Analysis of the influence of lately excavated tunnel blasting on the vibration of early excavated tunnel in small-space tunnel

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Abstract. In order to study the impact of the blasting construction of lately excavated tunnel of the large-section tunnel with small spacing on the early excavated tunnel, the propagation law of vibration velocity of initial support of early excavated tunnel under blasting load is analyzed by combining field test and numerical simulation based on the Mongol Road Tunnel of the Zamalong-Daotanghe Highway Reconstruction and Expansion Project in Qinghai Province; The results show that the radial vibration velocity in the initial support of early excavated tunnel is obviously greater than the vertical vibration velocity and tangential vibration velocity in the blasting construction of lately excavated tunnel with large section and small spacing. The radial vibration velocity of the blasting side of the tunnel is obviously greater than that of the back side, and the maximum is found at the arch waist of the blasting side. The peak value of the radial vibration velocity of the initial support of early excavated tunnel is the maximum at the same section position as the blasting excavation face, and gradually decreases with the increase of the blasting center distance. Compared with the vibration velocity of the initial support before and after the excavation face, the peak attenuation rate of the vibration velocity in front of the blasting excavation face is slightly less than that behind the excavation face.

1. Introduction

Due to the limitation of mountain terrain and geological conditions, the clear distance between the up and down tunnels of newly-built mountain highway is often small, which leads to the influence on the supporting structure of the first tunnel during the blasting construction of the later tunnel. Therefore, the research on the impact of the backrow tunnel blasting construction on the supporting structure of the first tunnel has attracted much attention. Many scholars at home and abroad have studied the influence of tunnel blasting construction on the existing tunnel. Wang et al. [1] studied the safety and stability of the existing tunnel structure during excavation blasting. Zhao et al. [2] studied the influence of different excavation schemes on existing tunnels by taking small clear cross tunnels as an example. Song et al. [3] studied the impact of following tunnel blasting on the supporting structure of the first tunnel by combining numerical simulation and field test based on the small clear distance double-line tunnel project at the entrance of Sanxili Expressway. Feng et al. [4] analysed the impact of
blasting on existing tunnels under different surrounding rock types and different tunnel spacing by means of numerical simulation. Wei et al. [5] studied the impact of blasting construction of small clear distance underwater tunnel on adjacent tunnels. Zhu et al. [6] studied the construction control technology of tunnel blasting behind the ultra-small clear distance tunnel based on the ultra-small clear distance tunnel of Nanjing Subway. Jia et al. [7] studied the influence of excavation footage on lining structure of small clear distance tunnel with numerical simulation method. Li et al. [8] analysed the propagation law of blasting stress wave in existing tunnel lining by using ANSYS/LS-DYNA software, and put forward the control charge of blasting maximum section.

There are few researches on the influence of the initial support structure of the first tunnel with large cross-section and small clear distance under blasting. In this paper, taking Mongolian road tunnel in Qinghai Province as the engineering background, through the combination of field test and numerical simulation, the vibration velocity propagation law of the initial support of the first tunnel under blasting load is analyzed. The research results can provide experience for the design and construction of large section and small clear distance tunnel blasting in the future.

2. Overview of supporting projects

2.1 Project overview
Mongolia Road Tunnel is located in Mongolia Road Village, Heping Township, Huangyuan County, Xining, Qinghai Province. It is a key control project from Zhamalong road to Daotang River section of Qinghai Province. It adopts the type of two-hole six-lane separate small clear distance tunnel, and Figure 1 is the location map of Mongolia Road tunnel. The starting and ending pile Numbers of the left line of the tunnel are ZK50+110 ~ ZK50+740, with a total length of 630m; The starting and ending pile Numbers of the right line are YK50+115 ~ YK50+680, with the total length of 565m. The excavated section of the tunnel is about 16m wide and 11m high, and the excavated section area is close to 120m². The net distance of the tunnel is 38.5m (about 2.3b, where B is the span of the tunnel excavation), which is a typical large-section tunnel with a small clear distance. Figure 2 is the location diagram of the left and right cross sections of the Mongolia Road tunnel. The exit of Mongolia road tunnel is located on the bedrock slope of the river, and the slope is steep. The bedrock on the slope is continuously exposed, the surface granite has strong weathering, the weathering layer is 8~15m thick, and the rock mass is relatively broken. Under the influence of tunnel burial depth, weathering and hydrogeology, the surrounding rocks are dominated by Grade V. Considering the characteristics of large tunnel span and small net distance, it is necessary to pay special attention to the impact of lately excavated tunnel blasting on the early excavated tunnel during the blasting excavation of exit section of the tunnel.

![Figure 1. Location map of Mongolia road tunnel.](image1)

![Figure 2. Blasting design drawing of upper stage.](image2)

2.2 The construction plan
The V-level surrounding rock section at the exit of Mongolia road tunnel is constructed by three-step method. The initial support is single-layer support, and the footage of each cycle is 1 m. No. 2 emulsion explosive is selected. According to the previous research results, the vibration intensity produced by the up-stairs driving blasting is relatively large, so the up-stairs blasting of lately excavated tunnel is studied emphatically. FIG. 3 shows the design drawing of stepping blasting, and
the specific excavation drilling and blasting parameters are shown in Table 1. Wedge cutting method is adopted for upper step cutting hole. The millisecond delay blasting is used between each row of blast holes to realize the initiation from the inside to the outside layer by layer, so as to eliminate the superposition effect of stress wave caused by explosion and reduce the influence of blasting vibration.

| Blast hole name  | Detonator segment | Hole depth (m) | Hole number | Explosive charge per hole(kg) | Single-stage charge(kg) |
|------------------|------------------|----------------|-------------|------------------------------|------------------------|
| Cutting hole     | 1                | 1.2            | 6           | 0.48                         | 2.88                   |
| Driving hole     | 3                | 1.1            | 8           | 0.44                         | 3.52                   |
| Driving hole     | 5                | 1.1            | 11          | 0.44                         | 4.84                   |
| Driving hole     | 7                | 1.1            | 12          | 0.44                         | 5.28                   |
| Inner ring hole  | 9                | 1.1            | 19          | 0.44                         | 8.36                   |
| Inner ring hole  | 11               | 1.1            | 19          | 0.44                         | 8.36                   |
| Around hole      | 13               | 1.1            | 33          | 0.44                         | 14.52                  |

3. Numerical simulation analysis of blasting influence

3.1 Construction of blasting analysis mode
Midas/GTS NX simulation software was used for the impact analysis of blasting, and the K50+590~K50+660 sections at the exit of Mongolia Road tunnel were analysed. In order to reduce the boundary effect of the model, the boundary size of the model should be set as 3-5 times of the tunnel diameter. Therefore, the maximum length, width and height of the model size should be 174m, 144m and 70m respectively. The middle rock sandwiched between two tunnels is 38.5m thick. For the convenience of analysis, the surrounding rock of the tunnel was regarded as homogeneous rock body, and the influence of joints and fractures, fault fracture zones and surrounding rock damage was not considered. The constitutive model was Mohr-Coulomb model, and the model units were divided by spatial hexahedral elements. The initial support is simulated by plate element with the thickness of 0.28m. Free boundary is used on the upper surface of the model, and viscous boundary is used on other surfaces, so as to eliminate the reflection effect of artificial boundary on seismic waves. In MIDAS/GTS finite element analysis software, the ground surface spring can be set on the boundary to achieve the purpose of viscous boundary. The tunnel model is shown in Figure 4. The calculated parameters of the model are shown in Table 2.

| Material name  | weight density (kN/m³) | Elastic modulus(GPa) | Poisson ratio | Internal friction angle | Cohesion force(kPa) | Thickness(m) |
|----------------|------------------------|----------------------|---------------|-------------------------|---------------------|-------------|
| Granite(V)     | 18.5                   | 11.1                 | 2.32          | 23.5                    | 125                 | /           |
| Initial support| 23                    | 28.75                | 0.16          | /                       | /                   | 0.28        |

3.2 Calculation of blasting load
In this paper, the blasting dynamic load is calculated based on the triangular blasting load model. The triangular blasting load model can be determined by peak load P, boost time TR and unload time TD.
Firstly, according to the design scheme of tunnel blasting, the blasting load peak value of single hole at different stages of blasting is determined. According to the principle of elastic static equivalent of stress wave, the multiple single-hole loads at the same stage are simplified to the equivalent elastic boundary surface after blasting at the same stage. The blasting equivalent load attenuation on the equivalent elastic boundary of this section is applied to the contour surface of tunnel excavation according to the attenuation law of stress wave, and the final equivalent load of this section is formed. According to the triangular loading curve of blasting load and the time delay of different segment difference, the time history curve of equivalent applied load of full section blasting in one blasting of tunnel is obtained, as shown in Fig. 5.

![Figure 5. Time history curve of blasting load](image)

3.3 Simulation results and analysis of blasting influence

3.3.1 Transverse vibration velocity analysis

In order to study the variation law of vibration velocity of the initial support of large cross-section tunnel with small spacing under blasting, three different test sections are selected for early excavated tunnel, and then the vibration velocity results of seven key points of each section are analysed, including the vault, the arch shoulder of the blasting side, the arch waist of the blasting side, the arch foot of the blasting side, the arch shoulder of the back blasting side, and the arch foot of the back blasting side. The locations of typical measuring points are shown in FIG. 6 and FIG. 7.

FIG. 8, FIG. 9 and FIG. 10 show the peak vibration velocity of each test section through numerical calculation. It can be found that the radial vibration velocity of the initial support of the tunnel is greater than that of the other two directions, especially the blasting side. It indicates that the initial support of the tunnel is mainly influenced by horizontal stress wave. When the stress wave reaches the free surface of the blasting side, it will reflect, resulting in the superposition of stress wave, thus increasing the velocity of vibration. As a result, the radial velocity of the explosion-facing side is obviously greater than that of the other two directions. At the same time, the vibration velocity of each monitoring point on the blasting side of the same section all shows the arch waist > arch shoulder > arch foot > vault, and the maximum vibration velocity all appears in the position of the blasting side arch waist, so the key monitoring should be carried out on this position during the construction process.
3.3.2 Longitudinal vibration velocity analysis

From the above analysis, it can be seen that the horizontal radial velocity is dominant in the initial support of early excavated tunnel to blasting. Next, the propagation law of radial velocity in the direction of tunnel axis will be studied. It can be seen from Fig. 11 and FIG. 12 that the curves of the peak value of radial vibration velocity with the variation of distance from blasting center at different positions of early excavated tunnel are close. The peak value of the vibration velocity is the largest at the same section position as the blasting excavation face, and gradually attenuates with the increase of the distance from blasting center, and it is basically symmetrical distribution about the excavation surface. Comparing the vibration velocity of the existing lining before and after the excavation face, it can be seen that the peak attenuation rate of the vibration velocity in front of the blasting excavation face is slightly less than that behind the excavation face. The main reason is that the blasting stress wave cannot directly incident on the lining behind the excavation face, but can be reached by diffraction, so part of the energy is lost, resulting in rapid attenuation of the vibration velocity.

3.4 Comparative verification analysis

In order to verify the accuracy of the blasting vibration model, the radial vibration velocity time history curve of the arch waist on the blasting side of the first tunnel during zk50 + 650 blasting is extracted, and the results of field test and numerical simulation are compared, as shown in FIG. 15. It can be seen that the two have good consistency. Considering the complexity of engineering geology and the idealization of numerical simulation, it is reasonable that there is a certain deviation between them in the allowable range.
4. Conclusion

(1) During the blasting construction of lately excavated tunnel with large cross-section and small spacing, the radial vibration velocity is obviously greater than the vertical and tangential vibration velocity due to the horizontal stress wave in the initial support of early excavated tunnel, and the radial vibration velocity of the blasting side is obviously greater than that of the back blasting side, because the back blasting side is mainly affected by the diffraction of blasting stress wave.

(2) The results show that the peak value of the radial vibration velocity at different positions of the tunnel leading tunnel decreases with the increase of the distance from blasting center. The peak attenuation rate of vibration velocity in front of the excavation face is slightly lower than that behind the excavation face. Because the square shape of blasting excavation is free surface, the blast stress wave can reach the lining behind the excavation face through diffraction, so part of the energy is lost, resulting in rapid attenuation of vibration velocity.

(3) By comparing with the measured results, the correctness of the numerical simulation results is verified, which shows that the numerical simulation method is feasible to analyse the vibration impact of blasting construction of large section and small spacing tunnel.

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