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GROUTING AND DEWATERING IN BALANCING SETTLEMENT OF A BUILDING

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ABSTRACT

A case study using grouting and dewatering system to protect a residential building during an adjacent deep excavation is presented in this paper. The building was a 73-year old masonry structure with two additional stories added to its original designed four stories height. The building was located 5 m away from a 15 m deep excavation. The project was located in downtown Shanghai, China. Grouting was injected between excavation and the building to compensate for ground loss and stress relief to reduce the building's settlement. Dewatering was applied at the far end to increase the settlements and limit the differential settlement. This project was the first successful case using dewatering to protect a building in such a low permeability Shanghai clay. The results demonstrated that dewatering and grouting methods were an effective way of protecting buildings near deep excavations.

INTRODUCTION

Deep excavation induces a substantial ground settlement behind the retaining wall in soft ground, which can cause damages even structural collapse to buildings within its influence zone (Peck 1969). There is an acceptable settlement limit for building according to its structural types (Bjerrum 1963). A successful project using grouting and dewatering to protect a six-story masonry building during an adjacent deep excavation in Shanghai is presented in this paper. Grout was injected between excavation and the building to compensate for ground loss and stress relief caused by the excavation. Dewatering was applied at far end of the building to increase the settlements and then limit the differential settlement of the building.

ENGINEERING BACKGROUND

There is now an infrastructure revolution in Shanghai. By the end of year 2000, Shanghai had 3529 buildings eight or more stories high. Out of these, there are 1478 buildings 20 stories or higher. Most of them were built within the last two decades. Today, more high-rises are springing up like mushrooms all around the city. Because the urban environment imposes a strict requirement to underground construction, safe design and construction are very challenging tasks to achieve in Shanghai.

A project for protecting a building during an adjacent deep excavation is presented in this paper. The excavation had a plan dimension of 266 m by 20m with an average excavation depth of 15.5m. The retaining system consisted of a 0.8 m thick 26.5m long diaphragm wall with four level preloaded braces.

A 6-story masonry building, Central Apartment, was located 5 m away from the excavation. It was built in 1929 and its original design was a 4-story high building. In 1995 two stories were added without upgrading its foundation system. The foundation was a strip foundation supported with two timber piles for every 0.9 m. The piles were 0.15 m in diameter and 3.6 m deep.

The building was 52 m long and 17 m wide. It had a very narrow middle part of about 11m wide. The ratio of length to width was 3 to 1. The longer side of the building was perpendicular to the longitudinal direction of excavation. The layout of the project is shown in Fig. 1.

SOIL INFORMATION

Shanghai Clay is a typical marine deposit with a high water content, a high void ratio, and a low shear strength. The annual water table is within 1 m below the ground. Within 30 m below the ground, it consists of six strata. There are thin layers of silt sporadically embedded in layer 2 to 3, which were used to efficiently dewater the soil in this project. Typical layout of each stratum is shown in Table 1.

Based on a large amount of well-documented field monitored data, deep excavation in Shanghai Clay would have induced a substantial settlement behind retaining wall. The maximum settlement normally set at 0.7 times the excavation depth with a magnitude of 0.4 percentage of the excavation depth (Fig. 2). The influence zone would be about 2 to 3 times the excavation depth (Liu and Hou 1998).

Table 1. Typical Physical and Geotechnical Properties of Shanghai Clay.

No	Name	Color	Bottom depth	Water content	Density	Void ratio	Compression modulus	Permeability (cm/sec)	
								Horizontal	Vertical
	---	---	m	kg/m3	KN/m3	---	MPa		
2	Clay	Yellow	2.4-3.5	41.0	17.9	1.162	2.75		
3	Silty clay	Gray	7.0-8.0	47.4	17.4	1.296	2.79	8.1E-6	6.2E-7
4	Muddy clay	Gray	14.5-17.6	51.1	17.0	1.437	1.98	3.2E-7	1.0E-7
5	Silty Clay	Gray	23-26.5	41.7	17.7	1.189	3.71	6.0E-7	3.7E-7

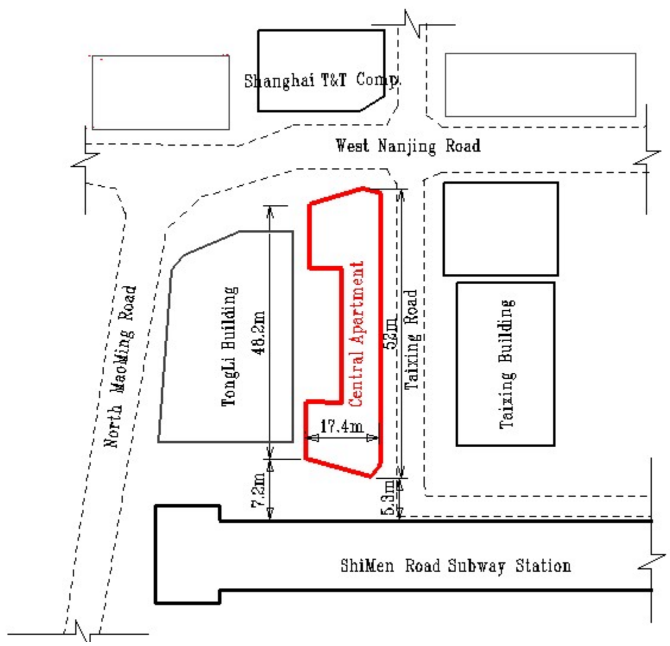

Fig. 1 – Layout of Excavation and Building Location

The proposed excavation was expected to cause a maximum settlement of 6 cm magnitude with its location 10 m from slurry wall. Regarding the high stress level in soil due to additional stories, the settlement of the building was expected to be higher than the value predicted above. The maximum settlement was within the building and the differential settlements was expected to exceed the safe limit for the masonry structure.

In the original plan, partial top-down construction was adopted to minimize the influence on the building. Excavation was first performed to the level above the middle slab. Reinforced concrete middle slab would then be built and followed by the top slab. Excavation below the middle slab would be the last. However, the building was found to be very sensitive to disturbance from surrounding construction based on the measurements. During the first five months of slurry wall construction and dewatering in the excavation, the building had settled 43.4 mm at point F17 near excavation, 19.5 mm at the middle (F19) and moved up 5.8 mm (F20) at the far end before the commencement of excavation (Fig. 3). The differential settlement ratios were 0.98 ‰ along one side (F17-F20) and 1.11 ‰ at another (F17-F19).

Several protection methods had been proposed to limit both the maximum settlement and the differential settlement of the building to ensure the safety of both the building and the residents inside during the construction. A comprehensive protection plan consisting of grouting and dewatering were selected based on their limited influence and disturbance on the soil beneath the foundation. Grouting would be used near the excavation to reduce the building settlement. Dewatering would be applied to the far end to accelerate the settlement and reduce or keep the differential settlement within the safety limit.

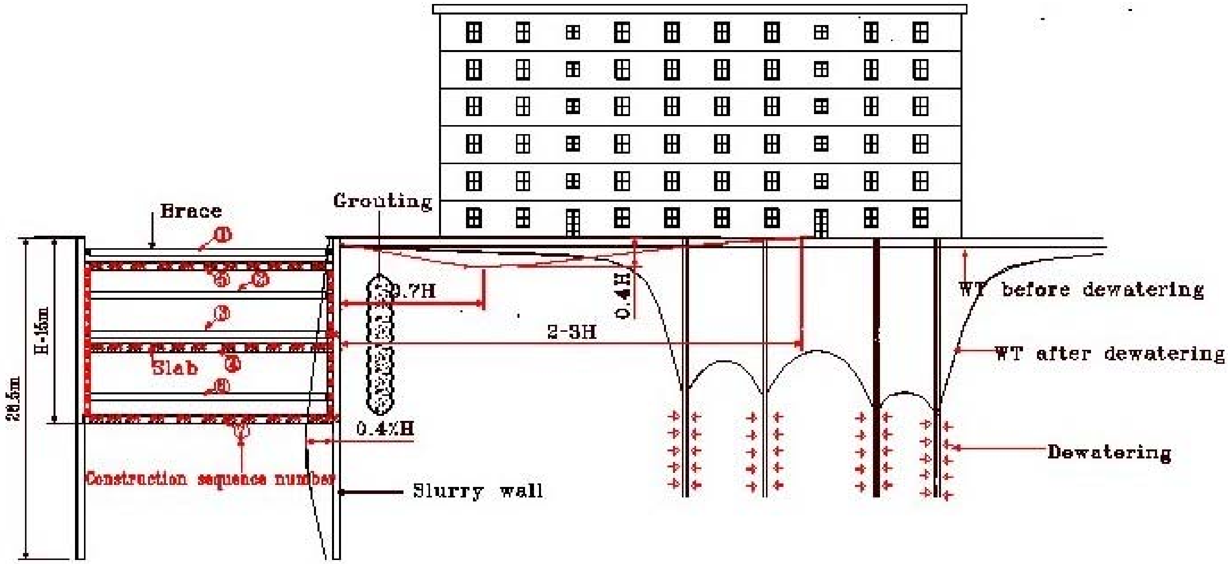

Fig. 2 – Settlement Profile of Deep Excavation in Shanghai Clay

Because the utilities pipes were relocated along the building, grout was injected about 3 m from slurry wall based on the available spaces. Chemical grouting using cement slurry and sodium silicate was used to compensate for the ground loss and stress release. The hardening time was controlled within a minute. Grouting construction started in half an hour after the placement of corresponding braces to ensure a good result. The volume of grouting was adjusted based on the volume loss calculated from the lateral deformation of slurry wall. Grouting was intensified immediately after excavation and reduced gradually afterwards. More details about the construction and design of compensation grouting behind slurry wall during excavation can be found in Liu (2003).

Dewatering wells were originally designed at both sides of the building with two wells at the middle and two at the far end. Due to many obstructions, including overhead electrical wires, and utility pipes and strict settlement requirements imposed by nearby Shanghai Telegraphy and Telephone Company, the wells had to be relocated toward the middle of the building, and wells at another side of the building were also canceled. A test pit was excavated for each well before boring to avoid the utilities. Four dewatering wells and two monitoring wells were finally bored in positions shown in Fig. 3.

In order to efficiently monitor the behavior of Central Apartment during excavation, additional settlement points (F40, F41, F43, and F44) were added to the original plan. The final layout of the measuring points is also shown in Fig. 3. The frequency of settlement measurement were once a day before excavation and intensified to twice a day during excavation with a resolution of 0.1mm.

The bored holes for wells were 16 m deep with a diameter of 67 cm. The steel casing inside had a diameter of 32cm to sink the 25 cm pump inside for dewatering. Bentonite slurry was used in the drilling. After completion of the boreholes, the steel pipe casing was inserted. The steel casing was 15m deep with a perforated screen of 8 m at the bottom. The perforated screen consists of ordinary well casing with uniform pattern slots along the wall. Graded sand filters were placed between the well casing and the borehole at the bottom 10 m. The remaining space above the screen was backfilled with regular sand. The water in the well was then "surged" by a boring tool to promote flow back and forth through the filter, and at the same time unwanted fines flowed inside the sump was cleaned before the submersible pump was installed (Tomlinson 1980). Even though great care was taken in the installation, the quality of two wells at the middle was not as good as two wells located at the far end of the building even after the further process, which can be found in the typical drawdown curves from the monitoring wells shown in Fig. 4.

A submersible electronic pump was used in dewatering construction. The control of dewatering was the depth of water in wells and the frequency of dewatering. Dewatering was performed four or five times a day during the corresponding excavation and reduced gradually to once two days after excavation. The maximum dewatering depth was 14 m from ground surface and minimum depth was 6 m. The average discharge was around 1.25 cubic meter per day. Typical discharge curve from a well is shown in Fig. 5.

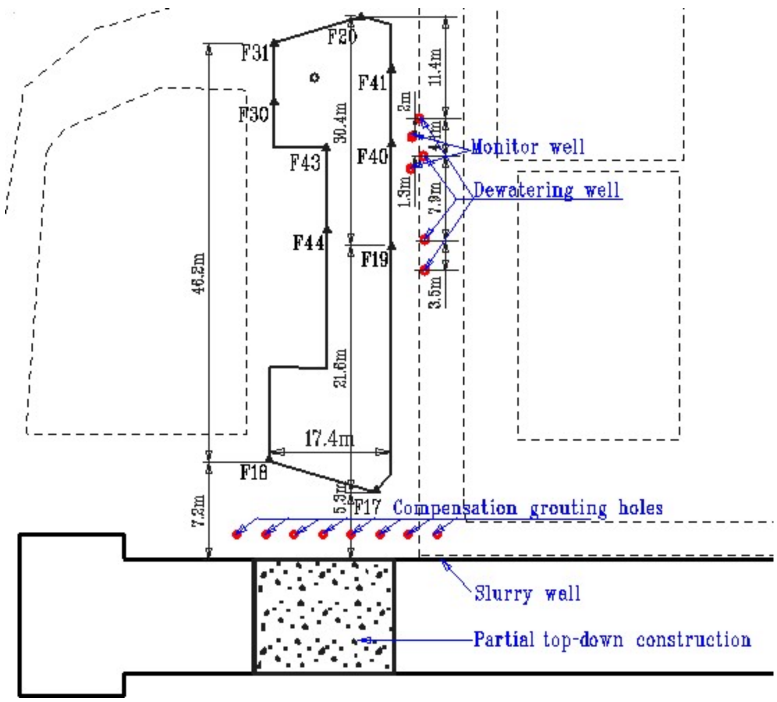

Fig. 3 – Layout of Dewatering Wells and Settlement Monitoring Points

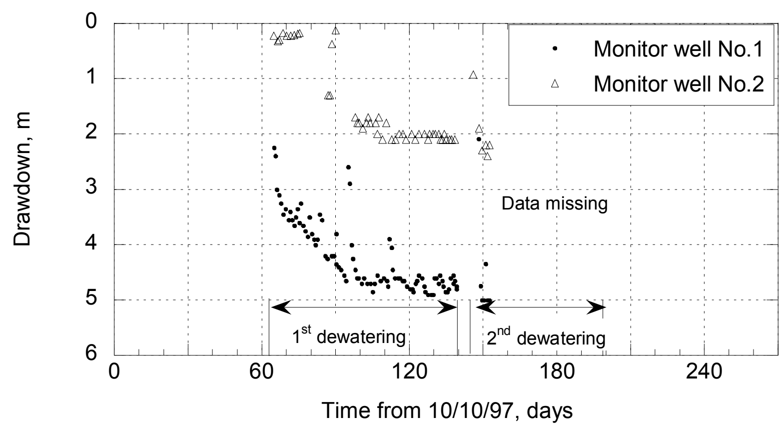

Fig.4 – Drawdown Curves at Two Monitoring Wells

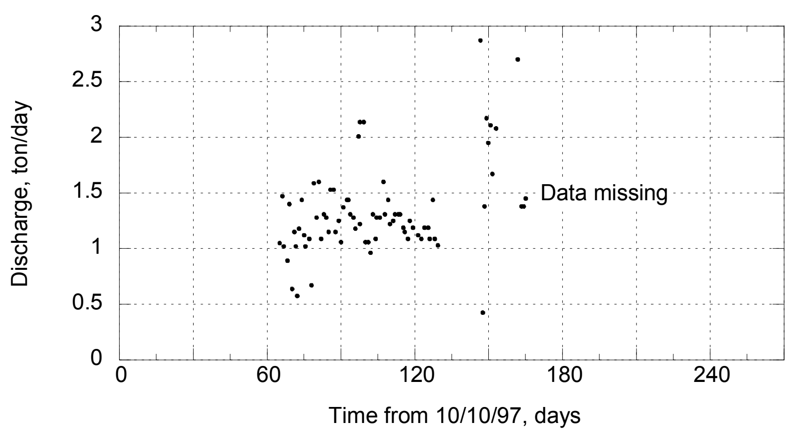

Fig.5 – Typical Surcharge of Dewatering Well

CONSTRUCTION DETAILS

The settlement measurement started from October 10, 1997, when slurry wall was constructed. The soil above the middle slab was divided into three layers. Excavation above middle slab started from December 12, 1997. The first level excavation and brace placement were finished on the same day. The second layer soil was excavated from December 13 to 14 and corresponding braces were put in position on December 15. The third layer soil was excavated from December 16 to 18 and followed by brace placement. Construction of reinforced concrete slab was delayed two days by a heavy rain and finished on December 22. By the time the top slab was finished (January 8, 1998), the settlement of building was getting stable.

Excavation below the middle slab started on March 16, 1998. Due to the limited space, excavation lasted longer than open excavation. It was finished by March 31 and the bottom slab was built on April 4, 1998.

Dewatering followed the excavation process very closely. Dewatering construction consisted of two stages. The first dewatering was from December 12, 1997 (63 days from October 10, 1997) to February 18, 1998 (130 days) during the excavation above middle slab. The second stage started on March 6, 1998 (147 days) following excavation at adjacent regions. It ended on April 6, 1998 (178 days) after the finish of bottom slab.

RESULT ANALYSIS

The settlement curves of the building are shown in Fig. 6. At the beginning of excavation, the building at the far end heaved about 5 mm, while settled 30mm at the end near excavation. With the excavation and dewatering, the building at the far end settled gradually from +5 mm to -10mm by the time middle slab was finished. During the two-week interval between two stages of dewatering, the building continued to settle. No sharp increase or decrease in the settlement curve demonstrated that consolidation took time to take effect in clay. Time effect of consolidation showed clearly after dewatering stopped on April 6, 1998, the building, however, kept settling until a month later. No rebound was found in the measurement. The differential settlement of building on both sides kept constant during the construction, shown in Fig. 7. The maximum settlement of the building reached 103 mm after the whole construction finished. No appreciable cracks were found in the building even under this high settlement. The settlement was considered higher than normal in this case because of the high soil stress in this building.

The settlements of the building during different construction stages are shown in Table 2. Obviously dewatering accelerated the building's settlement. From the table, dewatering contributed to the settlements at far end to around 40 mm. Based on a similar project, grouting was expected to reduce building's settlement to more than 30 mm in this project.

CONCLUSIONS

A successful case study using dewatering and grouting to protect a building during an adjacent deep excavation is presented in this paper. Because the high stress level in the soil underneath the foundation, the building was very sensitive to the disturbance from adjacent construction. The results of this case study demonstrated that dewatering and grouting is an efficient way in properties' protection in an urban environment. Though the maximum settlement of the building was 103mm, no cracks were found due to all the efficient control of differential settlement in the building.

Table 2 – Comparison of Building Settlements Before Middle Slab Construction

Point	Date	Date	Settlement rate (mm/day)	Date	Settlement rate (mm/day)	Date	Date	Settlement rate (mm/day)
	11/13/97	12/13/97	11/13-12/13	1/8/98	12/13-1/8	3/16	4/3	3/16-4/3
F17	-31.0	-43	-0.41	-55.5	-0.48	-76.1	-84.3	-0.46
F18	-28.8	-46.4	-0.59	-53.0	-0.25	-64.9	-78.2	-0.74
F19	-11.1	-20.2	-0.30	-33.2	-0.50	-57.5	-65.7	-0.46
F20	+3.7	+5.2	+0.05	-1.8	-0.27	-24.3	-28.3	-0.22
F31	+4.3	-1.2	-0.18	-3.5	-0.09	-17.5	-25.3	-0.43
Note	Slurry wall construction, no excavation and dewatering			Excavation above middle slab and dewatering		Excavation beneath middle slab and dewatering		

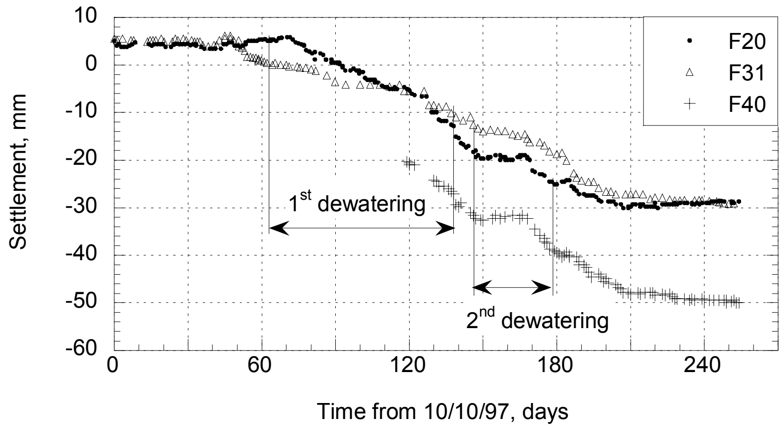

Fig. 6 – Settlement of Building During Dewatering

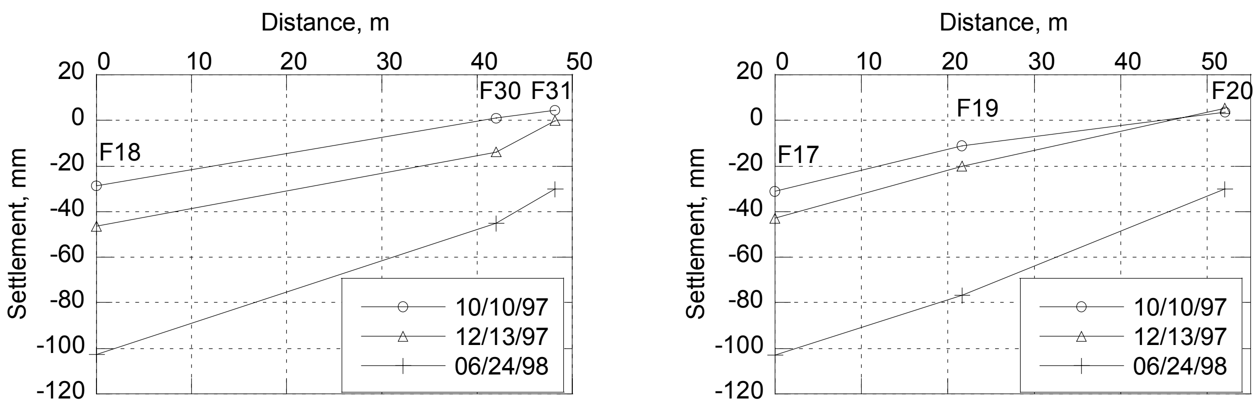

Fig. 7 – Differential Settlement of The Building During Construction

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