Tunnelling and Underground Space Technology 45 (2015) 20–33

Contents lists available at ScienceDirect

Tunnelling and Underground Space Technology

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

A case history of shield tunnel crossing through group pile foundation of a road bridge with pile underpinning technologies in Shanghai

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ARTICLE INFO

Article history:
Received 25 November 2012
Received in revised form 20 August 2014
Accepted 2 September 2014

Keywords:
Shield tunnel
Pile underpinning
Ground treatment
Load transfer mechanism

ABSTRACT

According to the planning of Shanghai metro line 10, the interval tunnel from Liyang Road station to Quyang Road station has to cross through the group pile foundation of Shajinggang Bridge on Siping Road. Therefore, how to guarantee the normal traffic function and the safety of bridge structure during the tunneling process becomes a challenge to engineers and technicians. To solve this problem, the pile underpinning technology was recommended for this project. This specific scheme mainly comprises following steps, i.e. ground improvement behind abutment, foundation pit excavation under bridge deck, underpinning pile with raft and cutting pile with shield machine directly, etc. In order to verify the feasibility of this scheme, a series of theoretical analysis and numerical simulation were carried out on the entire construction process to explore the load transfer mechanism of bridge structure. The calculation results show that both the bridge static loads and traffic live loads can be successfully transferred from pile foundation to raft after pile underpinning, and the removal of obstructed piles during tunneling has very limited influence on bridge structure. Furthermore, real-time field monitoring activities, including settlement of bridge deck surface, deformation of surrounding buildings and pipelines, etc. were also conducted to ensure smooth construction. The monitored results agree well with the numerical calculation ones, which prove again that the proposed scheme is reasonable and the calculation results are reliable.

1. Introduction

With the acceleration of urbanization process, traffic jam is becoming the bottleneck for further development of modern cities. Therefore, many major cities in the world are racing to develop urban rail transit system, especially for the subway tunnel, to alleviate the growing traffic pressure. However, with the increase of subway tunnels and the improvement of metro network, the tunnel construction environment is becoming more and more complex. For instance, new lines pass through old lines closely or cross through the embedded underground structures of roadway, bridge, buildings and so on. These complicated construction environments can be found in many practical engineering cases at home and abroad, which are always great challenges to the engineers and the technicians in design and construction. (Lee et al., 1994; Yamaguchi et al., 1998; van Hasselt et al., 1999; Coutts and Wang, 2000; Sharma et al., 2001; Yang et al., 2009; Afifipour et al., 2011; Sirivachiraporn and Phienwej, 2012; Yao et al., 2012, etc.).

Generally, the greatest challenge encountered in engineering practices is that the new tunnel has to cross through the pile foundation of existing underground structures. In such circumstance, the pile underpinning or cutting pile method may be adopted to remove the obstructed piles. For instance, Iwasaki et al. (1994) described a practical construction case in which the pile underpinning method was adopted to support the large underground structures of a subway in Nagoya city. Ishimura et al. (2006) introduced a new method of removing piles after underpinning the existing structure, namely, cutting the obstructed pile horizontally below the existing structure by operating a wire sawing system on the ground. Xiang et al. (2008) presented the case of underpinning an overpass foundation by means of tipping an additional pile at adequate distance below the metro tunnel floor.

In Shanghai, the city planners also make full use of subway tunnel to solve the traffic issue, of course, the number of obstacles encountered in tunnel construction is not within minority. For example, the construction of interval tunnel from Liyang Road

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http://dx.doi.org/10.1016/j.tust.2014.09.002
0886-7798/

station to Quyang Road station of Metro line 10 is such a situation, namely, the tunnel has to cross through the group pile foundation of Shajinggang Bridge on Siping Road. In order to ensure the normal traffic function and the safety of bridge structure during tunneling, a proper underpinning scheme was proposed for this project. Meanwhile, a series of theoretic analysis and numerical simulations were carried out on the whole construction process for the purpose of verifying the scheme rationality and reducing the potential construction risk. Subsequently, some real-time field investigations were conducted to ensure the smoothness of construction activities.

2. Project overview

2.1. Engineering background

Shanghai Metro line 10 lies in the city center, and the whole line is constructed by earth pressure balance shield machine. It is 42 km long, including 35 stations, which connects 7 districts in sequence, i.e. Minhang, Changning, Xuhui, Luwan, Huangpu, Hongkou and Yangpu district. According to the planning of Metro line 10, the interval tunnel from Liyang Road station to Quyang Road station will have to cross through the group pile foundation of Shajinggang Bridge. As shown in Fig. 1, Shajinggang Bridge is located in Siping Road, about 100 m south from the intersection of Siping Road and Quyang Road.

The spatial position relation of bridge and subway tunnel can be found in Figs. 2 and 3. The bridge is a three-span simply supported beam structure, with span length of 6 m, 14 m and 6 m respectively. It includes two piers and two abutments. Each pier is supported by 23 precast concrete piles with dimension of $0.4 \times 0.4 \times 26$ m, and each abutment uses 14 precast concrete piles of $0.4 \times 0.4 \times 27$ m in dimension as its support. The elevation of tunnel crown beneath the bridge is about −6.00 to −7.00 m. During the tunneling process, the shield machine would encounter 4 piles under each pier and 3–4 piles under each abutment, that is to say, totally 33 piles may affect tunnel excavation.

2.2. Surrounding environment

As shown in Fig. 4, there are many dense residential quarters with high buildings near the Shajinggang Bridge. In the southeast, there exists the 24-story Xinxing Building, one corner of which is only 11 m from Siping road. In the southwest, the Siping pumping station lies 4.69 m away from the road. While in the north, the foundation pit of Quyang Road station is still under construction. To the northeast and northwest of the bridge, there are a 6-story brick-concrete building and the 16-story Huaxi Stock Exchange Building respectively.

In addition, there are also intensive underground pipelines distributed on both sides of the bridge. Some of the important pipelines are listed in Table 1, including water supply pipes, power cable pipelines, telephone cable pipelines, sewage pipes and gas pipes.

2.3. Engineering geology

The topography along the interval tunnel is relatively flat, and the ground surface elevation is about +3.54 to +3.64 m. Part of the longitudinal geological profile is shown in Fig. 5.

The engineering geological investigation report shows that, at the construction site of Shajinggang Bridge, the stratum from ground surface to the depth of 60 m is divided into 9 layers in terms of soil characteristics, i.e. miscellaneous fill layer ①, brown to grey yellow clayey silt layer ②$_{3\text{-}1}$, grey sandy silt layer ②$_{3\text{-}2}$, grey silt clay layer ④, grey clay layer ⑤$_{1\text{-}1}$, grey silty clay layer ⑤$_{1\text{-}2}$, silty clay layer ⑥, straw yellow to grey-green clayey silt layer ⑦$_1$ and grey silt sand layer ⑦$_2$. Among which, layers of ②, ④ and ⑤ are Q_4 sediments, while layers of ⑥ and ⑦ are Q_3 sediments. According to the design technical documents, the shield machine mainly crosses through the grey yellow clayey silt layer ②$_{3\text{-}1}$, grey sandy silt layer ②$_{3\text{-}2}$, grey silt clay layer ④ and grey clay layer ⑤$_{1\text{-}1}$ when arriving at the Shajinggang Bridge. The soil mechanical properties are listed in Table 2. The cohesion and the inner friction angle were obtained by quick shear test, and the compression modulus was measured by standard consolidation test.

There are three main types of groundwater within the construction site, that is, phreatic water in the shallow clay layer, micro-artesian water in the shallow silt soil layer and confined water in the deep silty soil layer and sandy soil layer. The buried depth of the phreatic water table is 0.3–1.5 m, while the water table of micro-artesian water or confined water is about 3–11 m deep. Layer ⑦$_1$ is the first confined aquifer, and its top surface is about 12 m below the tunnel invert. This distance is large enough to neglect the influence of the confined aquifer on the tunnel safety.

3. Problems and solutions

3.1. Existing problems

The difficulties of tunnel construction exist not only in the obstructed piles but also in the busy traffic on bridge surface. Generally in the past, to solve this problem, the preferred method is to modify the line route avoiding the obstacles. But it is infeasible in this project due to following reasons: (1) the Quyang Road station is only about 100 m away from the bridge pile foundation, so it is impossible to modify the line route detouring the pile foundation in such a short distance; (2) due to the restriction of longitudinal slope, the tunnel cannot pass beneath the pile foundation by

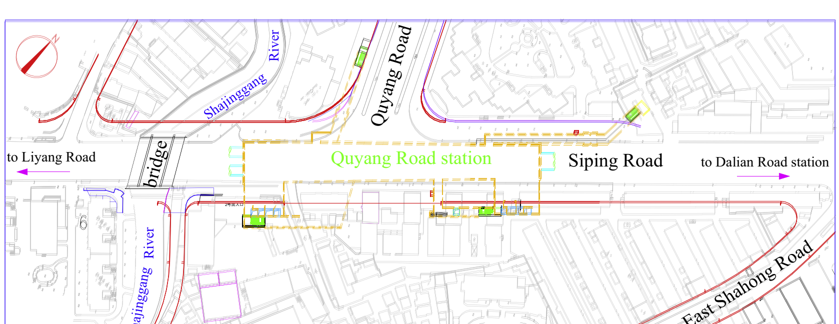

Fig. 1. Plan layout of the Shajinggang Bridge.