Survey on the Application of Prefabricated Structure in Underground Engineering

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Abstract. In this paper, the application status of prefabricated structure in highway, railway and subway underground engineering at home and abroad is analysed. It is pointed out that the application of prefabricated structure in underground engineering is still in the initial stage, and there are many problems such as immature design theory, unclear component style and joint form. And the development direction and application prospect of prefabricated structure in underground engineering are discussed from the aspects of new materials, new equipment and new technology.

1. Introduction
Prefabricated structure originated in Europe in 1920s and 1930s, and rose after World War II. After decades of development, European countries, the United States, Japan, New Zealand and other countries have established a relatively mature prefabricated structure system and widely used in civil buildings [1].

Prefabricated structure has the advantages of easy control of project quality, fast construction speed, good construction environment, small impact on the surrounding environment, low project cost, and less occupation of construction personnel [2], and some structural components can be reused [3]. Prefabricated structure has achieved good application effect in housing construction engineering. More and more countries try to apply it to underground engineering, and take the prefabricated level of components as an important sign of underground structure engineering development degree in a country [4].

From the development of Prefabrication Technology at home and abroad, prefabricated structure can be divided into two categories: all component prefabrication and part component prefabrication. At present, prefabricated tunnel lining refers to shield tunnel in most cases [5].

2. Application of Prefabricated Structure in Underground Engineering in foreign country

2.1. Application in Open Cut Metro Tunnel
Prefabricated structure has been used in underground engineering for a long time, especially in France, Russia, Japan, Netherlands and other countries.
Figure 1 shows a prefabricated reinforced concrete lining structure [6] which was established and popularized by the Soviet Union in the 1950s. The structure is suitable for the slope excavation foundation pit in anhydrous or water lowering strata and the foundation pit project with I-beam steel and wood lining board enclosure. The construction speed is faster than that of cast-in-place concrete. The bottom plate is cast-in-place concrete, the rest is prefabricated structure. The vertical joints are poured with mortar, the joints between the top plates are poured with concrete, and the closed outer waterproof layer is used for waterproofing. Finally, backfilling is carried out.

Figure 2 shows the "segmental lining" structure proposed in 1960s, which has been widely used in metro tunnels in Russia, Ukraine, Uzbekistan and other countries since 1970s [7]. On this basis, in the late 1980s, the integral pipe section lining structure [8, 9] was widely used.

2.2. Application in Open Cut Metro Station

2.2.1. Single arch structure. Russia has developed rapidly in the research and application of prefabricated metro station structure. Using the basic principle and characteristics of single arch structure, Russia has built the first double-layer transfer hub of subway, i.e. Olympic Station [9]. The overall structure of the station is a prefabricated floor single arch structure. Figure 5 shows the specific structural section of the double deck transfer hub station in Russia.

2.2.2. Rectangular structure. There are many rectangular sections used in the open cut fabricated metro station structure, as shown in Figure 6 [9], the station structure bottom plate adopts the integral cast-in-place concrete, the side wall and the top plate are prefabricated, and the top plate adopts the multi-ribbed plate structure, which reduces the weight and facilitates the assembly.
2.3. Application in Underground Excavation Metro Station

In the subway station constructed by mining method, the prefabricated structure is seldom used. France's Star Square Station is a subsurface subway station built with assembly structure [10]. The Star Plaza subway station is located in a sensitive location. There are already several subway lines operating on it, requiring all measures to ensure the stability of the stratum. After the demonstration of multiple schemes, the precast reinforced concrete segment assembly arch technology under the condition of construction by mining method is finally selected. This technology is widely used in the subsurface subway station in Paris. The technology first constructs the tunnel side wall from the gallery on both sides as the support of the prefabricated arch. After the excavation of the tunnel face, the steel arch frame is constructed and prefabricated segments are assembled one by one to form the main structure. The formation loosening caused by construction is very limited. The engineering cost of this method is not very different from that of traditional excavation method, and the construction period is short.

2.4. Application in Highway and Railway Tunnel Engineering

In Japan, in order to reduce the cost and improve the speed of the construction, the method of combining prefabricated components and mode concrete is used to build a tunnel invert. After excavating the bottom of the tunnel, pour the concrete with a slump of 0. Then, the prefabricated concrete slab with protrusion is laid on it and tamped with vibrator to make it integrated with concrete. Because there is no need to set and remove the formwork, the cost is reduced by 10% ~ 15% compared with the cast-in-place concrete. After the tunnel excavation, the inverted arch can be constructed immediately, so as to control the deformation of the bottom [11].

3. Application of Prefabricated Structure in Underground Engineering in China

3.1. Application in Open Cut Metro Station

The completion of Yuanjiadian Station of Changchun Metro Line 2 marks the completion of the first prefabricated open cut metro station in China. In the process of construction method implementation, technical problems such as division of prefabricated components, reasonable sequence of assembly, lifting of large components, positioning and deviation correction of components and research and development of supporting mechanical devices are solved [12], and the structural form is shown in Figure 7.

Using prefabricated structure construction technology can shorten the construction period by 4-6 months, thus solving the problem that the subway station structure cannot be completed within one year. Due to the use of factory prefabrication, no wood is consumed, and there is basically no construction waste on site, especially in the use of construction labor on site, which can save more than 50%, with low safety risk. And it can reduce the construction land, significantly reduce the impact on the urban environment during the construction of the station.
3.2. Application in Highway and Railway Tunnel Engineering
In China, prefabricated components [13] are used for the inverted arch of Qinling I line tunnel, which improves the safety of tunnel construction and durability of use. The inverted arch structure is shown in Figure 8.

In addition, a highway tunnel [14] in Shanghai adopts the form of open cut tunnel. A 100m long road section is selected as the demonstration section of fully assembled prefabricated assembling technology. Each tunnel section is divided into two structures, one is the upper and the other is the lower, forming two "mountain shaped" components, as shown in Figure 9.

3.3. Shield Tunnel
There are many researches on shield tunnel at home and abroad, and in recent years, many projects using shield method in China. The relevant domestic codes are relatively perfect, which can better guide the design and construction.

In addition to the prefabrication of shield tunnel segments, some domestic projects have carried out some beneficial explorations on the prefabrication and assembly of the internal structure in shield tunnel [15]. Qinghuayuan Tunnel of Beijing Zhangjiakou high speed railway is the first fully prefabricated high-speed railway tunnel in China. Its support structure, under rail structure and auxiliary structure are factory prefabricated, and the assembly robot is developed to realize the full prefabrication and assembly of tunnel [16].

4. Prospect
With the development of tunnel excavation technology, the over excavation and under excavation are effectively controlled. This is a good opportunity to further study prefabricated lining tunnel. The development of prefabricated structure in underground engineering should be in the following aspects:

(1) At present, the research on the calculation theory of prefabricated underground structure at home and abroad is insufficient, and there is no mature calculation theory to follow [4]. For the prefabricated lining tunnel, there is still a lack of sufficient engineering design experience and construction experience. And the research on waterproof design and anti-seismic theory is very deficient.

(2) At present, there is no clear and reasonable scheme for the component style and joint form of the prefabricated support structure of the tunnel. The research focus of the key technologies of the
prefabricated structure should be placed on the selection of the prefabricated component style, assembly mode, joint position, connection mode and waterproof measures, as well as the impact on the safety performance and service performance of the tunnel.

(3) The research and development of new materials, new equipment and new processes are equally important, which can greatly promote the realization of new construction methods and improve the safety of structures and the use performance of construction facilities.

(4) With the large-scale construction of urban infrastructure and deep tunnel, the prefabricated structure will be the future development trend of engineering by subsurface excavation method.

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