



Design of shield tunnel lining taking fluctuations of river stage into account



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ABSTRACT

Fluctuations of river stage are expected to induce changes in loads acting on the tunnel linings and cause readjustments of member forces in the segmental linings subsequently. Therefore, the evaluation of impacts of time-dependent river levels on the loads acting on the tunnel linings is of great importance in design of shield tunnel linings situated beneath the rivers. However, the loads acting the tunnel linings are generally considered as constant in most design methods available, taking no account of the influences of constantly changing river stage. In this study, the influences of river stage on design of shield tunnel linings are evaluated with respect to two common ground conditions: (a) impermeable overburden strata of low permeability and (b) permeable overburden strata of high permeability. Two earth pressure calculation models are correspondingly established. In addition, field observations in the Hangzhou Qiantang River Tunnel are described in detail to present the responses of tunnel linings to fluctuations in river stage and validate the established design model for the former case.

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1. Introduction

The shield-driven tunnelling method is widely adopted for construction of under-river tunnels in soft ground all across the world. Behaviors of the tunnels beneath the rivers, unlike those beneath the ground surface, are expected to be affected by fluctuations of river levels. Nevertheless, there are few studies focusing on the effect of time-dependent river stage on design of the shield tunnel linings.

The following loads should always be considered in the design of the linings: (1) ground pressure, (2) water pressure, (3) dead load, (4) surcharge and (5) subgrade reaction (British Tunnelling Society, 2004; ITA WG, 2000; Koyama, 2003; Mashimo and Ishimura, 2003). Generally speaking, all of these loads are maintained stable for tunnels beneath the ground surface that have been in service for a long period of time. So it is rational to take these loads as constant in most design methods available (Duddeck, 1981, 1989). But for tunnels beneath the rivers, imposed loads constantly change as a result of fluctuations in river stage. For cases like this, the time-dependent loads induced by changes in river stage should be taken into consideration in tunnel lining

design. However, the impacts of changing river stage are seldom counted in present practice.

Prediction of earth pressures acting on the tunnel lining is one issue of great importance in design of a tunnel (Kim and Eisenstein, 2006). In Japan, overburden earth pressure or reduced earth pressure calculated by Terzaghi's formula has generally been adopted as vertical earth pressure acting on the tunnel lining for the segment design on the basis of previous field measurements (ITA WG, 2000; JSCE, 1996; Mashimo and Ishimura, 2003). Murayama (1968) studied the vertical earth pressure in sandy layers by trapdoor tests. Mashimo and Ishimura (2003) evaluated the loads on shield tunnel linings in gravel by field measurements at two shield tunnels. Zhu et al. (2008) simulated relaxation effect of vertical earth pressure during shield tunnelling. They observed that the soil arching mainly occurred within 1–2 times the tunnel diameter above the crown and the vertical earth pressure acting on the tunnel lining was significantly decreased due to soil arching. This problem has attracted considerable interest in the last decades. However, changes in earth pressures acting on the tunnel linings induced by fluctuations of river levels have rarely been paid attention to. Moreover, there is a lack of calculation model for loads acting on the tunnel linings taking time-dependent river stage into account.

This paper evaluates the influences of river stage on design of shield tunnel linings with respect to two common ground

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conditions: (a) impermeable overburden strata with low permeability and (b) permeable overburden strata with high permeability. Two corresponding earth pressure calculation models are established. The average uniform rigidity ring method (Koyama, 2003), which has been widely adopted in Japan for shield tunnel lining design, is improved in this study taking stress relief prior to installation of the tunnel lining and time-dependent loads induced by changing river stage into account.

In order to assess the impacts of fluctuations in river levels on shield tunnels beneath the river, instrumentation was set up during construction of the Hangzhou Qiantang River Tunnel to measure river stage, earth pressures acting on the tunnel linings, strains of the reinforcing steel bars and convergence of the tunnel. The field observations are described in detail to present behaviors of the tunnel linings in responses to fluctuations in river stage and validate the established design model for the former case.

This study aims to provide an initial insight into behaviors of the shield tunnels subject to changing river stage and improve the average uniform rigidity ring method for design of shield tunnel lining taking fluctuations of river levels into account.

2. Design model for shield tunnel beneath river

According to differences in permeability of the tunnel overburden strata, the design models can be classified into two broad categories: (a) impermeable overburden strata with low permeability and (b) permeable overburden strata with high permeability, which are referred to as Design model 1 and Design model 2, respectively, hereinafter.

2.1. Design model 1

2.1.1. Computation of imposed loads

Fig. 1 depicts the calculation model of loads acting on the tunnel lining for Design model 1, in which the overburden strata are assumed to be impermeable. It is suited for shield tunnels beneath the rivers with overburden strata of low permeability, such as clay and silty clay.

For the overburden strata are very low in permeability, river water is anticipated to apply a surcharge that is equal to its own weight to the strata below the river bed level. The river water induced surcharge p_0 is a function of river stage as

$$p_0 = r_w H_w(t) \quad (1)$$

where p_0 is the surcharge imposed by river water; r_w is the unit weight of water; $H_w(t)$ is the river stage at time t , which constantly changes with time.

The strata beneath the river are assumed to be completely saturated with groundwater table at the surface of the river bed. Vertical water pressure acting on the crown of the tunnel lining is figured out using Eq. (2).

$$p_{w1} = r_w C \quad (2)$$

where p_{w1} is the vertical water pressure at the crown of tunnel lining; C is the depth of overburden.

Vertical earth pressure acting on the tunnel crown is presented in Eq. (3).

$$p_{e1} = (1 - \alpha) \left(p_0 + \sum r'_i H_i \right) \quad (3)$$

where p_{e1} is the vertical earth pressure at the crown of tunnel lining; α is the coefficient of stress reduction taking stress relief prior to installation of the tunnel lining into account; H_i is the thickness of Stratum No. i , which is located above the tunnel crown, note that $\sum H_i = C$; r'_i is the submerged unit weight of soil of Stratum No. i .

The horizontal earth pressure and water pressure are simplified to be uniformly varying loads that increase with depth acting on the centroid of the tunnel lining from the crown to the bottom, as shown in Fig. 1. They are calculated with Eqs. (4)–(7), respectively.

$$q_{e1} = \lambda \left(p_0 + \sum r'_i H_i + r'_j \frac{h}{2} \right) \quad (4)$$

$$q_{w1} = r_w \left(C + \frac{h}{2} \right) \quad (5)$$

$$q_{e2} = \lambda \left(p_0 + \sum r'_i H_i + \sum r'_j H_j \right) \quad (6)$$

$$q_{w2} = r_w \left(C + D - \frac{h}{2} \right) \quad (7)$$

where q_{e1} and q_{e2} are the horizontal earth pressure at the crown and the bottom of tunnel lining, respectively; q_{w1} and q_{w2} are the horizontal water pressure at the crown and the bottom of tunnel

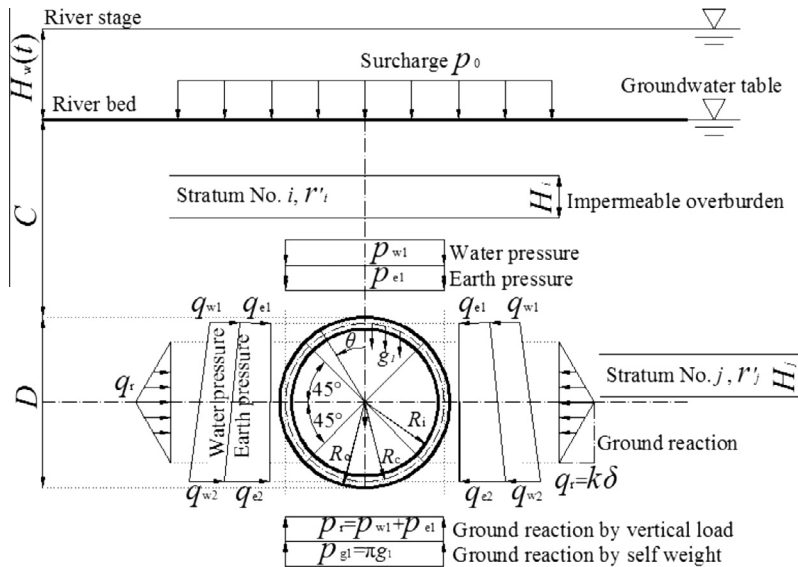


Fig. 1. Calculation model of loads acting on tunnel lining for Design model 1.

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