Behavior of subway tunnel driven by large slurry shield

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ABSTRACT: Based upon in-situ measurements of ground movement caused tunnel excavation with shield, several construction factors have been investigated and are found to be the cause of ground movements in decomposed granite soil. It is found that the ground settlements are as follows, (1) Preceding ground settlement depends upon effective slurry pressure against earth pressure and responds to the vibration of the slurry pressure. (2) Ground settlement above the shield machine depends upon the pose of machine. (3) Ground settlement at tail of the shield passing can be adjusted by controlling of simultaneous grouting.

1. INTRODUCTION

This paper presents a performance of large diameter shield tunneling for a subway, from Hakata Railway station to Fukuoka airport, Fukuoka city. The diameter of the shield tunnel is 10.2 m and the depth of the tunnel is 8 to 16 m from the crown to the surface. The soil in the excavation area is mainly decomposed granite. In urban area, the excavating condition is very serious at some place where tunnel passes beneath the buried pipe lines, large warehouse and apron area of the Fukuoka airport. To avoid excessive settlements of the ground at these sites, a systematic instrumentation is planned to monitor ground behavior during the excavation by slurry shield and to analyze the influence of construction factors on the ground movements.

2. GEOLOGICAL PROFILE AND GEOTECHNICAL PROPERTIES

Fig.1 shows geological profile of the shield tunnel section. The tunnel goes through the decomposed granite soil layer under the Holocene and Pleistocene deposit mainly consists of sand. Fig.2 shows the relation between tunnel depth and N-value of the ground. Fig.3 shows the grain size distribution of excavated soil.

3. IN-SITU OBSERVATION

Two sites are selected to monitor the ground response due to trial excavation by several kinds of shield tunneling. The first site is near the starting shaft and the second one is at the point where the depth of the shield changes to be shallow. Each site has three monitoring sections as shown in Fig.4, which correspond to different slurry pressures as well as grouting procedure. Section A and B are measured positions of only vertical settlements above the shield, while section C is a measured position of ground settlements around tunnel section as well as pore water pressure response. Fig.5 shows the observed ground settlements during shield excavation at the site No.2. The settlement can be characterized into three phases according to the position of

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Fig. 1 Geological profile  
Fig. 2 N-value distribution
shield machine away from the measuring point. The first phase is a small preceding ground response in front of the machine. The second phase is settlement above the machine passing. The final phase occurs after the passage of the machine tail. The settlement before shield machine pass through increases with the advance of the machine. The maximum settlement of surface right above the crown is about 5 mm. The ground movement when the machine passing through is mainly caused by the pitching of jack. The movement when tail goes away is the accumulation of the settlement caused by each tail void. The final settlement at crown and ground surface right above crown is about 8 mm, 7 mm respectively. Fig. 6 shows ground deformation at 7 meters after machine tail passing. Ground movement above the tunnel crown is approximately vertical. On the other hand, ground deformation of tunnel side moves horizontally into the tunnel center.

Fig. 3 Grain size accumulation curve

Fig. 4 Monitoring site No.2

Fig. 5 Observed ground settlement under shield driving conditions (section B at the site No.2)
4. SETTLEMENT BEFORE CUTTING FACE PASS THROUGH

The shield excavation factors that affect the ground settlement before the cutting face pass through can be thought as slurry pressure and its vibration. Fig. 7 shows relation between preceding ground settlement and slurry pressure. It is found that ground settlements decrease in proportion to increasing slurry pressure. Fig. 8 shows the slurry pressure vibrations and settlements against time. Observed slurry pressure values distribute within approximately +2.0 N/cm² around the prescribed value. At the point of arrow on Fig. 8, slurry pressure is temporary under the hydrostatic pressure, ground settlements increase at a moment.

5. SETTLEMENT WHEN SHIELD MACHINE PASSING THROUGH

The shield excavation factor affecting the ground settlement when shield machine passing through is mainly the controlling of shield machine pose. Those are two types as follows, (1) the inclination of shield machine concerning longitudinal direction, (2) temporary lifting the tail of shield machine by shoving jack stroke. Fig. 9 shows the settlement at 1m above shield crown during an ascending slope. The pose of shield machine is schematically shown in Fig. 10. Jacking operation causes the up movement the shield tail and then the ground heaves. Moreover, inclination of shield machine is less than the designed gradient in this figure, which also cause the ground to heave when shield passing through.
Fig. 11 Backfill grouting and ground settlement (site No.1)

6. SETTLEMENT AFTER TAIL PASS AWAY

Fig.11 shows relation between backfill grouting and ground settlement. Backfill grouting started after the jack advanced 30 cm. That is right the position where grouting hole of segment passed tail seal. Shield machine advances 1m per jacking. If keeping more than 5 minutes grouting under constant pressure for each jacking, the settlement can be repressed to negligible extent.

7. EFFECT OF SLURRY PRESSURE

As shown in Fig.7, ground settlements increase in proportion to slurry pressure. The effect of slurry on ground settlements depends on its properties and the geological conditions. The stability of cutting face depends on slurry pressure, therefore, it is very important to monitor the pore water pressure before the cutting face goes through the observational section. Slurry pressure acting on cutting face is transmitted through the ground, decreasing with the distance from the cutting face. Here, we defined U, the normalized slurry pressure loss.

\[
U(\%) = \frac{P_e - P_w}{P_b - P_w} \times 100
\]

where:
- \( P_e \): pore water pressure at observational point
- \( P_b \): slurry pressure at the center of cutting face
- \( P_w \): hydrostatic pressure
- \( U \): normalized slurry pressure loss
- \( L \): the distance from cutting face to observational point

L is the distance from cutting face to observational point. The relation between \( U \) and \( L \) is shown in Fig.12. In this figure, curve-c indicates that the loss of slurry pressure is small because the permeation of slurry into the soil forms the mud film. On the other hand, curve-a indicates that the loss is large. Fig.13 shows relation between \( U \) at \( L=0.5 \) m and the settlement at 1m above shield crown. It is found that settlement is decreasing in proportion to \( U \).

8. CONCLUSION

(1) Settlement before cutting face pass through is sensitive to the slurry pressure as well as the pressure changes. The settlement depends on the difference of pressure between the pore water pressure in the ground and the appreciated slurry pressure.

(2) Settlements when the shield machine passing through is found to be related to the pose of the shield machine.

(3) Settlements after the tail passed away can be controlled by the continuation of grouting under constant pressure, even though the simultaneous backfill grouting is filled up into the void behind the shield segments.

On this field monitoring, the shield excavation was controlled under the minimum disturbance of the ground. The settlements of ground surface were observed below 10 mm due to the shield excavation.

REFERENCES

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