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Reducing ground settlement caused by shield tunneling in soft clay

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SYNOPSIS: The shield method which has being widely used as urban tunneling method recently, is often applied in the excavation projects with very closed to surrounding structures. Therefore, it is necessary to develop the technology to repress as possibly as the ground deformation caused by shield advancing. For this reason, we used the following procedures to reduce the settlement caused by tunneling with earth-pressure-balanced shield in soft clay, (1)increasing the flowability of the excavated soil in the chamber of shield, (2) grouting lubricating materials to reduce the friction between shield and ground, (3) simultaneous back-fill grouting. Besides, by measuring the settlement of ground, horizontal displacement, earth pressure and pore-water pressure, the relation between the deformation of ground and constructing procedures is investigated. By an excavating procedure based on the result obtained from above investigation, the settlement of ground surface can be controlled within 1~3 cm.

1 INTRODUCTION

The most of the shields being used in urban tunneling in Japan are earth-pressure-balanced shield or slurry shield. Though great improvement has been made for these tunnel excavating methods, it is impossible to reduce the settlement of ground to zero. Hirata et al. (1986) pointed out the following typical excavating factors which affect the settlement of ground caused by shield advancing in soft clay,

(1) The unbalance of the earth pressure on cutting face.
(2) Over cutting needed for the pose controlling of shield machine.
(3) The friction between the skinplate and ground
(4) Tail void occurred after the passing through of the tail of shield.

These facts are related to the instant ground settlement during tunneling and the long-term settlement after the passing through of the shield. Hirata (1985) discussed the relation between back-fill grouting and settlement. Mori and Akagi(1980), Hirata(1985) discussed the mechanism of successive settlement.

In this paper, based on field measurement, the controlling method of earth pressure on cutting face and back-fill grouting aimed to repress the ground settlement is studied. The successive settlement is also considered based on the field measurement. Three tunnels with about one kilometer length each tunnel, located at Kyobashi, Imafuku and Tsurumi, had been excavated during 1987~1988. In the tunnel excavation, slurry, air and earth-pressure-balanced shields are used respectively. In the paper, the main consideration is focused on the excavating procedure and the ground behavior at Tsurumi tunnel.

2 GENERAL VIEW OF TSURUMI TUNNEL

Table 1 shows the general view of the construction of Tsurumi tunnel. Table 2 illustrates the arrangement of shield machine against settlement.

Table 1 Design of Tsurumi Tunnel

Style	Parallel twin tunnel
Length	1001m
Interval of two tunnels	3.3m~8.5m
Earth coverage	9.7m~17.5m
Shield machine type	Earth-pressure-balanced
O.D. of shield	5.4m
Opening ratio of face	22%

Table 2 Countermeasure of shield against settlement

Flowability in chamber	The central bearing style of cuter is used,The wing coated with polypropiren is installed
Reduction of friction	Lubricating material is spewed from skinplate at the rate of 0.7 liter/min
Tail void	simultaneous back-fill grouting is carried out. Theback -filling material is clay-sand mortar (mixed air is 31.5%)

As shown in Fig. 1, the ground from G.L. -1.5m~-20m is very soft sensitive clay layer. Beneath that, there exist relative loose sand and very dense sand with gravel. The clay layer is estimated to be normally consolidated, with the N value of 0~3 and uniaxial compressive strength q_u=0.5~1.0kgf/cm^2 as shown in Fig. 2. The sand layer and sand with gravel layer are aquifer with about 1.0kgf/cm^2 water pressure. The shield tunnel is excavated within soft clay layer at the starting and ending parts of the tunnel, while in the middle part, it is just at the boundary between clay and sand.

3 EXCAVATION METHOD AND FIELD MEASUREMENT

As for the controlling of the cutting face, the pose of shield

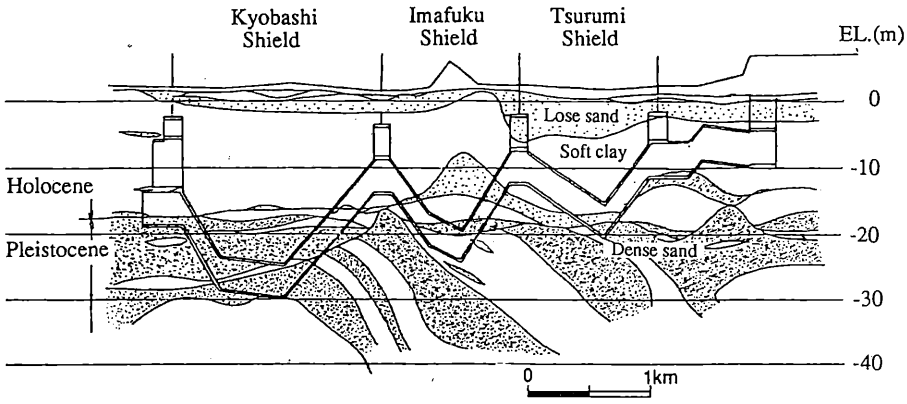


Fig.1 Geologic profile

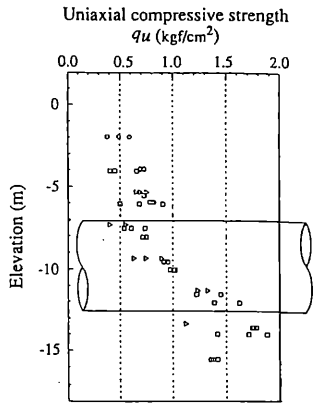


Fig.2 Distribution of uniaxial compressive strength along vertical direction

machine and tail of shield, the following technical arrangements in tunnel excavation are used,

(1) The earth pressure in chamber is within the value of initial earth pressure ±2 Cu.
(2) Based on the result of pre-experiment, the lubricating materials is spewed from skinplate at 0.7 liter/min.
(3) The back-filling pressure at crown is adjusted within initial earth pressure ± 2 Cu which is the net pressure that the pressure loss from pump to nozzle has already be deducted. The amount of grouting is controlled based on the complementary value in which the compressed air mixed in the grouting material has been taken into consideration and the standard that the expansion caused by grouting does not exceed, say the tangential strain in tunnel periphery $\varepsilon_\theta \leq 0.5\%$, so as to avoid large disturbance.

Fig. 3 and Fig. 4 show the typical observed results of ground deformation at one observing point. The tunnel is excavated under the condition that the vertical earth pressure at the center of shield is 2.1.kgf/cm^2, K_0=0.8 and the earth pressure in chamber is 1.7 kgf/cm^2. Here, K_0=(total horizontal stress/total vertical stress). When the shield comes near, the settlement at the place 0.5meter above the shield machine is almost zero, the horizontal displacement along shield advancing direction is about 7 mm and the horizontal displacement along cross section direction at the place 0.7m away from shield is about 5 mm. The deformation pattern shows expansive tendency.

During the shield pass through, some settlement occurred but the horizontal displacement did not increase.

As an example of lower grouting pressure, 2.0 kgf/cm^2 grouting pressure is applied, whose net pressure is equivalent to 1.3 kgf/cm^2 if the pressure loss is deducted. The grouting pressure in present case is thus lower than the initial earth pressure at the crown, that is, 1.6 kgf/cm^2. The settlement is about 4~5 mm and horizontal displacement along cross section is about 6 mm, showing expansive tendency.

We at first do excavation under several condition at trial area, then choose the best one under which the further excavation is carried out.

4 RELATION BETWEEN CHAMBER PRESSURE AND SETTLEMENT

Fig. 5 shows the relation between chamber pressure and deformation. Settlement occurs along vertical direction while the horizontal displacements are heaving. The suitable chamber pressure is found to be 1.6 kgf/cm^2, this is equivalent to 0.95 × initial earth pressure, on this condition, the horizontal displacement can be minimized.

5 EFFECT OF LUBRICATION

The instant deformation occurs when the shield pass through is found to be caused by the friction of shield machine and the over-cut needed for the controlling of shield pose. However, the lubricating effect cannot be distinctively identified by observed deformation.

Fig. 6 shows the changes of the thrusts of jacks in two shields. Within the two shields, the primary shield stopped spewing lubricating material at the point 54 meter away from starting point. Before stopping spewing, the thrusts of the two jacks are almost same. However, the thrust of the jack which stopped spewing after 54 meter away increased prominently. This improves that the spewing of lubricating material greatly reduces the friction between ground and skinplate, leading to the reduction of thrust of jack. This shows that the lubricating effect is useful for the repression of successive settlement.

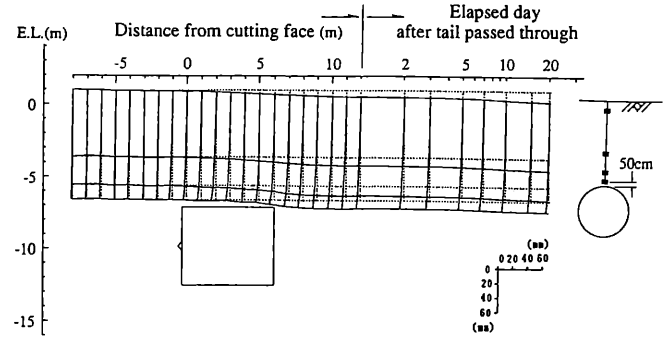


Fig.3 The vertical and horizontal displacements along vertical central axis

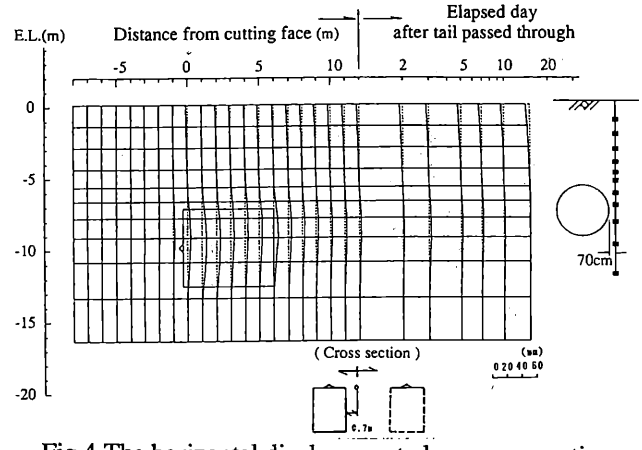
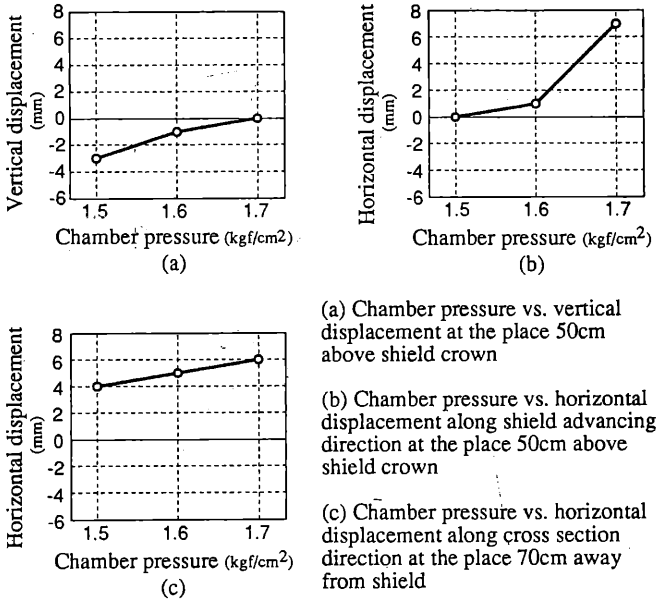


Fig.4 The horizontal displacement along cross section direction



(a) Chamber pressure vs. vertical displacement at the place 50cm above shield crown

(b) Chamber pressure vs. horizontal displacement along shield advancing direction at the place 50cm above shield crown

(c) Chamber pressure vs. horizontal displacement along cross section direction at the place 70cm away from shield

Fig.5 Relation between chamber pressure and deformation

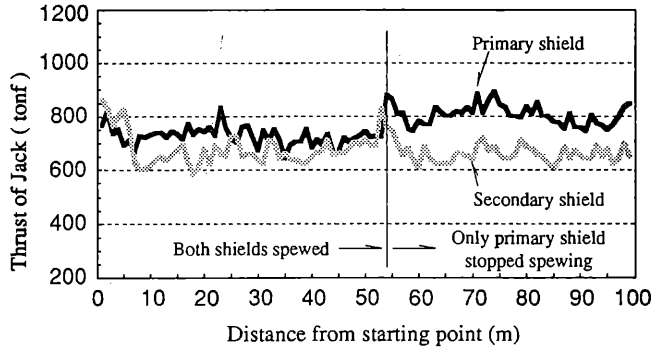


Fig.6 The change of thrust of jack

6 RELATION BETWEEN BACK-FILL GROUTING AND SETTLEMENT

In order to understand the net grouting pressure applied to tail void, it is necessary to estimate or measure the pressure loss from pump to nozzle. Fig. 7 shows the observed back pressure which acting upon outside of segment during the tail passing through. In the figure, P0 is the pump pressure. P1~P6 are back pressures. The observed grouting pressure changed a little immediately after excavation and soon transformed uniformly around tunnel periphery. The pressure loss of the grouting machine is found to be about 0.7 kgf/cm^2.

Fig.8(a) show the relation between the vertical displacement at the point 50cm above the crown when tail is passing through and complemented grouting pressure. The vertical displacement are within ± 10 mm. In Fig.8(b), most of the complemented grouting ratio are about 120 ± 10 %. The line which stand for the tangential strain $\varepsilon\theta$=0.5% is also given in the figures, which corresponds to the complemented grouting ratio of 120%.

7 SUCCESSIVE SETTLEMENT

Fig. 9 shows the successive vertical strains within the period of five months after six months of the shield passed through. It is found that only at the vicinity of shield, the successive long-term compressive strain increase after the shield passed through. We also set up settlement meters at the crown segment and the point 25 cm above the crown after the primary shield passed through one week. Fig. 10 shows the distribution of the vertical strain one year after the inclinometer set up. The strain in the vicinity of the segment of 0~25cm is about 2% and 0.8% for 25~50cm. The vertical strain at ground surface can be negligible, showing the exponential decreased distribution along the direction from tunnel to ground surface.

Based on above study, it can be estimated that the range where large shear strain will occur because of the long-term successive settlement caused by shield is only restricted to the vicinity of tunnel periphery.

8 CONCLUSION

In this paper, we try to find out the relation between the technical procedures of tunnel driving and the settlement caused by shield advancing in sensitive soft clay. The technique for the repression of settlement can be summarized as follow.

(1) Before shield pass through: The earth pressure in chamber should be controlled within the value of initial earth pressure ±2 Cu. As a result, the settlement will be repressed to minimum.

(2) During shield passing through: In order to reduce the friction between ground and skinplate, lubricating materials is spewed out from skinplate. The reduction of total thrust of jack is confirmed, which can be deduced to the conclusion that lubrication is effective to avoid disturbing clay.

(3) After tail pass through: The back-filling pressure is

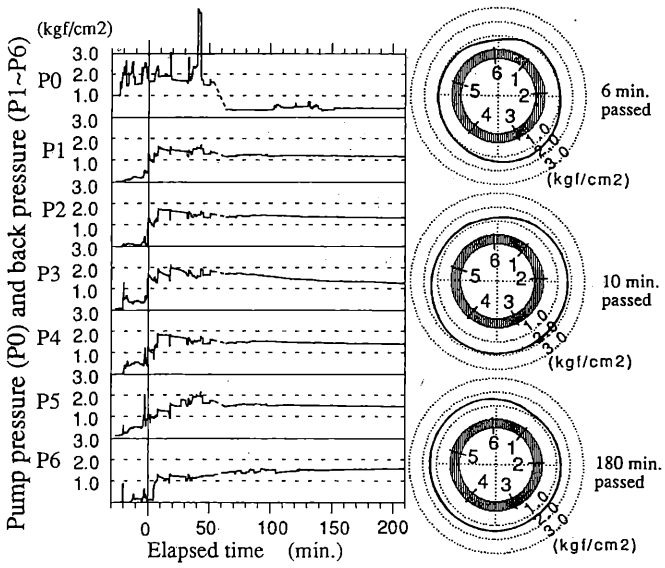
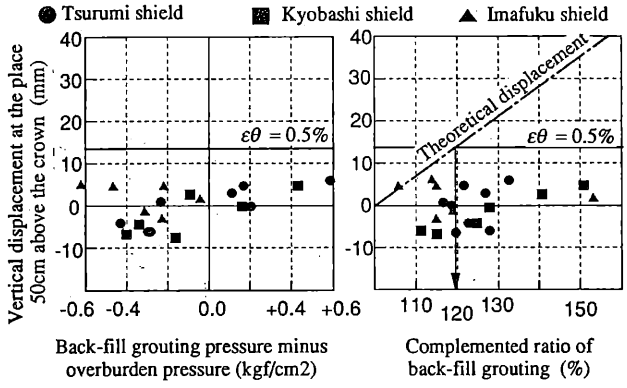


Fig.7 The observation of pressure loss of back-fill grouting



(a) Pressure vs. displacement (b) Complemented ratio vs. displacement

Fig.8 Relation between back-fill grouting and vertical displacement

adjusted within initial earth pressure at crown which should be the net pressure that the pressure loss from pump to spew month has already be deducted. The amount of grouting is controlled based on the concept that the large expansion caused by grouting does not occur. As a result, the vertical displacement is repressed within ±10 mm.

(4) Successive settlement: The successive long-term strain after shield passed through only occurs at the vicinity of tunnel. Because the final settlement is caused by the accumulated influence of all technical procedures of tunnel driving, the disturbance of clay by every constructing factor must be repressed.

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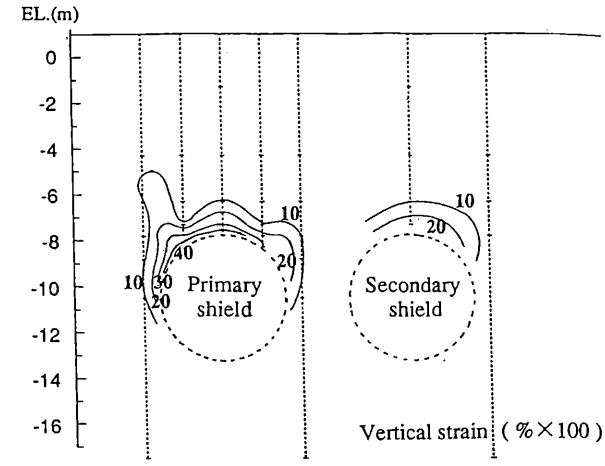

Fig.9 Distribution of vertical strain for six months after shield passed through

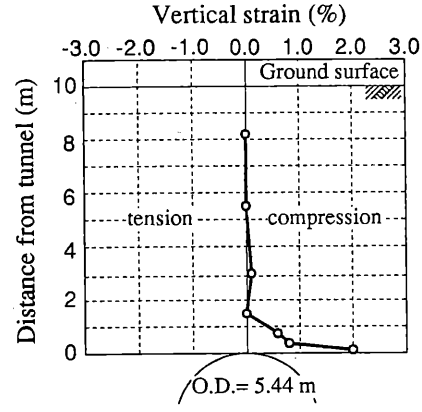

Fig.10 Distribution of vertical strain for one year after shield passed through