different excavation depths are obtained. The main conclusions are as follows:

(1) The blasting vibration velocity response of the first floor is the strongest, and the attenuation velocity is also the largest. Z-direction vibration has a greater impact on the building. Under the condition of the same charge, with the increase of the shaft excavation depth, the blasting vibration velocity of each floor is mainly attenuated.

(2) The Z-direction vibration velocity has obvious local magnification on the roof, the magnification coefficient is 1.4-1.9, and the magnification coefficient gradually decreases with the
increase of the elevation difference. The magnification coefficient of the back blasting side is smaller than the magnification coefficient of facing the blasting side.

3) The natural frequency of brick concrete building is in the main distribution frequency band of blasting energy, which is prone to resonance. Although the vibration velocity at the roof is relatively small, the vibration frequency is closer to the natural frequency of the brick concrete building. The monitoring and protection of the brick concrete building roof should be strengthened.

4) When the blasting seismic wave propagates from the first floor of the brick concrete building to the roof, the energy is reduced by about 67%-80%. 0-30 Hz is the main frequency band of the energy distribution of the blasting seismic wave of brick concrete building.

References

[1] Wang B, Guo X, Guo J Y, Fan X Q, Xuan Y, Cha S S. (2020) Influence of vibration caused by tunnel blasting on buildings: a case study. Science Technology and Engineering., 20: 10452-10458.

[2] Chen Z H, Du J W. (2019) Study on vibration response law of high-rise buildings under construction caused by urban rail blasting excavation. Journal of Safety Science and Technology., 15: 111-115.

[3] Zhang Y Q, Jiang N, Zhou C B, Wu T Y, Luo X D, Xia Y Q. (2019) Dynamic response of building structures with high-rise frames caused by blasting vibration at adjacent subway foundation pit. Journal of China Coal Society., 44: 118-125.

[4] Wang X C, Guan X M, Yu Y L, Yu Z W, Li W. (2019) Local dynamic stress response and damage of structure under tunnel blasting vibration. Chinese Journal of Underground Space and Engineering., 15: 125-133.

[5] Lu C, Wu X Z, Liu J W, Cheng J. (2021) Comparative analysis of the underground mine's deep-hole blasting vibration signals based on wavelet and EMD. China Mining Magazine., 30: 84-90.

[6] Song X L, Gao W X, Ji J M, Ye M B, Zhang D J. (2020) Influence of blasting vibration on cumulative damage of surrounding rock. Journal of Vibration and Shock., 39: 54-62.

[7] Tian X X, Song Z P, Wang J B. (2019) Study on the propagation law of tunnel blasting vibration in stratum and blasting vibration reduction technology. Soil Dynamics and Earthquake Engineering., 126.

[8] Li D, Xiang F, Liu H Q, Guo T, Wu G H. (2011) Blasting Vibration Signal Analysis Based on Hilbert-Huang Transform. Key Engineering Materials., 1244.

[9] Chen W Y, Zhang Y, Chen X, Bao R, Zhang J R, Tang Q T. (2018) Dynamic response of foundation pit blasting construction to adjacent buildings. Science Technology and Engineering., 18:281-287.

[10] Ma Y J, Tang H, Wan W, Zhu S, Ding A S, Wang J L. (2020) Study on the stability of surrounding buildings under blasting load. Mineral Engineering Research., 35: 36-43.

[11] Wang G, An J Y, Wang S M, Jin X, Lei H B, Yu Z W, Guan X M. (2020) Stress response characteristics of multi story buildings caused by tunnel blasting excavation., Low Temperature Architecture Technology., 42: 56-61.

[12] Zhao Y, Shan R L, Wang H L. (2021) Research on vibration effect of tunnel blasting based on an improved Hilbert–Huang transform. Environmental Earth Sciences., 80(5).

[13] Wu Z S, Liu Q, Hou Q P, Li Z D. (2019) Study on impacted parameters of blasting vibration on brick concrete structure based on HHT method. Chinese Journal of Underground Space and Engineering., 15: 449-453.