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A large-scale physical model test on frozen status in freeze-sealing pipe roof method for tunnel construction

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ABSTRACT

The Gongbei Tunnel, the most important and difficult part in Zhuhai Link of Hong Kong-Zhuhai-Macao Bridge, faces numerous troubles because of natural and human-related factors. A new pre-supporting technique, Freeze-Sealing Pipe Roof method, which combines Pipe-Roofing Method with Artificial Ground Freezing method, has been put forward and employed for the first time in China during the construction of the Gongbei Tunnel. An innovative freezing scheme is proposed by three kinds of freezing tubes (master, enhancing and limiting tubes) to cope with various conditions. A large-scale physical model test has been conducted so as to validate the freezing effect of Freeze-Sealing Pipe Roof method. The present paper focuses on the experimental set-up and results in detail, which confirms safety and rationality of the freezing scheme.

1. Introduction

In the presence of ever-increasingly complex circumstance of an urban underground construction, Shallow Tunneling Method (STM), proposed in 1987 and widely used in practical engineering, has been a complete construction technique for last two decades (Wang, 2010). It is the tendencies that STM strengths the auxiliary technique and simplifies the main procedure (Guo, 2012). The selection of the auxiliary technique is crucial for tunneling with the super-large cross section in the rich-aquifer strata. Even if it has some difficulties, one of the auxiliary techniques, Pipe Roof Method (PRM) (Zhang et al., 2013), meets the demands. Therefore, the combination method, making use of the complementarity, has been proposed. A composite technique, Freeze-Sealing Pipe Roof method (FSPR), which combines PRM with Artificial Ground Freezing method (AGF) (Pimentela et al., 2012a), has been put forward and employed for the first time in China during the construction of Gongbei Tunnel. Zhang et al. (2016) has concluded the key techniques about the pipe jacking of FSPR. With respect to the freezing, there are some literatures or examples of similar methods yet.

In Germany, for construction of underground line U5 'Unter den Linden' in Berlin, microtunneling was the selection for installation of the freeze pipe in construction, due to boulders and the requirement that freeze pipes must be installed in exact positions. Brun and Haß (2006) investigated all structure and thermal calculations for ground freezing by the finite element method (FEM). In Japan, scholars have already put forward the concept of composite structures, "Frozen soil & Steel pipe" for decades of years, and have done a series of basic works. Hamaguchi et al. (2005) combined microtunneling and ground freezing as the pre-supporting method for large cross-section excavation and did numerically basic research for the temperature field and the stress distribution. Then, Kamakura et al. (2005) gave an introduction in detail of the Shield Roof Pre-supporting System for Junction (SR-J), and Hamaguchi et al. (2006) did two groups of model tests and obtained mechanical properties of SR-J. What is more, Moriuchi et al. (2003, 2004a, 2004b, 2004c, 2008) performed the bending tests of the composite beam which included frozen soil and two steel pipes under constant and increasing loads.

Though the German projects and the basic works in Japan have quite many similarities with the method employed in the Gongbei Tunnel, there are still some significant differences. On the one hand, the space between two pipes or micro-tunnels in FSPR is much smaller than those in the literature. Therefore, the frozen soil is designed for imperviousness and less consideration of the bearing capacity should be taken into. On the other hand, a brand-new arrangement of freezing tubes is present in FSPR, which implements an effective Controllability of freezing soil in the strict circumstance.

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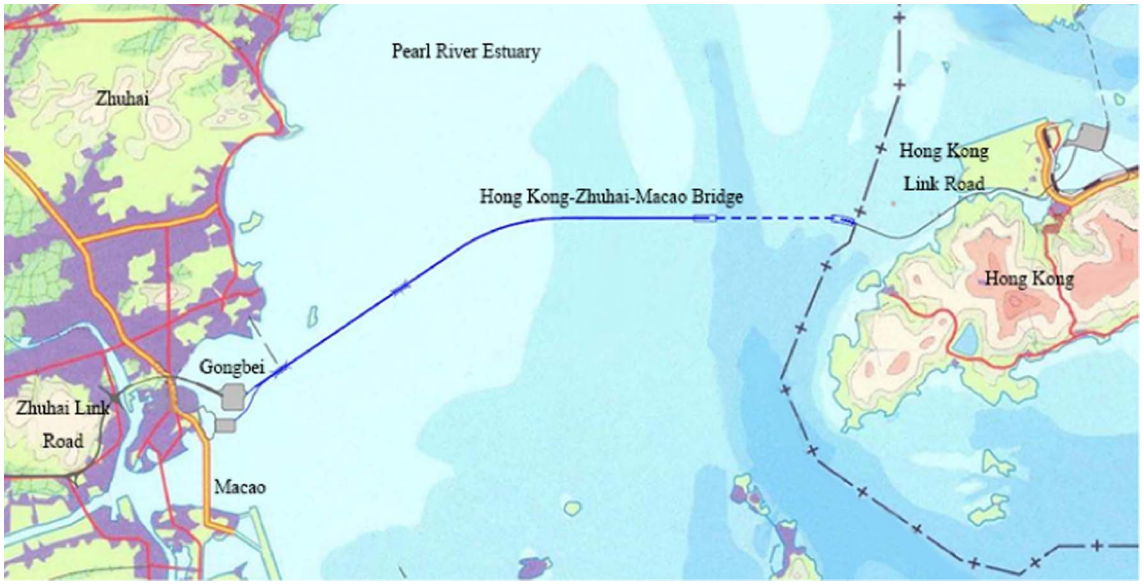

Fig. 1. Layout of the Hong Kong–Zhuhai-Macao Bridge.

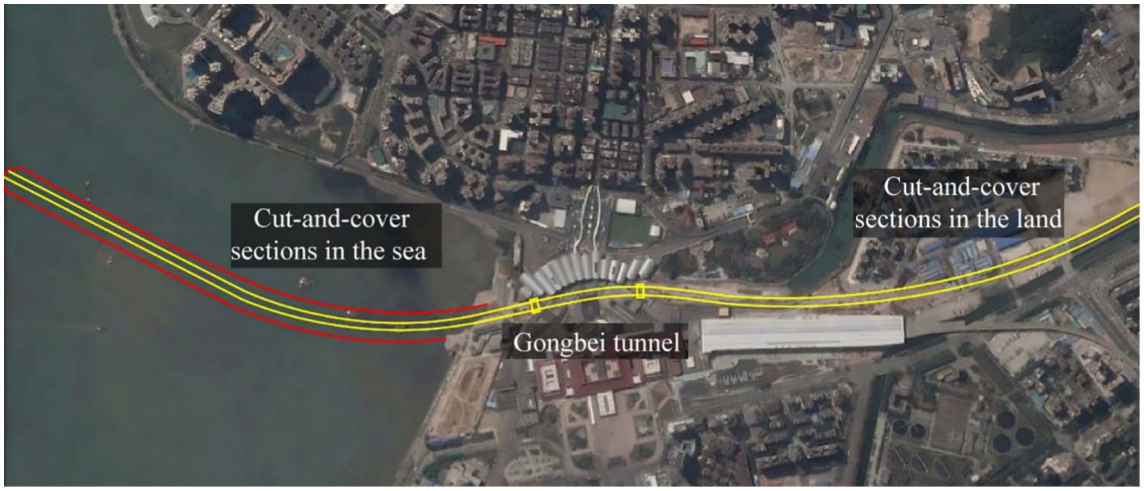

Fig. 2. Layout of the Zhuhai Link.

In China, authors of current paper have done some primary studies for the completion of Gongbei Tunnel. Hu and She (2013) numerically discussed different freezing schemes, which might appear in the construction and developed an effective freezing scheme. It was proved that FSPR with the scheme is valid for the project. Hu and Fang (2014) considered the influence of airflow on freezing by introducing the conjugate heat transfer theory and thus furthered the research on FSPR. Hu et al. (2016) did the partial tests in situ on freezing scheme of FSPR, which verified the validity of FSPR. However, the tests cannot checkout the freezing effects in passive period due to the limitation of the condition. Furthermore, Wang (2013) did laboratory tests for the mechanical properties of "frozen ground + steel pipes" izn FSPR, according to the actual size and the similarity criteria, which indicated that the structure maintained safety in normal conditions.

The present paper starts with the brief introduction of Gongbei Tunnel and analyzes the decisive factors for the usage of FSPR. Then, it continues with a succinct statement about the physical model test. Finally, a comprehensive analysis about the measured parameters, temperature, is presented.

2. Project

2.1. Background

Zhuhai Link project is an important component of Hong Kong-Zhuhai-Macao Bridge project (HZMB), whose routes are shown in Fig. 1. According to design, the total length is 13.9 km. Since restrictions of site environment and characteristics of construction methods, the design schemes of Zhuhai Link are divided into three parts, as shown in Fig. 2, Gongbei Tunnel by Shallow Tunneling Method and cut-and-cover sections in the sea and in the land. FSPR is utilized for the construction of Gongbei Tunnel.

Gongbei Tunnel, a double-decker integral tunnel, is the main body of Zhuhai Link project, whose shape is decided by the administration district boundaries. It crosses the prosperous Gongbei Port, which has the maximal people flux in the world. In addition, there are plenty of buildings along the tunnel alignment, and pile foundations are utilized for most of them. Environmental consideration has been one of the major factors in the design of the Gongbei Tunnel. Hence, the alignment of the tunnel and the construction method should be carefully selected to not only minimize the visual, air and noise impacts on the nearby sensitive receivers but also avoid all recognized sites of conservation