Discussion On Prefabricated Assembly Plan Of Subway Underground Station

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Abstract: Prefabricated assembly technology has become an important direction for the development of subway underground stations. Comprehensively considering the three factors of stress, waterproof and construction environment, this paper proposes a set of prefabricated and cast-in-place assembly plans for subway stations. On the premise of ensuring that the overall stress form of subway station frame does not change significantly, the detailed prefabricated joint structure is designed, which effectively solves the waterproof problem of underground structure. The combination of permanent column and temporary column is realized, the investment of formwork support is reduced, and the assembly construction process of subway station is greatly simplified.

1. Introduction
As an efficient mode of transportation, urban rail transit has been developed by leaps and bounds with the acceleration of Chinese process and the expansion of urban scale. At present, Urban subway construction, especially underground station construction, has a great negative impact on urban traffic, environment and people's travel. A new construction technology is needed to solve these problems. In the new construction cycle, we should abandon the traditional extensive construction mode, and adopt prefabricated concrete or steel structures with high degree of assembly to reduce construction time and impact on urban roads and environment, so as to improve the level of urban infrastructure construction and management.

Prefabricated structure is widely used in civil residential construction, and gradually established a more mature prefabricated structure system, which has become an important way of building industrialization[1-2]. However, the research and application of prefabricated construction technology for large underground structures, especially for underground subway stations, are less. Therefore, it is necessary to study the prefabrication and assembly of subway station, which has important practical significance to improve the application and promotion of assembly technology in the field of subway station.

Using the basic principle of single arch structure, Russia innovatively applies prefabricated technology to underground subway stations. The Olympic Station, the first subway double-floor transfer hub built in Russia, is a fabricated single arch structure, as shown in Figure 1 [3]. The roof and
floor of the station are arched structure, which can produce large lateral force to balance the water and soil pressure on both sides. Minsk metro station in Belarus adopts arched prefabricated structure, as shown in Figure 2[^4]. The external section of the station is assembled by six prefabricated members, and the joints at the top and bottom and the cast-in-place section of the side wall are connected by post pouring concrete. Yuanjiadian station of Changchun Metro Line 2 is an open cut station supported by pile anchor structure. The main bearing structure is composed of 7 prefabricated components with a ring width of 2m. The "mortise grouting joint" is adopted between circumferential and longitudinal components, as shown in Figure 3[^5]. However, the applicability of these prefabricated station schemes to the most common internal supporting foundation pit is limited.

[^4]: Figure 1. Russia double deck transfer hub Olympic Station

[^5]: Figure 2. Open cut prefabricated station of Minsk Metro

[^6]: Figure 3. Structure of prefabricated station of Changchun Metro Line 2
2. Characteristics analysis of prefabricated Metro Station

2.1. Mechanical characteristics

Usually, the foundation of the overground building is embedded in the subsoil, and its upper structure is cantilever above the ground. The structure mainly bears vertical load, wind load and seismic force. Under the wind load and seismic force, the building structure will produce large horizontal displacement and vibration effect.

However, the environment and stress mechanism of underground structures are quite different. In addition to the structural weight, crowd and equipment load, the main load of subway station is the water and soil pressure in the peripheral circle, but it is also constrained by the stratum. The subway station needs to carry out seismic checking calculation at the same time. Under the seismic action, the station structure will vibrate and deform synchronously under the wrapping of soil, which is mainly reflected in the movement characteristics of foundation soil, rather than the natural vibration characteristics of the structure itself.

For prefabricated underground station, the key technology is to select stable structural system, analyze the mechanical behavior of structural system, select appropriate connection form and master the bearing characteristics of joints.

2.2. Waterproof characteristics

Underground stations are inevitably invaded by groundwater because they are buried under the ground. A large number of practical subway station projects show that water seepage often occurs in cast-in-place concrete structures due to improper treatment of structural joints or nonstandard construction. With the application of assembly technology in subway station, due to the joints between the prefabricated components, there are a lot of hidden dangers of water seepage in subway station, especially for subway station, which is a Centennial project.

How to effectively solve the waterproof problem of prefabricated underground station, the key is to choose a reasonable waterproof system, on the basis of local waterproof strengthening measures, make full use of the self-waterproof performance of concrete.

2.3. Characteristics of construction environment

Considering the construction environment of underground subway station, its construction technology is bound to be restricted by the soil excavation method. Even if the open cut method is adopted, the station construction technology is closely related to the form of support structure. For example, the pile anchor support structure can form an open construction environment, and large prefabricated components can be used for lifting and assembling. The multi internal support structure will greatly limit the size of prefabricated components, and also affect the hoisting mode and construction accuracy of components.

3. Prefabricated assembly scheme of subway station

The most common underground station (non transfer station) in China is usually an underground two-story Island Station, and its structural form is usually a two span or three span frame structure[6], as shown in Figure 4.

![Figure 4. common Island station forms](image)

Taking the underground two-story Island Station in the form of two span frame structure as an example, the distribution pattern of the typical supporting structure of foundation pit and main
The structure of the station is shown in Figure 5. The main structure of the current station usually adopts the cast-in-place concrete form, while the air duct on the top of the rail and the platform plate are cast-in-place after the completion of the station frame.

Figure 5. Supporting structure and main structure form of common Island Station

Combined with the construction method and site construction environment of subway station, fully considering its bearing characteristics and waterproof performance, and referring to the successful experience of assembly of aboveground buildings, the assembly technology is applied to the structure of subway station to meet the waterproof requirements of long-term "immersion" in underground water and the bearing capacity requirements of 100 year service life. Based on the existing subway station construction technology, the combination scheme of "prefabrication + cast-in-place" is proposed[7]. On the basis of convenient on-site construction, the prefabrication rate is increased as far as possible, the investment of formwork and construction scaffold is reduced, and the construction period is shortened. The specific assembly scheme is shown in Figure 6.

Figure 6. "prefabrication + cast in place" combined assembly scheme of common Island Station
The "cast-in-place + prefabricated" scheme of typical subway stations is mainly used in the following aspects:

(1) According to the national industry standard technical specification for prefabricated concrete structures (JGJ1-2014), "under various design conditions, the assembled integral structure can adopt the same method as cast-in-place concrete structure for structural analysis". On the basis of meeting the ultimate bearing capacity, changing some cast-in-place components of the frame structure into prefabricated components or composite components will not reduce the overall bearing capacity of the station structure, and reasonable designs of joint connection such as wallboard, beam and column cannot greatly change the stress mechanism and force transfer path between the components.

(2) The self waterproofing capacity of reinforced concrete structure is used to ensure the long-term impermeability of the underground station. On the basis of not changing the waterproof design of the outsourcing and strengthening layer, a certain thickness of concrete is cast in place around the station (such as structural bottom plate, side wall and top plate). Considering the construction convenience of the structure, cast-in-place concrete structure is adopted for the bottom slab and bottom longitudinal beam, and composite structure is adopted for the side wall, top slab and top longitudinal beam. Among them, the prefabricated structure is also used as formwork, which can greatly reduce scaffolding and formwork in construction.

(3) On the basis of no change in the overall structure form, the optimization design is carried out. The final determination is that the permanent structure column adopts the concrete-filled steel tube structure, and the middle plate and longitudinal beam adopt the precast reinforced concrete structure, so as to ensure that the structural bearing capacity and deformation can meet the relevant requirements. The permanent structure column is also used as temporary column, which reduces the investment of temporary column and avoids the risk of water leakage caused by temporary column passing through the floor.

(4) The air duct on the top of the rail and the platform plate are not the main load-bearing components, so the prefabricated structure can be adopted according to their own stress characteristics. The air duct at the top of the rail can be prefabricated with the middle plate as a whole or separately, both of which are feasible. When the whole prefabrication is adopted, the construction sequence can be simplified, and the transportation will be inconvenient.

(5) Considering the space limitation of foundation pit support, road transportation requirements and hoisting capacity, the station adopts segmental prefabrication scheme in longitudinal direction. The combination of fixed length and special length is adopted for prefabricated components in the longitudinal direction while reducing the types of prefabricated components and the number of steel formwork, which is in line with the construction concept of green economy.

(6) In order to facilitate the implementation of the assembly scheme, the steel support distribution should be optimized according to the structural column spacing in the design of station foundation pit support structure. At the same time, it is suggested to adjust the crown beam position to the outside of the foundation pit to facilitate the hoisting and installation of prefabricated side wall components.

4. Research on connection form of prefabricated components

By analyzing the stress forms of components and the mechanical characteristics of joints, and fully comparing the advantages and disadvantages of connection joints and the applicability of on-site construction, the connection mode of each component is finally determined. It provides practical ideas for the application of prefabricated assembly technology in subway station.

4.1. connection of wall and plate

Under the action of external water and soil positive and lateral pressure and other vertical loads (self weight, equipment and crowd load, etc.), there are shear force and negative moment between the side wall and the plate at the connection. The thickness and reinforcement of the side wall and plate (except the middle plate) are usually controlled by the concrete cracks. If the connection of wall and plate is set in the form of hinge, it will increase the mid span bending moment and bearing angular
displacement of the side wall and plate, raise the section area or reinforcement amount, and increase the probability of leakage at the connection part. Therefore, the rigid connection form should be adopted for the prefabricated connection of wall and plate of metro station to reduce the risk of water leakage. The specific connection type is shown in Figure 7 ~ 9.

Figure 7. Connection diagram between side wall and top plate

Figure 8. Connection diagram between side wall and middle plate

Figure 9. Connection diagram between side wall and bottom

Taking the connection structure of side wall and middle plate as an example, the rationality and construction feasibility of this structure are discussed.

(1) Considering that the prefabricated side wall of the second floor is used as the support structure of the middle plate, the top of the prefabricated side wall is set as corbel type, which can ensure the accurate positioning and safe assembly of the middle plate without adding vertical support.

(2) Using the prefabricated side wall of the first floor as the formwork of cast-in-place side wall section, several rows of support points can be set at different heights of the prefabricated side wall, and the support points are connected with the middle plate by the support.
(3) To avoid slurry leakage during pouring affecting the appearance of the external surface of prefabricated components, water stop strips can be set at the horizontal and longitudinal joints to realize civilized and green construction.

(4) In order to realize the rigid connection between the side wall and the middle plate, it is necessary to ensure the reliable connection between the concrete and steel bars, and the stiffness of the connection joints does not weaken.

① The effect of "equivalent to cast-in-place" can be achieved by adopting appropriate rough surface treatment method for the joint surface of prefabricated components, among which the effect of punching exposed aggregate is better. The rough surface treatment method of full section punching exposed aggregate is adopted for each joint surface to ensure that the concrete on the joint surface is fully and effectively cemented, forming an organic whole to jointly bear the structural internal force. At the same time, the tie bars of the prefabricated side wall can be densified and welded to the main reinforcement of the side wall to improve the shear capacity of the joint surface.

② Ensure the continuity of the main reinforcement of the cast-in-place side wall at the joint position. At the same time, the main reinforcement of the middle plate is embedded into the side wall, and the anchorage length meets the structural requirements of the reinforcement, so as to realize the effective transmission of internal force in the joint.

③ The main reinforcement of the precast side wall of basement 2 and basement 1 are connected by grouting sleeve widely used in the construction industry to ensure the effective connection of the main reinforcement. The grouting sleeve is set at the bottom of the prefabricated side wall of basement 1 to avoid the influence of phase II concrete cast-in-place and ensure that the sleeve is not blocked by concrete.

④ The precast side wall of basement 1 is installed after concrete of phase II is cemented. There will be a gap in the contact surface, which can not form an effective connection, resulting in the actual thickness of the side wall becoming smaller and the stiffness weakening. Due to the effect of water and soil pressure, the shear force at the connection position is relatively large, and shear pieces are set at the connection section to compensate for the weakening of shear bearing capacity caused by the loss of concrete section. At the same time, the bending moment at the joint is also large, but mainly negative.
The concrete inside the station is under pressure. After the completion of the main construction, the joints can be cleaned and high-strength epoxy mortar can be injected to ensure that the gap is filled tightly and has strong tensile and compressive capacity, so as to ensure the effective connection of the upper and lower parts of the joint.

4.2. connection of beam and plate

In the subway station, the longitudinal beam and plate usually adopt the rigid connection form, and the longitudinal beam is used as the support of the structural plate. In practical engineering, it is common to adopt hinged connection and rigid connection between beam and plate. Considering that the load of the roof is large, the thickness and reinforcement of the roof are usually controlled by concrete cracks. According to the analysis in Section 4.1, the rigid connection should be adopted for the beam slab connection. However, the load of the middle plate is small, and there is no water seepage problem at the connection position of the middle beam plate, so the hinged form can greatly reduce the construction difficulty. The specific connection form is shown in figures 12 and 13.

![Figure 12. Connection diagram of top longitudinal beam and top plate](image1)

(1) The middle part of the beam is set as corbel type to complete the installation of precast slab without vertical support.
(2) The top plate and the top longitudinal beam are composite structure to ensure the rigid connection of joints.
(3) The middle plate is hinged with the middle longitudinal beam, so it is necessary to meet the requirements of the corbel bearing capacity of the middle longitudinal beam. At the same time, the middle longitudinal beam and the upper reinforcement of the middle plate can be set in the form of a pair of hooks to prevent cracks in the connection parts under the action of load and affect the appearance quality of the station hall floor. special attention should be paid to the lap length of the middle plate to ensure that the middle plate can be effectively supported on the corbel of the middle longitudinal beam after deformation under seismic load.

![Figure 13. Connection diagram of middle longitudinal beam and middle plate](image2)
4.3. connection of beam and column

In order to reduce the loss of the temporary structure, it is considered that the permanent structure column has the function of temporary column, and the two columns are combined into one. In view of the high bearing capacity of CFST columns and the characteristics of easy construction and connection in the later stage, the permanent structural columns are designed in the form of CFST.

The choice of connection of beam and column is very important to the structure of subway station. Considering no changing the frame structure form of subway station, the connection of beam and column should be designed as rigid connection, so as to enhance the reliability of connection, meet the requirements of joint bearing capacity and coordinate the deformation of both.

According to the structural characteristics and construction sequence analysis of components, the specific connection form of beam and column is defined as shown in figures 14 ~ 16.

Figure 14. Connection diagram of square steel column and top longitudinal beam

Figure 15. Connection diagram of square steel column and middle longitudinal beam
Figure 16. Connection diagram of square steel column and bottom longitudinal beam

From the aspects of structural characteristics, reliability and feasibility, the design concepts of beam column joints are compared and analyzed as follows.

1) The steel corbel is set at the top and middle of column to ensure that the precast beam is installed without support. There is no need to set steel corbel at the bottom of column because the bottom longitudinal beam is a cast-in-place structural beam.

2) Connection of column and top beam: During the construction of the top structure of the subway station, the part above the corbel of the top steel column can be removed. The joint area is open space, which is convenient for planting steel bars in the square steel concrete column and laying steel bars in the cast-in-place layer of the top longitudinal beam. After pouring concrete, the top of the steel column is fixed with the top longitudinal beam to realize the effective transfer of shear force and bending moment between them.

3) Connection of column and bottom beam: Referring to the structural form of beam column fixed joint of steel structure, the steel structure meeting the requirements of internal force is selected and fully welded to the steel column to ensure the fixed connection. The upper and lower flanges of the steel structure match the position of the main reinforcement of the bottom longitudinal beam [9]. At the same time, the main reinforcement of the bottom longitudinal beam is welded on the upper and lower flanges of the section steel, and the welding length is more than or equal to 5d. After pouring concrete, the beam, the section steel structure and the steel column form an effective connection, which ensures the internal force transmission and coordinated deformation between the structures.

4) Connection of column and middle beam: Due to the overall precast form of the middle longitudinal beam and the limited construction space of the joint, it is impossible to select the section steel with enough stiffness to form the fixed joint as the bottom beam column. In this scheme, the outer side of the steel column is wrapped with ring beam to form a fixed structure. The stud and shear parts are welded around the steel column in the connection area, and the concrete is poured. Pouring concrete and internal reinforcement to realize ring beam clinging steel column to form reinforced joint. Anchor the main reinforcement of the composite beam to the ring beam and ensure that it meets the structural requirements, so as to realize the fixed connection between the middle longitudinal beam and the ring beam. Through this scheme, the reinforced fixed joints of beam and column are finally obtained [10-11].

①The bending resistance of the ring beam can be calculated according to the equivalent beam. The equivalent longitudinal reinforcement tension can be obtained by the vector synthesis method of the longitudinal reinforcement tension of the ring beam. The shear capacity of ring beam is undertaken by shear members, and the shear capacity of shear members is designed according to the current code for design of steel structures (GB 50017-2017).

②After the precast beam is hoisted to the steel corbel, the reinforcement in the joint area is connected and then the precast slab at this position is installed. The main reinforcement and stirrup of the ring beam are overlapped and installed from both sides of the precast beam with shape of "凵".

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In order to conveniently anchor the bottom reinforcement of the middle longitudinal beam into the ring beam, the ring beam needs to be heightened, and a rigid cushion block is set outside the corbel.

4.4. connection of rail top air duct and middle plate
The prefabrication and assembly of rail top air duct can be carried out in two ways: the integral prefabrication of rail top air duct and middle plate and the independent prefabrication.
(1) The overall prefabrication scheme of rail top air duct and the middle plate reduces the station construction process, and ensures the installation accuracy of structure, and avoids the dense holes on the precast middle plate to weaken the strength and stiffness of the precast slab. Therefore, this scheme is recommended in this paper.
(2) If rail top air duct is prefabricated separately, it can be constructed according to Figure 17. The steel bar and the steel plate in the reserved hole of the middle plate are connected by bolts, and self compacting concrete filling is carried out.

4.5. connection of platform plate and bottom plate
The prefabricated platform plate can be hinged with the bottom longitudinal beam and bottom plate respectively. (1) In order to limit the horizontal displacement of the platform plate, holes are reserved in the upper part of the prefabricated platform plate, and embedded steel bars at the corresponding positions of the longitudinal beam are penetrated into it and self compacting concrete is poured. (2) The steel plate with bolt hole is set at the lower part of the prefabricated platform plate, and the bolt is used to connect with the embedded reinforcement of the bottom plate to restrict its vertical and horizontal displacement.

5. Conclusion
With the acceleration of the national assembly construction process, the assembly technology of subway station has also been researched and developed, but there are still some problems, such as waterproof and complicated construction technology, which hinder the promotion of assembly technology in subway station. In this paper, considering the three factors of stress, waterproof and
construction environment, a set of assembly scheme of "prefabrication + cast-in-place" for subway station is put forward.

1) On the premise that the frame structure of the station remains unchanged, the assembly of subway station is realized by the combination of cast-in-place bottom plate, prefabricated square steel column, composite side wall, prefabricated middle plate and composite top plate. Through the cast-in-place floor, composite wall and composite roof, the peripheral concrete of the station can be cast in situ to ensure the waterproof ability of the underground station.

2) The prefabricated square steel column is used to replace the temporary column to realize the combination of the permanent column and the temporary column, and the assembly construction procedure is simplified.

3) Prefabricated side wall, square steel column and longitudinal beam are equipped with corbel structure to realize less support installation in the station.

4) The feasible joint structure is designed, and the mechanical properties of the joint are considered on the basis of the convenience of construction.

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