Vibration response law of high-rise building to tunnel blasting

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Abstract. In order to study the propagation and attenuation process of blasting seismic waves on high-rise buildings, taking the blasting construction of the entrance A of Xizhen Station of Qingdao Metro Line 1 as an example, the vibration velocity of the 33-story frame structure under the blasting construction condition were analyzed. The results show that: under the action of blasting seismic waves, the vertical vibration velocity of the building structure is greater than the horizontal direction; the vibration velocity of the underground structure of the building presents an oscillation trend, the vibration velocity of the above-ground structure decays rapidly, and there is an elevation amplification effect on the top floor; the research results have certain reference significance for urban blasting construction, monitoring, and seismic protection measures of high-rise buildings.

1. Introduction
With the development of country's economy and increasing traffic pressure, the construction of subways is an effective way to alleviate the pressure on urban traffic. Subway tunnels are often located in densely populated and building areas in cities, and more drilling and blasting construction methods are used at this stage, which brings harmful effects, such as blasting vibration, noise, individual flying objects, explosion shock waves. Among them, blasting vibration is considered to be the "first of blasting pollution"[1]. In order to prevent damage to surrounding buildings and casualties caused by blasting vibration, this paper studies the response law of high-rise buildings to tunnel blasting vibration through field monitoring, and proposes corresponding preventive and protective measures according to the response characteristics of different floor elevations.

2. Project overview
Xizhen Station is the 14th station of Qingdao Metro Line 1, with effective platform center mileage (right line) of K32+492.000, starting and ending mileage (right line) of K32+416.2 ~ K32+606.329, with a total length of 190.1m. The buried depth of the vault is 15.72 ~ 23.6m, and the overburden is 10.72 ~ 23.1m.

The entrance A of Xizhen Station is located on the north side of Feixian Road and the south side of Xizang Road Community. The construction section of the subsurface excavation method is 58m long, the excavation section is 7.2~7.7m wide, 8.95~9.66m high, and buried depth 2.5~25m. The main geological type is strong and slightly weathered granite, and the surrounding rock grades are II and IV. The building of Xizang Road Community is reinforced concrete frame structure and raft foundation. The floor -2 of the building is underground garage, and the floor -1 is basement. There are 33 floors on the ground, and the height of the floor is 2.58m.
3. Blasting vibration monitoring

3.1. Blasting scheme
During the monitoring period, the entrance A was excavated to the level II surrounding rock, and the drilling and blasting method was used for construction, and the excavation was divided into upper and lower steps. The blast hole diameter is 42mm, the No. 2 rock emulsion explosive and the digital electronic detonator is used to detonate, the delay time is set to 50ms, and the single hole is single shot. In order to reduce the blasting velocity, a proper number of damping holes are drilled on the side close to the protection building. The blasting parameters of upper steps are shown in Table 1.

| part     | blast-hole type | blast-hole depth(m) | The number of blast-hole | Single blast-hole charge(kg) | Maximum single-stage charge(kg) | Total charge quantity(kg) |
|----------|-----------------|---------------------|--------------------------|-----------------------------|--------------------------------|---------------------------|
| upper steps | cut hole        | 0.6                 | 9                        | 0.2                         | 0.2                            | 1.8                       |
|          | satellite hole  | 0.6                 | 54                       | 0.2                         | 0.2                            | 10.8                      |
|          | periphery hole  | 0.6                 | 32                       | 0.1                         | 0.1                            | 3.2                       |
| total    | —               | —                   | 95                       | —                           | —                              | 15.8                      |

Technical indicators: Circulation footage: 0.5m, excavation area: 18.7m². Number of blast holes: 95, explosive quantity: 15.8kg powder factor: 1.7kg/m³.

3.2. Monitoring program
In the process of drilling and blasting for entrance A of Xizhen Station, Building 2 of Xizang Road Community (hereinafter referred to as "Building 2") is selected as the monitoring object. The relative position relationship between Building 2 and entrance A is shown in Figure 1.

![Figure 1. Schematic diagram of the plane location of Building 2 and entrance A](image)

The monitoring instrument is TC-4850 type vibrometer (hereinafter referred to as "vibrometer"), which can simultaneously monitor the vertical, tangential and radial vibration velocity. The vibrometer was arranged on the wall in the corridor of Unit 1 of Building 2 near the explosion source[2], and all the monitoring points were arranged at the same corner of the floor. The ground is defined as the 0th floor, which is sorted according to the floor number.

Due to the limited number of vibrometers and many floors, the layout of the vibrometers should be adjusted in time to achieve the best monitoring effect according to the site conditions. In response to the blasting of the upper steps of entrance A, building 2 was monitored 5 times. Table 2 shows the distance between the floor 0 of Building 2 and the explosion source on different monitoring dates.
Table 2. The distance between the floor 0 of Building 2 and the explosion source at entrance A

| Date       | Horizontal distance(m) | Vertical distance(m) | straight-line distance(m) |
|------------|------------------------|----------------------|---------------------------|
| 20201010   | 28.4                   | 22.1                 | 36.0                      |
| 20201012   | 29.4                   | 22.1                 | 36.8                      |
| 20201014   | 30.4                   | 22.1                 | 37.6                      |
| 20201015   | 30.9                   | 22.1                 | 38.0                      |
| 20201016   | 31.4                   | 22.1                 | 38.4                      |

4. Monitoring data and analysis

4.1 Peak combined vibration velocity analysis

The three-vector vibration velocity peak value and frequency were extracted and analyzed by using the software "blasting Vibration Analysis". The peak combined vibration velocities of each floor in the five monitoring data are shown in Table 3.

Table 3. Monitoring data of peak combined vibration velocity of building 2

| floor | 20201010 | 20201012 | 20201014 | 20201015 | 20201016 |
|-------|----------|----------|----------|----------|----------|
| -2    | 0.695    | 0.999    | 0.619    | 0.598    | 0.450    |
| -1    | 0.359    | ×        | 0.464    | 0.313    | 0.098    |
| 0     | 0.501    | 0.588    | 0.464    | 0.482    | 0.396    |
| 1     | 0.312    | ×        | ×        | 0.450    | 0.233    |
| 2     | ×        | ×        | ×        | ×        | 0.125    |
| 3     | 0.152    | 0.467    | ×        | ×        | ×        |
| 5     | 0.092    | ×        | ×        | ×        | ×        |
| 6     | ×        | ×        | ×        | ×        | 0.124    |
| 7     | 0        | 0.117    | ×        | ×        | ×        |
| 9     | 0        | 0.092    | 0.119    | 0.098    | 0.072    |
| 11    | ×        | 0.108    | ×        | ×        | ×        |
| 12    | ×        | ×        | ×        | 0.067    | 0.073    |
| 15    | ×        | 0.092    | ×        | 0.077    | 0.097    |
| 17    | ×        | ×        | 0        | ×        | ×        |
| 18    | ×        | ×        | ×        | 0.128    | ×        |
| 19    | ×        | 0.056    | ×        | ×        | ×        |
| 21    | ×        | ×        | 0        | ×        | ×        |
| 25    | ×        | ×        | ×        | 0.056    | ×        |
| 29    | ×        | ×        | 0        | ×        | ×        |
| 33    | ×        | ×        | 0.090    | 0.152    | ×        |
a The "×" in the table means that no vibrometer are laid out.
b The " 0 " in the table means that the vibrometer has been arranged, but no data has been collected.
c The " - " in the table means that no data has been collected due to the vibrometer itself or personnel mistake.

This article uses "relative enlargement, absolute enlargement, relative reduction, and absolute reduction" to describe the law of vibration velocity changes with floors. Among them, the ground vibration velocity is defined as the reference point of the blasting vibration parameters[3].

It can be seen from Table 3 that the peak combined vibration velocity in the five monitoring results is less than 1cm·s⁻¹, which is less than the safe allowable value of 1.5cm·s⁻¹ for the particle vibration velocity of general civil buildings.

The peak combined vibration velocity generally appears at the floor -2 and presents an oscillating trend between the floor -2 and the floor 0. Above the floor 0, the combined vibration velocity rapidly attenuates with the rise of the floor, and attenuates to disappear in the high floors. In some cases, the relative amplification phenomenon of vibration velocity appears on the top floor (the floor 33).

4.2. Typical monitoring data analysis
In order to analyze the different phenomena of blasting vibration response of high-rise buildings, the monitoring data on October 10 and October 15 were extracted for analysis, and the radial, tangential, vertical and peak combined vibrations of the two monitoring days were made respectively. The curve of the peak vibration velocity change with the height of the floor, as shown in Figures 2 and 3.

![Figure 2. Variation of peak vibration velocity along floors on October 10](image-url)
Figure 2 and Figure 3 show that:

(1) The vibration velocity in the vertical direction of high-rise buildings is greater than that in the horizontal direction, indicating that the vertical vibration response of the building structure is greater. Under the action of blasting seismic waves, it is important to consider the vertical shock absorption measures of high-rise buildings[4].

(2) Taking the monitoring data on October 15 as an example, the vibration velocity decreases sharply from floor 0 to floor 9, with the attenuation rate reaching 98%; the vibration velocity decreases steadily from floor 12 to floor 25, and the vibration velocity increases slightly from floor 25 to floor 33, resulting in relative amplification [5], with the amplification coefficient of 1.4%~2.7%. Under the action of blasting seismic wave, not only the closest position to the explosion source, but also the top floor of the building should be monitored and protected.

(3) In the monitoring data on October 10, the vibration response of the building structure did not show the "elevation amplification effect", but an absolute decrease, and the vibration velocity decayed to disappear on the floor 7. This is because the seismic wave is weak due to the change of blasting parameters and cannot propagate further to the upper floors[6]. Therefore, in the process of building blasting vibration monitoring, it is necessary to adjust the measuring points and damping measures according to the changes of blasting parameters.

5. Conclusions
Taking the blasting excavation of the entrance A of the Xizhen Station of Qingdao Metro Line 1 as the background, through on-site monitoring of blasting vibration, the law of blasting vibration velocity with the height of the floor is analyzed, and the conclusions are as follows:

(1) Under the action of blasting seismic waves, the peak value of the vibration velocity of the building appears at the location closest to the blasting center, and it decays rapidly within a short distance, and the relative amplification of the vibration velocity will occur in the high-rise buildings. These parts should be monitored and protected.

(2) The vertical vibration velocity of the high-rise buildings structure is greater than the horizontal direction, and more attention should be paid to the protection measures in the vertical direction.

(3) The blasting vibration response of high-rise buildings is affected by a variety of factors, and the monitoring points and protection schemes should be adjusted according to the site conditions.
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