Study on Blasting Vibration Reduction Construction Technology of Multi-Arch Tunnel without Central Wall in Rear Tunnel

Xu Lizhong, Wang Bizhen, Zhang Zequn

***Abstract*—In this paper, the test data and analysis results are used to guide the correction of late blasting parameters, adjust the scope of static excavation area and determine the blasting vibration velocity standard. The rock mass in the static excavation area becomes loose due to vibration after the excavation face blasting operation of the rear tunnel. The hydraulic crushing hammer is used to chisel out the surrounding rock in the static excavation area faster, which has little influence on the construction progress. At the same time, the static excavation method with excavator and crushing hammer has high controllability, which ensures that the excavation of the rear tunnel does not invade the initial support contour of the first tunnel, and reduces the construction disturbance to the initial support of the adjacent position of the first tunnel. Avoid the construction of the rear tunnel leading to the first hole lining structure cracking and instability, reduce the amount of the first hole lining cracks, improve the safety of the construction process, to ensure the project duration and quality requirements.**

***Index Terms*—Rear row hole; Multi-arch tunnel; Blasting vibration reduction**

I. INTRODUCTION

The middle partition wall is usually set between the double holes of the double-arch tunnel, which is built in advance by the way of the middle guide tunnel. It has the disadvantages of complex construction process, frequent transformation of structural mechanics system, high project progress and cost. In a tunnel project of our company, the steel arch of the rear tunnel is not closed and there is no middle wall with multiple arch structure. It is no longer necessary to set the middle guide tunnel and the middle partition wall. On the one hand, the construction efficiency is greatly improved, on the other hand, the setting of the two holes is more compact, which is conducive to connecting with the roadbed outside the tunnel. This method has carried out a series of researches on the excavation, blasting, monitoring, supporting structure and other technical and technological requirements of the multi-arch tunnel without central partition wall. On the premise of the construction of the cave step method first and the completion of the secondary lining of the corresponding position, the static and dynamic partition of the excavation of the rear tunnel step is set up, that is, the static excavation area is formed in a certain range near the initial support of the side wall. In the later stage, mechanical hydraulic crushing hammer was used to excavate and reserve enough protective layer during blasting construction, so as to isolate the influence of the blasting construction of the rear tunnel on the first tunnel and avoid the damage and destruction of the initial support and secondary lining of the first tunnel due to the blasting construction of the rear tunnel. On this basis, combined with the on-site summary, the construction method of blasting vibration reduction of multi-arch tunnel without central wall without steel arch frame closed in the rear tunnel is formed.

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II. PROCESS PRINCIPLE

The design feature of multi-arch tunnel without central wall is that the primary supporting structure of the left and right tunnels is directly connected, and the blasting operation of the rear tunnels is easy to cause damage to the lining structure of the first tunnels. In addition, the initial supporting steel arch of the rear tunnel is not closed, and the force is complex, which requires high integrity of the tunnel structure. The principle of the construction method mainly includes two parts: the protection of the first tunnel structure and the blasting vibration reduction of the rear tunnel.

The static excavation zone is set within a certain range of the initial support position of the side wall shared by the rear tunnel and the advance tunnel. This part of rock mass acts as the protective layer of the early support of the advance tunnel during the blasting operation, so as to avoid the destruction of the shotcrete of the early support of the advance tunnel due to the blasting of the rear tunnel.

The rock mass in the static excavation area becomes loose due to vibration after the excavation face blasting operation of the rear tunnel. The hydraulic crushing hammer is used to chisel out the surrounding rock in the static excavation area faster, which has little influence on the construction progress. At the same time, the static excavation method with excavator and crushing hammer has high controllability, which ensures that the excavation of the rear tunnel does not invade the initial support contour of the first tunnel, and reduces the construction disturbance to the initial support of the adjacent position of the first tunnel.

Before the formal blasting excavation of the rear tunnel, blasting excavation of the test section is carried out with four cycles (6m). Static excavation area is set near the rear tunnel to reduce the influence of blasting vibration on the lining structure of the front tunnel by increasing the propagation distance of blasting vibration. The range of static excavation area is adjusted timely according to the measured blasting vibration velocity of each cycle blasting excavation. The charging amount, charging structure and plugging length of single hole were adjusted, and the parameters of vibration speed control, blasting effect and driving speed of blasting excavation in the test section of rear tunnel were further optimized.

According to the blasting excavation effect of the test section, the range of static excavation zone and blasting parameters are optimized, and the normal section is driven. In the blasting driving process of the normal section of the rear tunnel, multiple vibration velocity test sensors are arranged on the secondary lining surface of the corresponding section of the first tunnel before each cycle blasting, so as to carry out the blasting vibration velocity test strictly. During the construction period, the surface integrity of the secondary lining of the advance hole should be comprehensively checked to determine whether there is a crack, and the vibration velocity test and crack recording should be done. The test data and analysis results are used to guide the correction of late blasting parameters, adjust the range of static excavation zone and determine the blasting vibration velocity standard. The above measures are taken to ensure the safety of blasting construction in the normal section of the rear tunnel and prevent the lining structure of the first tunnel from producing cracks and even structural cracks.

III. CONSTRUCTION TECHNOLOGY

2.1 Set the vibration speed control standard

In view of the particularity of the structure type and construction technology of the double-arch tunnel without central wall, this construction method further improves the allowable blasting vibration safety standard of the double-arch tunnel without central wall, and its vibration velocity control value is determined to be 0.8 times of that of the general tunnel, so as to ensure the safety of the structure of the rear tunnel, as shown in Table 1.

Table 1 Allowable Blasting Vibration Safety Standards

protected object types	safe allowable particle vibration velocity v (cm/s)		
	f≤ 10Hz	10Hz ＜ f≤ 50Hz	f ＞ 50Hz
general tunnel	10 ~ 12	12 ~ 15	15 ~ 20
double-arch tunnel without central wall	8 ~ 9.6	9.6 ~ 12	12 ~ 16

2.2 Blasting test

For different tunnels, due to the different geological conditions and rock characteristics, blasting tests must be done before the formal construction in order to determine the best blasting parameters, which provides the implementation basis for the design and construction of static excavation and smooth blasting integrated technology.figure

1 Smooth blasting test

According to the hole spacing (E) obtained by row blasting and the relative distance (E/V) in the specification, different resistance lines (V) are determined for testing and the minimum resistance line (V) value is obtained.

2 Single hole blasting seam test

Before the test, the single charge quantity, charge concentration and charge structure were selected according to the standard. During the test, the charging amount, charging structure, plugging length and other parameters are constantly adjusted until only cracks appear at the orifice after blasting and no blasting funnel is generated. The depth of the charge is the actual critical depth (the distance between the center of charge and orifice).

3 Pre-split blasting test

With reference to the charge structure of the single-hole blasting seam test, the spacing between the perforations is determined and the row hole blasting seam test is carried out until there is no blasting funnel, but only a through-through crack between the holes (the seam width should be 5 ~ 10mm).

4 According to the values of V, q and E/V obtained from the above tests, the test explosion is conducted in the cave, and the values are adjusted again to get the best blasting parameters.

2.3 Blasting Design

The cutting range of the rope saw is full section limestone layer, rock hardness up to 72Mpa. The transverse distance and vertical distance of the adjacent cutting holes of the rope saw are 0.4m and 2.94m. The Z1Z350A diamond drill is used to cut holes in the steel pipe sheet, and four holes are laid up and down. On the basis of meeting the strength of the consolidated soil, the water within the contact channel can be changed from liquid to solid state, so as to avoid water seepage in the cutting process of the rope saw.

Before excavation construction, the blasting design is carried out according to the optimal drilling and blasting parameters summarized from the blasting test, which is used as the basis of excavation and blasting construction. There are mainly the following aspects:

1 Borehole diameter D

Smooth blasting in tunnel engineering generally adopts small aperture (42 ~ 65mm) and hand-held pneumatic rock drill.

2 Drill holes spacing a

The following empirical formula is obtained through regression summary of blasting test:

$$a = k1 \cdot k2 \cdot (18 \sim 30)D$$

In the formula, k1 -- rock compressive strength coefficient, when the rock Przewaldt coefficient f > 6, k1=1.0, when f < 6, k1=0.86;

k2 -- the rock integrity coefficient, k2=1.15 when the rock is weakly weathered with good integrity, when the rock is strongly weathered with poor integrity, k2=0.83;

D - The bore diameter (unit: mm).

3 Borehole depth

According to the circular feed size is l and the hole utilization rate n, the drilling depth L=l/n, then:

1) The depth of cut hole and bottom hole is: L cut and bottom =L+0.2m

2) The depth of auxiliary and peripheral eyes is: L auxiliary and peripheral = L

4 Total charge per cycle

$$Q = qV$$

In the formula: Q -- total explosive required per cycle in tunneling (kg), 1.2kg/m3 for grade III surrounding rock;

q -- drug consumption per unit, (kg/m3);

V -- The total volume (m3) of rock exploded per cycle advance is

$$V = SL\eta$$

Where: S -- sectional area of excavation per cycle (m2);
L -- average hole depth (m);
η -- hole utilization.

5 Charge structure

In order to reduce the vibration caused by single-hole blasting, the uncoupled spaced charge structure is adopted for the peripheral holes, and the coupled continuous reverse detonation charge structure is adopted for the cut holes, auxiliary holes and bottom holes. See Figure 5.2-2 charge structure diagram.

6 Blocking length

The plugging length is based on the following empirical formula:

$$L_1 = (0.8 \sim 1.0)b$$

In the formula, b is the distance between the pre-crack hole and the buffer hole. b can be calculated according to the empirical formula:

$$b = (10 \sim 15)D$$

In the formula, D is the hole diameter, and b value is 40 ~ 60cm. The plugging length of orifice has great influence on smooth blasting effect. If the plugging length is too short, the gas will escape during blasting and it is not easy to form cracks or crack width is not enough; If the blockage length is too long, it is easy to form residual holes in the orifice. Therefore, the construction needs to be corrected according to the blasting effect, generally taking 40 ~ 50cm.

5.2.4 Excavation of rear tunnel of multi-arch tunnel without central wall

Due to the minimum free surface and maximum blasting vibration velocity in the upper step blasting of the rear tunnel, the blasting excavation of the upper step of the rear tunnel in this construction method is taken as an example according to the most unfavorable state. See Fig.5.2.4-1 technological flow chart of the excavation process of the rear tunnel without central wall and multi-arch tunnel.

According to the vibration velocity test results of the test section, the blasting design and detonation network are optimized, the scope of static excavation area is timely adjusted, the monitoring and measurement of static excavation area is strengthened, and the excavation range is well controlled by combining with the hydraulic crushing hammer and the artificial air pick, so that the vibration velocity control and construction progress of the blasting in the rear tunnel can achieve the optimal results.

1 Test section driving

Before the formal blasting excavation of the rear tunnel, blasting excavation of the test section was carried out with four cycles (6m), each cycle of 1.5m.

1) The blasting parameters obtained based on the blasting test shall be adopted for the first blasting excavation, specifically as follows:

a Blasting equipment: No. 2 rock emulsion explosive with Φ25mm and Φ32mm is used. The detonating equipment adopts plastic detonating tube and millisecond detonator initiation system, and millisecond detonator adopts 13 sections of millisecond detonator.

b Spacing of peripheral eyes: The peripheral eyes are arranged 0.1m ~ 0.2m away from the edge of the excavation contour line. The bottom of the borehole is tilted 3° ~ 5° toward the direction of the excavation contour line, and the spacing of the peripheral eyes is 0.55m.

c Optical burst layer thickness W: that is, the minimum resistance line of the peripheral eye, W is 0.6m.

d Hole depth L: cut hole and bottom Angle hole value 1.7m, peripheral hole and auxiliary hole value 1.5m. In the actual operation, according to the concave and convex condition of the palm surface, adjust the drilling length of each hole.

e Initiation method: Tunnel blasting initiation sequence is cut hole → auxiliary hole → peripheral hole → bottom hole. Multi-section millisecond millisecond detonator is used to initiate from inside out. See Fig. 1 hole layout of the test section.

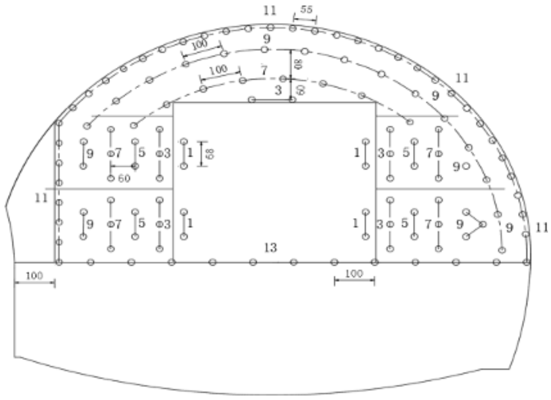

Fig. 1 Perforation Layout of The Test Section

2) Make puree

PNJ-A slurry mechanism is adopted to make mud foam (as shown in Figure 5-6, 5-7), with a diameter of 35mm and a length of 20-25cm for each section. The main components of gun-mud are clay and fine sand, and the mix ratio of gun-mud is clay: fine sand: water = 1:0.8:0.2.

3) Drilling and cleaning holes

Hand-held pneumatic rock drill was used to drill holes (as shown in Fig.2). The diameter of the holes was 42mm, and the cutting holes were in the form of wedge-shaped diagonal cutting. The external insertion Angle of the peripheral hole is 3° ~ 5°. The hole depth is adjusted according to the position of the hole and the degree of bump of the rock on the face of the palm, so as to ensure that the bottom of the other hole except the cut hole is on the same plane.

A small-diameter high-pressure air pipe is used to blow out the residual stone debris in the hole. Meanwhile, technicians check the hole row spacing and hole depth with the gun rod or tape measure one hole at a time, which is used as the calculation basis of blasting charge.

Fig. 2 Drilling Operation

4) Charge

According to the grade and strength of surrounding rock, the single-hole charge quantity is determined. The uncoupled interval charge structure is adopted according to the peripheral eye, and the coupled continuous reverse detonation charge structure is adopted for the cut hole, auxiliary hole and bottom hole. The emulsified explosive with 200g diameter of 32mm and 100g diameter of 25mm are cut along the axial direction, and the explosive, detonator and cannon mud are successively inserted into the gun hole. It should be noted that the slit direction should be consistent with the tunnel contour direction. In order to prevent the phenomenon of flying rocks, the charge length should be no more than half of the hole depth.

5) Arrange the vibrometer

Before detonation, five TC-4850 blasting vibration meter measuring points are arranged on the secondary lining surface of the first hole. After the measuring points, the palm surface of the row hole is arranged with equal spacing and symmetry in the center. The spacing D is 5 ~ 10m, and the measuring point is 1.5m above the ground.

The sensor must be firmly connected with the secondary lining surface (Fig. 3), otherwise the test accuracy will be affected. The three-way speed sensor matching TC-4850 blasting vibration meter is of rectangular structure and can be fixed with adhesives such as gypsum and 502 glue or matching fixture. Please note that the Z direction is vertical and the X and Y direction is horizontal during installation.

Fig. 3 Onsite Sensor Installation

6) Network initiation

Before networking, the whole area should be planned, and the detonating tubes should be gathered into bundles one by one or in different sections for connection. Before connecting the detonating detonators, the number of detonating tubes, the number of holes and the number of detonating tube roots should be checked to avoid leakage.

The network laying form should be as simple and orderly as possible, clear routing, to prevent the network cross, spiral connection. After the network is connected, special personnel should be responsible for the inspection. The detonation sequence is: cut hole → auxiliary eye (from inside out) → peripheral eye → bottom eye. The whole is divided into 1, 3, 5, 7, 9, 11 and 13 stages of blasting.

7) Check after explosion

The blasting personnel or security personnel enter the explosion area to check whether there are safety risks. The contents of post-explosion inspection include:

a There is no blind gun. Whether there is a blind cannon is preliminarily determined by the accumulation of surrounding rock on the face of the palm.

b Accumulation condition. Whether the surrounding rock accumulation condition of the face of the palm is stable and whether there are unsafe risks.

c Dangerous rock situation. Whether there is a dangerous stone on the face of the palm, whether there is still a dangerous stone hanging on the arch, etc.

d Whether there is any remaining explosive equipment at the site.

Due to the possibility of delayed explosion, smoke and other harmful factors, it is required to ventilate for 15 minutes before the inspectors are allowed to enter the blasting site.

8) Static excavation

The measuring control network is set up in the construction site, the total station is used to measure the excavation contour of the hydraulic crushing hammer accurately, and the contour is sprayed out with red paint.

During the construction of hydraulic crushing hammer, the excavator works with the crushing hammer to break the rock mass by top-down layered excavation, load the broken rock mass and transport it to the designated place.

After the completion of excavation with hydraulic crushing hammer, artificial air pick is used to modify the exposed surface of the initial support of the first tunnel. The attached rock mass on the surface is cut out to ensure that the initial support surface of the first tunnel is completely exposed outside the surrounding rock on the premise of not damaging the initial support concrete structure of the first tunnel.

9) Optimization of blasting vibration reduction

According to the maximum section charge of field blasting and Sadovsky's empirical formula, the collected blasting vibration velocity data are fitted and analyzed. When the correlation coefficient between the field blasting vibration test data and the unary regression line is greater than 0.8, it can be considered that there is a strong correlation between the two, and the reliability of the test data is high. Then, according to the safe vibration velocity, The maximum hole charge can be calculated by Sadovsky as the basis for adjusting the blasting parameters.

Based on the blasting parameter diagram, the detonation network is optimized by combining the test results of maximum vibration velocity in the test section and the original waveform of vibration velocity, so that the maximum vibration velocity is controlled within 16cm.

IV. PROJECT CASE ANALYSIS

1 The technology uses static excavation of left and right amplitude tunnels to share the side wall parts, reducing the amount of pyrotechnics used. The level IV surrounding rock carries 0.8~1.0m per cycle, saving the amount of explosive 5.4kg; Grade V surrounding rock is fed 0.6m per cycle, saving explosive consumption of 2.1kg, with obvious economic benefits. At the same time, the blasting vibration reduction construction technology is adopted in the rear tunnel, which effectively reduces the fracture risk of the lining structure of the first tunnel, and reduces the cost of quality defects and disease remediation of the lining of the first tunnel.

2 Based on the test and analysis of the blasting vibration velocity, this technology solves the construction technical problems of the blasting vibration velocity control in the rear tunnel of the multi-arch tunnel with no central wall in different geology through continuous feedback adjustment of the blasting process, ensures the integrity and safety of the lining structure of the advance tunnel, reduces the charging amount per unit area, reduces public hazards such as noise and dust, and is conducive to environmental protection. It provides a reference experience for similar projects in the future.

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