Simulation Analysis of Frame Structure Acceleration Response in Subway Buried Blasting

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Abstract. In order to analyze the response of the acceleration peak in different directions of frame structure to the variation of blasting distance and layer height in the shallow blasting. Based on the shallow blasting of subway, this paper uses ANSYS/LS-DYNA finite element analysis software to construct the framework structure calculation model and simulate the acceleration peak. The results show that the acceleration peak of the frame structure appears between the vertical three-layer and four-floor, and the longitudinal acceleration peak is one order of magnitude larger than the lateral direction. The acceleration peak and the blasting distance are negatively correlated, which is positively correlated with the layer height. Therefore, before the blasting construction, the seismic strengthening of the thin layer of the intermediate layer of the multi-layer frame which is close to the source of the explosion must be carried out.

Keywords: shallow blasting; framework; ANSYS/LS-DYNA; acceleration peak

1. Introduction

The blasting vibration caused by the shallow blasting of the subway will cause different degrees of damage to the surrounding buildings. For the blasting construction, the vibration response of the surrounding buildings is analyzed in detail, which can effectively prevent the building from destabilizing under the action of blasting vibration (Qiao, Chen, Wang, & Wang, 2016). At present, the general analysis of the blasting vibration law in China is mainly to calculate the blasting vibration velocity through the Sadolfsky empirical formula, and compare it with the peak velocity of the building material point specified in the Blasting Safety Regulations (GB6722-2014). This will determine whether the building will be unstable or destroyed during the blast (Yan, Chen, Zhang, Zhang, & Xu, 2010). In recent years, Chinese scholars have carried out a series of related research on the acceleration and speed of surrounding buildings under blasting vibration. Qian and Chen (2004) studied and analyzed the blasting seismic effect and obtained the physical standard of using the maximum horizontal velocity or maximum acceleration as the ground motion intensity. Xie, Luo, Jia, Li and Cheng (2013), Li, Fang, Qi and Liu (2004), Zhu, Ming and Li (2011), Tian and Zuo (2015), Xing (2015) and so on through a variety of methods to study the blast vibration acceleration to some extent. The analysis of the influence of blasting vibration on surrounding buildings not only studies the vibration speed, but also studies and analyzes the acceleration, the shear force received by the building under the action of blasting vibration is obtained, which provides a theoretical basis for the seismic design and blasting vibration safety control of the building structure.

Taking the blasting excavation of a shallow tunnel in a subway line as an example, the ANSYS/LS-DYNA numerical simulation software is used to simulate the acceleration of the...
four-layer frame structure closest to the excavation point, according to the simulation results, the response peak of the acceleration peak generated by the four-layer frame structure with the blasting distance and the layer height is obtained under the blasting vibration.

2. Project Overview
In this paper, the construction section is near the blasting inclined shaft of a subway line 1. The maximum slope of the inclined shaft is 12%, and the total length is 240.3m, including 79m for the open cut, 161.3m for the dark cut, and 7m for the inclined shaft. According to the engineering conditions and the surrounding environment of the blasting area, the inclined excavation section of the inclined shaft is constructed by the step method and is detonated twice. In this paper, the frame structure of the distance excavation section of 12.65m is selected as the research object in the first blasting. The first blasting parameters: excavation section 29.23m$^2$, expected loop footage: 1.5m; number of blastholes: 139; explosives amount 41.85kg; explosive unit consumption: 0.95kg/m$^3$, charge diameter 32mm, blasthole diameter 42mm, the frame structure parameters are four layers above ground, height 15m, length 34.5m, width 14m, each layer is 3.3m high and the foundation depth is 1.8m.

3. Frame Structure Acceleration Response Analysis

3.1. Establishment of Finite Element Model
When ANSYS/LS-DYNA finite element analysis software is used to simulate the frame structure, the frame structure is simplified, which is simplified into a four-layer frame structure composed of beams, plates and columns, combined with the solid model provided by the simulation software. Beams, plates and columns are all constructed using solid164 units provided by software to establish a calculation model consisting of air, explosives and structures.

3.1.1 Setting of model parameters. The beam, slab and column of the frame structure are all reinforced concrete materials. The geological conditions of the frame structure are mainly granite porphyry and diorite. The parameters of the model are shown in Table 1.

| Component Name | material | Bulk density (kN/ m$^3$) | Elastic modulus(MPa) | Poisson ratio | Section size(m) |
|----------------|----------|--------------------------|----------------------|--------------|-----------------|
| beam           | C30      | 28                       | 30000                | 0.2          | 0.5×0.5         |
| column         | C30      | 28                       | 30000                | 0.2          | 0.5×0.5         |
| plate          | C30      | 28                       | 30000                | 0.2          | 0.15(thick)     |
| pile           | C40      | 28.5                     | 32500                | 0.2          | 1.0(diameter)   |

3.1.2 Model eigenvalues and boundary conditions. In the calculation of eigenvalues, the elastic boundary is established for the bearing boundary conditions. The simulation of the bearing uses the damping spring unit. Therefore, the surface spring is used to define the boundary condition of the model. The value of the spring coefficient refers to the foundation of the road design specification. The reaction coefficient is used for calculation.

3.2. Analysis of Acceleration Response under Blasting Vibration
When ANSYS/LS-DYNA numerical software is used to simulate the first blasting construction of inclined shaft excavation, the monitoring point is set on the first floor of the frame structure closest to the explosion source. The distance between the measuring points is 4m, and the vertical measuring point spacing is the floor. The height of the layer is 1.65m, and the specific measuring point arrangement is shown in Figure 1.
3.2.1. Dynamic response simulation results. Under the action of blasting vibration, the distribution of acceleration output results of different measuring points in different directions is shown in Fig. 2 to Fig. 3.

Figure 1. Horizontal and vertical measuring point arrangement

Figure 2. Horizontal measurement point acceleration peak response simulation
Table 2. Peak lateral acceleration measuring points

| measuring points | 1   | 2   | 3   | 4   | 5   | 6   | 7   | 8   | 9   |
|------------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Blasting distance (m) | 20.65 | 24.65 | 28.65 | 32.65 | 36.65 | 40.65 | 44.65 | 48.65 | 52.65 |
| Acceleration ($cm/s^2 \times 10^{-9}$) | 27.822 | 5.337 | 7.796 | 4.408 | 4.335 | 4.01 | 3.68 | 3 | 14.467 |
| Time (s) $\times 10^{-3}$ | 14.1 | 8.02 | 13.2 | 14.1 | 18.1 | 11.5 | 20.1 | 19.3 | 17.2 |

Figure 3. Longitudinal measurement point acceleration peak simulation

![Figure 3](image_url)

Table 3. Longitudinal measurement point acceleration peak

| measuring points | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|------------------|---|---|---|---|---|---|---|---|
| Layer height (m) | 3.45 | 5.1 | 6.75 | 8.4 | 10.05 | 11.7 | 13.35 | 15 |
| Acceleration ($cm/s^2 \times 10^{-9}$) | 32.3 | 9.4 | 11 | 10.8 | 17.1 | 11.3 | 19.2 | 14.4 |
| Time (s) $\times 10^{-3}$ | 11 | 12.5 | 14.5 | 18.5 | 16 | 12.5 | 15 | 5.99 |

3.2.2. Analysis of simulation results. According to Figure 2 and Table 2, by comparing the nine measuring points, the acceleration of measuring point 1-9 is larger than that of other measuring points in the whole process of blasting vibration, and the acceleration of measuring point 2-8 is not only the acceleration small in value but also small in magnitude. Comprehensive analysis of measuring point 1-9 can be obtained: measuring point 1-9 are located at the edge of the outer wall of the frame structure, one side of the measuring point is constrained by the structure, and measuring point 2-8 are located inside the structure, measuring The two sides of the point are constrained by the structure.
Therefore, under the same blasting vibration, the acceleration peak of the measuring point on the external wall of the structure is larger than the internal measuring point of the structure.

According to Fig. 3 and Table 3, the longitudinal acceleration peak of the longitudinal measuring point 1 is the largest, the longitudinal acceleration peak of the frame structure appears at the midpoint of the column on the first floor, and the minimum value of the acceleration appears on the edge column of the second floor. Comparing the acceleration of the measuring point in the middle layer of the structure, the acceleration from the second floor to the fourth floor is relatively large. The acceleration of the measuring point on the high floor is larger than that on the lower floor, indicating that the blasting vibration has a certain amplification effect on the acceleration during the propagation with height.

Comparing Fig. 2 and Fig. 3, the lateral acceleration peak is one order of magnitude smaller than the longitudinal acceleration peak, and the vertical measuring point acceleration peak is larger than the lateral measuring point. Therefore, the blasting seismic shearing force of the longitudinal member of the frame structure is more horizontal than the transverse vibration. The component is large, and the longitudinal measuring point is the first to reach the maximum acceleration. As the duration of the blasting vibration is prolonged, the acceleration of the frame structure is continuously increased, so the blasting seismic shear force of the structure is also increased, and the probability of structural damage is increased.

3.3. Acceleration Peak Linear Regression Analysis
Regression analysis is performed on the peak of the acceleration of the measuring point. When the peak of the acceleration of the lateral measuring point is drawn, because the positions of the different measuring points are different, the bad values are removed before the image is drawn, and then the image is drawn and fitted, the fitting results are shown in Fig. 4 and Fig. 5.

![Figure 4. Horizontal fitting diagram](image-url)
Figure 5. Longitudinal fitting diagram

According to Fig.4-5, under the same blasting vibration, the acceleration peak decreases with the increase of the blasting distance. In the shallow blasting construction process, for the columns, plates, beams and other components of the frame structure close to the source of the explosion, it is necessary. Before the blasting construction, it is reinforced to prevent it from being damaged due to the excessive peak of the acceleration, causing the structure to be damaged by excessive blasting seismic shearing force. Under the same blasting vibration, the peak acceleration of the frame structure increases with the increase of the layer height. In shallow hole blasting construction, for the multi-layer frame structure, the weak part of the middle layer of the frame structure must be reinforced before blasting to prevent cracks or damage of the upper part of the frame structure due to blasting vibration, affecting the normal work of the structure.

4. Conclusion
(1) In shallow hole blasting, the longitudinal acceleration peak of the frame structure is one order of magnitude larger than the lateral direction, and the longitudinal acceleration reaches the maximum value before the transverse direction. The longitudinal direction of the structure is more sensitive to the blasting vibration.
(2) Under the action of blasting vibration, the maximum acceleration in the longitudinal direction of the frame structure appears between the second and fourth layers.
(3) The acceleration peak of the frame structure under the action of blasting vibration is negatively correlated with the core distance, and is positively correlated with the layer height. Therefore, before the blasting construction, it is necessary to strengthen the seismic fortification of the frame structural members with the near-explosive source and high number of layers to prevent the damage and affect the normal operation of the structure.

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