Design and Application of Mechanized Construction Equipment in Shallow Excavation Precast Utility Tunnel

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Abstract. Traditional open-cut method for utility tunnel has many disadvantages such as long-term occupation and large area of land, great disturbance to urban traffic and environment, high labor intensity of workers and so on. In order to overcome the disadvantages above, a machine for prefabricated utility tunnel construction was designed which drawing on the working principle of shield machine and pipe jacking machine. The above-machine is applied in shulong road utility tunnel of Chengdu. The applicable results show that: (1) The above-machine achieve movable streamlined synchronous construction of earth excavation, components assembling and earth backfill. It improve the shortcoming of traditional open cut method and cancel the majority of foundation pit bracing structure. (2) The above-machine can make mechanized and assemblage construction of shallow excavation precast utility tunnel come true. It effectively control construction quality and reduce difficulty of construction management.

1. Introduction

With the national promotion of the construction of comprehensive pipe gallery, various structural forms and construction methods of comprehensive pipe gallery have emerged [1]. However, mechanization, automation and intelligent construction equipment are barely used in the construction of utility tunnel. Huang [2] studied the application of prefabricated aluminium formwork trolley in Beijing new airport utility tunnel. Zhou[3] studied the application of hydraulic steel mold trolley in Canglang Avenue of Shiyan. Li [4] improved the traditional steel formwork trolley and put forward a new type of separated formwork trolley which could realize the structure flow construction. Li. [5] study the sphincter that could realize the lifting and turning of components. Jia[6] summarized the advantages and disadvantages of rectangular pipe jacking and proposed the possibility of pipe jacking machine in the construction of pipe corridor. Pan [7] summarized the key and difficult points of pipe jacking machine in the construction of utility tunnel in Xindu District, Baotou City. Zhang[8] analysed the application prospect of shield machine in utility tunnel construction. Zhu [9] compared the advantages and disadvantages of open-cut and shield construction and analysed the key problems in the design and construction of shield construction in the application of utility tunnel. Wang[10] proposed the
mechanized construction method of U-shaped shield tunnelling that could realize the function of mobile support and was successfully applied to the utility tunnel in Haikou.

To sum up, the current research on open-cut utility tunnel equipment mainly focuses on a certain process in construction, such as hoisting, formwork casting or other construction steps. It is difficult to avoid the disadvantages of open-cut construction method, such as large construction area, great influence on traffic and great disturbance to the urban environment. U-shaped shield tunneling mainly realizes the function of moving support. So that only the starting foundation pit and the receiving foundation pit need retaining structure, but it can hardly use in the horizontal and vertical curve. The trenchless construction equipment is shield machine and pipe jacking machine, which has not been improved according to the characteristics of utility tunnel. Utility tunnel node appear every 200m at most[11]. The handling of nodes in the construction of the comprehensive pipe gallery by shield machine and pipe jacking machine is relatively complicated, and there is no mature scheme and relevant standards [12]. Domestic pipe jacking method and shield method are mainly used to cross the section construction which cannot be cut or the cost of cut is enormous. The pipe jacking method is limited by the formation type and the construction distance is short, the longest construction distance is only 233.6m[13]. Most shield machines are round, which leads to a low utilization rate of the section of utility tunnel. At present, the longest comprehensive pipe gallery constructed by shield machine is 5468m[14].

In view of the characteristics of the buried depth and the significant node ratio of utility tunnel, this paper caters to the green construction trend of utility tunnel [15] and improve suitable of equipment for the shallow buried prefabricated utility tunnel. The length of the equipment is 24m. Considering other supporting construction equipment, the construction area can be controlled within 100m, which can realize earthwork excavation, pipe gallery assembly and earthwork backfilling mobile flow operation. Moreover, it can overcome the shortcomings of conventional open cut method and avoid enclosure structure.

2. Research background

2.1. Project profile
Total length of utility tunnel in Chengdu Shulong road is about 1.1km and precast section is about 700m. The buried depth of the utility tunnel is about 4.2–5.4m. The main strata are clay and silty clay, and the groundwater is 8m below the ground. The prefabricated utility tunnel is a double-cabin structure. The standard cross-section is composed of the middle wall block, the side wall block, the bottom block and the top block. The width is 7.83m and the height is 3.8m, as shown in Fig. 1. The thickness of the middle wall block is 250mm and the weight is 3.4t. The thickness of the side wall block is 300mm and the weight is 5.4t. The thickness of the bottom block is 300mm and the weight is 9.2t. The thickness of the top block is 300mm and the weight is 10.4t.

![Figure 1. Cross-section of precast utility tunnel (unit: mm)](image)

2.2. Equipment design requirements
Prefabricated pipe tunnel assembly heading machine is based on the concept of mobile support, assembly of prefabricated components and highly mechanized construction, which can realize the
simultaneous operation of multiple processes, such as earthwork excavation, hoisting assembly of prefabricated components and earthwork backfilling, in the equipment. Therefore, the equipment should have the following functions:

1) Mobile support. The structure of the heading machine meets the function of retaining soil and water, and has the ability of moving, so it can provide a movable dry working space for pipe gallery assembly construction.

2) Component pose control. Heading machine can accurately adjust the pose of components, which can meet the precision and efficiency of component assembly.

3) Satisfy the line requirements. The heading machine can adjust its attitude in the process of tunneling to meet the requirements of the horizontal and longitudinal curves of the integrated pipe gallery.

3. Design of prefabricated utility tunnel heading machine

3.1. Structural components
In order to adapt to the horizontal and vertical curves of the integrated pipe gallery, the structure of three cabins is designed, and the cabins are connected with each other by articulated oil cylinders. The equipment moves forward by the reaction force of utility tunnel.

The heading machine consists of five main structures. The five major structures include excavation chamber, assembly chamber, support chamber, top platform and gantry crane. The overall layout of heading machine is shown in Fig. 2.

3.2. Design of excavation chamber
The excavation chamber, located at the front of the equipment, mainly provides working space and equipment guidance for excavation, as shown in Fig. 3. The box-shaped structure at the back of the excavation chamber is equipped with an active pushing cylinder and a passive articulated cylinder, which can rotate relative to the assembly chamber under the joint action of the active pushing cylinder and the articulated cylinder and is suitable for the construction of the horizontal and vertical curve section of the pipe gallery. The active propelling cylinder can be extended into the assembled pipe gallery in the assembly room, and the passive hinged cylinder is connected with the assembly room.

It is only to remove part of the soil in excavation chamber and the heading machine forward by the propulsion system. Therefore, the top of retaining structure is long whereas bottom of retaining structure is short. Therefore, the side plate of the excavation chamber is a trapezoidal structure with wide upper part and narrow lower part.
3.3. Design of assembly chamber and backfill chamber

Assembly chamber is located in the middle of the equipment, mainly used for component hoisting assembly, as shown in Fig. 4. It is connected to the excavation chamber through the articulated cylinder installed on the passive articulated cylinder plate. The tail is provided with a pin shaft for connection with the support chamber. The top of the assembly room is provided with a door crane mounting leg for the installation of the door crane. The clamping cylinder is arranged on the side plate and the bottom plate of the assembly room, the sealing brush is arranged on the rear baffle, and the grouting hole is also arranged on the tail and the bottom plate to fill the gap between the pipe gallery and the soil layer after it comes out of the assembly room. The front panel is provided with an opening so that the jacking cylinder installed on the excavation chamber can be extended into the jacking pipe gallery formed in the assembly chamber.

The support chamber is located at the end of the equipment and is hinged with the assembly chamber through the pin shaft. Its main function is to provide support for utility tunnel that has been installed and formed, as shown in Fig. 5. Because the side and bottom of utility tunnel are filled with cement mortar in the process of pushing, the part above the top of the pipe gallery is only needed to be backfilled in layers when backfilling, so the height of the backfilling chamber does not need to cover the bottom of the utility tunnel. From the perspective of construction efficiency, the length of the backfill chamber should be as long as possible. In order to facilitate backfilling, the backfilling chamber shall be an unsupported cantilever structure, whose length is affected by stiffness.
3.4. Design of gantry crane and top platform

The top platform is located above the excavation chamber and is a box girder structure, as shown in Fig. 6. It mainly provides a platform for hydraulic power station, grouting power station and grease injection system equipment. It can also strengthen the stiffness of the cutting edge of the excavation chamber and increase the ability of the cutting edge to be inserted into the soil.

The gantry crane is composed of a door frame arranged on the upper part of the assembly room, a cart walking on the door frame and a trolley walking on the cart, as shown in Fig. 7. The door crane has 4 lifting units. The main hook is located on the trolley which is mainly used for taking components from the transport vehicle and lifting them to the assembly station. The secondary hook is located at the cantilever which is mainly used to assist the component turning over action. Two main hooks are respectively suspended below the main girder can be used to lower the assembled utility tunnel.

4. engineering application

4.1. initiation and reception of heading machine

The initiation foundation pit is the same as the conventional foundation pit. The three sides of the foundation pit are the retaining structure, and the heading direction is the slope excavation. The concrete cushion layer are set at the bottom of the foundation pit, and a concrete wall with a thickness of 0.5m is set at the beginning. The reaction frame of the steel structure is backed against the concrete end wall, as shown in Fig 8.
After the assembly of the excavation chamber and assembly chamber of the heading machine in the initiation foundation pit, the assembly of the first ring is completed in the heading machine, the top of the first ring is pushed to the counterforce frame, and the bolt is connected with the counterforce frame. The support chamber is installed after pushing 5~6 rings.

The receiving of heading machine does not need the foundation pit. After the construction of the last ring, the excavation chamber, assembly chamber and backfill chamber are successively removed and hoisted out.

4.2. hoisting and assembly of components
The lifting and assembling sequence is bottom block - side wall block - middle wall block - top block, as shown in Fig. 9.

![Figure 9 Hoisting and assembling components](image)

Lift the bottom block to the bottom of the assembly chamber, position it with the platform limiting device, then lower the side wall block, and connect it with the bottom block with the assistance of the lateral cylinder. Then lower the middle wall block, and finally lower the top block to connect with the middle wall block and the side wall block, to complete the assembly of a ring utility tunnel.

4.3. Jacking
After a ring utility tunnel is assembled and formed, the whole ring utility tunnel is connected with the upper ring by jack. After the connection is completed, the heading machine pushes the forming utility tunnel forward, and the utility tunnel pulls out of the assembly chamber. In the process, the grouting fills the gap between the utility tunnel and the surrounding soil synchronously.

In the process of heading machine jacking, two excavators are configured to remove the soil in the excavation chamber. When the soil is excavated about 5m below the ground, the heading machine can rely on the top of the cylinder to push forward, as shown in Fig. 10.

![Figure 10. earth excavation and heading machine launching](image)

4.4. Node construction
The node of utility tunnel has two floors. The lower layer contains the side wall block and the bottom block of the standard section. The prefabricated components on the upper and lower sides are connected as a whole by ring beams. Because the first floor of node doesn’t have top block and middle wall block, part of cylinders have no loading point. In order to solve this problem, reusable steel arch shelf was used as a temporary structure in the middle of two side wall blocks, as shown in figure 11.
(red steel arch steel structure). The temporary steel arch frame will be lifted out when the node is completed, so as to ensure the uninterrupted jacking of the heading machine. In this way it can shorten the construction period.

Figure 11. Construction of utility tunnel nodes

5. Conclusion
This paper, based on the precast utility tunnel in Chengdu, the heading machine is developed for the construction of shallow buried prefabricated utility tunnel. Combined with the actual construction, it shows that the equipment can realize mechanized construction and achieve considerable economic benefits. The main conclusions are as follows:

1. The excavation chamber, assembly chamber and backfilling chamber of the heading machine realize the synchronous flow operation of earthwork excavation, prefabricated utility tunnel assembly and backfilling, which significantly reduces the construction space and has little disturbance to the city.

2. The heading machine completes the construction of straight line section and curve section through the propulsion system, articulated steering system and measurement and control system, which can meet the construction accuracy of the pipe gallery.

3. In the joint construction, the assembled temporary steel arch is used to provide the reaction point for the propulsion system, which can realize the synchronous construction of the joint and shorten the construction period.

4. The heading machine can realize the mechanized construction of prefabricated utility tunnel. Compared with the conventional open-cut method, it greatly reduces the labour, the difficulty of construction management and controls the construction quality.

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