Safety Analysis of the Tunnel Excavation Blasting and the Supporting
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Abstract. Wuhan east lake tunnel project is located in the national 5 a grade within the east lake scenic area, and it is a key project of Wuhan, which has a higher requirement on safety civilization construction. Using traditional unidirectional drivage CRD construction method in tunnel construction, significant impact on construction period, dismantling temporary arch suppression and middle wall for large drivers for construction, improve the efficiency of production of tunnel excavation. The removal of temporary inverted arch will affect the integrity of the original upper arch closed bracket and disturb the surrounding rock and soil around the excavation guide hole. Regarding the tunnel excavation blasting scheme design, through the dynamics of FLAC3D numerical simulation calculation, the dynamic response to blasting two-dimensional elastic-plastic time history analysis, the research analyzed the lining in the early dynamic response under blasting vibration, based on the control of blasting vibration measurement experiment, and through the measured results, the safety of the surrounding rock resistance to vibration is evaluated according to the construction under the condition of dismantling temporary inverted arch bottom drift of CRD method.

Introduction

Underground tunnel is located in the scenic spot, designed for two-way six lanes. The distance between the two tunnels is from 10.6 m to 16.7 m, which is in the form of small clear distance tunnels. The maximum depth of the tunnel is 50m. It is constructed by neo-austrian method, using composite lining. In the initial stage, the supporting content is composed of steel wire mesh, anchor rod and steel arch, etc. The reinforced concrete is the secondary supporting, and the waterproof layer is the composite waterproof board arranged between the two linings. Geological exploration shows that the geological conditions along the tunnel are complex and changeable. The Triassic ~ carboniferous soluble carbonate rocks in the site are distributed in karst caves with different sizes and fillings, and the rock fissures are well developed. The tunnel line is adjacent to east lake tuanhu, with abundant underground water and large karst water volume. The tunnel excavation is prone to landslides, water inrush and other geological disasters, and the construction is difficult and risky, which is the controllable project of this project.

In the traditional CRD construction, the four-step CRD method is bounded by the middle wall. The left and right parts of the tunnel are divided into two parts, each of which has two steps. Each step forms a chamber through the middle wall, the initial support and the temporary inverted arch. The caves are interlocked and link up step by step. For the excavation and support of weak and dangerous rock, the effect of controlling tunnel deformation is good. However, as the temporary invert is connected with the middle wall and the initial support at each step, the space is narrow and the large construction machinery cannot be put to use, resulting in low operating efficiency and increased construction cost. Therefore, the temporary invert is applied, which increases the cost of materials.

The tunnel construction adopts the traditional CRD construction method of one-way tunneling,
which significantly affects the construction period. The site project department creatively proposes to remove the temporary arch suppression and the middle wall to facilitate the large excavator tunneling construction, improve the production efficiency of tunnel excavation, and ensure the construction period and project economic benefits. The removal of the temporary invert will affect the integrity of the original upper arch closure bracket, and also cause disturbance to the surrounding rock and soil around the excavation guide tunnel. The optimized construction scheme puts forward new requirements for the stability and safety of the surrounding rock mass and the primary lining structure. The removal of the temporary invert will affect the integrity of the original upper arch closure bracket, and also cause disturbance to the surrounding rock and soil mass around the excavation guide tunnel. The optimized construction scheme puts forward new requirements for the stability and safety of the surrounding rock mass and the primary lining structure.

Chen Zhi et al. conducted the construction and monitoring analysis of a shallow buried underground subway tunnel in Chongqing[1]. Gu Shuancheng et al. studied the influence of CRD method and step method on the deformation of surrounding rock of subway tunnel[2]. Qi Yuliang studied CRD construction simulation analysis of large cross-section shallow buried undersea tunnel[3]. Chen Guozhong studied the reasonable procedure of CRD method for tunnel construction of red-bed soft rock tunnel[4]. Ning Fangduan et al. studied deformation monitoring and risk control of CRD tunnel construction in soil-rock composite strata[5]. Zhu Zancheng et al. studied the micro-vibration blasting technology of underground tunnel in Guangzhou metro[6]. Wang Guoxi et al. studied the blasting vibration monitoring and control technology of urban rail transit large-span shallow buried tunnel[7]. Cai Lujun et al. conducted research on controlled blasting technology of multi-arch tunnel in songjiawan[8]. Duan Baofu et al. studied the blasting vibration monitoring and control technology of shallow buried tunnel under complex environment[9]. You Pengfei conducted risk mechanism analysis of subway tunnel construction[10]. In this paper, aiming at the blasting engineering of tunnel excavation rock in the optimized construction scheme, the blasting design scheme of tunnel excavation rock is studied, the 2-d elastic-plastic time history analysis of dynamic response of blasting construction is carried out, and the dynamic response analysis of blasting construction is carried out to evaluate the safety of surrounding rock against vibration under the condition of optimized construction scheme.

**Blasting Design of Tunnel Excavation Stone**

According to the type of surrounding rock and the condition of soil layer of the tunnel, the corresponding construction method is selected. In the process of excavation, geological advance prediction and prediction should be made, blasting vibration monitoring and measurement should be strengthened, and timely feedback information should be provided to guide construction and ensure construction safety. The excavation of the intersecting section of earth and rock adopts the excavation construction method of small pipe reinforcement in advance and blasting. According to the range of rock intrusion into the palm surface, different blasting methods are used. In order to reduce the disturbance of blasting to the surrounding rock, the upper part adopts wedge cut method. The upper roof hole and the lower side hole are designed according to smooth blasting to reduce the blasting disturbance to the surrounding rock and maintain the stability of the rock mass.

The blasting holes in the blasting section of this mining method are respectively set as: cut hole, secondary ring hole, peripheral hole, floor hole and row hole. The blasthole layout is left and right symmetrical, and the cutting hole is set on the upper step with two rows on each side. The spacing between auxiliary eyes and peripheral eyes is 600mm, the width of tunnel excavation is about 6300mm, and the height is 6648mm.

If the scope of the dome is soil layer, local blasting will be carried out according to the scope of rock intrusion into the palm surface. In the local blasting method, cutting hole is not required, but vertical hole is directly drilled. If all rock is distributed within the range of the tunnel, the excavation is carried out with the method of upper and lower step blasting, and the blasting footage is 1.0 ~ 1.5m. Local blasting is based on the range of rock intrusion into the palm surface. If rock intrusion is 1 meter above the arch waist, peripheral eyes and row eyes should be arranged. The
layout of row eyes and the layout of lower steps are the same. Shallow hole step blasting is used if rock intrudes below the arch waist.

**Controlled Blasting Vibration Test**

**Test Scheme**

A fixed speed sensor is installed in the lower opening of the primary lining side wall. One hour before the start of each blasting, the three-direction speed sensor (z to the vertical direction, x for the longitudinal direction of the tunnel, y for the transverse direction of the tunnel) should be installed, and the test equipment should be connected. Half an hour before the blasting, the trigger level should be set, so that the instrument can enter the state of waiting for excitation, ready to record the blasting vibration wave. Once the blasting occurs, the vibration wave comes, the instrument automatically triggers the recording speed waveform.

**Test Data**

After the field test, remove the sensor, retrieve the instrument, and export the data. High frequency filtering of the original velocity time history data is performed first, and then displacement baseline correction is performed. The displacement time equation can be obtained through the first order integral, and the acceleration time equation can be obtained through the first order derivative.

Fig.1 shows the y-direction test data. Since the final test data are within the required range, that is to say, the impact of blasting construction on the initial support of the project is acceptable, which can ensure the safety of blasting construction.

![Figure 1. Y-direction test data.](image)

**Two - dimensional Elastoplastic Time History Analysis of Blasting Dynamic Response**

**Establishment of Dynamic Analysis Model**

Dynamic analysis inherited the two-dimensional plane strain model used in static analysis. As the discrete finite element model will bring "low-pass effect" and "dispersion effect", the disturbance component of which is higher than the cutoff frequency, it will be hindered by the discrete model and thus cannot be effectively propagated. And in a physical sense, that's the essential difference between a continuum and a discrete. However, in very small units, the effect becomes so small that it does not affect some of the properties of the wave at all. Therefore, the dynamic analysis must select the appropriate size of the unit. To divide the geometric model into grids, the control principle of maximum cell size is \( \Delta l \leq \lambda/8 \) (\( \lambda \) is the shortest wavelength in the input vibration spectrum).

The typical finite element discrete model is established by homogenizing or continuously changing the mesh to avoid the false reflection of vibration wave in the model.

**Blasting Load Boundary Conditions**

Here, two methods can be used to apply load to effectively simulate the numerical value of blasting vibration propagation. One is to use the dynamite material with relatively high performance built in the LS-DYNA module and its equation of state to simulate. The object of simulation is the whole blasting process of blasting explosive, and some complex processes of the interaction between blasting products and rocks are simulated. Second, the blasting load pressure curve with
semi-empirical and semi-theoretical characteristics can be applied to the hole wall. To obtain such a load curve, detonation wave and cavity expansion can be used to calculate it. Of course, when the theory is not feasible, it can be obtained by referring to the previous successful engineering tests.

Therefore, the blasting load is simplified as a piecewise function load with exponential falling section and linear rising section, and it is assumed that the blasting load is acted on the boundary surface of engineering tunnel excavation. According to a large number of practical measurement experience, the time of the rising section was taken as 1ms, and the end time of the falling section was taken as 5ms. To understand the situation of particles after the end of the load, the total computing duration was taken as 1s.

**Simulation Steps and Static and Dynamic Boundary Conditions**

The simulation steps of time history analysis of blasting dynamic response are as follows:

1. Generation of geostress field. (2) After the displacement field returns to zero, the static excavation is simulated step by step until the stress field after the excavation is established. (3) After the displacement field returns to zero, the blasting vibration is input from the excavation boundary inside the model. And the dynamic wave absorption boundary condition is applied, the complete time history reaction of each physical quantity of the model is explicitly solved by the stepwise direct integration method.

The boundary conditions were set as follows: On the basis of static analysis of the initial state, the left and right side boundary and bottom of the dynamic model are set as the absorbing boundary. The free field response characteristics of the semi-infinite rock medium around the cavities are simulated to absorb the reflected waves from the cavities. The upper surface of the model is the free surface of the mountain.

**Analysis of Dynamical Calculation Results of Blasting**

**Vibration Velocity Response Analysis of Surrounding Rock**

The velocity response of surrounding rock is the most original value of dynamic physical quantity. By monitoring the velocity time history of several key points of surrounding rock, the rationality of the calculated value can be checked and the intensity of surrounding rock vibration response can be judged.

Under the action of blasting vibration, the surrounding rock will generate a dynamic stress response, and an additional vibration response stress field will be superimposed on the original stress field. The degree of disturbance to the original stress field will affect the stability of the surrounding rock, and also reflect the strength of the surrounding rock's dynamic response. Since the tensile failure zone is more likely to occur in the arch roof and arch bottom, the first dynamic response of the main stress in the surrounding rock arch roof and the middle of the arch bottom of the excavated tunnel is given in Fig.2.

![Surrounding rock in the middle of the vault](image1.png)
![Surrounding rock in the middle of arch bottom](image2.png)

Figure 2. Dynamic response of the first principal stress in surrounding rock of the tunnel.
As shown in Fig.2, the first principal stress of the element at the key point of the surrounding rock of the tunnel fluctuates in a small range above and below the initial equilibrium stress of the static excavation. It indicates that the vibration has little influence on the stress field of the surrounding rock at the arch roof and bottom of the tunnel.

Analysis of Plastic Zone Characteristics of Surrounding Rock

Fig.3 shows the distribution results of the plastic zone in the static analysis. The plastic zone of surrounding rock of the tunnel is mainly concentrated on both sides of the arch roof, with a large upward expansion. Compared with the total plastic zone distribution at the termination time of blasting dynamic calculation given in Fig.4, after the dynamic action of blasting vibration, the plastic zone concentration area of the surrounding rock arch and the bottom arch further expands outward. The plastic zone expansion of the side wall is not very significant, and the plastic zone under the blasting excavation surface is relatively large.

Figure 3. Plastic zone distribution under static action.

Figure 4. Plastic zone distribution under static superposition blasting force.

Under the action of blasting vibration load, the plastic zone of surrounding rock will be further expanded to a certain extent. By comparing the changes of plastic zone area before and after vibration, the vibration stability of surrounding rock can be quantitatively evaluated. The results of blasting calculation show that the surrounding rock is stable under blasting dynamic load.

Dynamic Response Analysis of Lining Internal Force

Fig.5~6 show the calculation results of the maximum axial force, shear force and bending moment of the key parts of the tunneling primary lining respectively.

Figure 5. Axial force and dynamic response of primary lining in the middle of arch bottom.
According to the time history diagram of the internal force dynamic response of the lining section, it can be found that the internal force response of the initial lining also presents a shock wave effect, but the change range is not large, which is within the safe allowable range.

**Overall Safety Evaluation of Vibration Condition**

Through the two-dimensional elastic-plastic time history analysis of tunnel blasting excavation, the numerical simulation calculation and field test of the dynamic response of the tunnel under the design blasting vibration action are carried out. Based on the above calculation results, the following basic conclusions can be obtained:

1. The first additional principal stress response of the surrounding rock is within the range of 0.2 mpa, failing to reach the tensile strength of the rock mass, so no large-scale strength failure will occur in the cavern.
2. The time history analysis of the development of the plastic zone under the action of dynamic vibration shows that the final state of the plastic zone of the surrounding rock will not lead to the overall plastic flow failure of the surrounding rock at the end of the vibration.
3. Under the action of blasting vibration, the initial support surface vibration velocity is within the safety margin. The impact effect of lining internal force is small and the bearing capacity is safe. To sum up, under the action of blasting vibration wave, the seismic stability of the tunnel lining support is good.

**Implementation and Effect of Blasting Construction**

**Implementation of Blasting Construction**

According to the explosives and parameters in the blasting scheme, the test blasting was carried out, and it was found that the site overexcavation was serious, with more gravel and dust, which was easy to cause damage to the surrounding environment and was not conducive to the site safe and civilized construction. In view of the complex tunnel geology and diverse lithology, it is difficult to meet the site requirements to adopt a single blasting parameter. Through scheme comparison and selection, different blasting parameters are adopted for different lithology to achieve better blasting control effect. In addition, in the selection of explosives, the original design of ammonium nitrate explosives was optimized to emulsified explosives with good water resistance, good explosive performance and low mechanical sensitivity to ensure the safety of the blasting construction process and the influence of controlled blasting on the initial support.

**Control the Effect of Blasting**

1. Cycle footage is ideal. When the depth of perforation reaches 1.2m, each cycle footage reaches more than 1m.
2. The excavation surface is shaped in a regular manner, with the average line overexcavation <10cm, the maximum line overexcavation <20cm, and the partial underexcavation <5cm.
3. The retention rate of perforation marks is up to 90%. After blasting, the surrounding rock is stable with basically no spalling.
4. The maximum size of the...
connecting step of the two guns is 15cm, and the perforation utilization rate is more than 95%. Fig.7 shows the effect of blasting vibration.

![Figure 7. Effect diagram of blasting vibration implementation.](image)

**Analysis of Monitoring Results**

The measured results of the subsidence of the hollow arch roof of the tunnel with a small net distance between shallow buried and dark excavation are shown in Fig.8.

![Figure 8. Analysis curve of vault subsidence.](image)

The maximum settlement value measured on site was 25.2mm, while the maximum settlement value obtained by numerical simulation was 18mm. It is found that the deformation measured by field monitoring is larger than that calculated by field numerical simulation. The main reason is that the numerical simulation analysis is obtained under ideal conditions, which is difficult to achieve in practice. There are some differences between the measured values and the numerical simulation, but they are all within the allowable range of the specification. This indicates that the surrounding rock-support system of this section of the left and right caves has reached stability, and the support measures can meet the actual safety construction needs.

**Conclusion**

1) For tunnel construction, if the traditional CRD construction method is adopted for one-way tunneling, the construction period will be significantly affected. It is proposed to remove the temporary arch suppression and the middle wall to facilitate the tunneling of large excavators, improve the production efficiency of tunnel excavation, and ensure the construction period and economic benefits of the project. The removal of the temporary invert will affect the integrity of the original upper arch closed bracket, and also cause disturbance to the surrounding rock and soil around the excavation guide tunnel. It is necessary to analyze the stability and safety of the surrounding rock mass and the primary lining structure with the optimized construction scheme.

2) According to the geological conditions of the tunnel, the blasting scheme is designed. The blasting vibration test can show that the influence of blasting on the initial support of the tunnel project is controlled within the required range, and the construction safety can be guaranteed.

3) Through the two-dimensional elastic-plastic time history analysis of the tunnel excavation by blasting, the numerical simulation of the dynamic response of the tunnel under the designed blasting vibration action is carried out. The results show that under the action of blasting vibration wave, the seismic stability of the initial lining support of the tunnel is good.

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References


