Application of cantilever roadheader in tunnel construction

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Abstract: Cantilever roadheader is widely used in coal roadway engineering, but it is rarely used in urban subway tunnels. The underground boring tunnel in Guiyang City is selected as the object. The background and purpose of the cantilever roadheader, the construction technology and method, the advantages and disadvantages analysis and the construction optimization are selected to study its application in the underground karst tunnel. Studies have shown that the use of cantilever type roadheader can speed up construction progress, reduce surrounding rock disturbances, reduce safety risks and improve excavation quality, which is unmatched by traditional drilling and blasting construction.

1. Introduction

With the continuous advancement of science and technology and tunnel construction technology, especially the introduction of special machinery, the tunnel construction will be diversified, heavy-duty, automated, efficient, and economical. For the hard rock roadway, the blasting rock boring machine is the main way of excavation, but in some areas, the full-face boring machine gradually replaces the blasting rock boring machine; in the lower hardness of the whole rock roadway and the semi-coal rock roadway, the cantilever The excavation opportunity is the main way of excavation; in the coal roadway excavation with suitable conditions, the continuous miner and the excavation combine unit with higher excavation efficiency will be promoted and applied[1-6].

Cantilever roadheaders are widely used in coal roadway engineering, but they are rarely used in urban subway tunnels. Because subway tunnels are criss-crossed in the city underground, in order to reduce the impact on ground buildings and surrounding rock disturbances, cantilever roadheaders will become the main excavation method in subway tunnel construction. This paper is based on the use example of cantilever roadheader in Guiyang City rail transit undercut karst tunnel. The background and purpose of the roadheader, construction scheme, construction technology and method, cantilever type tunneling machine advantages and disadvantages and construction optimization are studied. For the future cantilever type roadheader to provide reference in the construction of underground tunnels[7-9].

2. Project introduction

Guiyang City Rail Transit Line 1 Railway Station – Sha Chong Road Station Tunnel (hereinafter referre to as: Huo-Sha Tunnel) is located in Nannong District. The line passes through Guiyang Railway Station's passenger platform, ticket office, railway track, and line. Private rooms, Nannong District People's Court and several small high-rise residential buildings. The fire-sand tunnel is a double-hole single-line structure. The right tunnel has a mileage of YDK26+143.2~YDK27+073.8, and the short chain is YDK26+294.811~YDK26+300.000 (ie 5.189m). The distance between the left and right lines is changed from 16m to 13.5m, the left tunneling mileage is ZDK26+143.2~ZDK27+073.8, the short chain is ZDK26+272.779~ZDK26+300.000 (ie 27.221m), the right tunnel is 925.41m, and the left tunnel is 903.379m.
The Huo-Sha tunnel is located in the core area of the main urban area of Guiyang City. The passage area is densely populated with civil buildings. The topographic height difference is 7.4m. The upper cover layer is block stone layer and red clay, and the underlying bedrock is the second section of Songkanzi. Rocks, karst weak development, the main source of groundwater recharge is atmospheric precipitation, groundwater elevation is 1051.78-1064.32m.

3. Test section selection and test purpose
The fire-sand tunnel is designed for “cold digging” construction, using ordinary machinery. The construction of each tunnel is 30~48h, and the completion of each cycle is about 3d, which cannot meet the requirements of the owner. The cantilever type roadheader only needs 8~9h per cycle, and each cycle is about 24h. In order to ensure the overall construction period target, after multiple inspections, with reference to the construction of Dalian Metro and Sichuan Mianyang cantilever type roadheader, it is proposed to select Huo-Sha tunnel YDK26+300～YDK26+862, ZDK26+300～ZDK26+880 mileage excavation tunnel is used as the test section, and the cantilever type roadheader of model EBZ260 is used for tunnel cold excavation construction.

During the construction of the test section, real-time monitoring of the deformation of the face and the initial branch is required, and emergency rescue materials for tunnel construction are provided to ensure the safety of the construction. The following work shall be carried out during the construction of the test section:

(1) Test the working conditions of different surrounding rocks, analyze the excavation efficiency, surrounding rock stability and initial deformation of different surrounding rock tunneling machines.

(2) The design of the step-by-step construction method is changed to the full-section construction method to test the disturbance of the surrounding rock and the construction safety of the full-face excavation.

(3) Because the operation space of the cutting head of the roadheader needs to increase the face of the face of 80cm, it is necessary to analyze the stability of the surrounding rock and the safety of construction.

(4) Summarize the process flow of the mature cantilever tunneling machine.

(5) Analyze and summarize the labor, materials and mechanical equipment generated by the roadheader construction.

After the completion of the excavation construction of the test section, it is necessary to analyze and summarize the data of the test section. After optimizing the scheme, it is used to guide the excavation construction of other mileage passages in the section and the preparation of the excavation plan for the special mileage section (below the train station section, etc.).

4. Cantilever roadhead construction method

4.1 Preparation before work
(1) Equipment preparation
Because the working machine uses in this construction has a working voltage of 1140V, it is necessary to match a special transformer for each roadheader to ensure that the output voltage is 1140V to meet the working requirements of the roadheader. At the same time, it is necessary to prepare 630KV high-voltage power and supporting cables, water pipes, ventilation and slag-discharging vehicles.

(2) advance geological exploration cooperation
Acoustic sounding method, advanced horizontal drilling and other geological advance prediction technologies are adopted. For example, understand clearly the engineering geological condition in front of the palm, to ensure the safety of people, money, materials and materials, so as to reduce or avoid possible geological disasters.

According to the test results of the saturated compressive strength Rc of the rock sample in the fire-sand tunnel area, it is found that the maximum Rc is 85 MPa. According to the selection of the EBZ260 type roadheader, the excavation of the full section of the tunnel (except the inverting part) can
be guaranteed. The excavation volume is about 34m³ per metre.

4.2 Cantilever tunneling method
When the roadheader is in place, first, a groove along the horizontal direction is cut at the bottom of the face; secondly, the roadheader is moved forward again, and then the cutting head is cut from bottom to top, left and right; at the same time, the blade jaws shovel the rock into the transporter 1, and then transport it to the transporter 2, and transport it to the abandoned farm by the exit truck; finally, the excavation is completed by the S-shaped or Z-shaped circulation from the bottom to the top of the face. After that, the tunnel section is refurbished to meet the design criteria. In the process of tunneling, if the local hard rock with a strength of more than 100MPa is encountered, soft rock around the hard rock shall be excavated first to make the hard rock fall under the self-weight, and then treat separately to reduce the difficulty of tunneling and cut tooth loss.

If you use a right-rotating cutting head to cut hard rock, start from the bottom to the left, then press right to left, top to bottom or left to right, and bottom to top. When it is better to have a rock but the joints are developed, it is better to cut the rock step by step along the joint.

Different picks correspond to different hardness rocks, and the pick spirals are arranged to ensure the best cutting ability of the roadheader. The ideal cutting head can also be selected according to the actual working conditions to improve the work efficiency. If the hard rock is partially encountered, the small-diameter cutting head is used, the cutting force is large, and the cutting force is strong, which can reduce the difficulty of excavation and the loss of picking. The cutting mode of the roadheader is shown in Fig. 1.

![Fig.1 Cutting mode of roadheader](image1)

![Fig.2 Physical diagram of roadheader](image2)

4.3 Tunneling construction technology
During the construction of the tunneling machine, it first enters the tunnel from one side entrance, and then cuts the tunnel face with cutting teeth. The ballast soil is first transported to the back of the tunneling machine by conveyer 1, and then loaded into the ballast truck by excavator to the shaft, and then lifted vertically to the temporary ballast storage area. After the completion of tunneling, the tunneling machine will transport the initial support platform car to the palm surface to start the initial support work, such as steel arch erection, shotcrete, etc., while the tunneling machine will be pushed back to the position without affecting the follow-up work to wait for the next process. Excavators are also used for invert excavation, enabling the tunnel to be fully mechanized, which can reduce
disturbance of surrounding rocks and avoid affecting surrounding buildings.

Fig.3 Tunneling construction with roadheader

Tunnel construction with tunneling machine can realize small disturbance of surrounding rock, strong adaptability of rock stratum, high excavation quality, round cross section, convenient sneezing support, shorten construction period and safety.

5. Cantilever roadheader construction features and program optimization

5.1 Cantilever roadheader construction advantages

1. Construction quality
The mechanical excavation has a high degree of roundness, which improves the quality of the tunnel section and facilitates the initial shotcrete operation, and also significantly improves the quality of the initial support.

2. Construction progress
   (1) The cantilever roadheader combines cutting, mounting, transporting and self-integration to achieve cutting and shipping synchronization. It has the advantages of high continuity of excavation and strong adaptability of geology, and is a suitable cold excavation equipment.
   (2) The cantilever roadheader has many functions and good maneuverability. In case of accidental working conditions, it is convenient to adjust the construction plan in time without affecting the construction progress.
   (3) The construction progress of the cantilever roadheader depends on the support process, and the section of the cantilever tunneling excavation is regular, and the steel frame and the mesh piece can be quickly assembled, which greatly saves the operation time of the jetting.

3. Construction safety
   (1) The construction of the roadheader can not only improve the mechanization of the tunnel, but also reduce the construction risk.
   (2) The mechanical cutting and excavation operation has minimal disturbance to the surrounding rock, which improves the safety index of the high-rise buildings and stations.
   (3) The efficiency of the cantilever tunneling operation is high, and the support can also be applied in time to reduce the empty time of the operation.

4. Working environment
The cantilever road boring machine is equipped with water spraying and vacuuming equipment at the cutting part, which can reduce the rock dust and dust, so that the working environment can be purified and the air quality is superior.

5.2 Insufficient operation of the cantilever roadheader
Of course, the cantilever type roadheader also has its shortcomings, mainly reflected in the following three aspects:

1. Because the cutting head of the roadheader is long, the working surface of each face of the excavation work needs to reserve about 0.80m. In order to prevent the initial branch that has been applied from being damaged during the next excavation, the palm is caused. There is a large empty surface at the surface.
2. Because the interval tunnel project is a small-section tunnel, but the size of the roadheader is relatively large (i.e: length × height × width = 11.7m × 2.0m × 3.6m), it is impossible to pass the secondary lining trolley at the same time in the tunneling. Once the secondary lining starts to work, the roadheader can only dig one-way forward.

3. Because the cutting part of the roadheader is restricted by its own length, it cannot meet the sub-step excavation construction.

5.3 Optimization scheme of oversized suspended surface caused by roadheader construction

If the suspended surface of roadheader is too large, the cutting head length of roadheader and partial section excavation of roadheader can be improved to carry out roadheader construction. The designed spacing of the primary support steel frame in the lower crossing station room section of this section is 0.35m/ truss, and each circular footage should be controlled within 0.6m during tunneling. The steel frame should be reserved close to the hole body near the primary support, and be repaired by air picks or excavators. The designed spacing of the primary support steel frame in the lower crossing section is 0.5m/ truss, and each circular footage during tunneling is controlled within 0.8m, and the hole body near the primary support is reserved, and the air pick or excavator is used for dressing.

1. Improve the length of the head of the roadheader

After research, it is decided to replace the smaller cutting head to minimize the face of the face facing 50cm.

2. Using the roadheader to implement partial section excavation

When using the roadheader for excavation work, only the section of the tunnel is excavated, that is, if the initial branch is not damaged, the cutting head is used to cut the hole as much as possible. For the reserved excavation surface, the excavator is used for excavation and trimming.

Fig.4 Tunneling section of roadheader

(1) the reserved excavation face for air pick excavation: after the excavation machine is opened, the top of the initial support platform is moved in place, the excavation machine is retreated to the back of the platform, and then the workers carry air picks to repair the reserved excavation face. This method requires a pneumatic pick to repair the hole about 5m3/ m, about 4 ~ 5 hours.

(2) use excavator to excavate reserved excavation face: the excavator moves back to the horizontal channel after the completion of excavation, and the excavator moves to the part of reserved excavation face for repairing the palm face. This method requires an excavator to repair the hole about 5m3/ m, and takes about 1 ~ 2 hours.

5.4 Optimization scheme of inverting arch, inverting arch filling and second lining construction

1. Construction measures to ensure the normal construction of the inverted arch and the inverted arch

During the construction of the inverting arch and the inverting arch, it is necessary to erect a steel bridge between the infilled portion of the inverted arch that has been constructed and not constructed. Equipment such as slag trucks, excavators, and workers can use steel bridges to pass through, and the roadheader can use steel bridges to reach the face of the face for excavation construction.

2. Construction organization measures to ensure the normal construction of the second lining
For the ordinary mileage section tunnel of this section, it is proposed to complete the second lining after the initial branch is completed 300m; special support is applied to the individual surrounding rock weakness and special mileage section.

In view of the problem that the roadheader can not pass through the second lining trolley normally, it is proposed to arrange two roadheader in the hole to carry out the tunneling construction. When the large mileage direction of the left line passes through the contact channel, a roadheader is set up in this direction, and the second lining construction is carried out in the direction of large mileage with the contact channel as the starting point. The other roadheader excavates the remaining three tunnels through the contact channel and the horizontal channel.

5.5 Optimization plan for step-by-step construction of roadheader
Because the geological conditions of the site are good, most of the sections are Grade IV surrounding rock. During the tunneling process, the geological prediction of the face is carried out in strict accordance with the design requirements, and the deformation of the initial branch is monitored in real time. In the stable section of surrounding rock, the tunnel construction can be flexibly selected by the step method and the full section method. When the geology of the palm surface is poor, the surrounding rock is unstable, and the cave is encountered, the excavation construction should be stopped and the palm surface should be closed. The design units, geological prospecting units and supervision units are invited to study the treatment plan on the spot, and then carry out the excavation construction after the treatment is completed according to the agreed scheme.

6. Conclusion
(1) the underground tunnel adopts ordinary cold excavation machinery, the construction time of each cycle is as long as 30 to 48 hours, and and the completion of each cycle is about 3 days; the construction time of each cycle of cantilever roadheader is only 8 to 9 hours, and the completion of each cycle is about 1 day.

(2) During the construction process of cantilever tunneling machine, it is necessary to test different working conditions of different surrounding rock, analyze the efficiency of different roadheaders, stability of surrounding rock and initial deformation; the design of the step-by-step construction method was changed to the full-section construction method, and the disturbance of the surrounding rock of the face and the construction safety of the full-face excavation were analyzed; the 80cm free surface of the face is required to test the operation space of the cutting head of the roadheader, and the stability of the surrounding rock and construction safety are analyzed.

(3) according to the rock with different joint development degree or different hardness, the spiral arrangement pick and the cutting head with different diameter can be scientifically selected, which can improve the construction efficiency, reduce the difficulty of excavation and the consumption of cutter.

(4) the cantilever tunneling machine can improve the degree of mechanized operation and reduce construction risks;By cutting, the disturbance of surrounding rock can be greatly reduced, the safety index and the quality of excavation can be improved, the excavation section is relatively smooth, and the supporting effect of shotcrete is good. The excavation efficiency of roadheader is high, which can shorten the hanging time of excavation face. The cantilever excavation progress depends on the supporting time, and the cantilever excavation section is regular, which can realize the rapid assembly of steel frame and mesh, and save a lot of time of shotcrete.

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