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Model test of immersed tube tunnel foundation treated by sand-flow method

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ABSTRACT

In order to explore the immersed tunnel foundation treated by sand-flow method, modeling principles for the full-scale model test of sand flow were put forward. In addition, a sand-flow test model was built, which consisted of model system, equipment system and measurement system. The situation of sand-deposit expanding and the water pressure in the foundation trench were evaluated through the model test. The results show that a semi-closed space was formed between the model board and the expanding sand deposit, which made the water pressure in it rising with little range of volatility. The sand deposit gradually became non-circular truncated cone which shaped with its expanding radius, and the difference of the water pressure increased at each direction. The water pressure in crater had a linear increase with the sand-deposit radius, with a maximal value of 0.015 2 MPa. The volatility of the water pressure under the tunnel board and the water pressure value in the crater could be used as bases of construction control.

1. Introduction

The main underwater tunnel methods for crossing rivers and straits are mining methods, shield methods and immersed tube methods. Since 1910, the advent of the first true sense immersed tube tunnel-the Detroit River immersed tube tunnel built, immersed tube tunnels have been developed in USA (Grantz, 1997), Europe (Glerum, 1995; Rasmussen, 1997) and Asia (Kiyomiya, 1995; Janssen et al., 2006; Yang et al., 2008) vigorously. Its advantages are obviously evident.

There are several factors affecting the settlement of the immersed tube tunnel, such as sub-soil conditions, foundation, siltation, surcharge, and trench dredging methods (Grantz, 2001a), but it is difficult to accurately predict and control the final settlement. Grantz (2001b) shared his immersed tunnel experience with several typical tunnel types and actual settlement records, which shows that the immersed tube tunnel foundation and the treated methods of it have a significant influence on the final settlement.

Considered as one of the treatment methods of immersed tunnel foundation used nowadays, sand-flow method (Glerum, 1995; Chen et al., 2002), with a number of advantages, is one of the mainstream construction methods.

Sand-flow method was first used in Vlake Tunnel of Holland (Tongeren et al., 1978), corresponding model test was carried out and the mechanism of the method and construction parameter were explored before construction. Water pressure near the injection opening and sand content in the sand-flow mixture were recorded in the construction.

Though immersed tunnel construction started relatively late in China, a large number of sand-flow model tests were taken. By the Guangzhou Pearl River Tunnel, Li (2001) built a sand-flow test model and pointed out that the pressure near the injection opening and buoyancy force increased with the expansion of sand deposit, providing a technical basis for the construction. Before the construction of the Shengwudao–Daxuecheng Tunnel, Wang et al. (2009) studied the sand-deposit radius, void ratio and pressure by the 1:5 reduced scale model test, verified the original design and construction program.

The authors take the Guagnzhou Zhoutouzui Tunnel (GMED&RI and MCAL, 2008) in China as the background, and put forward modeling principles for the full-scale model test of sand flow. Sand-flow test model, consisting of model system, equipment system and measurement system, was built. The relationship of sand deposit and time, as well as the distribution law of water pressure in the foundation trench was gained. Furthermore, forecasting methods of the sand-deposit radius and construction-control index

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for engineering practice were proposed. The authors hope that this paper could provide basis for the sand flow method and the test model could provide a reference for further studies.

2. Model system

2.1. Zhoutouzui immersed tunnel project

The length of Guangzhou Zhoutouzui immersed tunnel (GME-D&RI and MCAL, 2008) is 340 m. The designed pipe segments of the tunnel in Pearl River are E1 (85 m), E2 (85 m), E3 (79.5 m), E4 (90.5 m), of which the E1 and E4 are variable cross-section segments. The tunnel foundation will be treated by sand-flow method. The typical pipe segment and the designed sand deposit are shown in Fig. 1.

2.2. Modeling principles for immersed tunnel

In order to guarantee the rationality and validity of the model test, the test model was designed in accordance with the following principles:

(1) The plane shape of the model board was equivalent to the floor of the tunnel in a full-scale sand-deposit area, which simulated the top boundary condition of the fluid in construction.
(2) The space between the model board edge and the tank wall was similar to the one between the lateral wall of immersed tunnel and the trench slope, which was equivalent to the lateral boundary condition of the fluid.
(3) By plugging the side of the trench, the various "artificial boundary plugging" caused by the sand deposit already existed at the one side or both sides of the constructing sand deposit could be simulated.
(4) The model board was immersed in water to simulate the underwater construction condition. The only difference happened between the depth of tested water and that of the actual construction water, which would generate no significant differences in the test and had been verified by the preliminary experiment (Fang et al., 2012).
(5) The performance parameters of the test equipment system were fully consistent with those of the construction equipment, which could provide stable sand–water flow as those in construction.
(6) Measuring system worked accurately and continuously without influencing the test.
(7) Test sand had the same category and the similar particle size distribution with the construction sand material.

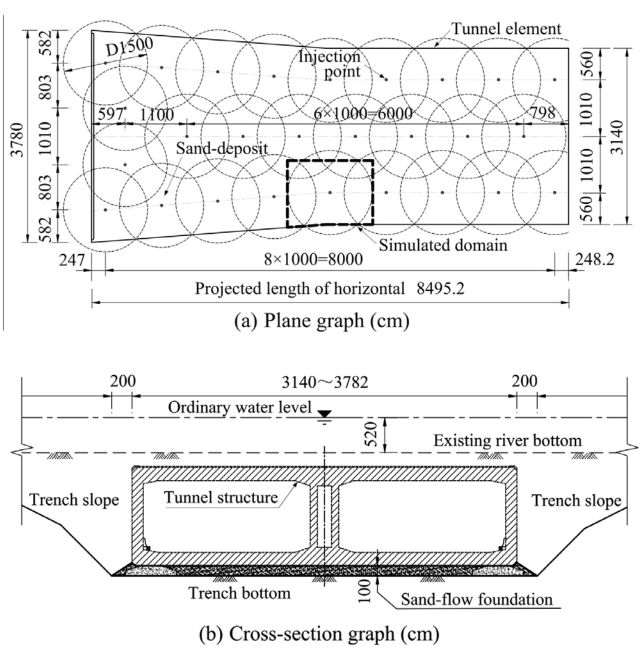

Fig. 1. Plane and cross-section of Guangzhou Zhoutouzui immersed tube tunnel/cm.

2.3. Model system of immersed tunnel

According to the modeling principles above, a variable cross-section pipe segment in a sand-deposit range was modeled and a full-scale test model for sand-flow method was built. The simulated area is shown by coarse dotted line in Fig. 1(a).

The model system of immersed tunnel consists of a model board, a experimental tank, a circulation tank and a underground reservoir, as shown in Fig. 2.

The model board is a reinforced concrete, with a dimension of 8.2 m ∗ 15.2 m (length ∗ width), which was used to full-scale simulate the floor of the immersed tunnel in a sand-deposit range. The clearance between the model board and the ground is 1.0 m, which simulated the clearance of foundation trench. An injection opening was simulated by a 6-in. steel nozzle, which was installed on the board centre, connecting the sand pump by steel-wired hose. Opening–closing holes for observation and sampling were installed at the centerline of the board.

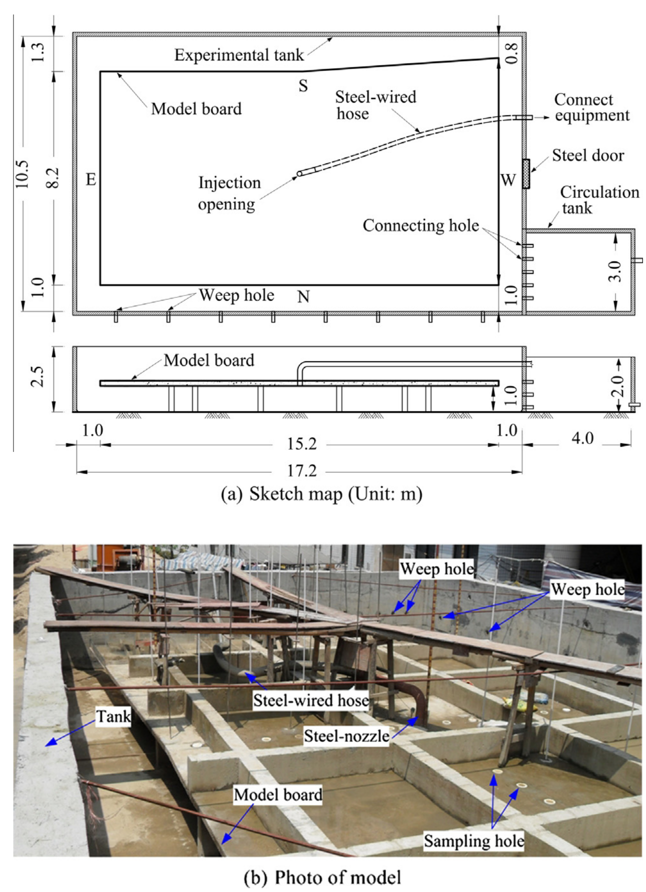

Fig. 2. Test model system. Note: The E, S, W, N in the paper expressed the East, South, West and North direction of the model board.