Study on optimization technology of protective engineering for submerged tube overburden in crossing river tunnel

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Abstract: Under the influence of many complex factors, such as flood, tidal power, ship operation, earthquake and construction quality, the stability of the tunnel’s underwater overburden layer is crucial to the safe operation of the project. A technical line combined with measured data analysis and physical model testing were utilized to study the features of scouring and sediment for tunnel overburden under several extreme hydrodynamic conditions. In order to ensure the rationality of anti-scouring stability and economy for tunnel engineering project, optimization design for overburden layer of tunnel was proposed after detailed experiments and analysis. The slurry block stone and stone throwing method can be used to protect the slope and the bottom of the embankment downstream of the tunnel line, which can effectively control the possible scouring of the concave embankment foot and river bed. The technical line and research methods applied in this paper can be extended to satisfy the engineering design optimization for overburden layer of similar tunnel engineering.

1. Introduction

The anti-scouring stability of protection layer for immersed tunnel engineering is affected by many factors such as water depth, water and sediment dynamics, geological conditions, anti-scouring ability of overburden, construction quality, shipping activity and other human activities\cite{1-2}. Dynamic characteristics of water and sediment, human factors are the main factors which can affect the dangerous scouring of tunnel overburden\cite{3-5}. Usually, two-dimensional flow-sediment dynamic mathematical model and physical model are used to study the maximum scouring depth of River section for tunnel engineering. A research method of erosion protection technology for tunnel overburden can be applied to similar tunnel engineering.

2. Overview of river-crossing tunnel for Guang-Fo line

Crossing Dongping channel 50m upstream of lanshi pier, the river crossing tunnel project is located between Chancheng district and Shunde district in Foshan, China. Map of excavation and backfilling of foundation trench for this river-crossing tunnel is shown in Fig.1. The tunnel overburden is basically backfilled to the original riverbed elevation. Moreover, the tunnel overburden layer of interlocking concrete block for only covers the range of the main channel.
3. Analysis of River bed Evolution near the Tunnel
Based on the river topographic maps in 1980, 1990, 1998, 2004 and 2009, the variation of riverbed and average scouring and silting intensity at tunnel site were analyzed in details. With a minor amplitude of swing, the dynamic axis of the river is insubstantially stable state. According to the historical evolution and scouring envelope for the cross section of the tunnel’s central axis, the elevation of the riverbed on both sides of sinking pipe varies relatively greatly, and the main channel section is relatively stable.

4. Physical model test of eosi on protection for tunnel overburden
4.1 Model design and verification
(1) According to the scope of the river channel and the site conditions, the horizontal and vertical scales of physical model are respectively 100 and 50, and the river roughness of the prototype is 0.024-0.026. On the basis of roughness similarity criterion, the roughness of the model should be 0.018-0.019. The plane layout of physical model for the tunnel of Guang-Fo Line is shown in Fig.3.
(2) The choice of model sand. The critical starting velocity formula proposed by Dou Guoren of the Republic of China is as follows:

\[
V_s = \left( \ln \frac{11 \gamma H}{m_{\gamma} k_s} \right) \left( \frac{\gamma - \gamma_H g d + 0.19 s_\gamma + gH\delta}{d} \right)
\]  

(1)

In the formula (1), \( m \) is the coefficient of starting velocity; \( H \) is the water depth. According to the results of scouring experiments in the water tank, the starting velocity of physical sand is between 7.5cm/s and 12.0cm/s under specific water depths introduced previously, which conforms to acceptable similarity of the starting velocity for sediment basically.

Table 1 statistical table for physical model scales

| Law of similarity | Scale name     | Calculated value |
|------------------|----------------|------------------|
| Geometric similarity | Horizontal scale \( \lambda_h \) | 100 |
|                   | Vertical scale \( \lambda_v \) | 50 |
| Hydrodynamic Similarity | Velocity scale \( \lambda_v \) | 7.07 |
|                   | Roughness ratio \( \lambda_n \) | 1.36 |
|                   | Scale for flow time \( \lambda_t \) | 14.14 |
|                   | Flow ratio \( \lambda_Q \) | 35355 |

(3) Verification for physical model. Under typical hydrological conditions, water level, velocity, scouring and silting of physical model should be verified in details. The hydrographic data of water level and velocity measured in the dry season of "2009.2" were used to model calibration. The partial verification results of velocity process of high tide in dry season of "2009.2" were shown in Fig.4.

Figure 4 Verification of the "2009.2" spring tide flow rate process

4.2 Model experiments for hydrodynamic characteristic

Under boundary conditions of frequency floods including P=0.33%, 1%, 5% and "99.7" (a middle flood with large tide), the fixed bed current model tests were carried out for hydrodynamic characteristics on the cross-section of tunnel engineering. Before the construction of the project, the
effect of hindrance and transverse-flow the lower reef is evident, and the mainstream leans slightly to the right bank. Considering the main flow will be blocked and deflected by the concave bank on the north side, disadvantage erosion on the riverbed and foot of the embankment by the turbulent flow should be concerned in details.

4.3 Analysis of scouring test results of moving bed

(1) Scouring test of riverbed before the project construction. After two hours of extreme frequency flood \( P = 0.33\% \) scouring in the river channel under topographic conditions of 2009, the result of scouring test is shown in Fig. 5. The reef named upper Qu long locates in the mainstream area of the concave bank.

(2) Scouring test of overburden after the project construction. The riverbed is relatively flat, and the upper and lower reaches of the river are connected smoothly after the project construction. After 2 hours scouring of frequency flood \( P = 0.33\% \), the top and the shoulder of the overburden can remain stability. The area of throwing stones connects smoothly with the upper and lower reaches of the river bed. With few siltation in the north and slight siltation in the south of cross-section of the channel where the tunnel is located, the mixing of bed sand and throwing stones are beneficial to the scouring resistance stability of the tunnel overburden layer.

![Fig. 5: Results of scouring test before the project construction](image)

*Fig. 5: The results of scouring test before the project construction (After 2 hours of extreme scouring under frequency flood \( P = 0.33\% \) and topographic conditions of 2009)*
(a) After project construction (b) Protection scheme for the north concave embankment toe.

Figure 6: The results of extreme scouring test after the tunnel construction (The frequency flood (P=0.33%) with the low tide level of “05.6 flood”)

(3) Scouring test of the protection scheme of the north concave bank embankment. The block stones with a diameter of 30~50cm (50~180kg) were selected, and the throwing thickness is twice the stone particle size (0.6m to 1.0m). The length and width of the filling range are 180m and 25m respectively. So, the protective area of throwing stone is about 4.6×10^3 m^2. The scouring test results of extreme hydrodynamic conditions frequency flood (P=0.33%) are shown in Fig. 6.

5. Conclusion

(1) The rationality and optimization of the scour stability of the overburden of the newly-built river-crossing tunnel project should be carried out by utilizing the advantages of many technical means, such as the analysis of measured hydrological data, the analysis of riverbed evolution, the mathematical model and physical model test. The optimization and demonstration method of the tunnel overburden scour protection project established in this paper can be extended to similar projects in the future.

(2) For the easily scoured embankment near the tunnel project, the necessary protective engineering should be taken to ensure the stability of the riverbed and the foot of the embankment. The use of masonry slope protection above the low water level and riprap bottom protection at the foot of the embankment can effectively control the adverse scouring of the embankment foot and riverbed on the north concave bank.

(3) The level of construction technology and human activities are main factors which affect the stability of tunnel overburden. Moreover, the destruction of tunnel by human and mechanical forces during operation, the illegal operation of ship anchoring and sand dredger may have adverse effects on the stability of tunnel overburden. Regular monitoring on the safety of underwater terrain, stringent safety monitoring system and emergency plan should be carried out by the tunnel management departments, so as to detect and dispose the hidden dangers of tunnel overburden timely.
Acknowledgments
The authors would like to thank Professor Xiaoming Wu and Rongli Chen from Pearl River Hydraulic Research Institute, and Pearl River Water Resources Commission for their assistance, and Professor Weiguo He and Yonghui Xing from China Railway Tunnel Survey and Design Institute Co., Ltd., for giving many suggestions and guidance to this paper.

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