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The double-o-tube shield tunnel in Shanghai soil

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ABSTRACT: The high building density of shanghai and the wish to construct bigger city transport system lead to an obvious conflict. The double-o-tube shield tunneling was introduced to save underground space. In 2002, Shanghai has built its first double-o-tube shield tunnel in No.8 line. The stress and displacement distribution around the double-o-tube shield tunneling was investigated from an in-situ test.

1 GENERAL INSTRUCTIONS

Shanghai, as one of the biggest city in China, the density of building is quite high. But with the big development of urban city, more and more building and transportation constructions are needed. So the questions that use limited space of shanghai to satisfy all kinds of needs come out these years. In subway area, the double-o-tube shield tunneling was introduced to save underground space. In 2002, Shanghai has built its first double-o-tube shield tunnel in No.8 line. Figure 1 shows the double circular shield which just finished one part of tunnel and broke through the working shaft.

Figure 1. Break through of a double circular shield.

The origin of the double circular shield tunnel may be traced to 1981, when a basic patent was applied for in Japan. The patent was registered in 1987, and a horizontal double circular shield tunnel field trial was performed in the same year. In 1988, a vertical double circular shield tunnel trial was conducted in the field. In the construction of the national road No. 54 tunnel in Hiromiosa, a double circular shield, which was designed and manufactured by Ishikawajima-Harima Heavy Industries Co. Ltd, was used to build the first double circular shield tunnel in the world with length of 853.8 m (Moriya, Y., 2000).

The shield used in Shanghai subway was made in Japan by Ishikawajima-Harima Heavy Industries Co. Ltd and assembled in Shanghai by Shanghai TBM Company. The width of shield is 11.12 m; the diameter of a circular is 6.52 m. The diameter of mostly single circular shields used in Shanghai is 6.4 m. The length of shield is 12.76 m. The distance between the lining and shield is 11 cm. Figure 2 shows the main dimension of double-o-tube shield tunnel shield machine.

The double-o-tube shield tunneling Method is applied for an earth pressure balanced shield machine with interlocking spoke-equipped multiple cutters that are positioned in the same plane. Adjacent cutters rotate in the opposite directions to avoid touching or smashing one another and are thus controlled synchronously. The double circular shield machine is

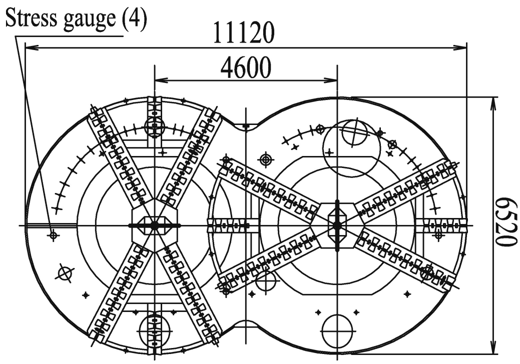

Figure 2. The dimension of the double circular shield.

equipped with cantilever-arm-type erector to erect joint and panel segments, so it provides wide working space. The double-o-tube shield tunnel is composed of 11 prefabricate concrete segments (including the columns in the middle of the tunnel) per section.

2 COMPARISON BETWEEN SINGLE AND DOUBLE-O-TUBE SHIELD TUNNEL

Compared with the single circular shield, the most important advantage of the double-o-tube shield tunnel is saving space. Most of Shanghai metro was built under the road, and the space is limited when the road is relatively narrow. Apparently, the double circular shield tunnel may pass narrower underground corridors, and the impact on nearby structures is minimized (Moriya, Y., 2000 and R.C. Sterling, 1992). Meanwhile, the double circular shield tunnel has an optimized cross-section with a minimized section area, enabling the most efficient use of underground space. Moreover, the cross-passage between two circular shield tunnels is unnecessary for a double circular shield, and construction risk is therefore eliminated. Figure 3 shows you the concept that double circular shield tunnel can save space comparing with two single tunnels.

On the other hand, the double-o-tube shield tunnel has its own disadvantages. The first one is cost. China can produce the single circular shield now, but the double circular shield is made in Japan and assembled in China. Moreover, the construction cost of the double-o-tube shield tunneling is more expensive than two single circular tunnels. Secondly, the double circular shield is not easy to be controlled in small curvature route. Sometimes it needs extra load to balance the shield. Thirdly, the speed of double-o-tube shield tunneling is slower than two single circular tunneling which shared the same shield. The main reason is that the linings fix spends more time.

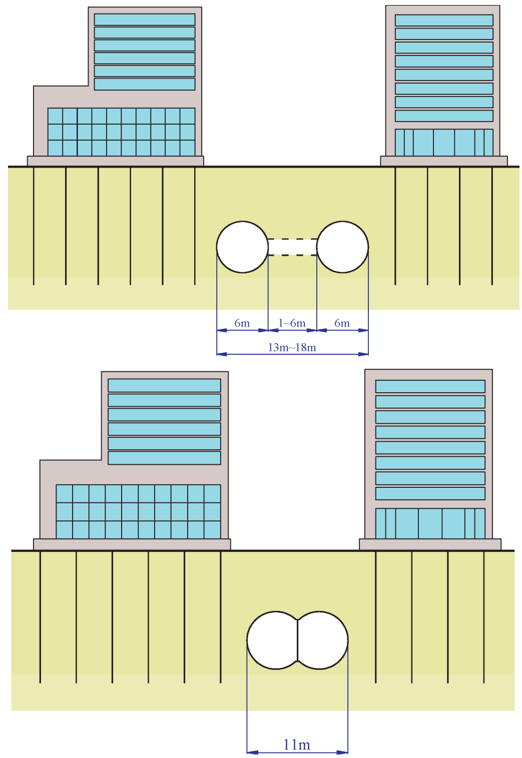

Figure 3. Comparison between single shield tunnel and double circular shield tunnel.

During the tunneling process, there are three important construction parameters: face pressure, speed and grout volume. The face pressure which the double-o-tube shield tunneling used is little higher than which used in the single circular tunneling. Higher face pressure can reduce the settlement while tunnel is finished, however it would induce the higher heave before the opening face.

The speed of the double-o-tube shield tunneling is much lower than the single circular tunneling. The main reason is the lining fix cost more time in the double-o-tube shield tunneling. And maintaining a certain low speed is efficient way for the settlement control. According to the construction experience of Shanghai, lower speed correspond smaller ground settlement especially for shallow cover depth case.

Although grout pressure is more frequently mentioned in theoretical and numerical calculation of the tunneling as the mechanical parameter, in the practical tunneling work of Shanghai, grout volume used to present the effect of grout instead of grout pressure. The main reason is that the grout pressure is unstable and hard to control for real work. The grout volume which the double-o-tube shield tunneling need is much more than the volume which single circular tunneling

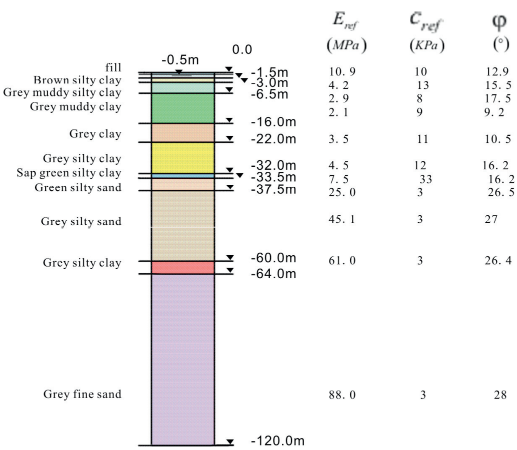

Figure 4. Typical profile of ground condition in Shanghai.

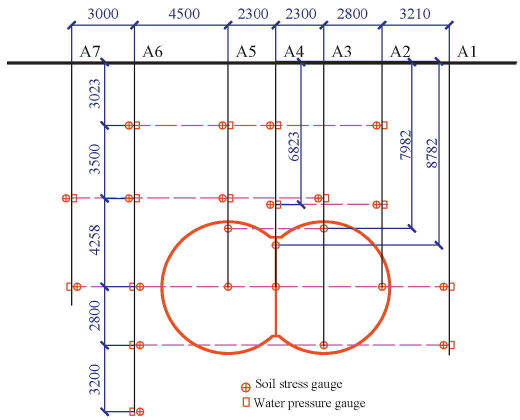

Figure 5. Gauges layout in cross section A.

need. But the grout volume is not a fixed value. It is depend on different soil types, cover depth, grouting point, and grout material. Even while all the factors are same, the grout volume would still be different for different company which in charge of tunneling. It is more based on the experience but not theoretical result.

3 GEOLOGY CONDITION

Since Shanghai is located near the confluent of Huangpu River and Chang jiang (Yangzi River), the soil has been progressively constituted by sedimentation and ended in a superposition of layers. The Shanghai soil can be assumed as homogeneous in most Shanghai land except partial place where some soil layers are missed. In Shanghai area, the mucky soil stratum is down to about 30 m deep from ground surface. It is basically saturated fluid-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 in 4 ~ 5, and evident rheological behavior (Wang Zhen Xin & Bai Yun, 2004). The water table is ranged from 0.3 m ~ 1 m. In this very soft ground, deep excavations for constructing underground metro station and high building basement encounter many difficulties in environment protection. The general ground condition of Shanghai Metro Line is shown in Figure 4.

There are mainly two soil types which double-o-tube shield tunnel cross through. One is the Grey muddy clay and Grey clay which are the typical soft clay layers. Another situation is in the place where the Grey muddy clay is missed and Grey clay is very thin. It means that layer Grey muddy silty clay almost connects with layer Grey silty clay. So the tunnel mainly crosses the silty clay.

Along the tunneling route, most of the cover depth varies from 6 m to 16 m. There are two typical cases according to the different cover depth. One is 8 m cover depth representing shallow cover. Another one is 16 m for deep cover. Surface settlement due to tunneling is significant different between these two cases.

4 IN-SITU TEST

4.1 *Stress distribution in the soil due to the double-o-tube shield tunneling*

Geotechnical engineers discussed on a theoretical base about the soil stress distribution due to double-o-tube shield tunneling at the beginning of double circular method applied in Shanghai. They try to compare the soil stress distribution due to double-o-tube shield tunneling with the results from single circular tunneling. Two theories came out. One opinion is that the soil stress distribution from the double-o-tube shield tunneling could be assumed as the combination of soil stress from two separate single circularities which their location are coincident with double-o-tube shield tunnel. Other engineers prefer to believe that it should be modeled from a bigger equivalent single circular which share same center point with the double-o-tube shield tunnel.

An in-situ test has been done by Shanghai Tunnel Engineering Co. Ltd to investigate the stress and displacement distribution around the double-o-tube shield tunneling. There are 4 sections in which the displacement inspector and stress gauge were placed along the line of tunneling.

Cross section A was designed for observing the soil stress increment and water stress increment. Figure 5 shows the layout of gauges on cross section A.

Figure 6 shows the vertical soil stress increment in the plane which in 1.5 m ahead of the opening face.

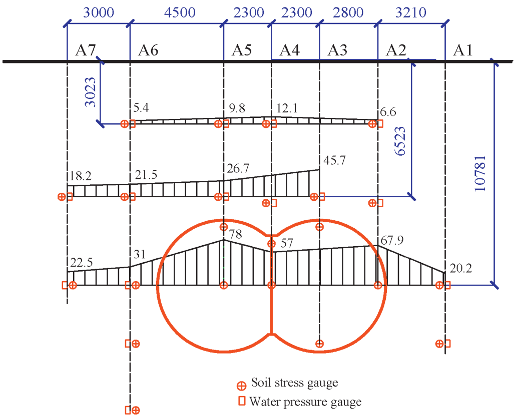

Figure 6. The vertical stress increment in 1.5 m ahead of the opening face.

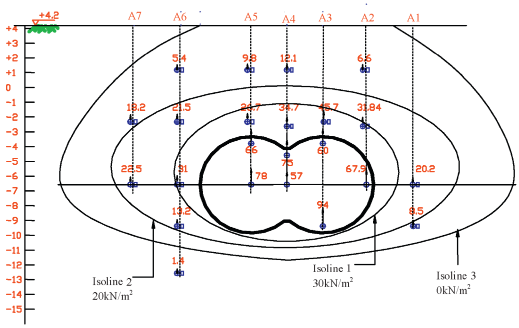

Figure 7. The vertical stress increment distribution in 1.5 m ahead of the opening face.

There are three soil stress increment distribution line in figure 7 with different depth. It is drawn from 4 inspectors at 3.02 m deep, 4 at 6.52 m and 6 at 10.78 m. It is different tendency for these distribution lines. A triangle shape which the largest soil stress increment occurred on the middle vertical line of double-o-tube shield tunnel is got for the top distribution line which near to ground surface. For the bottom distribution line which lies on the same depth level with tunnel horizontal central line, the stress increment in the middle point of tunnel is smaller than the one in the center point of two circles.

Figure 7 shows the soil stress distribution due to the double-o-tube shield tunneling of one section. The black line in figure represents the isoline soil stress around the tunnel at the time while the opening face is 1.5 m behind.

From the result, the soil stress distribution induced by tunneling is more closed to an ellipse than the combination of two single circularities or a big circularity.

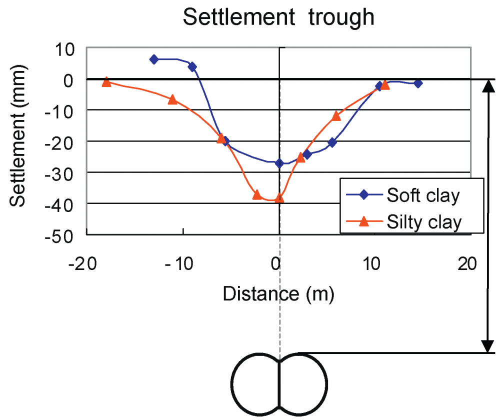

Figure 8. The settlement troughs with cover depth of 8 m.

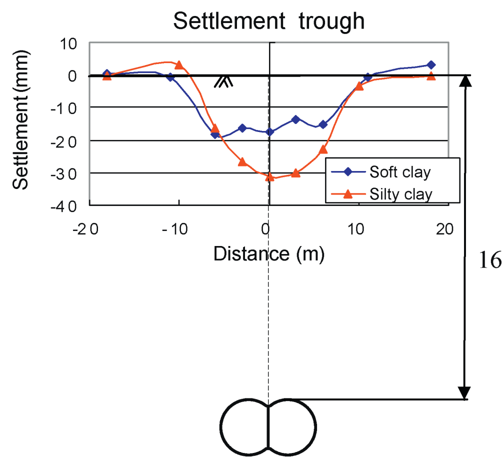

Figure 9. The settlement troughs with cover depth of 16 m.

And the effective influence width from double-o-tube shield tunneling is mostly 2.5 times to width of tunnel.

4.2 *Surface settlement due to the double-o-tube shield tunneling*

The requirement of surface displacement due to tunneling is $+1 \sim -3$ cm in Shanghai. In the beginning of the double-o-tube shield tunneling, the settlement was surprisingly high. Many people suspected this tunneling method at the beginning of double-o-tube shield tunnel applying, however after some projects; the engineers acquire the experience of the double-o-tube shield tunneling, the settlement has been under control in most conditions.

Figure 8 and Figure 9 give the surface settlement trough due to tunneling in two cases. And each figure shows two soil types which tunnel cross through.

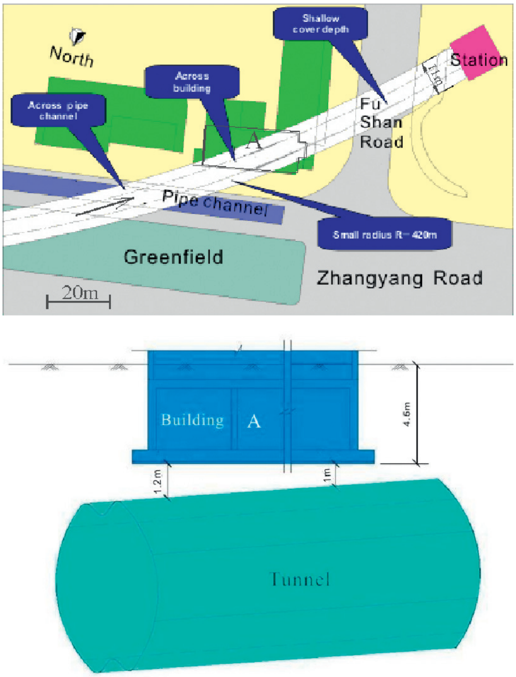

Figure 10. The plan view and transverse section of the double-o-tube shield tunnel crossing building A.

It is hard to obtain equal volume loss for each circle in the advance of tunneling, especially in the curve. So from these two figures, it is quite normal phenomena that the settlement trough is asymmetry to the center of shield.

Concerning the influence of soil type, the maximum settlement of silty clay is higher than the value of clay. Meanwhile the settlement trough of clay is wider. The main reason is that the influence area in the soft clay is lager than the one in silty clay with the same construction conditions, not only in the cross section but also in the longitudinal direction.

Comparing the data in different cover depth, the maximum settlement of 16 m cover depth is less than the one of 8 m cover depth. In the same time, the settlement trough of 16 m is wider than the one of 8 m cover depth. This phenomenon is coinciding with the Peck formula.

5 DOUBLE-O-TUBE SHIELD TUNNEL CROSSING BUILDING

Here is an interesting project during the double-o-tube shield tunneling. There are three key construction phase of this double-o-tube shield tunnel line. The shield need across three key section- pipe channel, five-floor buildings and shallow cover depth area. The current paper will represent the second key section which tunnel crossing a five stories building.

Figure 10 shows the plane view of three key construction phases and the cross section of second one. The distance of the building and the tunnel is very close; it ranged from 1.2 m to 1.0 m. It is great risk that the tunnel crosses a building with such close distance. Especially this building with raft foundation has already had 0.3% inclination. According to Chinese foundation code, the maximum inclination of building should be controlled under 0.4%. Meanwhile it has been mentioned before that there are not enough experiences of the double-o-tube shield tunneling comparing with the single circular tunneling.

Shanghai Tunnel Engineering Co. Ltd take series actions to control the ground settlement and reduce the influence of tunneling to building raft foundation. In the process of tunneling, the face pressure remains high level. The grout volume happened in the tail is larger than the value which used normally. The tunneling speed was maintained at very low in the whole process. Moreover, extra grout was used while the tail passed. With all these construction method, it results in that the settlement and the inclination of the building was controlled well.

There were 6 displacement inspectors installed in the foundation of the building. The final measurement data were given in Figure 11.

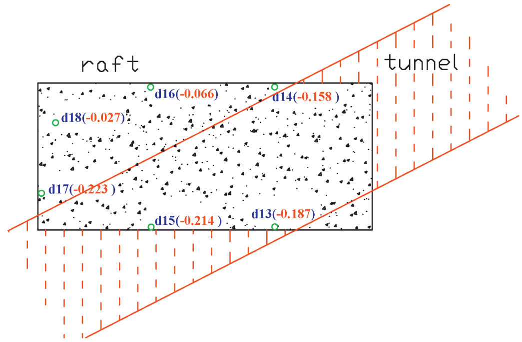

Figure 11. The measurement results of building settlement after tunnel crossing.

The blue number shows the location of displacement inspectors. The red number is the settlement of raft foundation respectively corresponding to each inspectors and the unit is centimeter. The measurement of settlement ranged from 0.3–2.2 mm. It means that the tunneling is successful. The building is almost intact and no change can be detected by eyes.

6 CONCLUSIONS

The double-o-tube shield tunneling has been applied in Shanghai successfully. The settlement can be controlled in a very low value. The construction is more based on the experience but not theoretical result. Furthering research need to be done to get a theoretical guarantee for future work.

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