International Journal of Value Engineering (2024) Volume 1 Issue 1

ISSN: 3060-950X (O)
3060-9518 (P)

RESEARCH ARTICLE

Key technology of roof-lifting conversion construction for Karst geological shallow-buried large-span Subway Station: A Case of Beijing road station in Guiyang metro line 3

Yuhua She[1], Jin Chang[2], Chaoying Chen[3]

[1] *China Railway Fifth Bureau Group Guizhou Engineering Co.，Ltd.，Guiyang 550001，China；*

[2] *Guiyang Public Transport Investment and Operation Group Limited，Guiyang 550001，China；*

[3] *School of Civil Engineering，Guizhou University，Guiyang 550025，China*

ABSTRACT

In order to solve the problems of difficult control and easy deformation in the construction of inclined shaft leading-in tunnel in Kras Guiyang metro station, the inclined shaft leading-in tunnel in Beijing Road station of Metro Line 3 is taken as an example. This paper puts forward the key construction technology of the top-lifting conversion of the inclined shaft entering the main tunnel, condenses the construction scheme, the construction flow and the construction key technology, and realizes the safety, the order, the fast and the high quality in the whole top-lifting conversion process. It not only ensures the safety construction of this project, but also provides reference for other similar projects.

Keywords: karst; shallow buried long-span; subway station; pick the top switch

1. Introduction

For large-span subway station tunnels, auxiliary tunnels such as vertical or inclined shafts are generally set up during tunnel construction to enter the main tunnel through roof lifting, in order to increase the working face [1-4]. However, during the transition process between the inclined shaft and the main tunnel, if the construction is not suitable, it can cause engineering problems such as collapse at the top of the tunnel, especially in construction areas with poor geology [5]. In this regard, Liu Yi et al. [6, 7] studied the key technology of vertical roof jacking construction for inclined shafts in large-span subway tunnels and found that by strengthening support methods, the displacement of surrounding rock can be effectively controlled. In addition, Zeng Yi et al. [8] compared and analyzed the strengthening of support in actual construction by combining numerical simulation methods with the engineering practice of underground excavation stations in Chongqing rail transit. Zhang Hongda [9] conducted research on the construction technology of the upper connecting tunnel+gantry method for roof jacking, innovated the construction method, accelerated the construction progress, and effectively avoided various safety risk factors. Li Ming [10] adopted a construction plan of rapid lifting of large equipment into the tunnel during construction, which improved the economic efficiency of the construction. Yu Jiawu et al[11]. Proposed a safe and effective scheme for cantilever roof support with small

ARTICLE INFO
Received: 21 March 2024 | Accepted: 15 May 2024 | Available online:

CITATION
She YH, Chang J, Chen CY. Key technology of roof-lifting conversion construction for Karst geological shallow-buried large-span Subway Station: A Case of Beijing road station in Guiyang metro line 3. *International Journal of Value Engineering* 2024; 1(1): XXXX. doi: 10.59429/ear.v2i1.XXXX

aperture prestressed anchor cable support technology as the core. At present, although a large number of scholars have conducted research on the construction technology of inclined shaft entering the main tunnel, the research on large-span and large-section tunnels still needs further investigation, especially in karst geological areas where karst is more common. This article takes the Beijing Road Station of Guiyang Metro Line 3 as an example and proposes a method and process flow for the inclined shaft to enter the main tunnel and top lift conversion, which can be used as a reference for engineering in karst geology.

2. Overview of supporting projects

2.1. Project introduction

The Beijing Road Station of Guiyang Metro Line 3 overlooks the intersection of Anyun Road and Beijing Road, and can transfer to Line 1 at this station. The station is 259.5m long, with a maximum excavation width of 28.02m. The rectangular section is buried at a depth of 13.2-16.2m for an underground two-level island platform, with a longitudinal slope of 2. The main structure is constructed using the arch column excavation method. The station has a total of inclined shafts 1 and 2, and the way to enter the station is the same regardless of whether it is inclined shaft 1 or inclined shaft 2. The internal passage of the inclined shaft station adopts I20b steel as the initial support steel frame, with a net width of 7m and a height gradient with the station arch. The internal passage is 1172mm higher than the station arch. The inclined shaft is divided into two stages for construction at the station. The first stage involves entering the upper part of the station to complete the excavation of the station roof, and completing the initial support arch of the station main tunnel. The second lining structure of the upper arch cover of the station is also constructed. Enter the station for the second time, 1.6m below the middle plate, excavate the rock mass within the middle plate range, and complete the construction of the middle plate and upper side walls. The highest height of the first excavation of the arch is 8.7m, and the total height after the second excavation is 12.547m.

2.2. Engineering geology

The Beijing Road Station of Guiyang Metro Line 3 is located in Guiyang City, Guizhou Province, and belongs to a typical karst geological area. After drilling, it was revealed that 7 karst caves (gaps) were encountered, with a dissolution rate of 21.8%. The geological strata in the construction area mainly consist of miscellaneous fill soil, widely distributed within the surface area of the site, locally consisting of bricks, porcelain tiles, mixed with powdery clay, construction waste, etc., with irregular distribution and loose structure. Soft plastic red clay and hard plastic red clay are mainly distributed at the rock soil interface, dissolution channels, caves, dissolution channels, and surface of the site. They have high natural water content, saturation, plastic boundaries, and natural porosity, and exhibit unconformity contact with the underlying bedrock. The bedrock is mainly moderately weathered dolomite, occasionally interbedded with karst breccia. This project is characterized by moderately developed karst, with karst caves, gullies (grooves), and cracks as the main karst forms. The thickness of the Quaternary cover layer within the engineering site is relatively large, and most of the strongly weathered rock structures are damaged. Weathering cracks are developed, and the thickness is uneven. The overall surrounding rock level of the station is classified as Grade Yu.

2.3. Hydrological conditions

There is an Anyun sewage ditch (3.0 × 4.0, buried at a depth of 4.0m) on the sidewalk on the north side of Beijing Road, which is a reinforced concrete structure. The sewage ditch has been fully constructed and is in good operating condition. Besides, there is no other surface water. The types of groundwater in the construction area are divided into carbonate karst fissure water and Quaternary loose aquifer pore water. The upper stagnant water mainly occurs in the soil voids, with irregular distribution and obvious seasonal characteristics in water volume. Diving water is stored and transported through weathered cracks, joints, and dissolution pores, with atmospheric precipitation as the main source of supply and domestic sewage from surrounding residents. The groundwater level in the site is relatively stable, and its burial depth varies with the overall terrain fluctuation trend. Through simple water level observation, the groundwater level is higher than the rail surface elevation, which has a significant impact on engineering construction. The overall direction of groundwater runoff is from north to south, with discharge towards lower terrain. The depth of groundwater in the site varies with the overall terrain fluctuation trend, with an elevation of around 1071.40 and a depth of approximately 5.0-5.5m.

3. Topping conversion construction technology

During the process of roof transition, the construction process is mainly divided into the following seven steps: the first excavation of the horizontal passage → excavation and installation, initial support and replacement of the main tunnel of 108 Daguanshangyin Station → opening of station 3 # and 4 # guide tunnel doors → excavation of the upper main tunnel of the station → second excavation of the horizontal passage (reducing the elevation of the inclined shaft) → excavation and construction of the middle plate and upper side wall (**Figure 1**).

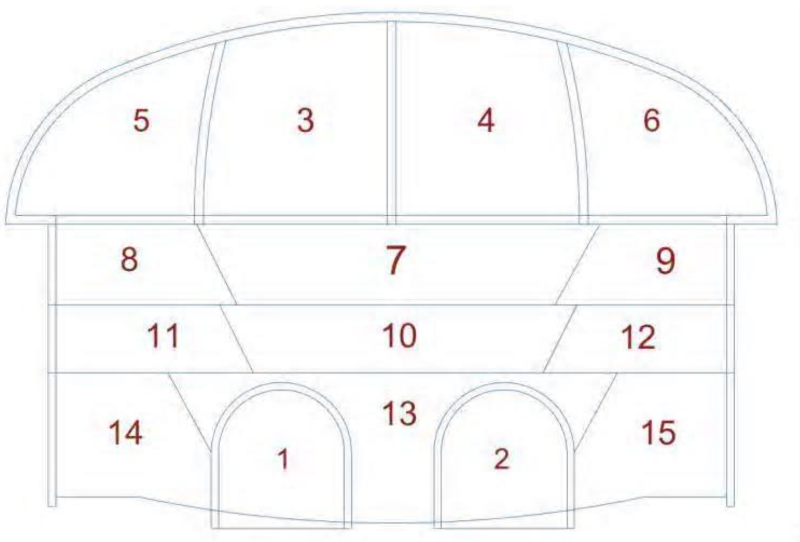


Figure 1. Numbering diagram of tunnel pilot tunnels.

3.1. First excavation of horizontal passage

The cross-sectional dimensions of the inclined shaft excavation are shown in **Figure 2**. The upper channel inside the inclined shaft station is set according to the elevation of the upper arch cover bottom of the station's main tunnel. The arch of the inclined shaft adopts a 4.5m long Ø32 grouting steel flower pipe, arranged in a plum blossom shape with a spacing of 1.0 x 1.0m (circumferential).

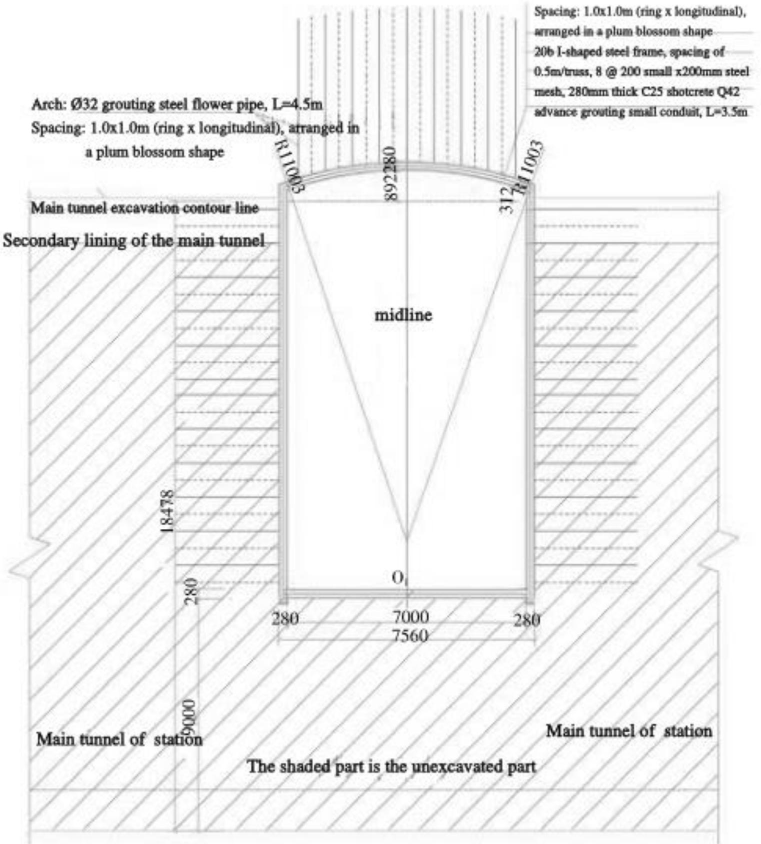


Figure 2. Cross section of inclined shaft.

As shown in **Figure 3**, the excavation height of the steps on the channel is confirmed to be 5.8m (the first excavation height of the inclined shaft is 8.7m) based on the working height of the tunneling machine and the pipe shed drilling machine. Use a tunneling machine to excavate the upper steps of the channel inside the inclined shaft station. Each excavation shall not exceed the spacing between one steel frame, and the initial support for the upper steps shall be applied (i.e. 4cm thick initial sprayed concrete+steel mesh+steel frame+locking anchor rod, and after the system anchor rod is drilled, the concrete shall be sprayed again to the design thickness). After the construction of the greenhouse is completed, the excavation of the lower steps will be completed, which will match the bottom elevation of the main tunnel arch cover secondary lining structure.

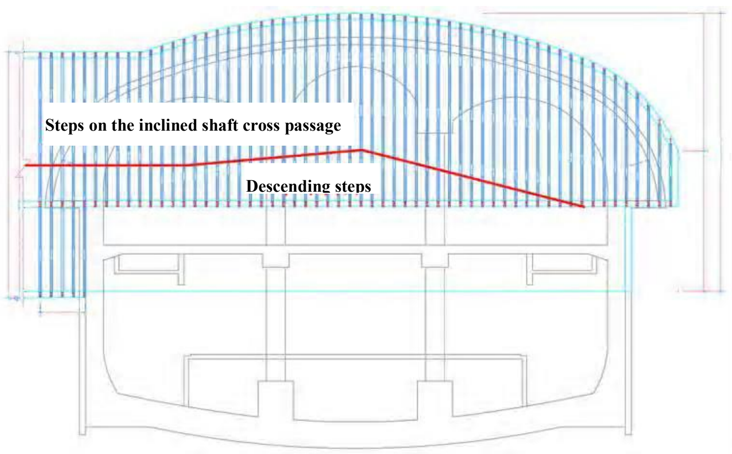


Figure 3. The first excavation of the inclined shaft and the layout of the advanced large pipe shed.

3.2. Advance greenhouse construction

After the completion of the first excavation of the horizontal passage and the construction of the upper platform, the construction of the station's Ma Tou Men arch large pipe shed began. The large pipe shed adopts Ø108 × 6mm hot-rolled seamless steel pipes, with L=20m, circumferential spacing of 0.4m, and longitudinal spacing of 15m. It is set at the arch of the station's horsehead gate, with 85 pipes in each ring. The construction guidance of the pipe shed adopts the “I25b guide frame+Ø127 guide pipe” method, with a wall thickness of 6mm and a length of 0.5m. The Ma Tou Gate guide wall adopts two I25b steel frames in the main tunnel of the station as the guide wall for the large pipe shed. The steel frame design diagram is shown in **Figure 4**.

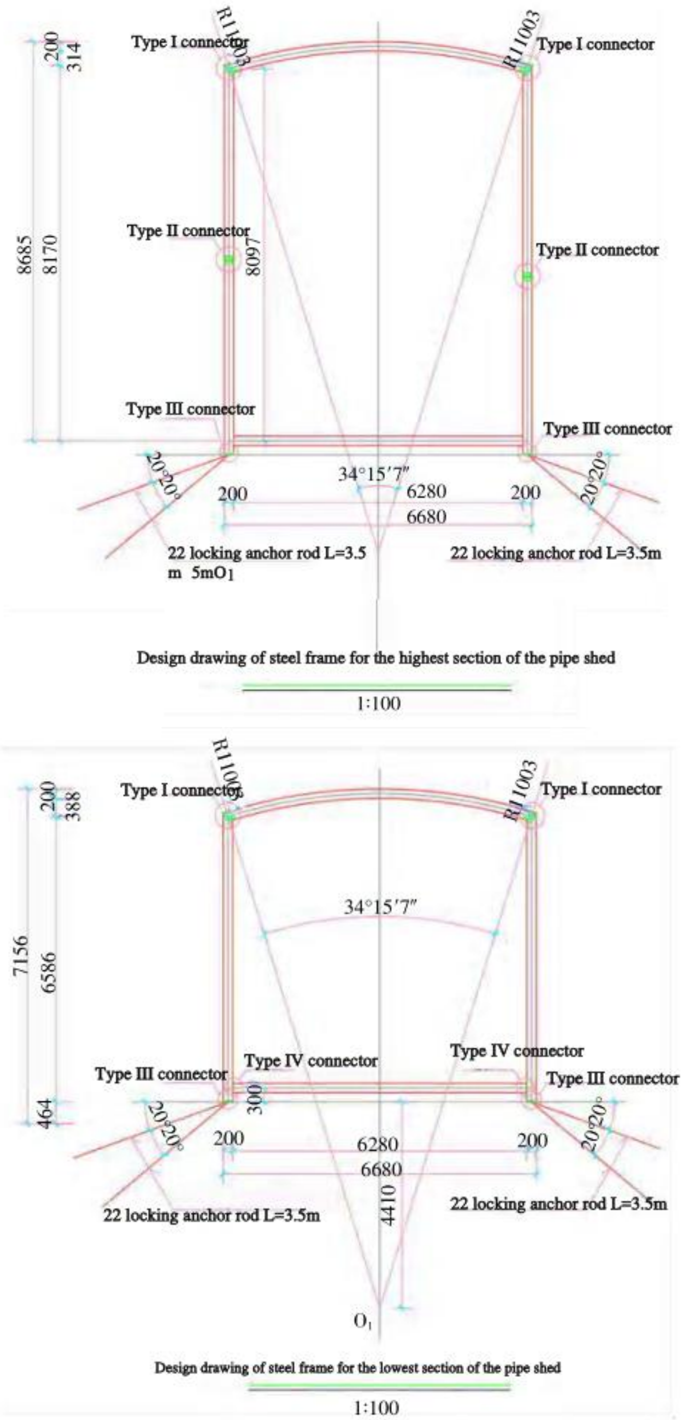


Figure 4. Section of steel frame for pipe shed (unit: cm).

3.2.1. Advanced greenhouse processing

The steel pipes are processed in the steel bar processing center and transported to the site in advance for stacking. According to the design, Ø108 × 6mm seamless steel pipes are used for the pipe shed. To ensure a staggered length of no less than 1m, segmented piping is adopted, numbered odd or even, and installed in a staggered manner, with each section of 1.5m or 3m. And drill holes on the steel pipe with a diameter of 14mm and a spacing of 20cm, arranged in a plum blossom shape. The two sections of the steel pipe are connected by screws, and the length of the screw thread section is greater than 15cm. It must have sufficient strength and stiffness, as shown in **Figures 5 and 6**. A 1m non drilled section is reserved at the head of the steel pipe in the greenhouse as the grout stop section. The opening section of the pipe shed should be welded with a flange to facilitate the installation of the grouting pipe.

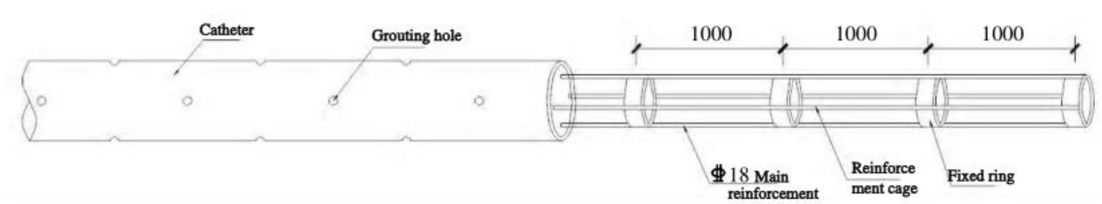


Figure 5. Construction diagram of pipe shed.

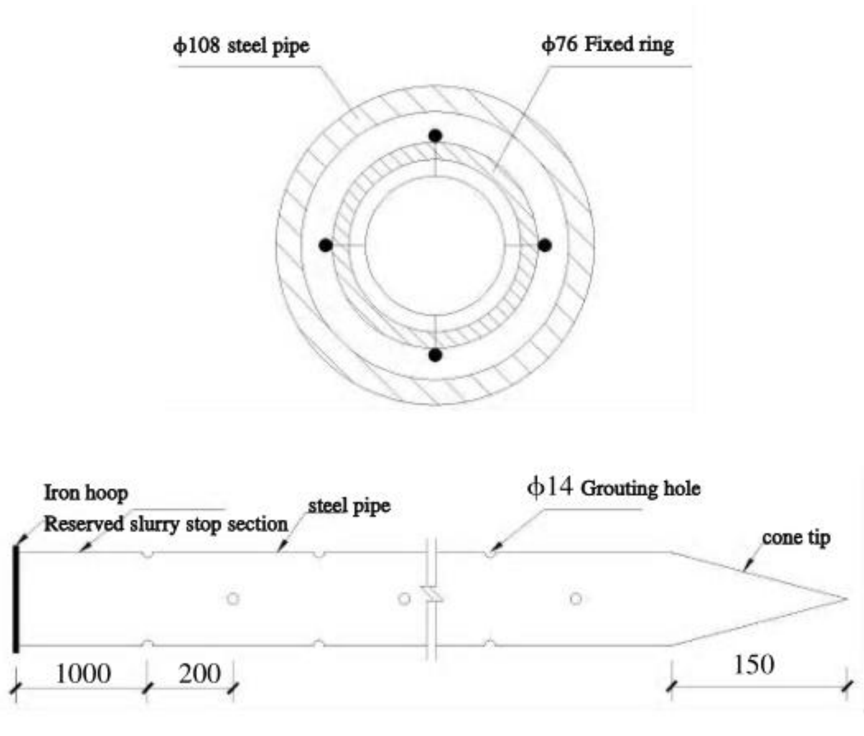


Figure 6. Section and conduit structure of large pipe shed (unit: cm).

(1) The greenhouse unit adopts two types of section lengths of 1.5m and 3m, which are used alternately to ensure that the joints on the same section do not exceed 50%; The units are connected by screws, and the sleeve is still made of 108 steel pipes.

(2) Two plum blossom shaped grouting holes are arranged, with a diameter and spacing of 14mm and 200mm respectively. No drilling is required within a range of 1.0m from the tail of the steel pipe to serve as a grout stop section. The pipe mouth is equipped with a flange and ball valve.

(3) The grouting slurry for the three pipe sheds is pure water slurry, with a water cement ratio of 1:1 to 0.5:1, and should be as dense as possible within the injectable range; The specific parameters such as grouting final pressure should be determined based on the actual geological conditions and through experiments.

(4) Construction error: The allowable horizontal deviation and vertical deviation for drilling should be greater than 50mm and not greater than 100mm (for the front end of the pipe shed, not the hole opening of the pipe shed).

(5) A steel cage consisting of four main bars (Ø18mm) and a fixing ring (76) will be added to the 5 pipe sheds to improve their bending resistance. Short pipe joint fixing rings will be welded to the main bars at a spacing of 1m.

3.2.2. Guided construction

Lay out the structural line of the guide frame on the side wall of the inclined shaft cross passage, and the guide frame directly uses the upper main tunnel arch of the station as the pipe shed guide frame.

According to the layout structure line, two I25b steel frames are erected adjacent to the side wall sprayed with concrete, and longitudinal connecting bars and steel plates are welded.

Install L=0.5m, Ø127 * 6mm guide pipe, adjust the angle of the guide pipe according to the installation of the greenhouse, and weld it firmly with the steel frame. Use a leveling rod and a slope plate to determine the inclination angle of the orifice pipe, and then use the front and back difference method to set its external insertion angle. After determining the inclination angle and external insertion angle, firmly weld it with the I-beam to prevent displacement during shotcrete construction.

C25 shotcrete is used to complete the construction of the guide frame.

3.2.3. Drilling construction

The pipe shed adopts a self-propelled follow-up drilling method, starting from the arch and drilling at intervals from top to bottom. The self-propelled follow-up drilling method is used, and after the steel pipe is pushed in, it is promptly grouted.

Before drilling, the pipe shed drilling rig should be accurately positioned according to the design hole position, and the pipe shed drilling rig should be parallel to the guide steel pipe, with an angle of 2°-3° with the excavation contour line. When positioning the drilling rig, the axis of the drill pipe and the pipe shed should coincide, and the drilling direction should be parallel to the centerline of the inclined shaft. At the same time, considering that after drilling, the drill pipe gradually grows, causing its own weight to sag, and the construction elevation angle should increase by a certain value compared to the design value. Ensure that the power unit, stabilizer, and alloy drill bit are drilled in concentric circles during drilling.

Drilling rig: When drilling, low-speed and low-pressure drilling should be carried out first, and the drilling parameters should be gradually adjusted according to the geological conditions after the drilling depth reaches more than 1m. When encountering weak surrounding rocks or flowing clay, use low-pressure drilling instead. When serious mud flow or geological complex zones occur during drilling and cannot be drilled into holes, grouting should be carried out, and the holes should be scanned and drilled after the surrounding rock solidifies.

During the drilling process: inclination measurement should be carried out three times at 2m after the opening, 1/2 of the hole depth, and the final hole. The inclination measurement of the drilling can be done using a inclinometer. It is also possible to measure and feedback drilling information at any time during drilling to determine whether there is deviation, and adjust parameters in a timely manner based on drilling status to ensure drilling quality. In case of drilling related accidents, timely handling is required.

When the steel pipe needs to be extended, the extended steel pipe also needs to meet the mechanical performance requirements, with adjacent joints staggered by at least 1m and the number of joints on the same section less than 50%.

When drilling, original records should be kept, and geological judgments and descriptions should be made in a timely manner based on the rock debris at the borehole, providing geological reference materials for tunnel excavation.

After drilling is completed, quickly insert the steel cage, weld a flange at the pipe shed hole, and install a grouting pipe valve.

3.2.4. Grouting construction

After drilling, weld a grout stop valve at the end of the pipe and fill the gap between the guide pipe and the pipe shed with mortar. After the mortar solidifies, prepare for grouting. Before grouting, clean the mud inside the hole (which can be washed with high-pressure water), and then proceed with grouting. The grouting slurry adopts cement slurry, with a water cement ratio of W: C=1. The final grouting pressure is proposed to be 1.0 MPa. According to the actual geological conditions and monitoring of grouting during construction, adjust grouting parameters appropriately through experiments. To prevent grouting, steel pipes are installed and grouted immediately after each hole is drilled, and the next hole is constructed. The grouting pipe is equipped with inlet and exhaust holes. When there is slurry flowing out of the exhaust hole, the exhaust hole can be closed and the grouting can be continued. When the grouting pressure reaches the value shown on the construction diagram, the grouting can be stopped.

3.3. Initial support and replacement of the main tunnel

Before opening the Ma Tou Gate in the main tunnel of the station, the initial support and replacement of the main tunnel of the station need to be carried out in the inclined shaft passage. The main tunnel is initially supported and replaced, with one side using unexcavated bedrock as the foundation for the initial steel frame, and the other side adding a steel beam as the foundation for the initial steel frame in the channel (**Figure 7**). The joists are connected to the main tunnel steel frame using M24 * 80 high-strength bolts.

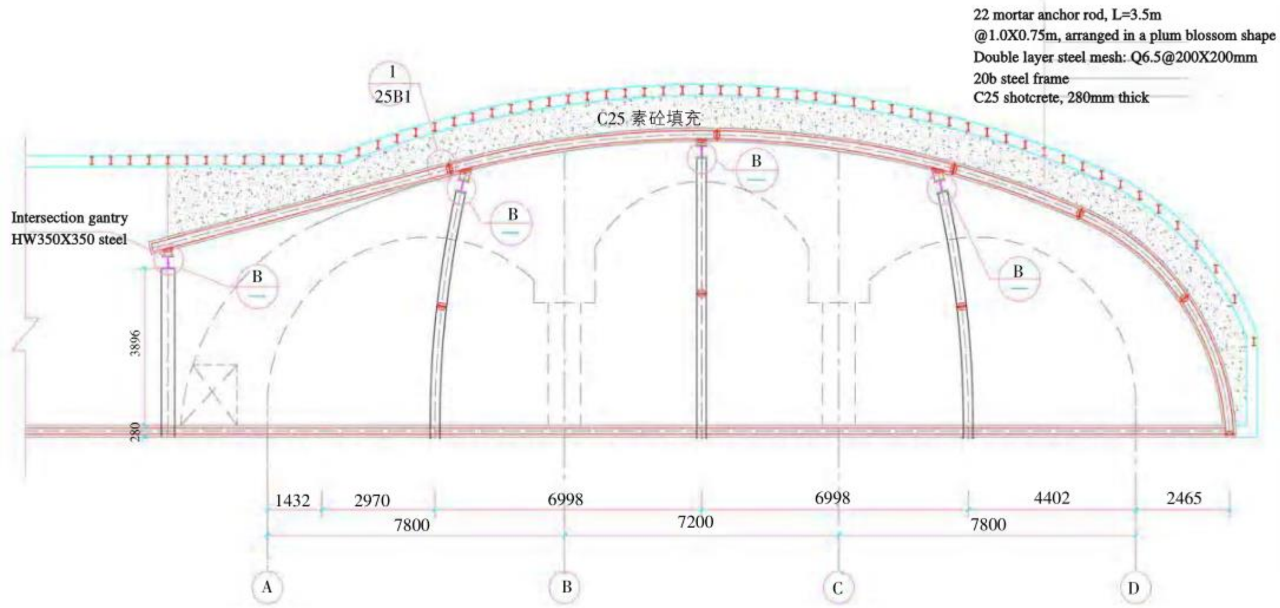


Figure 7. Conversion diagram of main hole steel frame (unit: cm).

3.3.1. Installation of joists

The supporting beam is made of a 10.2m long 350 * 350 * 10 H-shaped steel. Processing will be carried out at the steel structure processing center of the section, and unified delivery will be made to the site. Drill bolt holes on the upper and lower flanges of the H-shaped steel, corresponding to the position of each steel frame in the main hole, to ensure a firm connection with the main hole steel frame. Attach a 25b vertical support to the side wall of the inclined shaft horizontal passage inside the tunnel, and weld the vertical support side by side with the inclined shaft steel frame. Use L=3.5m C22 mortar anchor rods to install on both sides of the steel frame with a vertical spacing of 0.5m, and fix the vertical support of the supporting beam (**Figure 8**).

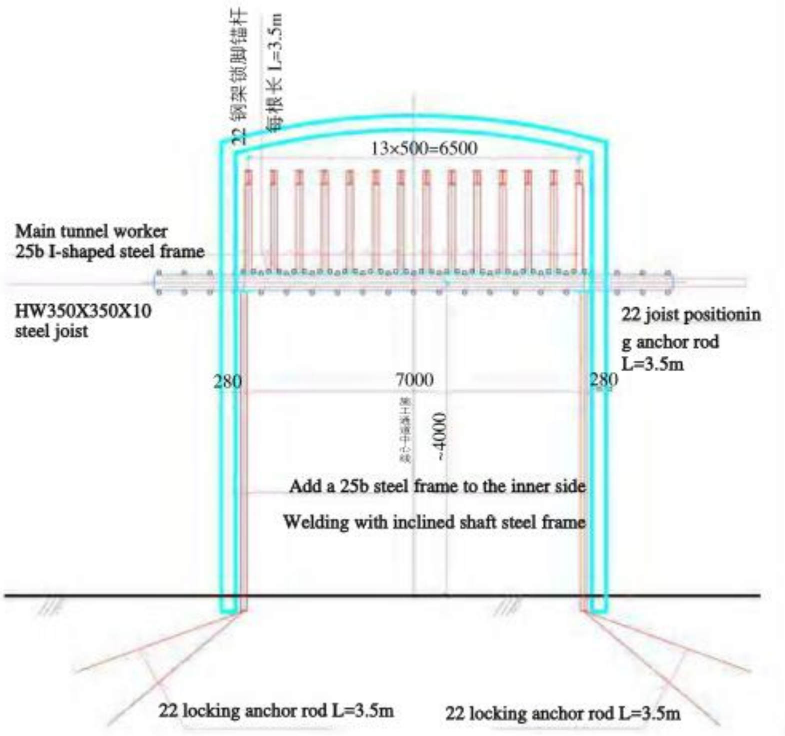
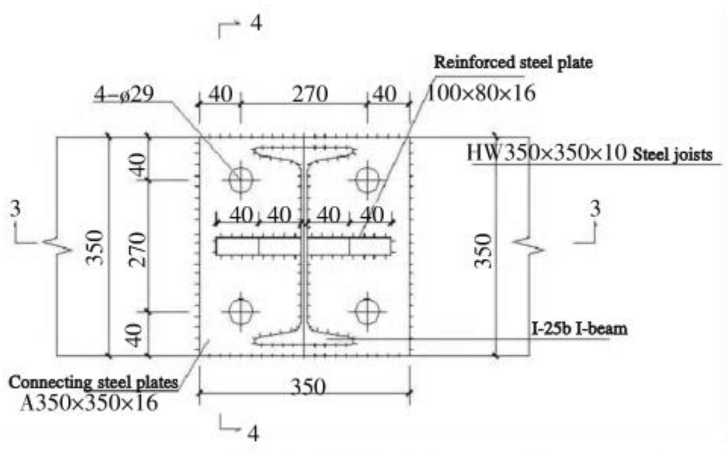


Figure 8. Installation diagram of joists (unit: cm).

Using a pipe shed drilling rig, replace the 350mm diameter drill bit and drill holes with a depth of 2m on the corresponding positions of the supporting beams on both sides of the inclined shaft channel. Install the corresponding position on the supporting beam, embed a chain hoist in the arch crown, lift the steel supporting beam to the corresponding position, and insert it into the hole (**Figure 9**).



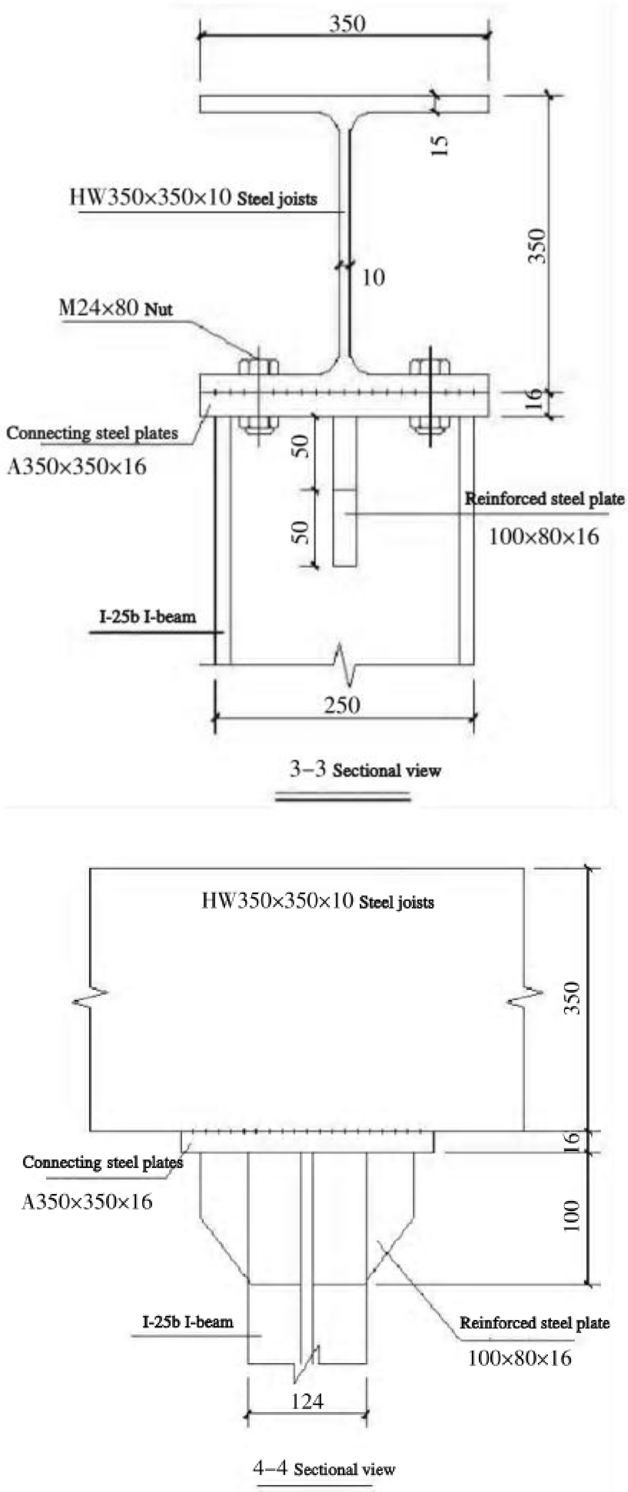


Figure 9. Detailed diagram of beam connection (unit: cm).

3.3.2. Initial support of the main tunnel in the channel

Install 14 steel frames of the station main tunnel one by one, fasten the 14 steel frames of the station main tunnel in the channel onto the support beams, and firmly connect them with the support beams through M24 high-strength bolts. During the process of arching the main arch of the arch, C22 steel bars are used to weld the main arch steel frame firmly with the inclined shaft arch steel frame, and U-shaped clamps are used to weld the steel bars firmly with the section steel. After the installation of 14 steel frames is completed, C25 shotcrete is used to spray the main tunnel steel frames and inclined shaft channel arches of the station in a full and dense manner.

3.3.3. Opening the main tunnel entrance

After the completion of the arch replacement system for the main tunnel of the station, the guide tunnel doors for station 3 # and 4 # will be opened. To avoid the effect of group tunnels, the sequence of tunnel openings is set as the excavation sequence of the 3rd pilot tunnel with small mileage, the 4th pilot tunnel with large mileage, the 4th pilot tunnel with small mileage, and the 3rd pilot tunnel with large mileage. First, remove the initial support of the straight wall on the side channel of the small mileage towards the 3 # guide tunnel. After removing the initial support side wall, quickly erect three main tunnel steel frames to complete the initial support of the main tunnel and supporting beams, reduce the exposure time of surrounding rock, reduce the suspension time of supporting beams, and ensure the safety of the station's initial support arch replacement. Subsequently, excavate the main tunnel one by one, and quickly install the main tunnel steel frame after excavation is completed. According to the above method, sequentially open the 4th pilot tunnel with a large mileage → the 4th pilot tunnel with a small mileage → the 3rd pilot tunnel with a large mileage.

Construction method for breaking down the initial support of the channel: lay out the outer contour line of the excavation guide hole on the right side of the station on the straight wall of the horizontal channel; Erect scaffolding work platform; Manually using air picks to segment and layer by layer remove the sprayed concrete for initial support of the vertical shaft wall; Using vibration free cutting technology to chisel and cut off the steel frame of the section and layer by layer at the opening of the initial support shotcrete.

3.4. Secondary excavation of horizontal channels

Due to the fact that there are only two construction channels in the entire station, in order to facilitate construction, after completing the secondary lining structure system of the station arch cover, it is necessary to lower the elevation of the inclined shaft bottom to about 1.6m below the middle plate, excavate the rock mass within the middle plate range of the station, and construct the middle plate and upper side walls to completely seal the secondary lining structure system of the station arch cover into a loop. The distance between each excavation of the inclined shaft section shall not exceed 2 steel frames. After excavation is completed, the upper steel frame shall be quickly extended and the initial support and closure shall be completed. The cross passage inside the station does not require initial or temporary support, and the excavation of the cross passage inside the station is quickly completed to accelerate subsequent construction.

4. Conclusion

This article relies on the Beijing Road Station of Guiyang Metro Line 3, and proposes a construction technology of inclined shaft entering the main tunnel for roof lifting and replacement under the premise of difficult construction in karst geological areas. Elaborated on the construction plan, construction process, and key construction techniques for the roof transition. The key technologies in the construction of the roof transition can be divided into four main steps: the first excavation of the horizontal passage, the advanced construction of the large pipe shed, the initial support and replacement of the main tunnel, and the second excavation of the horizontal passage. Detailed description of the main process during construction and the design of support. And it has been effectively applied in practical engineering, with high economy, safety, and timeliness. To provide reference and guidance for the construction of inclined shaft roof transition into the main tunnel of large-span and large-section tunnels in karst areas.

References

1. Song Jingui. Research on Design Optimization Scheme for Intersection of Hengdong and Zhengdong [J]. Tunnel Construction, 2017, 37 (S1): 168-73
2. Zhang Xuewen, Wang Meng, Zhao Xupeng. Construction technology for the main tunnel of No. 3 inclined shaft of Taoshuping Tunnel [J]. Tunnel Construction, 2011, 31 (06): 728-32
3. Yuan Zhe, Li Qingguang, Lu Guang. Key Technologies for Topping Construction of Extra Large Section Tunnels [J]. Highway, 2017, 62 (09): 49-52
4. Xiong Xiaohui. Research on the Double Support Caving Technology of Large Span Tunnel with Squeezing Surrounding Rock [J]. Railway Construction Technology, 2017 (05): 68-72
5. Xue Ping, Wang Changshuai. Key technology for the construction of the inclined shaft of a water conveyance tunnel entering the main tunnel roof [J]. Modern Tunnel Technology, 2019, 56 (S2): 688-692
6. Liu Yi, Zhang Yong, Peng Zhen, et al. Key Technologies for Vertical Jacking Construction of Large Span Subway Tunnel with Oblique Shaft Entry [J]. Modern Tunnel Technology, 2020, 57 (04): 201-207
7. Liu Yi, He Zuhao, Wang Zhimin, et al. Research on Tunnel Topping Construction Technology under Broken Surrounding Rock Conditions [J]. Modern Tunnel Technology, 2020, 57 (06): 200-206
8. Zeng Yi, Wu Gang, Bian Yuewei, et al. Exploration of Excavation Technology for Construction Channels of Ultra Shallow Buried and Large Span Underground Excavated Stations in Rail Transit [J]. Tunnel and Rail Transit, 2019 (04): 13-7, 57
9. Zhang Hongda. Construction technology of upper connecting tunnel and gantry method for auxiliary tunnels in weak strata entering the main tunnel [J]. Tunnel Construction (Chinese and English), 2021, 41 (12): 2150-2156
10. Li Ming. Rapid Jacking Technology for Large Equipment in the No.1 inclined shaft of Hengling Tunnel [J]. Urban Road and Bridge and Flood Control, 2018 (08): 256-258, 27-28
11. Yu Jiawu, Long Wenhua, Guo Xinxin, et al. Application of pre-stressed anchor cable support technology in the construction of high-altitude stress large-span tunnels - Taking the Muzhailing Tunnel on the Weiwu Expressway as an example [J]. Tunnel Construction (Chinese and English), 2021, 41 (08): 1392-1398