Research on Construction Technology of New Type Waterproof Formwork Support System for Metro Station

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Abstract. The leakage water of metro station is an annoying problem, so the quality of concrete construction is the node which is very concerned. This paper combined a new type of induced joint and takes Qingpu station engineering of Shanghai metro line 17 as the background, intends to design and manufacture one special formwork support as a part of waterproof system, which can make the structure of floor and side wall separately constructed. The formwork support is composed by the button steel bracket, the triangle frame of side wall and the combined large steel mould. And through the analysis of three-dimensional finite element simulation, puts forward the new method of combined scheme of induced joint construction.

Key words. Metro station, Waterproof, induced joint, Formwork support, Construction technology

1. Introduction

When the subway stations are constructed in the soft clays, such like Shanghai, the induced joints are often located along the longitudinal direction in subway stations[1][6]. Which is a kind of artificial control technology, through the "cracks" set in the desired positions of station structures to release the longitudinal stress, but by setting the induced joint method to reduce structural stress, because of construction reasons, there will be leakage water through these induced joint. The paper takes Qingpu station engineering of Shanghai metro line 17 as the background, which takes a new type of induced joint sealing material-combined inducing joint[7]. On the basis of not increasing the number of conventional induced joints, in addition to releasing the longitudinal stress of concrete structure, it can effectively reduce the leakage of wall cracks.

Figure 1 shows the new type of induced joint sealing material, which can not only be set in the specified location, but also can ensure the sealing of the part and anti rust. The construction method only needs to tie the knot wire to fix on the steel bar, does not need specialized skills. Compare with previous induced joint, this new type of combined induced joint need not to break the steels, which plays a decisive role to waterproof from the structural style.
How to cooperate with the new type of induced joint pouring underground continuous wall mass concrete is an urgent problem to be solved [8] [9]. In this paper, through optimization design, puts forward a optimized model for inducing joint of formwork support system - plate type steel bracket, side wall and triangular steel frame combined steel formwork. Through the analysis of three-dimensional finite element simulation, presenting a feasible scheme which is for the construction program of the new type of induced crack. Through the application in Qingpu underground station to achieve good results.

2. Project Summary
The length of Shanghai metro line 17 Qingpu station is about 165m, which is the Island Station and has two layers. The main body of the station is 800mm thick wall enclosure, the depth is 28~32.0m, the excavation depth is 15.8~17.8m. The main structure of the station is divided into seven sections, which are set four construction joints, two conventional induced joints, as shown in Fig. 2.

The side wall and the plate are separately concrete constructed. Each section of the structure is constructed by 5 times. The continuous walls and lining walls are composite structures, the beam slab and side wall concrete are C35 grade, and the durability of the concrete is P8. In the construction process of diaphragm wall, take 24m as one standard section. Set four new induced joints by optimization design, unlike conventional induced joints, the steels at the induced joints need not be broken. The cracks are induced at the new joints by setting up new induced joints, which are formed the weak links. For this reason, especially the concrete construction near the new induced joints, the concrete pouring and molding need to be strictly controlled.

3. Composition analysis of large formwork system

3.1. Formwork support system features
According to the characteristics of this project, the formwork support system can be divided into two types. One is taking middle plate and the top plate [10]. The technology is adopting fastener steel tube and full hall scaffold support. The other one is the lining template [11], adopting large steel formwork system which is composed of steel formwork and supporting truss. The retaining wall is an underground continuous wall and is connected with the inner wall. Plate, beam, lining wall and column are constructed from bottom to top, taking steel pipe fastener scaffold support system.

The concrete pouring height of the large formwork is 4200mm. The part of lining wall more than 4200mm is constructed by double support brackets with the top plate simultaneously. The lower part of
the lining wall adopts the large formwork, and the upper part adopts the form of the double support bracket.

3.2. Foundation
The structure of the station adopts the method of open excavation and bottom-to-up construction, the steel pipe fastener scaffold, and the whole full framing is arranged on the completed structural board without foundation treatment.

3.3. Engineering features and difficulties analysis
This project takes the construction period into account, quality, safety and contract requirements, so in the choice of programs, should take full account of the following points:
1. The structure of the frame design should strive to achieve safe and reliable structure, and takes economic and reasonable cost in simultaneous consideration.
2. In the specified conditions and service life period, the structure can fully meet the expected safety and durability.
3. The selection of materials should strive to achieve common, circulation utilization, maintenance.
4. The selection of structure should have the advantages of clear mechanical behavior and convenient construction. In addition, the construction of the lining wall and columns take large form templates, which should consider the state of the large formwork and construction steps to ensure safety and reliability. The construction joints and the new type of induced joints should be taking special measures, so as to make the waterproof measures.

The main station is two layers of underground structure, the pit excavation method is bottom-to-top, approximately 165m in length, each plate thickness respectively from the roof of the bottom plate are 800mm, 400mm and 900mm/1000mm (end wall), clearance are respectively 4260mm and 6370mm/8070mm(end well), the thickness of standard section of inner wall and end wall respectively are 400mm, 600mm. Due to the shape of the pit is long rectangular structure, the excavation of the pit is divided into eight sections, including the six standard sections and the East and West end walls. The structural plate formwork bracket is made of steel pipe fastener scaffold with full support erection and the lining wall template is assembled with the large steel mould.

Table 1. Main structural dimensions of station.

| No. | Structural units       | Size(m)     |
|-----|------------------------|-------------|
| 1   | roof                   | 0.8         |
| 2   | End tip                | 0.9×1.8     |
| 3   | Standard section       | 0.8×1.6     |
| 4   | Interlayer             | 0.4(0.6×0.9) |
| 5   | floor                  | 0.9/1(1×2.26)|
| 6   | Inner wall             | 0.4         |
| 7   | stele                  | 0.55×1.1, 0.6×1 |
| 8   | Plain concrete cushion | 0.2         |

4. Formwork support scheme

4.1. Support scheme design
The width of each side wall of the station is 2m, the thickness of the panel is 6mm, the inner lining adopts No.10 channel steel, and the edge plate adopts 8mm steel plate. The main frame template of large formwork adopts No.16 channel steel, the truss web adopts No.10 channel steel, the scaffold bracket adopts No. 8 channel steels. Steels are all adopted Q235. Each large formwork is set three brackets. The top of the large formwork bracket is fixed by M14 counter bolt. The bottom left corner is fixed by the anchor bolt in the bottom plate, and the anchor bolt is made of HRB400 steel with a diameter of 32mm.
The lower right corner is supported by an adjustable support frame, as shown in Fig. 3.

Figure 3. The large formwork support

4.2. Finite element model

According to the design scheme of the large formwork, the finite element model is established by the software of Midas GTS, and the overall model and constraint conditions are shown in Fig. 4.

The template is calculated according to the smaller value of corresponding formula in relevant standard [11], takes $F=40.6 \text{ kN/m}^2$ as the model load of template side pressure standard value, the layout is shown in Fig. 5.

Figure 4. Finite element model of 24m station

Figure 5. Model loading
4.3. Calculation results analysis

![Deformation](image1) ![Stress](image2)

**Figure 6.** Formwork system analysis

![Support stress](image3) ![Anchor bolt counterforce](image4)

**Figure 7.** Support system analysis

The largest deformation of template is 1.4mm as shown in Figure (a), meets the requirement of deformation. The maximum stress of template is 82.3MPa as shown in Figure (b), meets the requirement of strength. The maximum stress of support is 76.9MPa as shown in Figure (a), meets the requirement of strength. The counter-force of each anchor bolt is 272.5kN as shown in Figure (b). The three grade steel C32 is used as ground anchor, and the stress is about $272.5 \times 1000/804.2 = 338.8 \text{MPa} < 360 \text{MPa}$, which meets the requirement of strength. The design scheme meets the requirements of deformation and strength.

According to the results of checking calculation, the load of ground anchor is large, close to the limit value. So as to ensure the stability of the truss, the foot of the truss is embedded M14 counter bolt, the bolt angle and surface at an angle of 30 degrees, which is perpendicular to the longitudinal truss bevel, spacing 600mm, fixed angle. Detail chart as shown in Figure 8.

![Detail of foot bolts embedded in medium plate](image5) ![Detail of foot bolts embedded in bottom plate](image6)

**Figure 8.** Bolt analysis
4.4. Web member checking of ground anchor

According to the design scheme of the formwork support, the length of the anchor bolt in the lower left corner is about 0.8m. Section 16 adopts double channel steel. The design value of the axial force in the lower left corner of the web is 78.1kN.m, and the counter design value of the anchor bolt is 272.5kN. According to the calculation of both ends of the consolidation, the bending moment of the middle span is PL/8=27.3kN.m, and the shear force is P/2=136.3kN. The belly bar also meets the strength requirements (Figure 9).

![Figure 9. Web member checking](image)

5. Composition of formwork systems

According to the large formwork design and the results of the finite element analysis, the internal force and deformation of the side formwork support system. Finally, the following material structure is determined.

The side mould system is composed of the panel and the support system. The width of the panel is 2m, the thickness of the panel is 6mm, the inner channel is No.10 channel steel, and the edge plate is 12mm steel plate.

The longitudinal position of the panel is positioned by locating pin on the frame and is connected with the bolt arranged at the waist hole, as shown in Fig. 10(a). The side formwork support system is composed of triangular truss system and an angle movable cushion block. The main frame template of large support is No.16 channel steel, web member adopts No.10 channel steel, the scaffold support adopts No.8 channel steel. Steel are all Q235. Each large formwork is set with three supports.

Single pouring height of large formwork by concrete is 4.2m; single formwork is 2.1×2m, two vertical assemblies, the height of truss is 4.6m, as shown in Fig. 10 (b). The large formwork is fixed by the pre-buried steels in bottom wall lining and the bottom angle fixing style. The pre-buried anchor steel bars are third level grade HRB400 steel, and the space between anchor bolts and each truss is matched. The length of reinforcement anchorage is not less than 32D, about 1m.

![Figure 10. Detail of steel formwork fixation](image)

(a) Detail of steel foot fixation  
(b) Detail of medium steel foot fixation
6. Conclusion
Combined with the principle of new induced joint, developing an important step-the corresponding formwork support system, and the waterproof system is applied for the first time in the Shanghai metro line 17 Qingpu subway station project. Combining with the detailed scientific theory and finite element analysis, the paper proposes a new feasible scheme which is suitable to the new type of induced joint formwork support construction. At the same time achieving the aim of improving the appearance quality of the side wall, effectively reducing the side wall leakage, improving the construction efficiency and the stability and reliability of the structure. Finally, the scheme provides a reference for the application of the new type of induced joint and formwork support system in other projects.

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