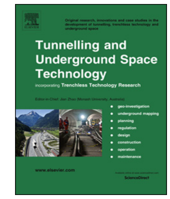
Tunnelling and Underground Space Technology 81 (2018) 296–305

Contents lists available at ScienceDirect

Tunnelling and Underground Space Technology

journal homepage: www.elsevier.com/locate/tust



A bottom-to-up drainage and water pressure reduction system for railway tunnels

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ARTICLE INFO

Keywords:
Tunnel drainage
Numerical simulation
Bottom drainage system
Water pressure

ABSTRACT

Due to the high water pressure at the bottom of the tunnel, when drainage system is not well designed, railway ballast bed may suffer from diseases such as contamination, mud pumping, excessive settlement and so on. Poor drainage will significantly reduce the performance and durability of ballast bed. In this paper, a novel conceptual drainage and water pressure reduction system at the bottom of railway tunnel is proposed. The proposed bottom drainage system includes a transverse catchment system, a longitudinal water conducting system and a bottom-to-up water drainage system. A series numerical analyses were carried out to validate the performance of the proposed drainage system. Results show that the proposed drainage and pressure reduction system can effectively discharge the water at the bottom of the railway tunnel and reduce the water pressure. Factors that influence the performance of the proposed drainage system are also discussed by parametric studies. The permeability of the surrounding rock, the initial support and the secondary lining invert have great influences on the external water pressure. The groundwater level that influences the water pressure reduction effect are also discussed.

1. Introduction

With the rapid development of urbanization in China, more and more infrastructures were constructed such as transportation, energy, water conservancy systems and so on. In recent yeas, the construction of tunnel has made remarkable achievements. For example, by the end of 2016, there are about 14,000 railway tunnels with an approximate total length of 16,000 km have been in operation in China. Meanwhile, about 4460 railway tunnels with an approximate total length of 9700 km are under construction. About 4450 railway tunnels with an approximate total length of 10,800 km are under planning in China. During the construction of railway tunnels, new engineering problems arise and should be carefully addressed. Among these problems, the damages of the railway ballast bed have attracted more and more attentions to engineers. These damages include uplift, mud pumping and cracking at the bottom of the ballast bed and so on. Damages of railway bed will affect not only the duration of service life of the tunnel, but also endanger the safety of railway transportation (Lee et al., 1999; Shin et al., 2014). In addition, for the high-speed ballast less track railway tunnels, even a small damage of the railway bed can cause terrible disaster. And the maintenance of such railway bed is usually difficult and costly. As it is known that the damages to railway bed may cause by the high groundwater level and high pressure under the railway bed, where damages like contamination, mud pumping, excessive settlement are observed. Thus, how to eliminate the external water pressure on the tunnel structure is critical to solve the above-mentioned diseases. In order to reduce the water pressure at the bottom of a railway tunnel, an efficient drainage system is needed (Chabot et al., 2013).

Water proofing and drainage system plays an important role in the control of external water pressure on the lining. There are two main types of water proofing and drainage system. One is the undrained waterproofing system and the groundwater is not permitted to ingress into the tunnel. The other is the drainage system, the groundwater is allowed to inflow into the tunnel. The waterproof lining can increase the external water pressure (Wang et al., 2008), but a drainage system can decrease it (Arjnoi et al., 2009). Many researchers investigated how the external water pressure affected on the mechanical characteristics of lining by analytical analysis, numerical simulations and physical test (Fahimifar and Zareifard, 2009; Kolymbas and Wagner, 2007; Wang et al., 2004). In the engineering practice, some strategies including grouting as well as pin-hole drain method have been proposed based on these researches (Fan et al., 2017; Fang et al., 2015; Farhadian and Katibeh, 2017; Ma et al., 2017).

However, very rare studies focusing on the water proofing and

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https://doi.org/10.1016/j.tust.2018.07.027
Received 31 July 2017; Received in revised form 8 June 2018; Accepted 12 July 2018
0886-7798/

drainage system for tunnels, although it has a significant effect on the external water pressure on linings. Yuan et al. (2000) systematically summarized the waterproofing requirements and measures in different special tunnels in China. Jang et al. (2015) measured various types of geocomposites in a laboratory to evaluate their filtration and discharge capacity characteristics for their potential application in tunnels. Yoo (2016) presented results of an investigation into the effect of decrease in drainage capacity by hydraulic deterioration of tunnel geosynthetic drainage systems on the structural performance of tunnel linings. Comparative work was carried out to figure out the advantages and disadvantages between the two types of water proofing and drainage system.

In this study, a new drainage system at the bottom of a railway tunnel is proposed. Different from the conventional drainage system, by taking advantage of high water pressure naturally concentrated at the bottom of tunnels, an automatic bottom-to-up drainage system can be fulfilled. The outline of this paper is as the following: First the state-of-art of drainage and waterproof system is briefly reviewed. Then the detailed design of the bottom-to-up water pressure reduction system is introduced. Finally, a series of numerical simulations are conducted to validate the proposed system. Some key factors that influence the performance of the proposed drainage system are discussed by parametric studies.

2. State-of-art of the drainage and waterproof systems in the world

In this section, a brief review of the state-of-art of the drainage and waterproof systems in the world is carried out first, aiming clarify the structures and techniques used in different countries. And the novelty of the new drainage system proposed in this study is emphasized.

2.1. Typical drainage systems in European traffic tunnels

According to Gamisch and Girmscheid (2005), the drainage systems can be classified as 4 types according to the position where to mount the floor drainage, see Fig. 1.

- Type A: the floor drainage which is also the collecting pipe is mounted in the central bottom of the tunnel. Water first flows into side-wall drainage and then goes through the transverse pipe, finally collects in the collecting pipe. The transverse pipes are mounted between the manhole of side-wall drainage and the manhole of collecting pipe. The distance between two manholes in the longitudinal direction is regularly 88 m.
- Type B separates the floor drainage and the collecting pipe. The floor drainage is set in central bottom of the tunnel, while the collecting pipe is set near side-wall.
- Type C cancels floor drainage, and the combined collecting pipe is mounted outside the lining.
- Type D add a floor drainage in each side of the tunnel compared with type C, and it set decline to floor drainage in lean concrete.

2.2. Sweden and Norway

Most of the tunnels are rock tunnels in northern Europe countries like Sweden and Norway, because there are many rock mountains. Single shell lining are widely applied in rock tunnels, the waterproof and drainage systems of rock tunnels are made up of shotcrete and bolt. The drainage system is first covered with a layer of ordinary shotcrete, then drill some holes in the rock and mount threaded 16 mm steel rods with cement paste. The diameter and depth of the holes are approximately 40–60 mm and 1 m, respectively. The distance between the holes is about 0.7–1 m. On the steel rods a foamed polyethylene mat will be mounted with different kinds of steel fittings, shown in Fig. 2. Finally the mats will be covered with two layers of ordinary shotcrete, one layer is made up of 60 mm steel reinforced with polypropylene fibers and the other is only with polypropylene fibers, which can improve the fire resistance of the shotcrete. The water is collected on the mats and proceeds down to the drainage pipes in the bottom of the tunnel which lead the water out of the tunnel.

2.3. Japan

Most mountain tunnels in Japan are drained to decrease water pressure behind the lining, but some tunnels constructed in areas where are not allowed water level change or in natural reserve are sealed. The structure of Japanese waterproof and drainage system is most likely the same with that in China. It contains waterproof board between two linings, longitudinal drainage pipe, annular drainage pipe, central drainage ditch, manhole and so on. The main difference is that the position where the central drainage ditch is set. Fig. 3 shows 3 types of drainage ditch that were applied in Shinkansen tunnels. Type A is suitable for a majority of geological conditions. The drainage pipe is set below inverted arch and surrounded by gravel. The water in the surrounding rock can flow through gravel filling and holes drilled on the drainage pipe beforehand. This solution can avoid confined water below the inverted arch. Type B is suitable for high-water sandy soils. Compared with Type A, Type B replaces gravel by concrete to avoid quicksand. Meanwhile, the risk of confined water increases. Type C is suitable for soft rock with large deformation. To avoid unduly disturbing bottom surrounding rock, the central drainage pipe is set above inverted arch. It makes the bottom of the inverted arch complete and forms an impervious boundary.

2.4. South Korea

The tunnel waterproof and drainage system in South Korea is roughly the same as that in China. Shown in Fig. 4(a), the PVC membrane should be mounted between the initial shotcrete lining and the final concrete lining for waterproofing, behind the membrane there is a geotextile or geocomposite as a drainage layer. The water will collect in the sidewall drain pipe, then lead to the main drain in the central bottom of the tunnel through the transverse pipes. These pipes except the main drain are perforated in their upper parts. Below the transverse pipe, there is a gravel drainage layer. The lining in tunnels with this type of drainage system can be designed lighter and thinner.

Fig. 4(b) shows the cross-section of lining system, some different details from that in China can be seen. Before mounting the drainage layer, some drain boreholes should be drilled through the shotcrete lining into the surrounding rock, which will benefit to drainage. The membrane between the shotcrete lining and final concrete lining could be either fleece of composite geosynthetics or air-gap membranes which depends on water discharge. It should be noted that polyester should not be used as it can be destroyed by hydrolysis in an alkaline environment such as concrete (Kolymbas, 2005).

2.5. China

The vast majority of railway tunnels in China are constructed by the New Austrian Tunnelling Method (NATM). In order to improve the safety and the durability of the support structure, composite lining has been designed. Water proofing and drainage system is adopted between the initial support of shotcrete and the secondary lining of cast-in-place concrete. The waterproof and drainage standards system of the railway tunnel in China is relatively sound, the waterproof and drainage system of railway tunnel is formed, which is based on the combination of self-waterproof lining structure, partition waterproof system and tunnel drainage system. Fig. 5(a) reflects the typical waterproof and drainage design of domestic tunnel, and the bottom detail is shown in Fig. 5(b). The circumferential blind tube is arranged at every 10 m in the longitudinal direction between the initial support and the secondary lining