Advances in Frontier Research on Engineering Structures
A. Cheshmehzangi and H. Bilgin (Eds.)

doi:10.3233/ATDE230198

Performances of a Top-Down Deep Excavation and Its Surroundings in Shanghai Soft Clay

Kaiyong HUANG[1], Xiang WEI and Zhirong LIANG
Shanghai Shen Yuan Geotechnical Engineering Co., Ltd., Shanghai 200011, China

Abstract. The project of Emergency Treatment Complex Building in Shanghai Tenth People's Hospital is presented in this paper to illustrate the behaviors of the two-floor top-down excavation and its complicated surroundings in Shanghai soft clay. In order to restrict excavation deformations and expand construction site, the two layers of permanent floor slabs were adopted as horizontal supporting systems and the B0 slab was meanwhile exploited as working place and traffic passageway. Before construction, numerical simulations were conducted to predict the responses of the pile walls and the structure slabs. Based on the calculation results and monitoring data, it can be concluded that buildings without piles have significant impacts on the wall deflections while those with piles hardly influence the ground movements during excavation. Furthermore, the magnitude of displacements is related to the length of side and the construction loads around excavation. Buildings subside larger as their distances to excavation get closer. Settlements of buildings without piles are much more remarkable than those with piles.

Keywords. Deep excavation, top-down method, soft clay, numerical simulation, field monitoring

1. Introduction

Deep excavation normally causes notable deformations of its retaining structures and surroundings in soft soil areas, for instance the city of Shanghai [1]. Therefore, a series of design and construction methods have been innovated in excavation engineering to restrict the displacements, including the top-down method which takes permanent floor slabs instead of temporary struts as horizontal bracing systems [2].

Based on a database of over 300 case histories of wall deflections induced by deep excavations in Shanghai soft clay, Wang et al. [3] concluded the top-down methods tended to result in average smaller lateral wall deformations owing to the stiff supporting systems compared to the conventional bottom-up approaches. Many researchers from Shanghai also observed and analyzed the behaviors of excavations executed by the top-down methods as well as the adjacent buildings via field monitoring or numerical simulation [4-8]. Moreover, the top-down methods generally contribute to shorten construction periods and save costs in ways of removing the construction and demolition stages of temporary struts from the critical paths of projects [9, 10].

[1] Corresponding Author, Kaiyong Huang, Associate Professor of Engineering, National Registered Civil Engineer (Geotechnical), National Class 1 Registered Structural Engineer, Shanghai Shen Yuan Geotechnical Engineering Co., Ltd., Shanghai 200011, China; E-mail: can24816@163.com.

In this paper, the project of Emergency Treatment (ET) Complex Building in Shanghai Tenth People's Hospital is introduced to elaborate the performances of the top-down deep excavation and its sensitive surroundings in Shanghai soft ground. Permanent structures slabs were served as struts to control the displacements of the excavation and the environment. Their responses are discussed through numerical simulations and field monitoring.

2. Project Overview

2.1. Project Location and Scale

Shanghai Tenth People's Hospital is located on the north of Middle Yanchang Road and west of New Gonghe Road in Jingan District of Shanghai. The project of ET Complex Building lies in the south side of the hospital and occupies the position of entrance and exit. The overall floorage is 11550m^2, including aboveground area of 6700m^2 and two-floor underground area of 4850m^2. The excavation is 2895m^2 in area and 10.8~11.1m in depth. With a length of 78.05m in east-west direction and a width of 36.85m in north-south direction, the shape of the excavation is approximate rectangular. The plan view of the excavation and its surroundings is shown in Figure 1.

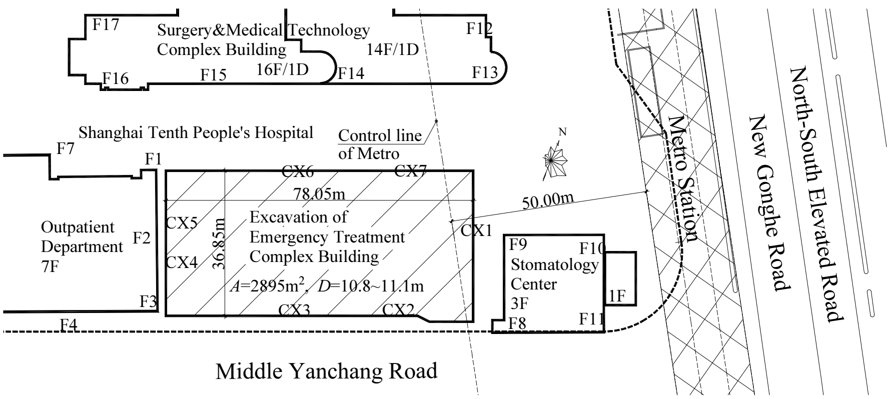

Figure 1. Plan view of the excavation and its surroundings.

2.2. Site Condition and Surroundings

- On the east of the site, there lies a three-floor building built in 1980s without basement and piles, i.e. Stomatology Center (SC), which is 4.9~7.9m away from the excavation. The excavation locates in the protected zone of metro (within 50m from the tunnels) and its minimum distance to the Yanchang Road station of Shanghai Metro Line 1 is 42.7m.
- The south of the site borders on Middle Yanchang Road, under which kinds of buried pipelines are 2.5~27.5m behind the excavation. Details of the underground pipelines are listed in Table 1.

Table 1. Underground pipelines of Middle Yanchang Road

Type	Diameter(mm)	Minimum distance to the edge of the excavation (m)
Telecom		7.5
Water	300	10.0
Water	200	11.5
Rain	900	15.0
Sewage	530	19.0
Gas	300	27.5

- On the west of the site, there is a seven-floor building with prefabricated square piles served as Outpatient Department (OD), which is only 2.1~2.5m from the excavation.
- The north of the site is Surgery & Medical Technology (SMT) Complex Building with 16-floor superstructure and one-floor basement. The complex building is 22.1m apart from the excavation and the bottom of its basement is 6 m under the ground with bored piles.

2.3. Geological and Hydrological Conditions

According to geotechnical investigation before construction, the site belongs to coastal plain in landform and the ground mainly contains saturated clay, silt and sand due to high underground water table with a burial depth of 0.5-0.7m in Shanghai. The results of laboratory tests and in situ tests are presented in Table 2.

Table 2. Physical and mechanical parameters of soils

Stratum number	Soil Classification	Unit weight γ (kN/m^3)	Peak intensity of consolidated quick shear	
			Cohesion c (kPa)	Angle of internal friction φ (°)
②$_1$	silty clay	18.4	18	18.5
②$_3$	clayey silt	18.4	6	30.5
③	muddy silty clay	17.5	12	18.0
④	muddy clay	16.7	11	12.0
⑤$_{1-1}$	clay	17.6	13	12.0
⑤$_{1-2}$	Silty clay mixed with clayey silt	18.2	12	22.0

- With a thickness of 1.7~3.2m, the top soil layer is artificial fill (Layer ①) with plenty of underground obstacles including waste pipelines and building foundations which would negatively affect the construction quality of piles.
- Layer ③ and Layer ④ in the site are flow plastic, high compressive and low intensive, which are adverse to control the ground movements.

3. Design and Construction Measures

3.1. Waterproof Curtains and Retaining Walls

Tri-axial soil mixed walls (3Φ850@1200) of 18.5~20m in length were employed as waterproof curtains (Figure 2 and 3) to alleviate the hydraulic connections between regions inside and outside the excavation. In order to restrict the displacements of excavation, contiguous bored pile walls (Φ900@1100/Φ1000@1200) of 25~26.5m in length were adopted as retaining structures (Figure 2 and 3).

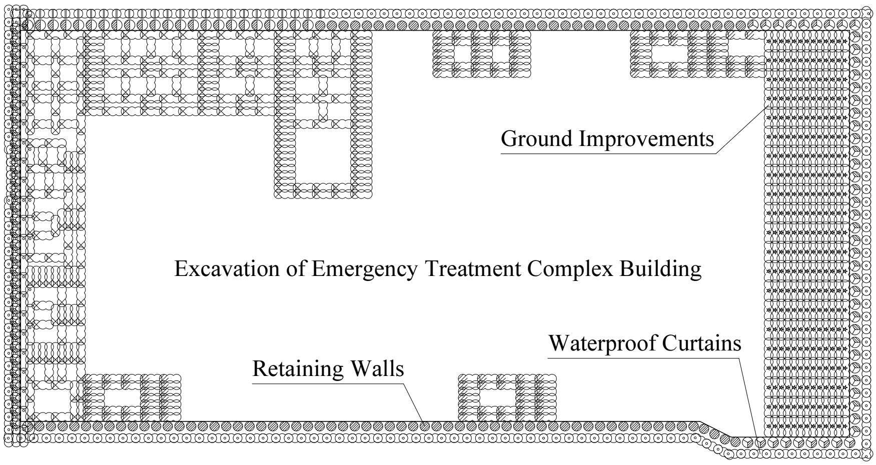

Figure 2. Plan view of the excavation and supporting structures.

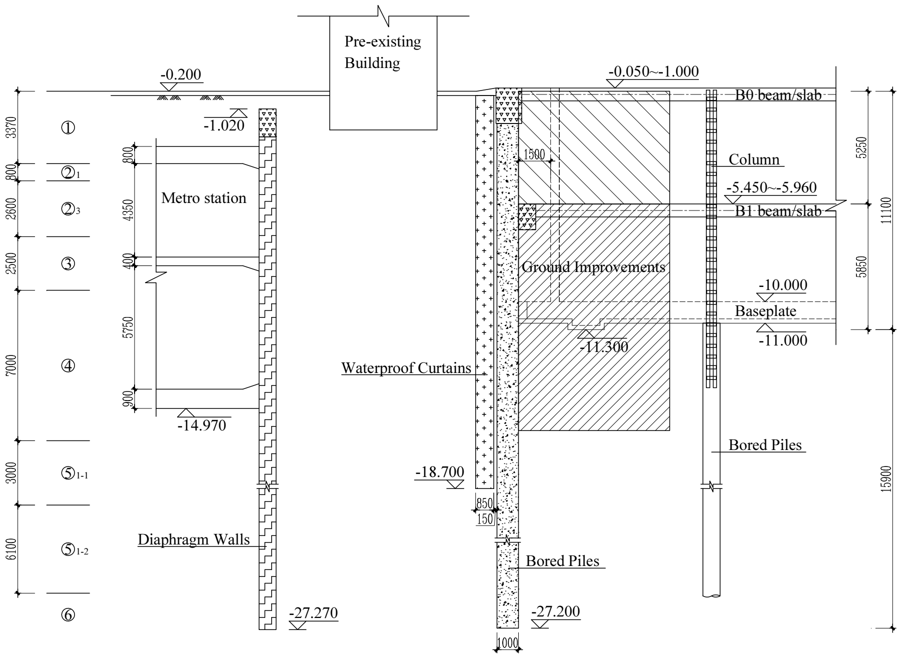

Figure 3. Typical section of the excavation and supporting structures (in the east side).

3.2. Horizontal Supporting Systems

As mentioned above, the complicated environment surrounding the excavation was extremely sensitive to deformations. Besides, the site was so narrow that construction machineries could not pass around the excavation if the conventional bottom-up method was utilized during the construction of basements, let alone meet the demand of ordinary vehicles. In consideration of these reasons, the top-down construction method was chosen where the high stiff slabs were served as not only horizontal bracing systems but also passageways. More specifically, the permanent B0 and B1 floor slabs were exploited as the first and second layers of struts respectively while the B0 slab was applied as construction site and traffic passage at the same time.

3.3. Ground Improvements

Along the sides of the excavation, tri-axial soil mixed piles (3Φ850@1800) were put to use to improve the ground. In regular areas, the improvements were 4.45~5.65m in width and 14.8~15.3m in length. The cement content was 20% below the bottom of the excavation while 10% above. In the east side, considering the SC building and the metro station, the improvement width was 8.05m with a length of 15.8m. The cement content was 20% below B1 structure slab while 10% above.

4. Numerical Simulation

A basic numerical model was established without the pre-existing buildings or any other facilities to predict the deformations of excavation with no influences of the surroundings. The calculation results (Figure 4) show a maximum displacement of 19.02mm, which is less than 0.18% of the excavation depth.

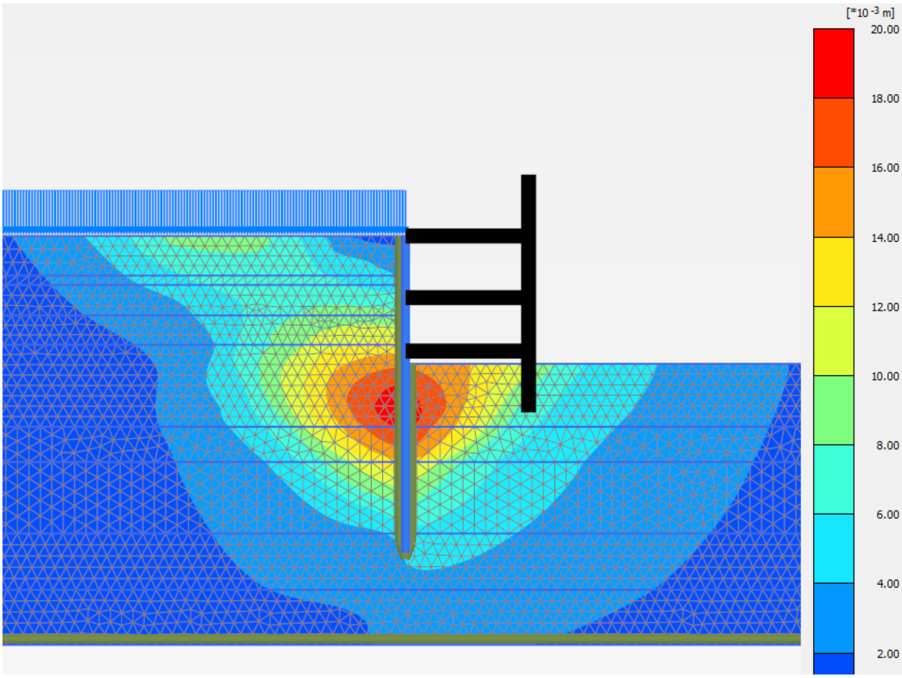

Figure 4. The calculated ground movements.

Responses of the B0 and B1 slabs were also simulated by finite element method (FEM). Figure 5 presents the stresses of the B0 floor slab and the peak value of 1.24MPa is much smaller than the compressive intensity of the concrete structure.

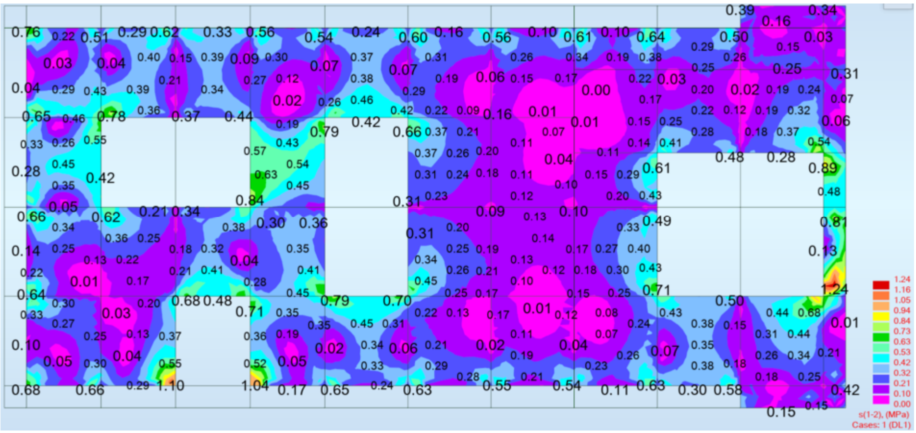

Figure 5. The simulated stresses of the B0 structure slab.

5. Field Monitoring

Performances of the retaining walls and the surroundings were monitored during excavation and construction from November 2018 to October 2019. Main construction stages and the corresponding periods are presented in Table 3.

Table 3. Time periods of main construction stages

Construction stage	Time period
Construction of piles and the B0 slab	2018/11/10-2019/6/4
Excavating to the elevation 1m below the B1 slab	2019/6/13-2019/7/2
Construction of the B1 slab	2019/6/28-2019/7/20
Excavating to the bottom	2019/7/28-2019/8/20
Construction of the baseplate	2019/8/21-2019/9/2

Figure 6 shows the deflections of retaining walls on July 20, August 20 and September 2 in 2019, respectively. It can be seen that the deformations grew apparently during excavation and the peak value in each side appeared at the bottom of excavation. In the west side, the maximum displacement was 21.28mm and quite close to the numerical simulation result, which implies the building with piles had almost no impact on the excavation. As a comparison, the value in the opposite side was 40.65mm and nearly twice the computed result due to the heavy load from the adjacent building with shallow foundation. The displacements of the south and north sides were significantly larger than the other two sides. It seems that the length of the side played an important role in the wall deflections. Additionally, the dynamic load of vehicles through the two sides and the construction surcharge in the north sides are also momentous inducements of the excavation deformations.

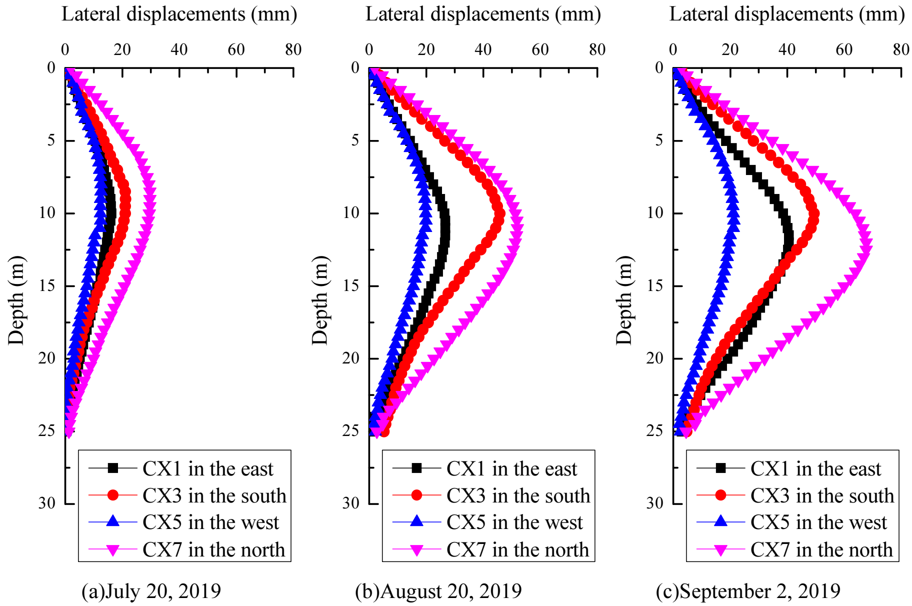

Figure 6. Wall deflections during excavation and construction.

Figures 7 shows the settlements of buildings around the site along with the process of construction. The final settlements of buildings with piles on the north and west side were 1.25~1.71mm and 2.23~5.9mm, respectively. The OD building seemed to subside a bit larger due to a closer distance to the excavation. The settlements of the two buildings with piles were tolerable and all along under control during excavation. The trend of settlements of the SC building with shallow foundation was similar to the buildings with piles until the earthwork under the B1 slab began. Then the building subsidence grew sharply from 1.45~1.89mm to 38.61~40.62mm which accorded with the magnitude of the retaining wall deflections.

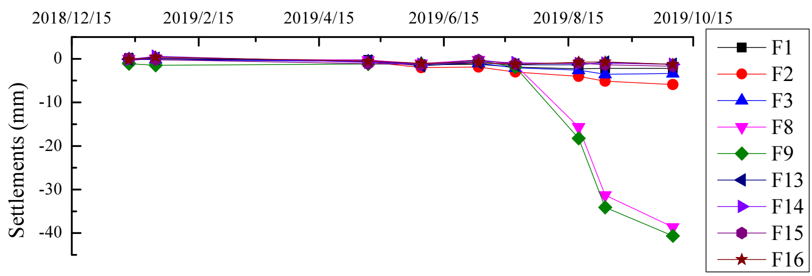

Figure 7. Settlements of the buildings.

6. Conclusions

The case history of the two-layer rectangular excavation of the ET Complex Building in Shanghai Tenth People's Hospital is minutely illustrated in this paper.

In considering of the sensitive environment and the narrow site, the top-down construction method was employed in this project to restrict ground movements and provide construction site as well. Contiguous bored piles were utilized as retaining structures while soil mixed piles were adopted as waterproof curtains and ground improvements. The two layers of structure slabs were served as horizontal struts while the B0 slab was further used as construction trestle and driving area.

Numerical models were built before construction to predict the performances of the retaining walls and the floor slabs. Field data during excavation is analyzed combined with the numerical simulation results. Conclusion is obtained that the influences of buildings with piles on the excavation are relatively small. On the contrary, buildings without piles and basements obviously affects the deformations. Meanwhile, additional displacements might occur due to the exceeding length of side and extra construction loads. It can also be concluded that the magnitude of settlements of buildings is related to their distances to the excavation. Buildings with piles hardly subside during excavation while those with shallow foundations deform remarkably.

Acknowledgment

This research is sponsored by Shanghai Sailing Program (No. 21YF1432600), Shanghai Geological Star Program (No. Dzxh202208), Program of Shanghai Technology Research Leader (No. 22XD1432800) and Shanghai Rising-Star Program (No. 21QB1404400).

References

[1] K.Y. Huang, Z.R. Liang, X. Wei, Effects of a deep excavation on its surroundings in Shanghai soft ground, *Advances in Civil Engineering: Structural Seismic Resistance, Monitoring and Detection* (2022), 3–10.

[2] C.Y. Ou, J.T. Liao, H.D. Lin, Performance of diaphragm wall constructed using top-down method, *Journal of Geotechnical and Geoenvironmental Engineering* **124** (1998), 798–808.

[3] J.H. Wang, Z.H. Xu, W.D. Wang, Wall and ground movements due to deep excavations in Shanghai soft soils, *Journal of Geotechnical and Geoenvironmental Engineering* **136** (2010), 985–994.

[4] M.G. Li, J.J. Chen, A.J. Xu, J.H. Wang, Performance of a deep top-down excavation under operating railway, *Tunneling and Underground Construction* **GSP 242** (2014), 965–973.

[5] M.G. Li, J.J. Chen, A.J. Xu, X.H. Xia, J.H. Wang, Case study of innovative top-down construction method with channel-type excavation, *Journal of Construction Engineering and Management* **140** (2014), 05014003.

[6] Y. Tan, D.L. Wang, Characteristics of a large-scale deep foundation pit excavated by the central-island technique in Shanghai soft clay. Part II: top-down construction of the peripheral rectangular pit, *Journal of Geotechnical and Geoenvironmental Engineering* **139** (2013), 1894–1910.

[7] J. Jia, X.L. Xie, J.Q. Zhai, Y. Zhang, K. Yang, X. Guo, Research and design on top-down method for large scale podium basement excavation of Shanghai Tower, *GeoCongress 2012* (2012), 770–779.

[8] Y.M. Hou, W.D. Wang, J.H. Wang, Three-dimensional performance of an over-size complex excavation in Shanghai. *GeoCongress 2008* (2008), 992–999.

[9] L.G. Arboleda-Monsalve, R.J. Finno, Influence of concrete time-dependent effects on the performance of top-down construction, *Journal of Geotechnical and Geoenvironmental Engineering* **141** (2015), 04014120.

[10] R.J. Finno, L.G. Arboleda-Monsalve, F. Sarabia, Observed performance of the One Museum Park West excavation, *Journal of Geotechnical and Geoenvironmental Engineering*, **141** (2015), 04014078.