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Research on the effect of buried channels to the differential settlement of building

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ABSTRACT: Great and differential settlement occurs under the building during an adjacent metro deep foundation pit construction. Factors influencing the building settlement in different construction stages are analyzed based on the monitoring data and geology distribution condition. The result shows that the large lateral deformation of retaining wall and time-depended deformation of soft clay under the building are the reasons that make the major settlement occur. The main factor inducing differential settlement of the building is local distribution of adverse geological condition. Some feasible means of improvements in practice are presented, which can reduce effectively the influence of adverse geological condition such as buried channel on excavation and surroundings. Though the paper the author hopes that engineers can attach more importance to the negative influence of adverse geological condition, and the results could be valuable reference to other engineering.

1 GENERAL INSTRUCTIONS

Shanghai has the representative soft ground in China. The stratum of Shanghai mainly made up of saturated clay, silty clay and sand. Most metro stations and tunnels of Shanghai lie about 20 m beneath the ground surface. Soil of such depth mostly is soft clay which characteristics such as water content, degree of sensitivity, compressibility and rheology are notable, and the unit mass, strength and permeability are bad. Except those, the adverse geological factors such as buried channel, shallow-buried methane, underground barrier etc. may be exist which will do harm to the constructing of deep excavation and adjacent buildings. So the adverse geological factors should be paid enough attention.

During the construction of a metro excavation in Shanghai, great and differential settlement occurs on an adjacent building. Factors influencing the building settlement in different construction stages are analyzed based on the monitoring data and geological distribution condition. Reasons which effect the major settlement are discussed and the results could be valuable reference to other engineering.

2 GENERAL SITUATION

The metro station of this study is designed as a two layers underground frame structure. The total length of the station is 364.7 m and the width of its standard segment is 24.5 m. The buried depth of the bottom plate is 17 m, and the thickness of retaining wall is 800 mm. As for the edge wells of the station ,the buried depth is about 18.6 m, the thickness of its retaining wall is 800 mm, Pre-stressed steel pipes of 609 mm in diameter (external) and 16 mm in thickness were installed at each levels (standard segment: level 1 to level 5; edge wells : level 1 to level 6) to support the retaining wall. The protective grade of the excavation is grade 1. The cross section of the standard segment is shown in Figure 1. Soil profile and geological description of the soils under the adjacent building of the excavation are given in Table 1.

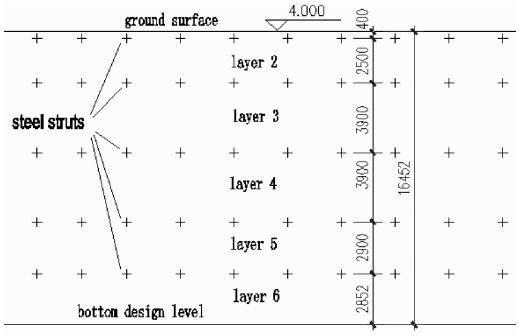

Figure 1. Strut profile of standard segment.

Table 1. Profile and geological description of the soils.

Serial number	Name	Thickness/m	Bottom level /m	Water content /%	Unit weight /kN·m^{-3}	Void ratio	Shear strength (peak)	
							C / KPa	Φ/°
①$_1$	filled soil	1.2	2.93	–	–	–	–	–
②$_1$	clay	2.6	0.33	34.6	18.2	0.99	21	17.5
③	silty clay	4.2	−3.87	43.0	17.3	1.21	13	17.0
④$_1$	silty clay	8.0	−11.87	49.1	16.8	1.39	14	11.0
⑤$_{1-1}$	clay	3.0	−14.87	38.9	17.6	1.12	16	14.0
⑤$_{1-2}$	silty clay	6.5	−21.37	34.9	17.9	1.02	15	18.5
⑤$_{2-2}$	sandy silt	14.5	−35.87	32.2	18.0	0.94	4	29.0
⑦$_2$	silty sand	No penetrated	No penetrated	26.3	18.8	0.77	1	32.0

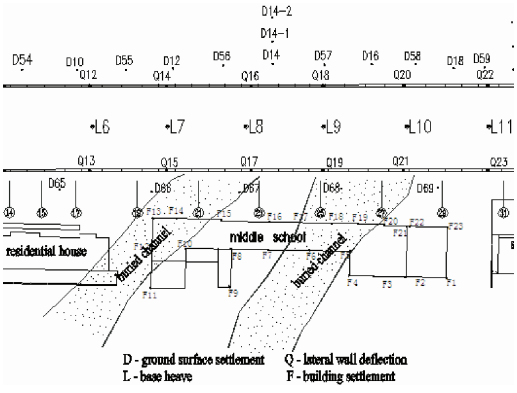

Figure 2. Plan of monitoring points and buried channel.

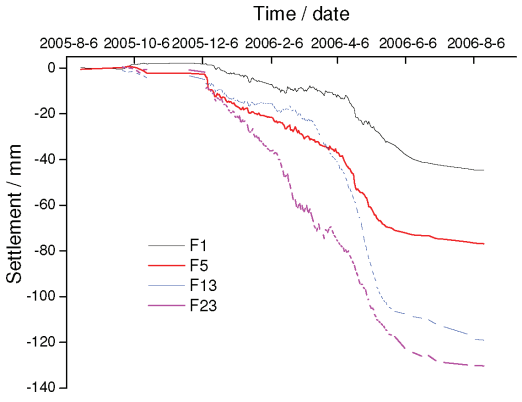

Figure 3. Building settlement with time.

2.1 *Adjacent buildings and surrounding condition*

The buildings around the excavation are relatively dense. The prime protection object is the nearer buildings on the south side of the excavation. Great settlement occurred under a teaching building belonged to a middle school which is sited 14 ~ 16 m away from the excavation on the south side. Total length of the building parallel to the excavation is 87.882 m and its width is 15.188 m on the east, 20.883 m on the west. The building was constructed at the end of 1970s, and it is the reinforced masonry structure with ring beam, shallow strip foundation.

According to the geological documents, there are two buried channels under the building (Figure 2). Influenced by the adverse geological factor, there has been about 400 mm total settlement happened before the excavation construct.

2.2 *Building settlement*

The curves of building settlement developed with time are shown in Figure 3 after the excavation constructed August, 2005. Figure 4 shows the accumulative total

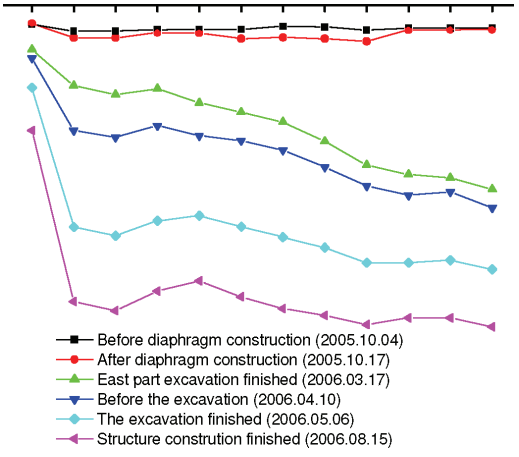

Figure 4. Accumulative total settlement of building during different stage.

building settlement of several main monitoring points during different construction stages.

From Figure 4, monitoring points of F13 and F23 have the large accumulative and differential

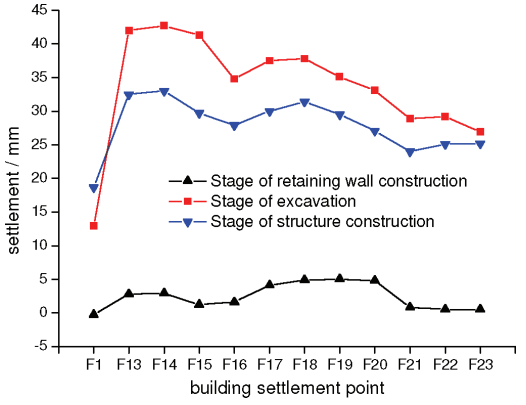

Figure 5. Building accumulative total settlement in different stages.

settlement. Until March, 17, the differential settlement in longitudinal direction between F13 and F23 has reached to 45 mm and inclining slope is 0.0005; and which is 60.7 mm and 0.0041 respectively transversely. Inclining slope of the two directions have exceeded 0.003 which is the allowable value according to national criterion. Many cracks appeared in walls of the building, some local width of cracks is about 10 mm. so did the parallel crakes on the ground surface between the building and the excavation.

3 BUILDING SETTLEMENT ANALYSIS IN DIFFERENT STAGES

Great and obvious differential settlement of the building is the result affected by several factors, which have dissimilar effect in different construction stages. Figure 5 and 6 respectively shows the accumulative total settlement and settlement velocity with different parts of the building during the main construction stages.

Based on the main construction stages of the part of excavation near the building, settlement of different parts of the building in different construction stages was analyzed.

3.1 *Stage of retaining wall construction*

Generally, deformation of the surrounding induced by retaining wall construction is relatively small and the effected area is limited. The building lies outside the influencing area of the retaining wall construction so that the effect can be neglected when the building settlement is analyzed.

Field data of the building in retaining wall construction stage is analyzed. Construction of the part of retaining wall began on Oct.4, 2005 and finished on Oct.17. During the period building subsided little and

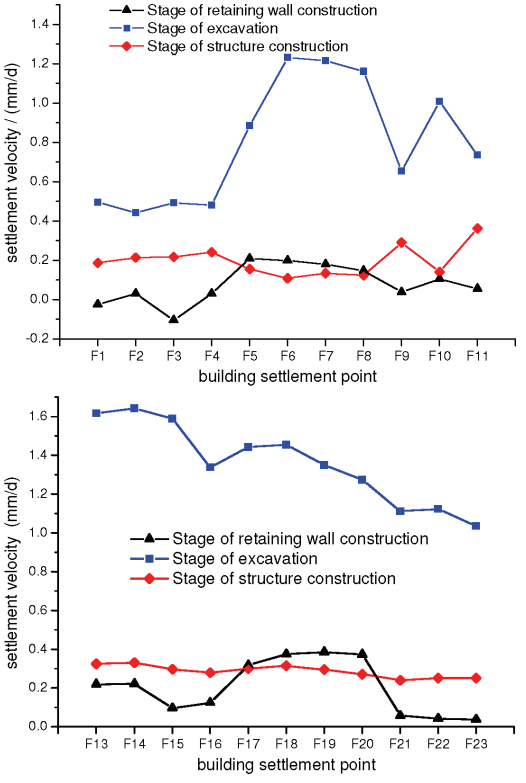

Figure 6. Building settlement velocity in different stages.

the average settlement is 2.7 mm. Settlement of F21 to F23 are less than 1 mm and that of F15 to F16 are 1.2 to 1.6 mm, as shown in Figure 4. Take the normal fluctuation of monitoring data into account, the construction of retaining wall has little influence on building settlement, which tests the conclusion of other correlative studies.

In Figure 5, settlement in different location of the building is of variation from the minimum 0.5 mm of F23 to the maximum 5 mm of F19. Because of the existing of the buried channel, building settlement of the location under which is the buried channel are greater than that of normal subgrade soil. At that time, there is no other construction, so the main reason leading to the settlement can be ensured as the existing of the high rheology of the soft soil.

3.2 *Stage of excavation*

Sequence of the excavation is from the east to the west. Differential settlement between the two ends was 45 mm till March, 17. In Figure 7, the lateral deflection of the retaining wall at Q17 is gathered according to each stage of the excavation. So do the deformation of excavation and the surroundings as shown in Table 2.

In Figure 7, large deformation produced at the early stage of the excavation. There has been 32 mm lateral deformation after the 3rd level strut installed which is mainly related to high time-depended deformation of the 3rd level soft soil. In addition, long exposure time without struts and long laying up time after the installing of struts also made for the lateral deflection of the retaining wall increasing.

Cooperating with the excavation, basal heave and the ground surface settlement caused by lateral deflection of the wall are increasing, which also accelerate the settlement of the building. (Figure 5 and Figure 6)

Settlement velocities of points F6 ~ F8 in the location of buried channel are double greater than those of points F1 ~ F4. Settlement velocities of points F13 ~ F15, F17 ~ F20 are also greater than the others. (Figure 8) The maximum local inclining slope of the building in longitudinal direction is 0.0006, and which is 0.0052 in transverse. They all exceeded the allowable value 0.003. So the reason of differential settlement of the building could be mainly attributed to the local distribution of buried channel.

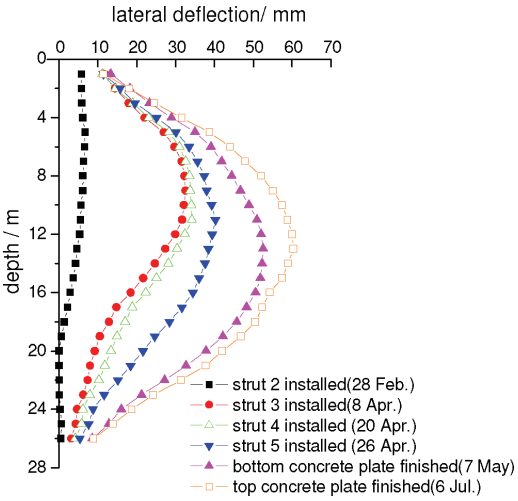

Figure 7. Lateral deflection of the wall at Q17.

3.3 *Stage of structural construction*

Compared with the excavation stage, lateral deflection of the retaining wall, basal heave and building settlement in this stage are steady relatively because of the strengthening of the structural stiff. But the building and ground surface surround the excavation still sank a little at the rate 0.3 ~ 0.4 mm/d. This can be explained

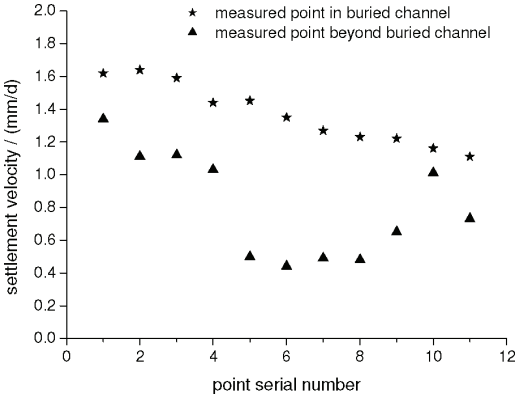

Figure 8. Comparison of settlement velocity between the parts in buried channel and the others.

Table 2. Deformation of excavation and the surroundings.

Item		Accumulative total on different moment / mm			Stage of excavation		Stage of structure construction	
		Before the excavation	The excavation finished	Structure construction finished	Increment / mm	Velocity / (mm/d)	Increment/ mm	Velocity / (mm/d)
Lateral deflection of the wall	Q13	31.8	59.1	76.4	27.3	1.05	17.9	0.15
	Q17	32.7	47.2	60.3	14.5	0.60	13.1	0.13
	Q19	49.7	61.6	68.6	11.9	0.70	7.0	0.07
Basal heave	L6	16.5	45.9	51.1	29.4	1.13	5.2	0.18
	L7	7.7	34.2	35.2	26.5	1.02	1.0	0.03
	L8	7.7	49.6	41.0	41.8	1.67	−8.6	−0.28
	L9	24.4	63.0	63.3	38.6	2.27	0.3	0.01
	L10	32.1	50.4	60.3	18.3	1.66	9.9	0.23
Ground surface settlement	D65	28.2	52.3	83.2	24.1	0.93	30.9	0.30
	D66	35.3	76.9	118.8	41.6	1.60	41.9	0.41
	D67	49.6	93.6	130.5	44.0	1.76	36.9	0.35
	D68	52.3	86.3	128	34.0	2.0	41.7	0.37
	D69	70.6	82.2	130.0	11.6	1.05	47.8	0.41

as the reason of time-depended deformation of the soil around the excavation.

4 REASONS ANALYSIS

1. Relatively great lateral deflection of the retaining wall causes the whole settlement of ground surface. Time-depended deformation of the soft soil disturbed from the construction, overload of the building, long exposure time without struts and long laying up time after installing the struts made the lateral deflection of the retaining wall increasing.
2. Time-depended deformation of the soft soil under the building increased the whole building settlement.
   Soft soil has obvious rheology and sensitivity. Time-depended curve of typical soft soil in Shanghai is shown in Figure 9. High time-depended deformation because of the disturbing of excavation construction causes the sustaining settlement of the building.
3. Differential settlement of the building mainly attributes to the local distribution of adverse geological action.
   Settlements in different location of the building are obviously of variation because of the local distribution of buried channel, the building settlements of the part under which is the buried channel are greater than those located on normal subgrade soil.

5 CONCLUSION

1. Optimizing the design of the retaining system of the excavation in complex geological condition, shortening the exposure time of retaining wall during excavation should be done to control the lateral deflection of retaining wall, which in turn could reduce the effect on the surroundings.
2. The adverse geological condition such as buried channel should be paid enough attention. The buried channel should be strengthened or separated from the building to decreasing the disadvantageous effect on the building in practice.
3. Monitoring data can give feedback to the designers about the construction so that they can adjust design parameters in time to instruct the construction and ensure the safety of the excavation and the surroundings.

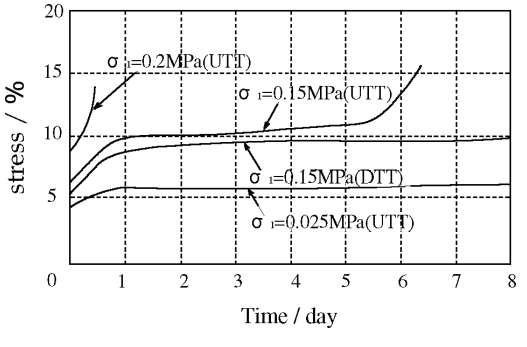

Figure 9. Dynamic triaxial rheology test of soft clay.

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