Research on structural status of operating tunnel of metro in Shanghai and treatment ideas

J.P. Li, R.L. Wang & J.Y. Yan
Shanghai Metro Operation Co., Ltd., Shanghai, P.R.China

ABSTRACT: Recently, with network operating and servicing time going on, the safety of operating tunnel in Shanghai is becoming a focus in the circle of civil engineering. It is well known that safety of operating tunnel is greatly influenced by the structural status of the tunnel. This article firstly give an introduction of main diseases of operating tunnel based on the large amount of information and date collected in the past decades about Shanghai Metro. Then causes for the disease are analyzed and related suggestions to prevent the diseases deteriorate are given. It is shown that the main problem of operating tunnel include leakage, crack, longitudinal settlement and constringency.

1 INTRODUCTION

Recently, with network operating and servicing time going on, the safety of operating tunnel in Shanghai is becoming a focus in the circle of civil engineering. However, only decades after shield tunnel was introduced to China, few successful experiences can be used for reference from domestic and abroad, especially for Shanghai metro where tunnel was constructed in thick soft clay soil. This article firstly gives an introduction of main disease of operating tunnel based on the large amount of information and data collected in the past decades about Shanghai Metro. Then causes for the disease are analyzed and the related suggestions for prevention are given. It is expected that this article can be useful for those who is interested in the health of tunnel of Shanghai metro.

2 MAIN DISEASES

2.1 Leakage

Based on the large amount of information collected recently about Shanghai tunnel of metro, more than ten seepage spots can be found at each section between adjacent stations. Seepage spots in several sections could up to fifty places. Figure 1 indicates that leakage mainly occurs at both sides of tunnel, joints of station and tunnel and the by-pass between up and down line. Minority leakage places were founded at the hole of bolt and the hole of grouting. According to technical specification for water-proof of shield-driven tunnel (DBJ08-50-96, 1996), Leakage of the operating tunnel of Shanghai metro belongs to the second or the third level.

After decades of operating, the function of water-proof of sealing rod has already reduced to a low grade for the non-uniform settlement of tunnel caused by adjacent construction, pumping of ground-water, etc. For the special stress state, most segment rings exhibit an ellipse shape with horizontal radius enlarged and vertical radius reduced. Correspondingly, the compressive stress at the hance of tunnel segment ring decrease near outer surface and increase near interior surface. Gaps at the joint of segment rings maybe formed. Since the sealing rod was set at the outer side of segment ring, so the capability of water-proof was reduced at the hance of the tunnel, and this lead to that most leakage take place at the side of tunnel. In addition, for the great difference of structural style among the shield tunnel, the station and the by-pass, differential settlement occurs at these positions and this also leads to serious seepage.

2.2 Segment crack

Few cracks are formed in the segment itself, but the phenomenon that joint filler has pull-out can be found for non-uniform settlement of operating tunnel which makes the joints uncoupled. Most cracks located at the corner of segment or unfilled corner take place during the construction phase, such as production, maintenance, handling and consolidation. Additional, cracks can be found between segment and track bed at the position where large differential settlement take place and where turning radius is small.
2.3 **Longitudinal settlement**

Large settlement take place to the tunnel after decades of operation, and the longitudinal settlement represents with regional characteristic. Figure 2 indicates that the longitudinal settlement curve of Line 1 of Shanghai metro contains two huge settle pits. One of them is about 1400 m long, located at the Hengshan road station and the maximum settlement is about 20 cm. The other one is located at the interval from the South Huangpi road station to Shanghai Railway station with the maximum settlement is nearly 30 cm.

2.4 **Rate of settlement**

Figure 3 is duration curves of settlement of tunnel near the People Square. Although the tunnel have been constructed for more than ten years and the rate of settlement has being slowed down, it can not leads to that the tunnel has already been stabilized for the creep properties of Shanghai soft clay. How to control the settlement is still a difficult problem faced by civil engineering.

2.5 **Convergence**

Horizontal diameter of most segment ring enlarge from 2 cm to 4 cm, few of them even up to 7 cm. This already exceed the design safety limit (1 ~ 5D‰). According to statistics, segment ring with horizontal convergence deformation greater than 3 cm occupy 69.98% and those of greater than 6 cm occupy 6.63%. The maximum convergence is about 15 cm and the gap along the longitudinal joint is 11 mm which means that circumferential bolt have already reach yield limit.

3 **GENETIC ANALYSIS OF DISEASE**

According to decade’s subway monitoring results, the main factors related to the deformation of metro structure are listed as following:

(1) **Local Ground Subsidence**

Based on the ground subsidence database of Shanghai city, it shows that the settlements of subway station and tunnels are large if they located at the center.
of subsidence region. Comparison of time-settlement curves between ground surface and tunnel structure measurement in People Square region gives great agreement. Figure 4 shows the time-settlement curves from 1999 to 2008. But the exacted ratio of tunnel settlement to ground subsidence is not able to be obtained.

(2) Geology Conditions

In Shanghai area, the soft soil stratum is about 30 m deep from ground surface. The subway station and tunnel mainly located in soft soil. The soil is basically saturated flowing-plastic or soft-plastic clay with low shear strength (0.005 ~ 0.01 MPa), high water content (above 40%), high compressibility (0.5 ~ 1.0 MPa-1), sensitivity varying from 4 to 5, and rheological behavior. In this very soft ground, the influence of excavation and tunnel drive to environment could not be ignored either for construction period or for long-term operating period.

(3) Quality of Construction

It would lead to large deformation if there were some accidents occurring during the construction of station and tunnel driving. The differential settlement would develop along the operation life and overstep the operating safety standard eventually. There are some typical cases presenting this phenomena, such as the tunnel deformation near to West Ninghai Rd. pumping station of metro Line 1, leakage of water and sand in pumping station of metro Line 2 crossing river part, Shilong Rd. station of metro Line 3, have been found and treated against to the excessive settlement.

(4) Maintenance and Operation Work

Vibrations of running trains would lead to tunnel settlement, and then water leakage will takes place due to great tunnel settlement. In case the water leakage becomes serious, it will induce more water/soil loss and behave as larger settlement. The vicious circle is formed in this way. The in-time and frequent maintenance work is a good way to prevent this vicious circle. The research on long-term soil mechanics under vibration of high consistancy and low frequency is still undergoing. But it could be ensured that disadvantage of the complicated soil behavior is the main factor of tunnel operation safe.

(5) Loading and Unloading activities near to tunnel

Due to the shortage of landing resource in urban environment like Shanghai city, the projects of foundation pit located in the area of subway protection area tend to
be deeper, bigger, closer, more difficult and more risk. As a consequence, it is necessary to pay more attention to the influence of deep foundation pit excavation and high-rise building to the subway station and tunnel.

(6) Groundwater exploitation, dewatering and pore pressure reduction

Soil consolidation induced by the groundwater exploitation would also influence the subway structures.

4 CONTROL MEASURES

The safety guarantee system for subway structure should take many aspects into account, including the regulation, standard, monitoring management and pre-alarm management.

(1) Regulation and Standard for Subway Control and Protection

Supervised regulation should be established for subway line surveys, inspection and projects construction. Process management and responsibility definition should be enhanced to make sure that the whole subway lines are under control.

(2) Standard of the Monitoring Procedure

It is the responsibility of monitoring engineer to monitor, inspect and analyze subway structure, which aims to find the problem of structure in time and to guarantee the safety of subway. There are at least twice settlement measurements and one convergence measurement for operating line; 3～4 times settlement measurements and once convergence measurement for new line; several times inspection for key positions. More attention should be paid to the monitoring and inspection of projects located in the subway protection area. Up to now, 30000 settlement monitoring points and 1 convergence monitoring point every 5 segment rings were set for metro Line1 to Line 4 which are all operating metro lines in Shanghai.

(3) Disease Record Card System for Subway Structure

Based on decade's observation of longitudinal settlement curves of subway tunnel, positions with large longitudinal settlement curvature are found. Disease record card of subway structure were established to make sure that inspection and monitoring could focus on these positions. Then quick response and actions could be taken according to the results of inspection and monitoring in case of any abnormal situation.

(4) Digital Information System

An overall digital scan for running subway and a big GIS system are planning and constructing respectively. The GIS system would control the safety of subway structure and operation risk using information technology including inspects of geological conditions, tunnel structure, waterproof system, settlement and convergence.

(5) New technology and Equipment

The monitoring system with long distance, large range, high precision and automatization characteristic should be developed continuously. Remote monitoring system and equipment configuration would be set on the key position. The data, graphs and information are able to be transferred and analyzed instantly.

(6) Project located in the Subway Protection Area

Setting protection area aims to reduce the influence of loading and unloading effect from building and excavation to tunnel by enhancing control standard
to the projects located in the subway protection area.

(7) Scientific Research Project located in the Subway Protection Area

The investigation to structural problem of metro, including durability of tunnel, seepage and leakage, settlement and convergence, has been preformed cooperating with research institute. Evaluation system and index will be established to protect subway structure.

REFERENCES


