

Research on the waterproof design of the prefabricated assembled utility tunnel joints

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Abstract. With urbanization development and the introduction of national policies, the prefabricated utility tunnel has been the future direction of the utility tunnel development due to great advantages in the quality, time and cost compared with the cast-in-place utility tunnel. This paper introduces three joint forms and analyses the main existing problems in waterproofing technology of precast utility tunnel joints. Besides, the fourth most common waterproof materials and waterproof constructions of prefabricated utility tunnel in China are discussed. This paper aims at providing some new ideas of waterproof materials and constructions for researchers and engineers, further promoting development of prefabricated utility tunnel.

1. Introduction

With the rapid development of urbanization, the comprehensive renovation of urban underground pipelines is known as “Utility tunnel”, accommodates the directly-buried municipal pipelines, such as electric power, communication, gas, heating, water supply and drainage, and has a set of proprietary operating system. As the important symbols to measure the modernization level of urban construction in 21th Century, the utility tunnel can make full use of the underground space and reduce the repeated excavation of the road and green space to improve the city environment.

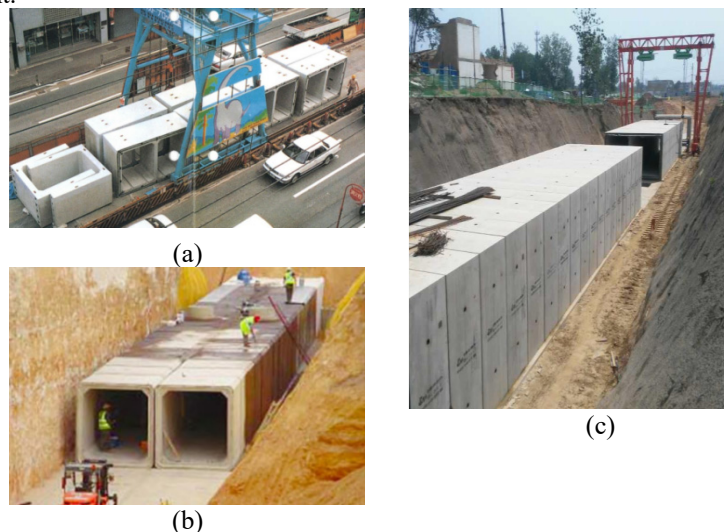


Figure 1. Construction site of prefabricated utility tunnel of (a) Japan; (b) Europe; (c) China



In recent years, the development of prefabricated technology has provided more options for the construction of the utility tunnel shown in Figure 1. Therefore, the prefabricated utility tunnel attracts wide attention and can apply to old town redevelopment and new town infrastructure, because of its many merits such as factory prefabrication, on-site standardization, less material consumption, strong corrosion resistance and high stability. The prefabricated utility tunnel shows greater advantages in terms of construction period and quality, compared with the cast-in-place utility tunnel in Table 1.

Table 1. Comparison of two types of utility tunnel		
Type	Cast-in-place utility tunnel	Prefabricated utility tunnel
Quality	influenced by the construction technology, low reliability	Factory prefabrication, high reliability
Cost	high cost of manpower, material and time	low cost standardized production.
Security	Complicated management, high safety risk	Great site safety performance
Construction-period (CP)	Long CP, wet operation workload needs long curing time	Short CP, high-efficiency production and assembly construction
Environmental effect	Great impact on the environment due to steel processing, formworks, concrete pouring-curing, etc.	Low environmental impact of factory precast, mechanized assembly, low noise, less dust.
Appearance	Ease to appear beehives, facial problems, etc.	Smooth surface
Aseismic performance	Good, Single section concrete, great influence of uneven settlement	Flexible structure, good adaptability to seismic deformation

The waterproof performance of the joints is one of the key technical problems that affect the safety and durability of the utility tunnel structure, and limit the further development of utility tunnel^[1]. Cracks are the main problems in the waterproofing technology of precast pipe gallery joints^[2]. In the construction of underground engineering, it is an important problem to improve the waterproof and sealing performance of the prefabricated utility tunnel and avoid the appearance of leakage accidents^[3]. This paper aims at discussing the common joint forms, waterproof material and its properties, waterproof construction measures to provide references for the design and improvement of the waterproof structure of the utility tunnel in city.

2. Joint forms of the prefabricated utility tunnel

The joint is a key factor in design and construction of the prefabricated assembled utility tunnel, related to the practical effect of maintenance and operation. According to the project characteristics, the utility tunnel should apply the appropriate joint form to achieve the precise design and construction. The precast utility tunnel can be mainly categorized into three types according to the joint forms, including inserting type connection, prestressed connection and laminated slab cast-in-place connection.

It is a prerequisite for the comprehensive and large-scale popularization and application of prefabricated public tunnels to adopt suitable joint forms to prevent leakage and a key factor affecting the normal operation of pipeline corridors. Among them, the joint form of inserting type connection in application of prefabricated pipe corridor is the most frequently-used, and its waterproof structure has three forms including sealed waterproof at end face, sealed waterproof at working face, sealed waterproof at end and working face simultaneously^[4]. Besides, the waterproof joint of prefabricated utility tunnel can be designed according to the waterproof structure of shield pipe.

The flexible connection type of the prefabricated assembly method (double rubber seal seal and double component seal) has many advantages, such as high reliability, strong durability, convenient installation and high cost performance^[5]. In addition, the flexible connection can effectively avoid the shortcomings of cast-in-place method, and has been widely concerned and applied in engineering practice. Sun Bei et al.^[6] studied the stress distribution of pipe joints, and found that the stress concentration phenomenon of flexible connections with double rubber ring joints is not obvious.

3. Waterproof material and its properties

3.1. Influence factors of waterproof and seal of utility tunnel joint

- Smoothness of the cushion. The evenness of the cushion has a great influence on the butt of the pipe joints.
- Component spigot joint size. Because the size precision of the prefabricated component inserting shape affects the position and tension butt of joints, the socket size and the best joint effect are guaranteed by strictly controlling the precision of the die processing.
- Hoisting technique. The stretching process are composed of three steps including initial positioning, accurate alignment, and hydrostatic test^[7].

- d) Waterproof material. In the waterproof construction of multi-defenses, the hardness, size and compression ratio of the rubber ring are the key factors to ensure its effectiveness. The aging performance of rubber ring plays a very important role^[8].

3.2 Analysis of various waterproof material

Urban utility tunnel has a high requirement for the quality and the service life of waterproof material, due to the requirement of long service life and difficulty in repairing waterproof engineering. Utility tunnel usually built under urban road, which are affected dynamic load and surrounding buildings, causing structural deformation. Hence, the waterproof material is required to be well adapted to the deformation. The waterproof measures for joints of the prefabricated structure mainly depend on the sealant strips, including hydrophilic expansion rubber strip, Ethylene-Propylene-Diene Monomer and putty compound rubber sealing strip.

a) Hydrophilic expansion rubber strip.

Hydrophilic expansion rubber strip is the most commonly used sealant with solid cross section. After volume expansion in water, it will fill up all irregular surfaces, holes and gaps of joints. Meanwhile, the volume expansion will produce larger contact pressure stress on the contact interface, improving its anti-leakage ability. The material can also be waterproof through the expansion of water absorption, when the joint gap is beyond the elastic range of the sealant strip due to the opened construction joint. Using hydrophilic expansion rubber strip as the sealing material is not only saving consumption, but also can eliminate elastic fatigue caused by the excessive compression, making the waterproof effect more reliable. At present, the shortcoming is that after long-time use and repeated expansion, hydrophilic expansion rubber strip will precipitate some substance^[9].

b) Ethylene-Propylene-Diene Monomer (EPDM).

EPDM is a copolymer composed of ethylene, propylene and a small number of non-conjugated dienes with the middle-opening section form, and widely used in waterproof engineering of assembly structures. EPDM is elastic sealing material with early application in underground tunnels in China because of its most important characteristics of good oxidation, ozone and corrosion resistance. EPDM has the lowest proportion in all rubber due to its good vulcanization properties. In addition, EPDM has some important merits such as low density, high filling property, aging resistance and water vapor resistance, though its adhesion is poor.

c) Hydrophilic expansion compound rubber strip.

The hydrophilic expansion compound rubber strip is made of two kinds of non-stratified rubber products of hydrophilic expansion rubber and EPDM, producing complementary characteristics of water expansion and strong resilience. Its cross section is middle opening and bottom slotting. Furthermore, the waterproof ability mainly depends on the elastic recovery with the water expansion assistance. It attracts great attention because of high resilience, high compression deformability, aging resistance, high strength and good weather resistance.

d) Putty compound rubber sealing strip.

The putty compound rubber sealing strip is a new kind of waterproof sealant, composed of an outer layer of the putty mud with better cohesiveness and an inner layer of EPDM foam with the middle-opening section form. This adhesive strip was first produced and widely used in some of the common underground trenches in Japan. Although there are some applications in China, it is still in the stage of research and development. Based on the compression test^[10], the result shows that the maximum compression after completely limiting the lateral deformation is 10-11mm caused by the compression of the inner hole in the compound adhesive strip and the extrusion of the inner air gap in the foaming EPDM. After the lateral deformation is limited, the compressive stress of this composite strip can reach 1.5MPa, which is the interface stress of elastic seal cushion specified in engineering code for urban utility tunnel^[11].

In conclusion, according to the compression test of the three different waterproof materials, results show that the elastic modulus of the first three kinds of sealants is much greater, and their compression increases uniformly with the compression force in the whole compression process, compared with the putty composite rubber strips. Besides, the compression amount of the first three kinds of sealant increases uniformly with the compression force, and their increase of compression in the later period is reduced. However, the compression quantity of the putty composite rubber strip is basically unchanged at the later stage, and its compression deformation has been basically completed in the early period of compression.

When the compression force is less than 20kN/m, the limit water pressure of the putty compound rubber sealing strip is higher than that of the other three kinds of sealant. Meanwhile, the waterproof performance is better than the other three kinds under the same compression force. The four kinds of waterproof materials have the same waterproofing capability when the compression force exceeds 30kN/m.

4. Waterproof construction of prefabricated utility tunnel joint

The rubber rings are the main waterproof material in the prefabricated utility tunnel, including single rubber ring or double rubber ring. The standard of GB 50838-2015 advocates the wide application of the compound rubber ring composed of elastic rubber and water swelling rubber. Usually, the waterproof construction of the prefabricated utility tunnel is composed of the inserting surface seal and the end surface seal (double apron seal). This waterproof construction has some advantages of the organic combination of the end face compression seal and the incline deformation seal, good sealing, good seismic resistance, good settlement resistance, high installation technical requirements.

Two typical waterproof constructions for inserting type connection are proposed in the Hunan engineering standard design atlas. As shown in Fig. 2 and 3, the double aprons are the main waterproofing functions, and the other are auxiliary waterproof measures. Among them, the outer double component polysulfide sealant and waterproof reinforced layer (or self-adhesive rubber seal) cannot form a sealing ring well, because the bottom plate cannot be constructed properly. Hence, it mainly prevents the plant root puncture and the destruction of animals such as the underground insect. Though the inside sealant can form a sealing ring, it mainly used to prevent insects from entering the joint gap and protecting the inner sealing ring, because the sealant has a large probability of producing bad bonding position and its waterproof ability is limited, based on the simulation test and the discovery of site construction^[12]. Compared with the waterproof construction in Fig. 3, the waterproof construction in Fig. 2 of the utility tunnel is easy to install due to more small installation butt resistance, however the installation of the rubber ring of its inserting surface requires fixed measures. In addition, the detection hole set in Fig.2 can be used as a remedy hole due to water stop failure, which is better than the construction in Figure 3.

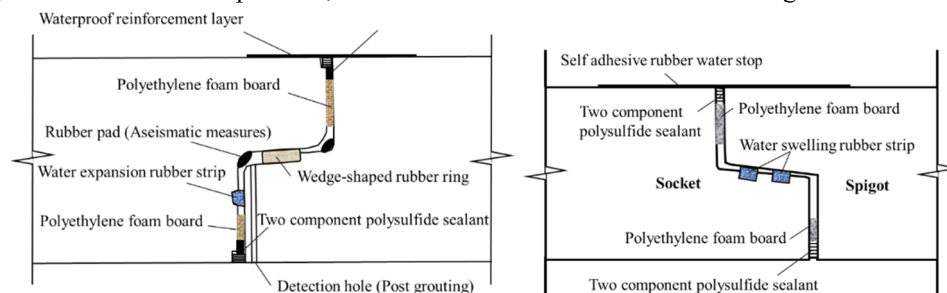


Fig.2 Waterproofing construction (1) of Hunan Atlas Fig.3 Waterproofing construction (2) of Hunan Atlas

Some similar waterproof constructions are proposed in references^[8,13], as shown in Figs. 4 & 5 respectively. In Fig.4, the grouting material is added in the middle of two road sealant. Compared to the cement grouting material, the elastic chemical grouting material can greatly enhance the seepage control ability, but it will increase the cost of waterproof construction. For the similar waterproof constructions in Fig. 2 and 3, a self-adhesive tape is added to the inside for the main purpose to prevent the destruction of insects and mouse bites. The function of sealant and sealing ring in the protective seam is same as that of the sealant in inner layer.

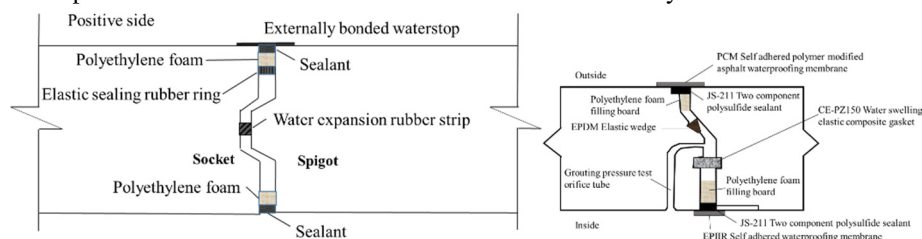


Fig.4 Waterproofing construction (3) of the inserting type connection.

Fig.5 Waterproofing construction (4) of the inserting type connection.

5. Conclusion

As the key development direction of underground space, the prefabricated utility tunnel can not only ensure the safety of construction environment, but also improve the construction efficiency. The waterproofing performance of joints becomes the key technical problem influencing the applicability and durability of gallery. This paper systematically summarizes the experimental results of waterproofing performance of prefabricated utility tunnel joints, and thoroughly analyzes the waterproof material and waterproof construction technologies to provide a reference for future studies and designs of the waterproof constructions. This paper proposes several suggestions for waterproofing structures:

1. The future studies of the waterproof performance about the prefabricated pipe gallery joints can be based on the researches results of the waterproof constructions of the prefabricated structural joints in similar tunnel structures.
2. Compared with traditional methods, multi-layer waterproofing design should be considered, which has great engineering application value for waterproof sealing and later maintenance of the utility tunnel joint.
3. According to different work environment, it is chosen economical and reasonable waterproof material and structural constructions to form a systematic waterproof scheme. Future study will be performed to develop the reasonable joint forms and high-performance waterproof material, and strengthen waterproof construction of transverse and vertical assembly joints.

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