Analysis of controlled blasting for Large-span Tunnel Passing beneath Cultural Relics Building

Jun Xiong\textsuperscript{1,2}, Junling Si\textsuperscript{1,2}, Yuchao Zheng\textsuperscript{1,2*}

\textsuperscript{1} Key Laboratory of Transportation Tunnel Engineering, Ministry of Education, Southwest Jiaotong University, Chengdu 610031, Sichuan, China.
\textsuperscript{2} School of Civil Engineering, Southwest Jiaotong University, Chengdu 610031, Sichuan, China.
Corresponding author’s e-mail: zhengyc218@126.com

Abstract. The section of No.3 Tunnel of Nanya Road passing beneath the botanical garden is very close to the cultural relic buildings and other buildings in the garden. Based on the project, the influence of blasting vibration on the cultural relic buildings is studied, and the blasting control measures are put forward through the FLAC\textsuperscript{3D} finite difference software. The results show that the corresponding blasting parameters are designed reasonably, which have a good effect on the blasting control.

1. Introduction
Blasting excavation, as an efficient excavation method for hard rock, has been widely used in urban underground engineering. It is necessary to reduce the impact of security on existing important buildings in addition to guarantee of the construction progress especially for the construction of ultra-shallow buried section. At present, there has been a lot of research of the influence of blasting vibration effect on the adjacent existing buildings worldwide. U Ozer [1] used the vibration velocity measured on site to predict the vibration velocity of the blasting construction on the existing building structure. R P Dhakal [2] simulated the impact of blasting vibration on the ground frame structure, and got the conclusion that the pulse quantity plays a control role in blasting vibration. Z H Zhang [3] adopted the method of pilot tunnel combined with smooth blasting in preserved strata in the construction of Changhongling Tunnel passing through the town, and he inspected the effect of controlled blasting through blasting vibration monitoring on site.

However, the vibration control of important and vulnerable buildings is different from that of general buildings, which is necessary to put forward more safe measures of controlled blasting in combination with the actual engineering situation. Based on the case of No.3 Tunnel of Nanya Road passing beneath the botanical garden, this paper analyzes the vibration effect of buildings especially the cultural relic buildings in the garden, and draws up the corresponding blasting control scheme.

2. Project overview
The starting point of No.3 Tunnel of Nanya Road is located in Guizhou Botanical garden behind Guizhou University of Finance and economics. And the tunnel passes through the cross mountain of Guizhou Botanical Garden. The plane position of the project is shown in figure 1. The maximum excavation area of the tunnel section is 245.7 m\textsuperscript{2}. The minimum buried depth of tunnel under the botanical garden is only about 1.8 m. The former site of Luchongguan Catholic Abbey in the garden is
the cultural relics under protection in Guiyang city.

Figure 1. Plane position of No.3 tunnel of Nanya Road.

According to the geological exploration, the section RK3+240~RK3+154 of the right line is in the surrounding rock of Type IV, the left line and the section RK3+154~RK3+100 of right line are in the surrounding rock of Type V. So based on the design scheme, the left line was constructed by both side drift method. The section RK3+240~RK3+154 of right line is constructed by three-step construction technique, and the rest sections are constructed by both side drift method.

3. Blasting design and control principle
As two different construction methods are proposed to be used in the construction. Combined with similar engineering experience [4], the designs of blast hole layout are shown in figure 2.

Figure 2. Blasthole arrangement.

The blasting vibration safety criteria of various buildings (structures) shall consider the peak vibration speed and main vibration frequency of the geological point where the protected object is located. The protection objects near the blasting area are mainly cultural relic buildings and residential buildings. The main vibration frequency of the blasting vibration spectrum is mostly 50 Hz-100 Hz. According to Blasting Safety Regulations (GB 6722-2014) [5], the allowable standard of blasting vibration safety is: the blasting vibration safety control value of cultural relic buildings can be determined as 0.3 cm/s and that of residential buildings is 4 cm/s.

4. Numerical calculation

4.1. Numerical model
The FLAC$^3$D dynamic analysis module is used for three-dimensional complete dynamic analysis. In the process of divisional construction, the blasting excavation in the first division is simulated only considering greatest impact. The surrounding rock, explosive, primary supports and temporary supports are simulated by solid units, and the blasting models of different construction methods are
shown in figure 3.

Figure 3. The model of the blasting excavation.

4.2. Calculation parameters
According to the design data of the actual project and relevant literature [6-8], the material parameters of surrounding rock and concrete support are selected as shown in Table 1. The explosive used in the actual project is RJ2# high power emulsion explosive. The model parameters of the explosive material are shown in Table 2.

| Type               | Elastic modulus E/10^4 MPa | Poisson ratio μ | Unit weight γ/kN m^-3 | Cohesion c/MPa | Internal friction angle ψ/(°) |
|--------------------|----------------------------|-----------------|------------------------|----------------|-------------------------------|
| Rock of Type IV    | 0.13                       | 0.35            | 2250                   | 0.6            | 32                            |
| Rock of Type V     | 0.08                       | 0.45            | 2000                   | 0.15           | 25                            |
| Primary lining     | 2.55                       | 0.23            | 2400                   |                |                               |
| Temporary support  | 1.7                        | 0.23            | 2300                   |                |                               |

Table 2. Parameters of explosive charges.

| ρ/g.cm^-3 | v/m.s^-1 | Cartridge diameter d/m | Blasthole radius r/m | m^3 | n^3 |
|-----------|----------|------------------------|----------------------|-----|-----|
| 1.0       | 4000     | 0.016                  | 0.021                | 0.039 | 0.052 |

A and n in the load calculation formula are adjusted to achieve the pressure increase and reduction time of explosion are 10ms and 90ms respectively.

4.3. Arrangement of inspection points
In the process of blasting, the vibration velocity in nodes near the surface buildings was being inspected, and the relationship between the vibration velocity and the position of blasting point can be verified. The arrangement of inspection points are shown in Figure 4.
4.4. Impact analysis of blasting vibration

4.4.1. Blasting vibration in right line

For the construction of right line, there are A and B two blasting plans. In plan A, there is a simultaneous initiation, with a cyclic footage of 1.5 m. While the blasting is divided into two steps, with a cyclic footage of 1.0m in plan B. In order to implement the strategy of rapid construction, the calculation is carried out for plan A, and the vertical vibration velocity of each inspection point of the building is monitored at different blasting mileage. If the vibration velocity exceeds the safe range, the further analysis should be carried out under the plan B.

The blasting vibration of each monitoring point under plan A is less than the safety control value before RK3+163, which means the section before RK3+163 can be constructed with plan A. However, with the working face advancing forward, the blasting point is gradually close to the inspection points, and the effect of vibration is more obvious. The maximum value of its vertical velocity appears in RK3+142, and its value is 11.3 cm/s (as shown in Figure 5 (a)) which is far greater than the safety standard of 4.0 cm/s. Therefore, the blasting parameters of plan A cannot meet the requirements of blasting control within full mileage. The maximum vertical vibration velocity still appears in RK3+142 under plan B after adjusting the explosive quantity and changing the initiation mode, and its value is 3.5 cm/s (as shown in Figure 5 (b)). It can be found that the maximum vibration velocity of each inspection point is within the safe range by adjusting the parameters under plan B.

4.4.2. Blasting vibration in left line

The numerical simulation of blasting excavation on the left line is firstly calculated according to the parameters adjusted like that on the right line (i.e. plan B). The blasting control standards of the cultural relic buildings near the left line are different from those of the residential buildings directly above the tunnel, so they need to be analyzed separately. From the calculation of the right line, it can

Figure 4. The arrangement of inspection points.

Figure 5. Vertical vibration velocity at RK3+142.
be seen that the blasting point closest to the inspection points causes the largest vibration effect, so only a few mileage points of the left line closest to the cultural relic building are selected to analyze, and the vertical vibration velocity is shown in Figure 6.

![Figure 6. Vertical vibration velocity of the cultural relics building.](image)

It can be seen that the maximum vibration velocity of cultural relics exceeds 0.3 cm/s a little only at LK+125 and LK+128 which are the closest mileage points to cultural relics buildings. At other mileage points, the vibration velocity of cultural relics buildings can be controlled within the allowable range by using blasting plan B.

However, according to the calculation of other inspection points of each mileage, the vibration velocity of some other buildings directly above the tunnel exceeds the blasting vibration control standard (4.0 cm/s) between LK3+173~LK3+128, which indicates that the safety of the surface buildings during construction in this section cannot be guaranteed even after the adjustments of blasting parameters. The calculation results of vibration impact of cultural relics and other buildings are summarized in Figure 7.

![Figure 7. Numerical computation results of the left line.](image)

For the mileage section which does not meet the safety standard under the blasting, other measures should be taken for construction, the tunnel shall be excavated without explosive blasting, and rock shall be directly broken by machinery.

Through the numerical calculation and analysis of blasting vibration on the left and right lines, the schematic diagram of blasting parameter segments can be obtained as shown in figure 8.
In addition, the propagation law of explosion energy along the longitudinal direction of the tunnel is studied. The maximum vibration velocity of each inspection point in different explosion mileages on the left and right lines respectively is extracted in figure 9.

![Figure 8. Segment of controlled blasting scheme.](image)

![Figure 9. Maximum vibration velocity at each inspection point.](image)

It can be seen that along the longitudinal direction of the tunnel, the trend of the maximum velocity of each inspection point with the mileage is roughly the same. For the same inspection point, the smaller the longitudinal distance from the tunnel is, the greater the peak velocity is. For different inspection points, the maximum velocity is different along the longitudinal direction of the tunnel, which is related to the buried depth and the horizontal distance of the tunnel. As the increasing attenuation of blasting vibration in rock mass, the remaining energy of the blasting vibration is getting lower when it is transmitted to the inspection points.

5. Conclusion

1. The calculation results show that along the longitudinal direction of the tunnel, the farther away the inspection point (ground buildings) is from the vibration source, the smaller the effect of vibration is. The buildings directly above the tunnel are the most affected by blasting vibration.

2. The vertical vibration velocity of the buildings is greater while the working face is being close to them. With the progress of construction, the impact of vibration increases first and then decreases.

3. The blasting parameters of the ultra-shallow buried section are optimized in sections, including the conventional blasting parameters section, the controlled blasting section and the mechanical
excavation section. The optimized blasting scheme can ensure the safety of cultural relics and other buildings.

Reference

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