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Field test and research on shield cutting pile penetrating cement soil single pile composite foundation

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Abstract. In this paper, due to the need for cutting cement-soil group pile composite foundation under the 7-story masonry structure of Zhenghe District and the shield tunnel of Zhengzhou Metro Line 5, a field test was conducted to directly cut cement-soil single pile composite foundation with diameter Φ=500 mm. Research results showed that the load transfer mechanism of composite foundation was not changed before and after shield tunnel cut the pile, and pile body and the soil between piles was still responsible for overburden load. The construction disturbance of shield cutting pile is a complicated mechanical process. The load carried by the original pile body was affected by the disturbance effect of pile cutting construction. Also, the fraction of the load carried by the original pile body was transferred to the soil between the piles and therefore, the bearing capacity of composite foundation was not decreased. Only the fractions of the load carried by pile and the soil between piles were distributed. On-site monitoring results showed that the settlement of pressure-bearing plates produced during shield cutting stage accounted for about 7% of total settlement. After the completion of pile cutting, the settlements of bearing plates generated by shield machine during residual pile composite foundation stage and shield machine tail were far away from residual pile composite foundation stage which accounted for about 15% and 74% of total settlement, respectively. In order to reduce the impact of shield cutting pile construction on the settlement of upper composite foundation, it was recommended to take measures such as optimization of shield construction parameters, radial grouting reinforcement and "clay shock" grouting within the disturbance range of shield cutting pile construction. Before pile cutting, the pile-soil stress ratio n of composite foundation was 2.437. After the shield cut pile is completed, the soil around the lining structure is gradually consolidated and reshaped, and residual pile composite foundation reaches a new state of force balance. This was because the condensation of grouting layer could increase the resistance of remaining pile end and friction resistance of the side of the pile.

Keywords: shield cutting pile; penetrating; cement soil single pile composite foundation; field test

1. Introduction

In recent years, with the continuous construction of urban subway projects in various countries, subway tunnel construction near original underground structures has increased significantly. Compared with the past, recent projects not only have larger scales, but also are closer to underground structures, and even touch the piles of buildings in some cases. Therefore, researchers around the world have performed a great number of research works on the impact of shield tunnel underpass construction on existing structures (Zhang *et al.* 2016, Ding *et al.* 2017, Fu *et al.* 2014, Bilotta *et al.* 2016, Carles *et al.* 2017, Giardina *et al.* 2015). However, many studies have focused on the penetration of natural foundations (Loganathan *et al.* 1998, Attewell *et al.* 1986, Verruijt *et al.* 1996) and pile foundations (Selemetas *et al.* 2017, Thayanan *et al.* 2014, Liu *et al.* 2014, Chen *et al.* 2011). Shield machines usually pass directly beneath the obstacle or pass by its side. However, to the best of the authors knowledge, no study has been conducted on the influence of shield cutting piles under existing composite foundations. At present, research on the special working conditions of cutting pile penetration under construction is extremely rare. Therefore, the impact of shield machine direct-cut pile construction on the bearing characteristics of composite foundations has become a major scientific challenge in the field of shield design and construction.

Composite foundations (Gong 2007) are composed of three parts: cushion layer, pile body and soil between piles. Composite foundations bearing mechanism is obviously different from those of natural and pile foundations. Due to the arrangement of cushion layer, upper load is exerted on pile and the soil between piles through cushion layer and pile and soil are deformed in a coordinated manner; therefore, the soil between piles participates in bearing work. Pile-soil stress ratio n is an important parameter reflecting the bearing behavior of composite foundations and is also an important index for calculating the bearing capacity and settlement of composite foundations. It refers to the ratio of pile top stress σ_p to soil stress σ_s in composite

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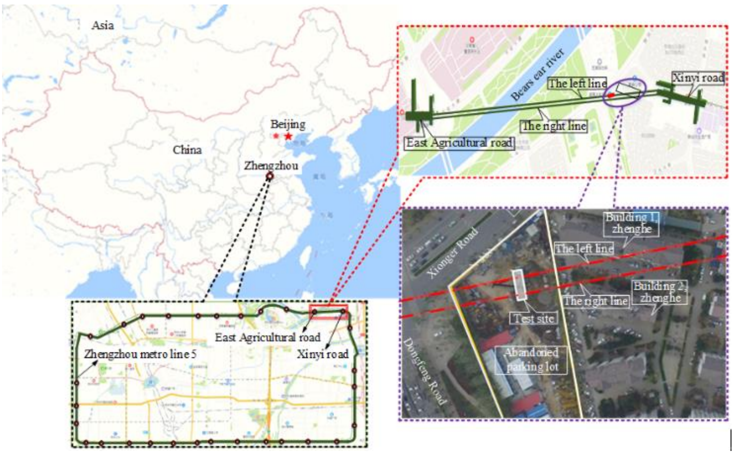


Fig. 1 Specific location of the test area

Table 1 Geological conditions and related parameters of shield tunneling

Soil layer number	Name	Layer thickness (m)	Bottom relative elevation	Bottom absolute elevation	Natural severity (kN / m^3)	Cohesion (kPa)	Internal friction angle (°)
①1	Miscellaneous soil	2.0	2.0	85.08	18.0	20	20
②31A	Clayey silt	3.5	5.5	81.58	18.9	20.0	22.1
②32	Clayey silt	2.6	8.1	78.98	19.4	19.9	21.2
②21	Silty clay	1.6	9.7	77.38	19.6	29.5	16.4
②33	Clayey silt	2.2	11.9	75.18	19.9	19.0	20.4
②22	Silty clay	2.1	14.0	73.08	19.4	31.2	15.6
②34	Clayey silt	1.9	15.9	71.18	20.2	19.3	20.7
②51	Fine sand	7.0	22.9	64.23	19.4	1.5	32.0
②52	Fine sand	7.2	30.0	57.08	19.5	1.5	34.0
③23	Silty clay	9.7	39.7	47.43	20.3	37.1	17.4
③52	Fine sand	5.2	44.8	42.28	19.5	1.5	35.0
③24	Silty clay	5.0	49.8	37.28	20.3	41.7	19.8

foundations; that is $n = \sigma_p / \sigma_s$.

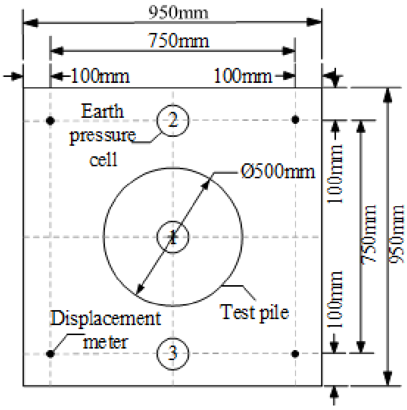
In this work, we have studied the shield construction section of Nongye East Road~Xinyi Road of Zhengzhou Metro Line 5. The background of the project is that the composite foundation of shield cut pile group passes through Zhenhe community. Based on the field test of shield cut cement-soil single pile composite foundation, the change rules of pile-soil stress ratio n, cumulative settlement S of composite foundation and surface settlement trough in the process of pile cutting were studied. The influence of shield cutting piles on the bearing behavior of composite foundation was explained based on the bearing mechanism of composite foundation. We have also tried to provide reference for similar projects in the future to reduce the probability of disasters caused by shield-cutting piles passing through composite foundations.

2. Engineering background

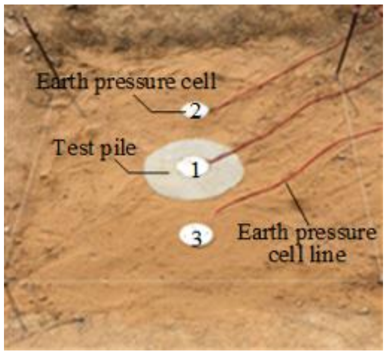
This study has investigated the 7-layer masonry structure project of shield cutting group piles of Zhengzhou Metro Line 5. The building is a semi-basement with a C30 concrete strip foundation. The elevation of the location is -4.3 m. A composite foundation of cement and soil piles was constructed with graded sandstone cushion thickness of 0.2 m, coarse sand to gravel ratio of 3:7, cement soil mixing ratio of 0.2, and cement number of 32.5. Also, soil diameter was 0.5 m, pile spacing was 0.95 m, effective pile length was 11 m and the soil thickness of shield tunnel was 11.7 m. Ø6420 earth pressure balance shield machine was adopted in experiments. Cutter type was panel type + spoke type, opening rate was 38%, and the maximum particle size of allowed slag was 0.3 m. The excavation of shield machine was mainly performed by cutting, supplemented by rolling. The fragments created by the cutting of cement soil pile by cutter head could directly enter soil bunker without being broken. The length of shield machine cutting pile was about 2.4 m~3.7 m and a total of 175 piles were cut under building section, accounting for 16% of the total number of piles in the composite foundation of the masonry building. The outer and inner diameters of segment D were 6.2 and 5.5 m, respectively, wall thickness was 0.35 m, lining ring width of lower penetration section was 1.5 m, segment material was C50 concrete and segment was assembled by staggering.

(a) (b)

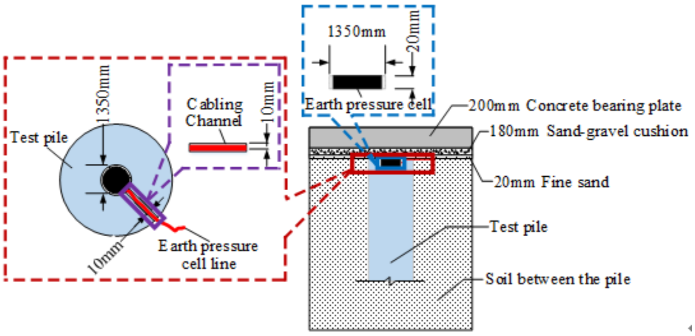
Fig. 2 Field test loading photos



(a) Layout of pressure cells and displacement meter



(b) The physical drawing of buried earth pressure cells buried



(c) Schematic diagram of embedding earth pressure cells

Fig. 3 Schematic diagram of layout, the embedding of earth pressure cells and displacement meter

The purpose of the field test of shield-cut cement-soil single-pile composite foundation was to guide actual engineering construction of the shield cutting pile passing through No. 1 building of Zhenghe Community. A field test study was carried out on shield-cut cement-soil single pile composite foundations. The specific location of test area is shown in Fig. 1 and formation conditions are summarized in Table 1.

3. Experimental study on shield cutting cement-soil single pile composite foundation

In order to optimize shield construction parameters and eliminate the adverse impacts of shield machine cutting pile under construction on the existing multi-layer masonry houses, a test section was selected at the construction site to carry out the load test of single pile composite foundation of cement-soil. Pressure plate settlement and pile-soil stress data were monitored and analyzed during the whole process of machine-cut pile passing through cement-soil single pile composite foundation. The specific content and work arrangement of the field test were as described in section 3.1.

3.1 Static load experimental design of single soil-cement composite foundation

3.1.1 Design parameters

In the field test, cement-soil pile properties were: cement-soil mixing ratio 0.2, cement grade 32.5, pile diameter 0.5 m, and pile spacing 0.95 m. Cushion was made

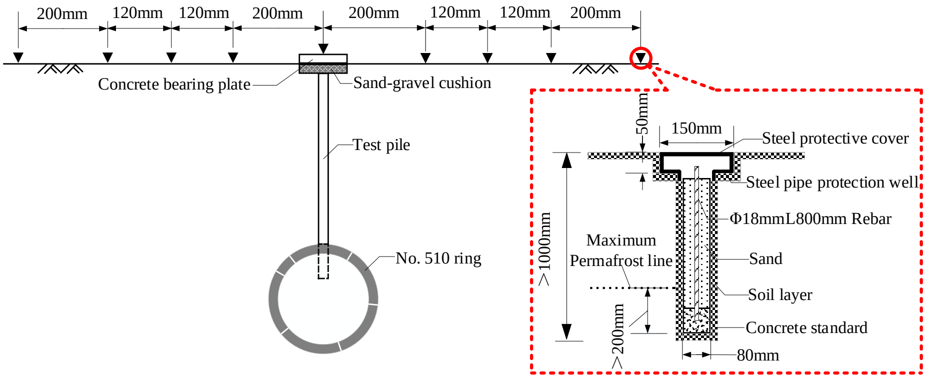
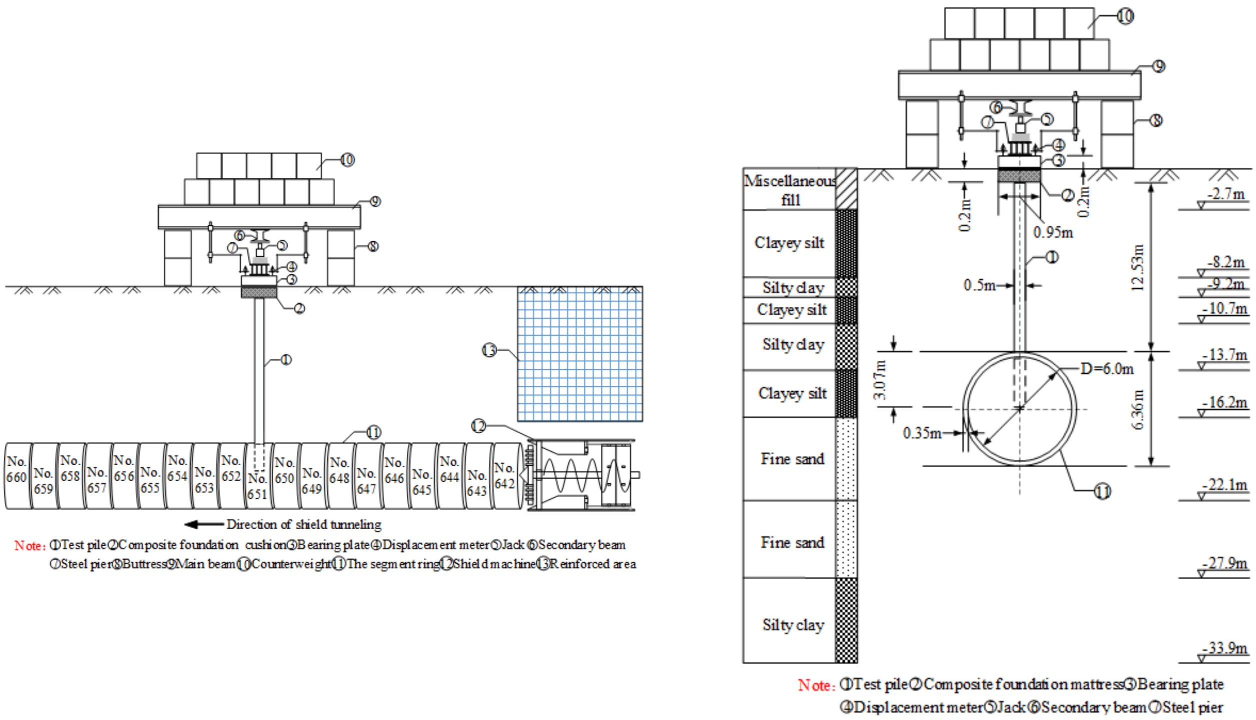


Fig. 4 Surface subsidence monitoring section and schematic diagram of measuring point embedding

Table 2 Earth pressure cell and displacement meter monitor frequency

Monitoring item	Monitoring method	Monitoring period	Monitoring frequency	Monitoring accuracy	Remarks
Bearing plate settlement	Resistive Displacement meter	Shield cutter head out of reinforcement area ~ 20 m after shield tail leaves test area	1 time / 0.5h	±0.05 mm	Special circumstances require encrypted monitoring
Soil pressure between piles and pile top soil pressure	Resistive Soil pressure cell		1 time / 0.5h	5‰ of component range	
Ground surface settlement	High precision level		2 times / 1 day	±0.01 mm	



(a) Schematic diagram of longitudinal section (b) Schematic cross-section

Fig. 5 Schematic diagram of shield-cutting pile under cement-soil single pile composite foundation

of graded sand with coarse sand to crushed stone ratio 3:7 and thickness 0.2 m and bearing plate was made of C30 reinforced concrete with dimensions of 0.95 m × 0.95 m × 0.2 m. (Test design parameters were adopted in strict accordance with "Technical Specification for Composite Foundation (GB/T50783-2012)")

3.1.2 Trial loading

According to the design drawings of the civil house structure and referring to the relevant provisions in "Code for Loads of Building Structures" (GB50009-2012), maximum load in the static load test of cement-soil single pile composite foundation was estimated to be Q_{max} = 100 kPa. According to the requirements of "Composite Foundation Technical Specification" (GB/T50783-2012), the pre-load Q was 5% of the maximum load Q_{max}, stacking weight was $2Q_{max}$, and graded slow loading method was used. 10 loading levels were applied and the

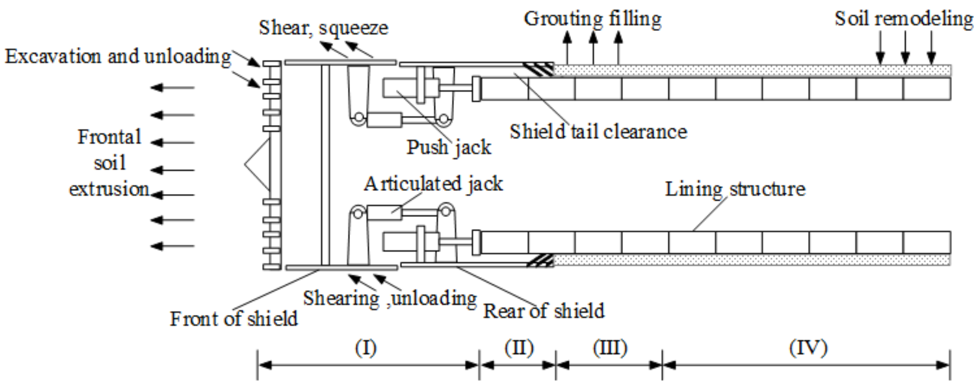


Fig. 6 Four mechanical stages of shield tunnel construction

Table 3 Working conditions of shield tunnel under pile cut through cement soil single pile composite foundation

Name of each stage	Start time of excavation	End time of excavation	Shield advancement ring number (Ring)	Shield advance distance (m)	Construction parameter value range					
					Earth pressure (MPa)	Total thrust (kN)	Driving speed (mm/min)	Rotating speed (rpm)	Torque (kN·m)	Grouting pressure (MPa)
A stage	2017.6.28 22:34	2017.7.17 17:53	644~650	10.5 m	0.062 ~0.09	24000 ~28000	5~20	1.07~1.12	1000 ~5200	2.6 ~6.5
B stage	2017.7.17 17:53	2017.7.17 21:53	651	1.5 m	0.065 ~0.085	21800 ~22300	8~18	1.08	3900 ~4550	3.6 ~5.2
C stage	2017.7.17 21:53	2017.7.18 20:03	652~656	7.5 m	0.05 ~0.1	22450 ~26500	5~20	1.07 ~1.09	3180 ~4630	2.8 ~4.8
D stage	2017.7.18 20:03	2017.7.21 11:30	657~669	19.5 m	0.085 ~0.112	24500 ~25600	5~26	1.07 ~1.09	3240 ~5000	2.6 ~3.8

Note: Stage A: Shield machine was sent to the front of the single pile of cement and soil after stopping and changing the tool in reinforced area (-1.75D~0D); Stage B: Shield machine cutter cutting pile (0D); Stage C: Shield machine shell penetrates through composite foundation with residual piles (0D~+1.25D); Stage D: Shield tail broke away from residual pile composite foundation to the end of field test (+1.25D~+3.25D)

obtained data were recorded after each level. When the settlement of the bearing plate was less than 0.1 mm/h, the following loading level was applied. Loading criteria were based on the requirements of "Technical Specifications for Composite Foundations" (GB / T50783-2012). The photos captured on site are shown in Fig. 2.

3.1.3 Monitoring instrument embedding method and monitoring frequency

In the field test, the settlement of pressure-bearing plate as well as stresses on the top of the pile under cushion and that on the soil between the piles were separately tracked.

Before burying earth pressure cells, 1~2 cm fine sand was laid to level excavation surface. The layout of earth pressure cells and displacement meter is shown in Fig. 3(a). Earth pressure cell No. 1 was placed on the top of the pile with a measuring range of 0.5 Mpa and earth pressure cells No. 2 and 3 were placed on the soil between the piles with a measuring range of 0.1 Mpa. After placing soil pressure cells, they were leveled with a horizontal.

Rule to ensure that the upper surface of soil pressure box between the pile top and soil between piles was on the same plane as soil-cement pile top. Then, 2 cm fine sand leveling (to prevent soil pressure box from being damaged by gravel in mattress bed) was laid. Finally, sand-gravel cushion was laid, as shown in Fig. 3(b) and 3(c). The monitoring frequencies of earth pressure box and displacement meter are given in Table 2. According to "Technical specification for urban rail transit engineering monitoring" (GB50911-2013), the monitoring section of land surface settlement and burying method of monitoring points are shown in Fig. 4.

3.2 Shield machine driving conditions

The relative positional relationship between shield tunnel and composite foundation is shown in Fig. 5. In reinforced area, shield machine was opened to replace pile cutting tool and continued to dig. At the same time, field test monitoring was started. When shield tail was separated from cut pile body by about 12 rings, field test monitoring was stopped and the whole process lasted almost one month.

Affected by the thickness of the overlying soil on test site and the tunnel of 12.53 m, the lengths of test and cut piles were considered to be 15.6 and 3.07 m, respectively. When pile length exceeded a certain value l_0, further increase of pile length created only a slight increase in the ultimate bearing capacity of the pile; therefore, pile length l_0 was called effective pile length. Effective pile length l_0 is related to pile-soil modulus ratio and pile diameter. The effective pile length of cement-soil single pile in this paper was calculated according to the method introduced by Wu *et al.* (2019) to be 4~10 m. The remaining pile length after cutting piles was 12.53 m, which was out of the effective range of pile length. Therefore, our results and conclusions were only applicable for short cut pile lengths and remaining length of the pile after cutting exceeded effective pile length.

According to the time sequence of ground settlement, in this paper, the construction of shield tunnel under cement soil single pile composite foundation was divided into four stages of A, B, C and D along the longitudinal direction of the tunnel. The working conditions of each stage are listed in Table 3. As shown in Fig. 6, shield tunnel construction usually includes the following four mechanical phases: (I) cutterhead excavates the soil in the front and supports the surrounding soil with shield shell; (II) the shield advances and internal lining is assembled; (III) after shield tail forms a building gap, it is grouted and filled outside the lining; (IV) the formation around the lining is consolidated and remodeled. Combined with shield construction mechanics, construction mechanical analysis was carried out during the field test process of shield tunnel cutting pile under cement soil single pile composite foundation In stage A, before shield reached pile body, the soil around the front pile of the shield cutterhead was first pressed. When shield was close to pile body, the soil on the front of the cutter head was excavated and unloaded. In stage B, the shield cutter cut the pile and the composite foundation pile and the soil around the pile vibrated slightly. The soil and piles outside C-stage shield were sheared and squeezed by the shield. In stage D, the soil and piles of shield were subjected to the pressure of synchronous grouting. With the passage of time, slurry began to solidify. After the soil was disturbed during the above four construction stages, soil was gradually consolidated and reshaped. At this time, piles were cut and composite foundation with residual piles reached a new state of equilibrium

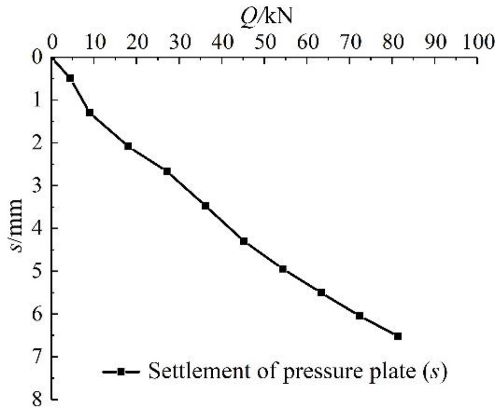


Fig. 7 *Q-s* curve of cement-soil single pile composite foundation

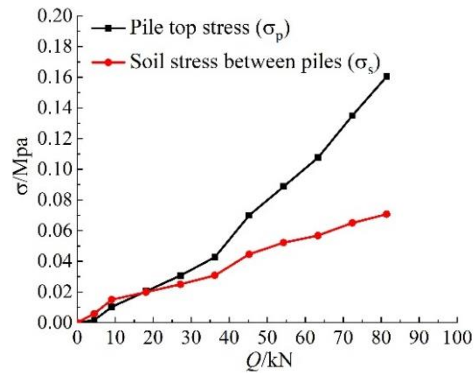


Fig. 8 Soil pressure variation curve between pile top and pile

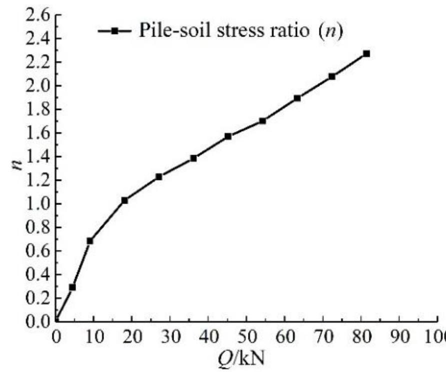


Fig. 9 Variation curve of pile-soil stress ratio

4. Test results and analysis

4.1 Analysis of static load test data of soil-cement single pile composite foundation

Figs. 7-9 show the field static load test data of soil-cement single pile composite foundation. With the increase of upper load, the cumulative settlement value of bearing plate, pile top stress and soil stress between piles were increased almost linearly. According to technical specification of composite foundation (GB/ T 50783-2012), the characteristic value of the bearing capacity of soil-cement single pile composite foundation was determined (s/b=0.006~0.008 where s and b are the cumulative settlement and width of the bearing plate of composite foundation, respectively). According to the theoretical calculation of s=5.7 mm~7.6 mm, the cumulative settlement of bearing plate in this test was 7.12 mm, which was within the theoretical calculation range.

In addition, the value of pile-soil stress ratio n measured in the test was similar to that reported by Zheng *et al.* (2005), indicating that the design of test scheme and test results were reasonable.

4.2 Analysis of test data for shield cut pile passing through cement-soil single pile composite foundation

4.2.1 Ground surface settlement

The formation process of transverse settlement grooves at ground surface measurement points was analyzed and formation rules were summarized, according to distance change between shield cutter head and monitoring section. Nine positions on shield cutter head and monitored section were selected at the distances of -3.75, 5.25, 6.75, 9.75, 11.25, 12.75, 14.25, 15.75 and 18.75m to draw transverse settlement grooves, as shown in Fig. 10. When shield cutter head was -3.75~9.75 m away from pile body (negative sign indicated that shield cutter head had not penetrated pile body and positive sign indicated that the shield cutter head had cut through the pile), shield cutting pile was in construction stage. Shield cutting pile was constructed in stage B, which resulted in the settlement of composite foundation by 15.9 mm, accounting for 57% of the total

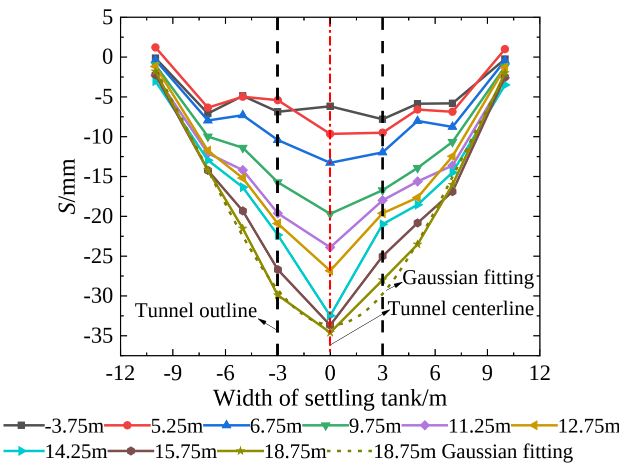


Fig. 10 Curves of ground subsidence grooves at various moments during shield cutting pile

settlement of composite foundation (the total settlement of composite foundation refers to that after shield cutting pile went through four stages A, B, C and D, residual pile composite foundation reached a new stress equilibrium state, and the settlement of composite foundation was fixed at a certain value). Cutter head distance monitoring section was 11.25~18.75 m. At post-construction settlement stage, the tail of shield machine was far from composite foundation. After shield tail passed 6 m (1D), most of the settlement was completed. The total settlement was 34.6 mm. Due to the better controlling effect of shield tunneling, the distribution of settlement tanks tended to be symmetrical. As shown in Fig. 10, Guass curve was used to fit lateral settlement trough after the stabilization of final settlement and the correlation coefficient of R^2=0.994 was obtained which showed a very high degree of agreement.

4.2.2 Pile-soil stress ratio n and bearing plate settlement

Figs. 11 and 12 show pile-to-pile soil stress, cumulative settlement of bearing plates, pile-soil stress ratio n, pile-soil load sharing ratio N and lateral cumulative settlement groove variation curves. In general, during the whole process of shield tunnel cutting under cement soil single pile composite foundation, the cumulative settlements of bearing plate and surface were gradually increased, soil stress between piles was first increased and then decreased, and pile top stress was gradually reduced. The stress and load-sharing ratios of pile-soil presented an "N" shaped change rule which was first increased, then decreased, and then increased again.

Phase A: during the modification of shutdown equipment and replacement of cutting tools of shield machine in reinforced area, the soil between shallow piles under the upper load was subjected to consolidation and compression deformation, which increased the cumulative settlement of composite foundation and at the same time, shared its partial load. Cushion layer was transferred to a single cement-soil pile, which increased pile top compression stress and stress and load sharing ratios of pile-soil. After shield machine started to leave the reinforcement area, the soil around the pile on the front of shield cutter head was first squeezed, resulting in an increase in horizontal earth pressure around the pile; that is, normal stress acting on pile body was increased and the side friction resistance of pile body was increased accordingly. As frictional resistance was increased, the stress on the top of the pile was increased and that on the soil between piles was decreased accordingly, showing that the stress and load sharing ratios pile-soil were increased simultaneously. When shield was close to pile body, the soil on the front of the cutter head was excavated and unloaded, resulting in horizontal and vertical unloading displacements of soil around and end of the pile. This change weakened the lateral and bottom binding forces of the soil around the pile, thereby reducing the friction resistance of the end and sides of pile ultimately leading to a decrease in the bearing capacity of soil-cement single pile and an increase in settlement. With the degradation of the bearing capacity of single cement-soil piles, the part of load that the pile could not bear was transferred to the soil between piles through cushion layer. In this way, the stress on the top of pile was decreased and that on the soil between piles was increased accordingly. The research results show that the pile-soil stress ratio n presents a trend of first increasing and then decreasing in the A stage of shield cutting pile construction.

Stage B: when cutting a single pile with a shield cutter head, the pile and the soil around it generated micro vibrations simultaneously. This phenomenon reduced the binding force of the soil above shield excavation surface on the pile; that is, pile side friction was decreased. In addition, a part of pile body was cut off and the remaining part was greatly weakened regardless of end and lateral resistances. In this way, the bearing capacity of the remaining pile was further reduced and the settlement of pile was increased. During the whole process of cutting the pile with the shield of shield machine, the bearing capacity of single pile was continuously weakened, such that the part of load carried by the pile was continuously transferred to the soil between piles through cushion layer.

As the load carried by the soil between piles was increased, soil settlement between piles was also increased. At the same time, the unloading of excavation face and vibration of cutter head cutting pile further increased soil settlement between piles. Compared with the soil between piles, shield cut pile effect on single pile bearing capacity was more obvious, such that during the whole process of cutting the pile with shield machine, stress and load sharing ratios of pile-soil continued to decrease. The cumulative settlement of foundation bearing plates was also increased.

Stage C: in the process of passing through the composite foundation of residual pile under shield machine shell, soil and pile bodies outside the shield were subjected to the shearing and squeezing action of shield body, such that shield body cut the pile and aligned it when shield body passed. Due to continuous disturbance of soil layer, the settlement deformations of pile and soil continued to increase under and stress and load sharing ratios of pile-soil were also decreased. As shown in Figs. 11 and 12, at this stage, there were two obvious turning points in the pile top stress and soil stress between piles. The settlement rate of pressure plate at inflection point 1 was less than that at

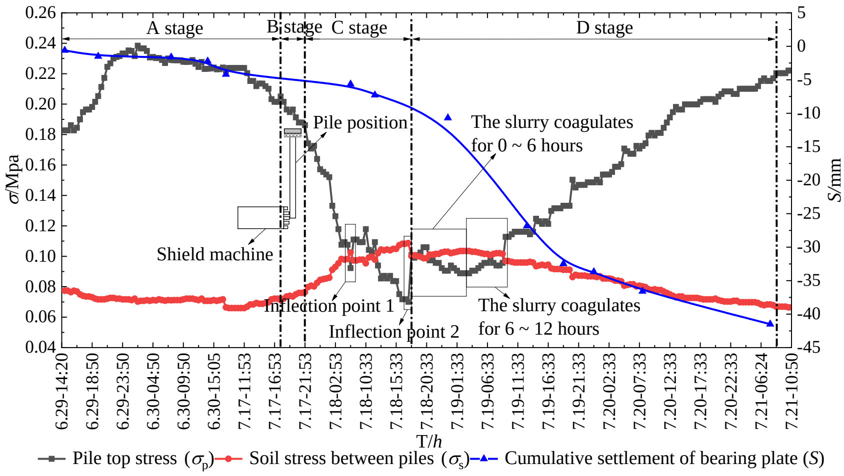


Fig. 11 Time history curve of pile top, the soil between piles and pressure plate settlement

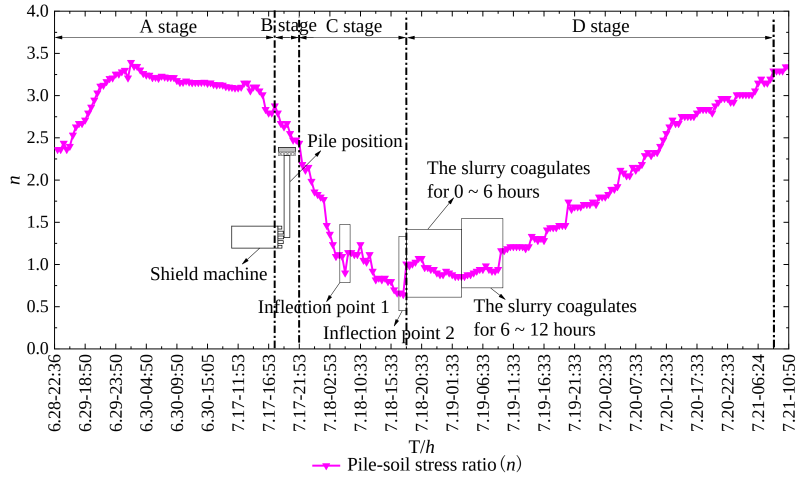


Fig. 12 Time-history curve of pile-soil stress ratio *n*

Table 4 Variations of cumulative settlement, pile-soil stress ratio and pile-soil load sharing ratio of composite foundation in stages

Stage Design Parameters	A stage		B stage		C stage		D stage	
	Amount of change	Change ratio	Amount of change	Change ratio	Amount of change	Change ratio	Amount of change	Change ratio
Accumulated settlement of pressure plates	-1.21 mm	2.916%	-2.98 mm	7.181%	-6.5 mm	15.663%	-30.81 mm	74.241%
Pile-soil stress ratio	0.517	21.215%	-0.453	-18.588%	-1.397	-55.97%	2.269	93.106%

inflection point 2.

Combining shield machine structure and construction condition analysis, it was found that, to meet the turning and tunneling of shield machine and realize the attitude adjustment of underground shield machine. Shield machine usually contains the front and rear of shield connected by a hinge system (Fig. 6) and there is a certain height difference between these two compartments. The hinge mechanism of shield machine through composite foundation was the main reason for inflection point 1. However, the existence of gap in the shield tail of shield machine caused it to break away from residual pile generating inflection point 2.

Stage D: as the shield tail separated from cement-soil single pile, simultaneous grouting began to fill the gaps in shield tail building. Due to the high initial pressure of grouting, not only the settlement of pile was slowed, but also pile end resistance and bearing capacity were rapidly increased. In this way, a part of the load shared by the soil between piles was quickly transferred to pile top which eventually increased pile top stress, decreased soil stress between piles and suddenly increased load sharing and stress ratios of pile-soil.

However, as the synchronous grouting pressure was dissipated, pile end resistance and bearing capacity were decreased slowly, and the initial setting of slurry took about 8~10h. During this period, due to the slow growth of slurry strength, the fluidity and compressibility of the grout were high. At this time, reaction force on the pile and soil between piles was small, which led to further settlement of pile and soil and pile-soil stress ratio n was decreased with the settlement of pile. After the initial setting of slurry, with the passage of time, the resistance of pile tip was gradually increased, the settlement rate of pile was decreased, and the consolidation and compression deformation of the soil between piles continued to increase, gradually moving upper load from soil top to pile top. This transfer caused stress and load sharing ratios of pile-soil to continue to increase as the cumulative settlement of composite foundation was increased.

5. Conclusions

In this paper, using the field tests on shield tunnel direct cutting of cement-soil single pile composite foundation with diameter 500 mm, the following main conclusions were drawn:

• Before and after shield cutting, the load transfer mechanism of composite foundation was not changed. Pile body and the soil between piles jointly bore the overlying load, but the load carried by the original pile body was affected by the disturbance effect of pile cutting construction. The part of load carried by the original pile was transferred to the soil between piles, therefore, the bearing capacity of composite foundation was not decreased and only the load carried by piles and the soil between piles underwent load and weight distribution.

• The settlement of composite foundation was mainly based on the settlement deformation caused by formation loss during the advancement of shield. The settlement of pressure-bearing plates generated during shield cutting stage accounted for about 7% of the total settlement. After pile cutting was completed, the settlement of bearing plates generated by shield machine during residual pile composite foundation stage and the tail of shield machine was far away from residual pile composite foundation stage (stage D) accounted for about 15% and 74% of the total settlement, respectively.

• The pile-soil stress ratio n of the composite foundation before cutting the pile was 2.437. After shield cut pile was completed, the soil around the lining structure was gradually consolidated and reshaped, and residual pile composite foundation reached a new state of force balance , pile-soil stress ratio n was 3.342, which was higher than that before pile cutting. This was because the strength of grouting layer was higher than that of soil after it was consolidated, such that the resistance of pile end and the friction resistance of the side of pile could be improved.

• Combining the obtained test results, it could be concluded that the vertical impact of shield cutting pile construction disturbance on cement-soil single pile composite foundation was -1.75D ~ + 3.25D. In order to reduce the impact of shield cutting pile construction on the settlement of upper composite foundation, it was recommended to take measures such as optimizing shield construction parameters, radial grouting reinforcement and “clay shock” grouting within the disturbance range of shield cutting pile construction.

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