Research on the Key Technologies in the Underground engineering Co-built by Cross-river Highway Tunnel and Large-scale Interchange Subway Station

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Abstract

This paper relies on Xujiapeng subway station, which is on Wuhan metro Line 7. The four key technologies in difficult underground engineering were investigated by theoretical analysis, numerical simulation and field test, respectively. A series of innovative researches have been made in the areas of station structural scheme selection, transfer structure scheme research, construction methods and special covered top-down excavation construction procedures, and ultra-deep diaphragm wall panel trench joint anti-seepage.

Keywords

Force transfer structure,two-point mechanical positioning method,RJP method.

1. Introduction

Wuhan Metro Line 7 is a completely underground subway line and it goes through the Yangtze River from the Sanyang Road Station to the Xujiapeng Station. Tunnel near Xujiangpeng Station is the intersection of highway tunnel and subway station, which enhances the design and construction difficulty. The upper part of the tunnel is highway lanes for car traffic and the lower part is tracks for the subway. Xujiapeng Station is the first underground project for large-scale subway stations and cross-river highway tunnels in China. It integrates commence, highway tunnels, and a large-scale interchange subway hub. The total length of the station is 264.36m, the width is from 25.3m to 78.15m. The depth of the foundation pit at the station center is 38.36m, which is the deepest open-cut metro station in China. The pit area of the station is 15000m2. For the large scale and multiple functions, the engineering is challenged in construction.

Fig. 1 Cross-river tunnel plan

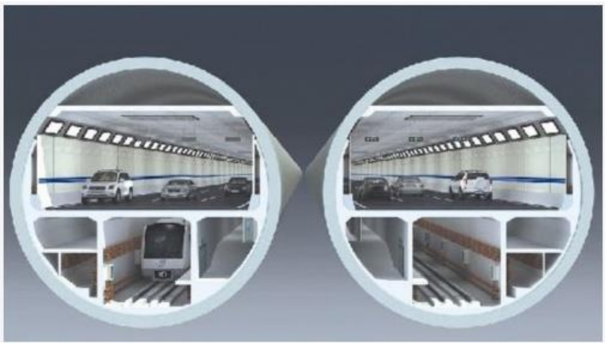

Fig. 2 Cross-section of the Crossing Tunnel

2. Engineering geology and hydrogeology

Xujiapeng subway station is only 800m away from the Yangtze River. The site geomorphology unit is a river accumulation plain and belongs to the Class I terrace of the Yangtze River. The surface of the site is a loose artificial backfill layer (Q^{ml}) with silt soil distributed locally, thickness 2 ~ 4m. The upper part of the Quaternary Holocene alluvial phase (q_4^{al}) is the clay with soft ~ plastic state, thickness 13 ~ 15m. The middle is fine sand with slightly dense ~ medium density, thickness of about 40m. The volcanic bedrock is chalky to sandstone and conglomerate in the East Lake Group (KE) of the Cretaceous to Lower Tertiary.

The groundwater of this station is divided into the upper layer of stagnant water, pore confined water and bedrock fissure water. The pore confined water mainly maintains in sandy soil. The overlying cohesive soil and the underlying bedrock are relative water-repellent layers. The thickness of the aquifer is about 40m. It mainly receives the recharge of lateral groundwater and has a close relationship of the Yangtze River, which means the abundant water in this area. The suggested design parameters for geotechnical and mechanical characteristic of rock and soil can be seen in Table 1.

Table 1 Rock and Soil Physical and Mechanical Parameters (Design Suggested Value)

Layer number	Name of soil	Naturally heavy γ (kN/m³)	Permeability coefficient K (cm/s)	Pile foundation parameters		Foundation pit support parameters			Bed coefficient	
				Pile side bearing capacity characteristic value (kPa)	Pile bearing capacity characteristic value (kPa)	Stress index		Static side pressure coefficient *Ko*	Vertical K_v (MPa/m)	Horizontal K_h (MPa/m)
						Cohesion *C*(kPa)	Friction angle *φ*(°)			
(1-1)	Miscellaneous filling	18.3	5.0×10-3	—	—	8	18	—	—	—
(3-1a)	Silty clay	18.6	4.3×10-7	20	—	18	9	0.60	10	12
(3-3)	Silty clay	18.1	7.8×10-7	10	—	12	6	0.65	7	8
(3-4)	Silty clay sandwich silt	18.6	7.9×10-7	21	—	15	10	0.58	10	12
(3-5)	Clay, silt, silt interbed	18.3	1.0×10-3	22	—	16	14	0.50	16	18
(4-1b)	Fine sand sandwich silt,clay	19.0	0.8×10-2	20	—	3	28(30)	0.47	22	25
(4-1)	Fine sand	19.2	1.0×10-2	24	—	0	30(32)	0.42	28	30
(4-2)	Fine sand	19.3	1.5×10-2	28	—	0	33	0.38	23	35
(4-3)	Fine sand	19.5	2.7×10-2	32	550	0	35	0.36	35	38
(15a-1)	Strong weathered mudstone	22.0	—	35	650	50	18	—	—	—
(15a-2)	Medium weathered mudstone	24.0	—	80	1400	100	28	—	—	—

The station ditch is so deep and large, that saturated fine sand becomes the difficult and key point in design and construction.

3. Structural solutions

This station is the intersection of subway station and road tunnel. Affected by the road tunnel and the Yangtze River, the burial depth of the station has to be very large. The structure of the station is an underground four-story reinforced concrete box frame. The first underground floor is built for commerce. The second underground floor is the road tunnel layer. The third underground floor is the subway station hall and equipment room. And the forth underground floor is the subway station platform. The vertical section of the station is shown in Figure 3.

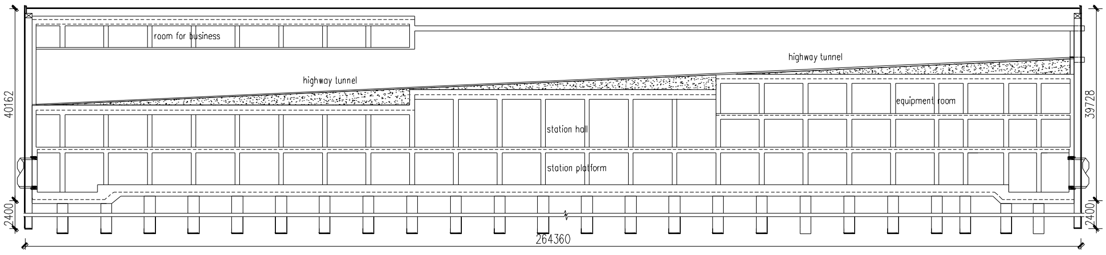

Figure 3 Vertical section of the station (unit: mm)

Because the arrangement of station room and road tunnel, the vertical structural forms of the first underground floor have obvious variance with the second one. The same difficulty also occurs between the second underground floor and the third one. There are two schemes in this paper to solve this discontinuity in vertical direction. And the vertical structures in this station is transformed two times safely and effectively The schemes are as follows:

Firstly, for the first and second underground floor, the vertical reinforced concrete columns of the first underground floor are exactly set above the reinforced concrete wall of the second underground floor, which can transmit stresses continuously. Secondly, some transformed structural storeys are used to keep the stress channel, since there is impossible to transmit stresses continuously by adjusting the structural layout. Transfer beams are widely used in buildings on the ground, but it's not applicable here for the densely pipelines along the station. We tried transformation floor to solve the problem. Long-span carriageway board (transformation floor) is one of the main form to realize the transformation. The transformation floor is 1 m thick. After the detailed design and finite element analysis, its static characteristics and dynamic seismic performances meet the actual needs of the project very well. In this project, we concluded that transformation floor can be good use in underground engineer despite its disadvantages while using in high buildings on the ground.

4. Construction methods and support plans

The excavation of this station is extremely difficult since its sizes are deep and large, and with poor geological conditions and abundant groundwater. The method of covered top-down excavation is adopted in Xujiapeng station to keep the safety of the surrounding buildings and the foundation, protect the environment, save project investment and meet the construction period requirements.. The covered top-down excavation method, which uses the structural floor of each layer as the horizontal support system, can control the deformation of the surrounding environment to the maximum extent to ensure the safety of the project and the surrounding environment. After the ceiling floor is completed, it can be used as construction land to restore traffic and relieve traffic pressure. At the same time, a large amount of concrete support, temporary pillars and pile foundations required for open-pit construction are reduced.

The supporting scheme is shown in Figure 5:

(1) The enclosing structure adopts a 1500 mm thick diaphragm wall panel trench. The diaphragm wall panel trench and the side wall of the station form a “superimposed wall” structure to bear the load together. (2) The beams and floors of the station are used as the horizontal support system duringexcavation. The construction process requires a certain number of temporary holes on the top floor for unearthing. (3) The permanent columns of the structures are used as the temporary horizontal support column at the construction stage.

The vertical structure of the station needs to transfer the vertical load between the frame and the box structure type. This new type of structure adopts covered top-down excavation method construction, which is both a difficult point in engineering design and construction as well as a new breakthrough for the method. This project solves this problem through a new construction method. Firstly, each layers of beam-plate structure and side walls are built from top to bottom with the support of concrete-filled steel tubular column, and a vertical direction force frame is forming. Then the vertical columns of underground second and first floor are constructed from the bottom to the top. Finally, the steel pipe columns in the first and second underground floor are cut off. We named the new method "reverse-forward-demolish ".

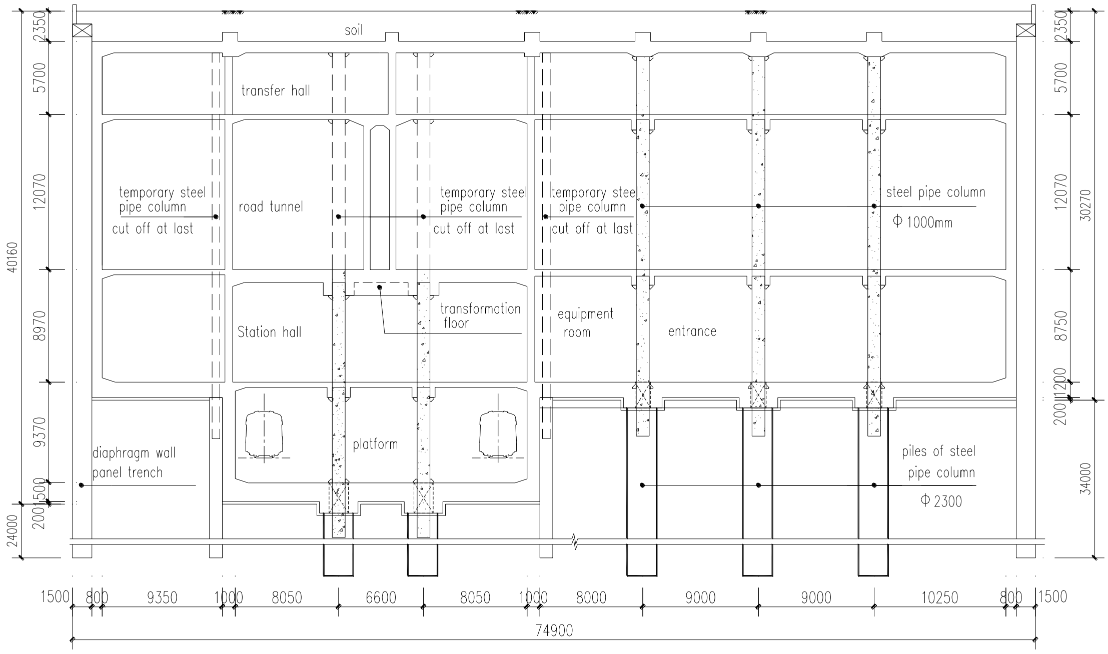

Figure 4 Cross section of the station (unit: mm)

5. Ultra deep diaphragm wall panel trench joint sealing and seepage prevention scheme

In order to effectively control the differential settlement between the diaphragm wall panel trench and the steel pipe column pile foundation, and the groundwater seepage stability (especially the inrush stability of confined water), the diaphragm wall panel trench around the station pit is inserted 1m into the medium weathered rock . Pressure grouting is used to reinforce the wall toe dregs. The internal and external hydraulic connections of the foundation pit are completely cut off to form a reliable falling-type waterproof curtain. The pit of the station is deep and huge. There is a 40m-thick saturated fine sand in the ground. The groundwater is abundant and the construction period is longer. As a result, The quality of water-stopping and impervious joints of the wall-to-wall seam directly decides the success of the project.

In order to effectively control the seepage at the wall joints, three Φ850@500 three-pipe rotary jet grouting piles are constructed on the outside of the wall joints in tradition. However, The depth of excavation in this station is about 56m, the conventional three-pipe high-pressure rotary jet grouting piles cannot meet the engineering design requirements. Therefore, it is required to adopt the "double high pressure" process of three-pipe jet grouting piles which called "RJP". The special of "RJP" is that the upper and lower jet injectors are equipped with high pressure water taps and high pressure jet nozzles, respectively. The cement slurry is also used on the basis of high pressure water flow and gas flow for the first time high pressure (above 20 MPa) jet impact crushing soil. Ultrahigh-pressure injection (above 40MPa) is used to expanded and impacted and crushed soil for the second time, thus the formed high-pressure jet has a larger jet energy, and has a stronger crushing effect on the soil, forming a larger diameter and a greater depth pile. The piles of "RJP" can fit the diaphragm wall panel trench pretty well and cut off all the water seepage path of the wall joints to ensure the safety of the project.

6. Steel Pipe Concrete Column Construction Plan

The vertical support system (the concrete-filled steel tubular columns) and its pile foundations are the core techniques in the special covered top-down excavation method. How to install concrete-filled steel tubular columns on the ground and ensure the installation accuracy and load-bearing capacity have become key issues in design and construction. There are fourmethods for the installation of concrete-filled steel tubular columns at home and abroad for the similar engineering project are as follows: 1) The steel pipe columns are lifted on the ground. Airbag method or mechanical adjustment method is used to adjust the vertical drop; 2) Large-diameter steel casings (from the ground to the pile bottom) are buried. Manually install locator, and then lift the steel pipe columns; 3) Manual digging piles and installing steel column locator; 4) HPE hydraulic vertical steel pipe plugging method.

Method 1 has poor construction accuracy and cannot meet the installation accuracy requirements for the ultra-long permanent steel tube concrete column. Method 2 requires a large number of large-diameter steel tubes, and the recovery rate is low. It needs to be manually lowered to the bottom of the foundation pit to install the locator. The investment and risk is high. Method 3 is not suitable at the station site for the abundant water. As for method 4, the equipment is advanced and the construction is convenient with high precision, low risk and high efficiency. However, but the construction equipment is in a domestic monopoly and the positioning costs is high.

Through research, a new method named "two-point mechanical positioning method" is invented and creatively used for lifting and positioning the ultra-long large-diameter concrete-filled steel tube column in this project. Two points are different between the new method and traditional method. The first point, the method use two locators at the top and bottom respectively instead of one locator. The second point, the new method uses more powerful and lager stiffness jack to lift the steel pipe. The method enhance the precision of steel tube concrete lifting to 1/1000H, while greatly reducing the investment in the project and improve work efficiency. Compared with the method 2, 2864 tons of steel can be saved. Compared with the method 4, 12.96 million yuan is saved for the cost of advanced machinery and equipment.

7. Conclusion

(1) The underground four-story, second-stress-conversion special structure type which co-built by cross-river highway tunnel and large-scale interchange subway station is the first underground engineering in world wide.

(2) Creatively adopting the new engineering construction method called "reverse-forward-demolish ", effectively solves the problem of the special covered top-down excavation construction and stress transmission .

(3) This paper developed a "two-point mechanical positioning method" for uplifting ultra-deep and large-diameter concrete-filled steel tubular columns and improved the accuracy to 1/1000H, while reduceing project investment and improving ergonomics.

(4) Under the condition of high water head, strong penetration, and deep foundation pit, the RJP method was successfully used for the first time to solve water Leakage problem of diaphragm wall panel trench joint.

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