Geotechnical Aspects of Underground Construction in Soft Ground – Yoo, Park, Kim & Ban (Eds)
 ISBN 978-1-138-02700-8

Case study of deep excavation in existing underground structure of three-story basement and diaphragm wall

C.J. Kuo, Y.K. Lin & C.L. Hung
Mice Engineering Consultants Co., Ltd, Taipei, Taiwan

S.S. Lin
Department of Harbor and River Eng., National Taiwan Ocean University, Keelung, Taiwan

ABSTRACT: In general, site size of an urban renovation case is small in Taipei. The difficulty of workability is added by the influence of the old building foundation on the to-be-constructed building foundation. This paper presents a renovation case of a building project, 12-story high with a 3-story underground basement covering area of 583 m^2 in Taipei. Perimeter of the planned site is about 80 m. The existing foundation and the diaphragm wall are 14.2 m and 25 m in depth, respectively. In addition, the diaphragm wall thickness of this old building is 70 cm. The new building foundation planned to set inside the existing diaphragm wall of the old building. New building is planned to excavate down to 21.5 m, with drilled shafts H414 × 405 × 18 × 28 mm installed down to 34 m. The new foundation had been constructed by incorporating with the old diaphragm wall, the new drilled shafts and cylindrical soil improvement . In addition, combining the top-down and bottom-up construction procedures was used by taking advantage of the B3 slab of to-be-constructed building to connect existing diagram wall and the new installed drilled shafts to complete the building project.

1 INTRODUCTION

For better development of Taipei city, many aged buildings are planned to be replaced by new and higher high rise buildings. Hence, How to deal in the existing basement is the key for success of the new building foundation construction. Demolishing of the existing retaining pile, diaphragm wall or/and other basement structure often has some technical difficulties and may damage neighbor buildings (Ho and Chen, 2007; Yin et al., 2007). It is often inevitable required longer underground construction schedule and more cost (Kuo et al., 2013).

The site area of studied building renovation project is about 583 m^2 with an aged building of 12-story high and 3-story of basement, whose foundation is only 14.2 m deep. The site perimeter of the project is only 80 m. Some conflict between old and new basement needs to be solved during new basement construction. In this project, the new building foundation is planned to set inside the diaphragm wall area of the old building. New building is expecting to excavate down to 21.5 m, with drilled shafts H414 × 405 × 18 × 28 mm installed down to 34 m. The new foundation had been constructed by incorporating with the old diaphragm wall, the new drilled shafts and cylindrical soil improvement. In addition, combining the top-down and bottom-up construction procedures was used by taking advantage of the B3 slab of to-be-constructed building to connect existing diagram wall and the new installed drilled shafts to complete the building project.

2 SITE AND GEOLOGICAL CONDITION

2.1 *Site condition*

The case presented herein is a renewal project located in the business district of Taipei city. The site location is shown in Fig. 1. The EWS side of the site is closely surrounded by a building of 12-story high and 2-story basement. Six meter away along the NE side of the site is also a 12-story high building with 2-story basement. The Keelung road is on the NW side of the project, whose SE side is open space.

2.2 *Geological conditions*

The geological conditions at the site had been investigated and summarized as shown in the following (C & M Hi-tech Engineering Co., 2011):

1. From ground surface down to depth of 4.1 m, there are backfill and silty clay with SPT-N values ranged from 5 to 6.
2. Gravel and silty sand: distributed from 4.1 m down to 16.8 m below ground surface. The SPT-N values ranged from 8 to 50, with average of 29.

3. Silty clay: distributed from 16.8 m down to 26.2 m. The SPT-N values ranged from 4 to 15, with average of 7.
4. Sandy silt and silty sand: distributed from 26.2 m down to 32.6 m below ground surface. The SPT-N values ranged 10 to 20, with average of 15.
5. Gravel with silty sand and sandy silty: distributed from 32.6 m to 35.1 m below ground surface. The SPT-N value is higher than 50.
6. Sandstone: distributed at 35.1 m below ground surface down to the end of investigation at 40.0 m. Again, the SPT-N value is higher than 50.

The ground water level at site is around 3.5 m below the ground surface. The engineering properties of each layer deduced from geological explorations and laboratory tests are summarized in Table 1.

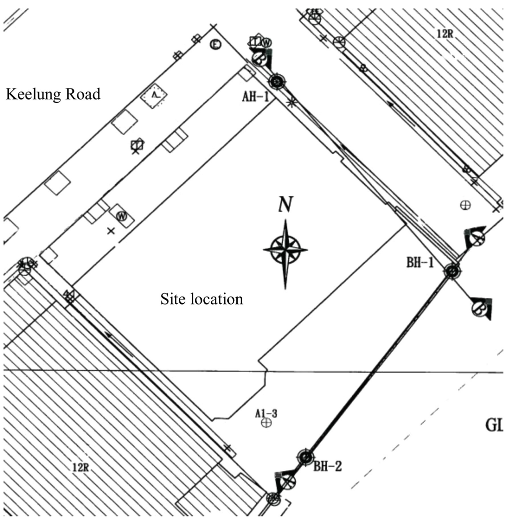

Figure 1. Site location (from C & M Hi-tech Engineering Co.).

3 DESCRIPTION ON PROJECT PLANNING

For such a limited construction space, destruction of the existing old basement is not cost effective and the time schedule will be prolonged. For the purpose to maximize the basement space of the new building, a better planning is to take advantage of the existing basement and diaphragm wall serving as part of the retaining structure of the new building. Since the existing diaphragm wall and the neighbor right of way is already back to back, the new building basement is planned inside the existing basement structure. In addition, incorporation of the H-pile along with the old diaphragm wall is used to serve as the retaining structure of the new building excavation. The outside wall of the new basement and the old diaphragm wall is to construct back to back to maximize the space of the new basement.

In summary, taking advantage of the old diaphragm wall and the basement serving as part of retaining structure of the new building is planned. The drilled shafts is adopt to another part of retaining structure of the new building excavation to compensate the insufficient depth of the old diaphragm wall . The old building contains the existing foundation 14.2 m in depth and the diaphragm wall of 25 m depth and 70 cm thickness. The new H-piles and secant ground improving piles is then constructed. Excavation is divided by six layers of H-beam struts, one layer of back supporting and top-down construction of B3. The new basement foundation is excavated down to 21.5 m in depth. The layouts of the drilled shafts and the soil improvement is shown in Fig. 2. Profile of the internal supporting strut for excavation is shown in Figs. 3 and 4.

Table 1. Geological parameters deduced

Layer	Depth (m)	Soil description	SPT-N	γ_t (t/m^3)	w_n (%)	s_u (t/m^2)	c' (t/m^2)	ψ' (deg.)	kh (t/m^3)
I	0∼4.1	SF/SM	5∼6 (5)	1.85	24∼40	–	0	28	625
II	4.1∼16.8	Gravel and Silty sand (GM/SM)	8∼>50 (29)	2.05	9∼29	–	0	33	3625
III	16.8∼26.2	Silty clay (CL)	4∼15 (8)	1.81	28∼40	5.51∼6.93 ($0.26\sigma'$)	–	–	1377∼1732
IV	26.2∼32.6	Sandy silty and silty sand (ML/SM)	10∼20 (15)	1.95	19∼28	–	0	31	1875
V	32.6∼35.1	Gravel with silty sand and silty clay (GW/SM/CL)	>50 (50)	2.15	–	–	1	35	6250
VI	35.1∼40	Sandstone (SS)	>50 (50)	2.45	–	–	–	–	–

*k_h is horizontal subgrade reaction modulus
k_h(t/m^3) = 125*SPT-N(for sand); 250*s_u(for clay)

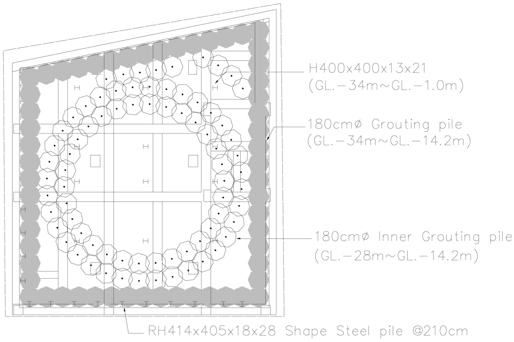

Figure 2. The layouts of the drilled shafts and the soil improvement.

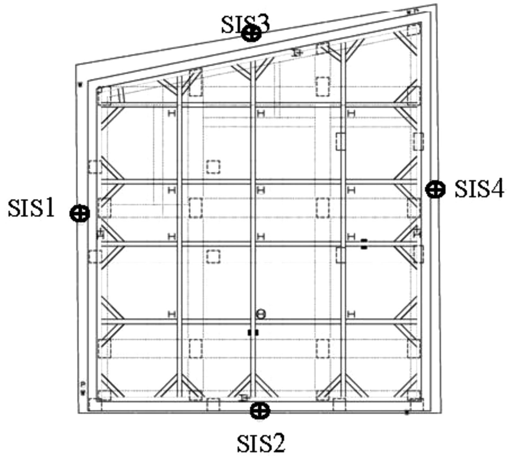

Figure 3. Internal supporting strut plan and inclinometer location.

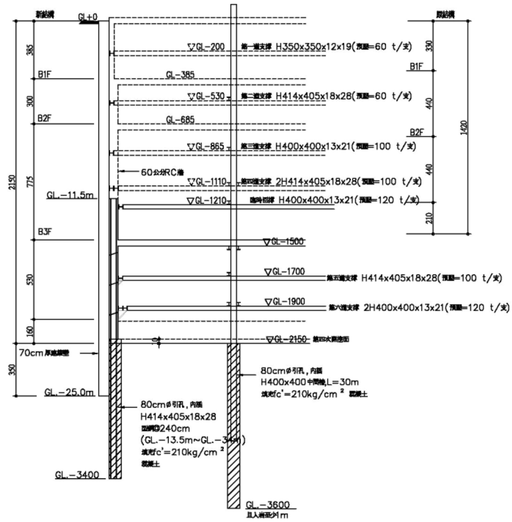

Figure 4. Internal supporting strut profile.

4 ANALYSIS, DESIGN AND CONSTRUCTION

4.1 *Stability analysis of the excavation*

Squeeze-in, heaving and piping analysis are based on the Building Foundation Design Code (2001). The depth of the excavation is down to 21.5 m with the lowest strut level at GL-19.0 m. Since soil improvement will be conducted in the site, the safety factor for squeeze-in after analysis is 2.03 when the retaining structure penetrates 12.5 m below the excavation depth. The safety factors for heaving is 1.56. Piping is not a problem for the soil below the excavation level is cohesive material. However, the fourth sandy soil layer is an aquifer based on the geological investigation, water pressure relief well and water pressure meter are required to install to prevent from possible failure of up-lifting. Hence, a total length of 34.0 m of retaining structure is needed for new foundation excavation. In addition, the new H-piles are used to install down to GL-34.0 m inside the basement for the existing diaphragm wall which is only 25.0 m deep.

4.2 *Consideration for soil improvement*

The new structure excavation is planned to reach 21.5 m while the existing diaphragm wall is only 25 m in depth. In order to prevent squeeze-in, high efficiency soil improvement is adopted. Assuming the grouting pressure acting on the H-pile is less than 4 kg/cm^2, the shear force and bending moment of the retaining H-pile is checked for satisfying the allowable stress. In addition, the maximum deflection of the H-pile is 4 cm by analysis. In order to reduce the effect of the grouting pressure on the H-pile, double-jet is used. The inclinometer is also installed inside the H-pile for obtaining possible effect from grouting.

4.3 *Deflection analysis of the retaining structures*

Available commercial computer code RIDO is used to check stability during excavation and the supporting system.

1. Retaining structure excavation: Existing old diaphragm wall is 70 cm in thickness and is located at ground levels of GL.0.0 m to GL.-25 m. The new retaining structure H-pile is 80 cm in diameter and 240 cm maximum spacing . The H-pile is installed from GL.-12.0 m to GL.-34.0 m. Considering the possible effects of the soil improvement on the existing diaphragm wall, the stiffness of the old diaphragm wall and the new H414 pile were considered in the analysis from GL0.0 m to GL -14.2 m and from GL-14.2 m to GL -34.0 m, respectively.
2. Supporting system: Internal supporting strut of each layer is given in Table 2.
3. Soil improvement of the project: During numerical analysis, the strength of the improvement area and the undrained shear strength of the in-situ soil are transformed into equivalent composite undrained

Table 2. Internal supporting strut of each layer.

Layer	GL. (m)	Strut Type.	Preload	Wale Type
1	GL.-2.00 m	H350*35012*19 mm	60 t/g	H350*350*12*19 mm
2	GL.-5.30 m	H414*405*18*28 mm	60 t/g	H414*405*18*28 mm
3	GL. 8.65 m	H400*400*13*21 mm	100 t/g	H400*400*13*21 mm
4	GL.-11.10 m	2H414*405*18*28 mm	2 × 100 t/g	2H414*405*18*28 mm
5	GL.-17.00 m	H414*405*18*28 mm	100 t/g	H414*405*18*28 mm
6	GL.-19.00 m	2H400*400*13*21 mm	2 × 120 t/g	2H400*400*13*21 mm
return	GL.-L2.10 m	H400*400*13*21 mm	120 t/g	H400*400*13*21 mm

shear strength. The equation is given as (Hsieh, 2002)

$$(s_u) = \frac{I_r \times q_u}{6} + s_u \times (1 - I_r) \qquad (1)$$

in which (s_u) = equivalent composite undrained shear strength; Ir = soil improvement ratio; q_u = unconfined compressive strength of the improved soil and s_u = undrained shear strength of the in-situ soil.

4. Procedures of the numerical analysis:
   - Step 1: Installation of the existing floor slab and foundation.
   - Step 2: Remove the slab of the first floor of the old building and then install the first level horizontal strut.
   - Step 3: Remove the first floor slab of the old basement and install the second level horizontal strut.
   - Step 4: Remove the second floor slab of the old basement and install the third level horizontal strut.
   - Step 5: Remove the BS and FS slab of the old basement and install the fourth level horizontal strut.
   - Step 6: Excavate down to GL-16.0 m and install the third floor slab of the new basement.
   - Step 7: Excavate down to GL-18.0 m and install the fifth level horizontal strut.
   - Step 8: Excavate down to GL-20.0 m and install the sixth level horizontal strut.
   - Step 9: Excavate down to GL-21.5 m and then install 10 cm thickness of PC.
   - Step 10: Construct the bottom slab of the new basement and the BS slab.
   - Step 11: Remove the fifth, the sixth level strut and Install strut at GL-12.1 m.
   - Step 12: Remove the third and the fourth level strut.
   - Step 13: Construct the second floor slab of the new basement and then remove the second level strut.
   - Step 14: Construct the first floor slab of the new basement and then remove the first level strut.
   - Step 15: Construct the ground level floor slab and remove the strut at GL-12.1 m.

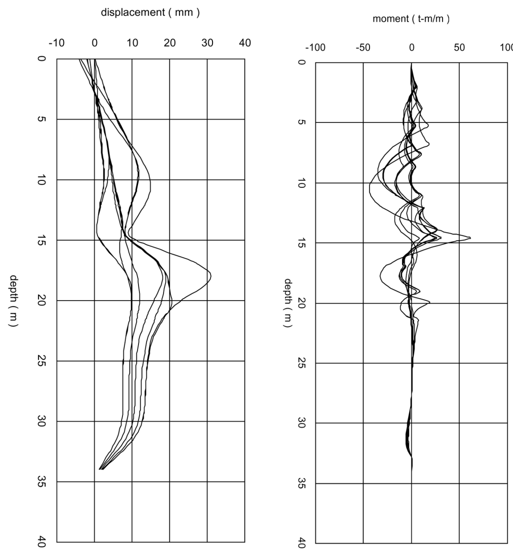

Figure 5. Deflection and bending moment profiles.

5. Results of the analysis: The maximum lateral deflection of the retaining system is 3.1 cm; the maximum bending moment and the maximum shear force of the H-pile is 25.96 t-m/m and 31.12 t/m, respectively. These values are within the allowable stress of the H-pile. Profile of deflection and moment is shown in Figs 5.

4.4 *Construction and other considerations*

In general, we backfill the basement to support construction machine and lateral force in the destruction of existing foundation (Kuo et al., 2013). In the case, the gravel layer at depth 4.1 m to 16.8 m can provide enough friction to prevent the uplifting problem of the basement after the upper structure of the building is demolished. It is considered that the underground floors can be reserved as retaining system instead of backfilling the basement. The foundation construction procedures are described in the following:

1. To inspect the existing basement condition and to reinforce the existing basement, if necessary, before

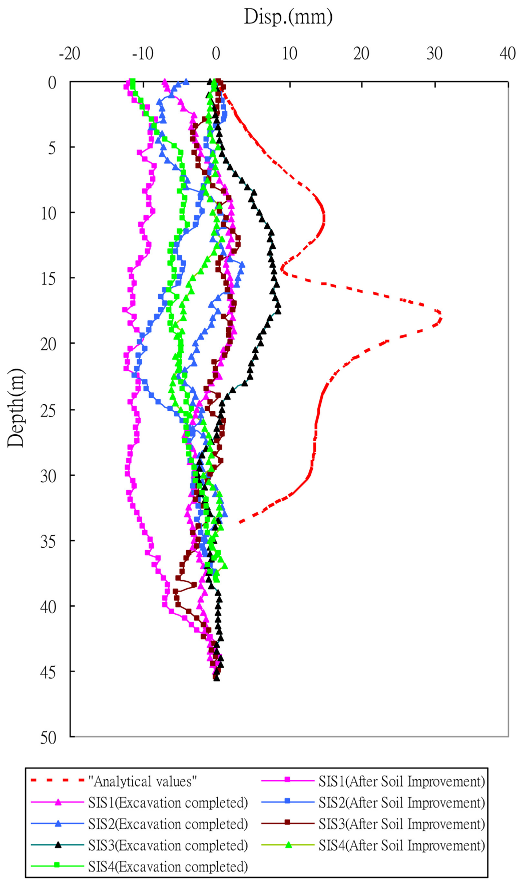

Figure 6. Comparison of the calculated deflection and measured.

new foundation construction. Subsequently, to set up the working platform in the ground level.

2. Installation of the drilled shafts from the working platform. Openings of basement and underground floors for pile shafts should be made during pile shafts construction and the opening should be rehabilitated by concrete simultaneously to reduce the unbalance force.
3. Soil improvement is carried out at B3 level of the old basement. In addition, in order to reduce the squeezing on the old diaphragm wall during ground improvement, double jet grouting method is adopted.
4. Four 45 m long inclinometers are installed nearby the old diaphragm wall, as shown in Fig. 3, before soil improvement construction. The max. Squeezing deflection of the inclinometers is about 12 mm during soil improvement construction. The maximum deflection of the inclinometer is about 11 mm after excavation. It is smaller than the analysis value. Comparison of the calculated deflection and measured is shown in Fig. 5.

5 CONCLUSIONS

In this paper, how to take advantage of the old building basement structure serving as the retaining structure of a new building construction project in Taipei was introduced. The features of this case can be summarized as follows:

1. A new foundation, 21.5 m in depth, had been constructed by incorporating with the old 25 m depth diaphragm wall, drilled H pile and cylindrical soil improvement.
2. Although high soil improvement ratio was design in this case, the squeezing deflection of the inclinometer installed nearby the old diaphragm is measured only 12 mm during soil improvement construction by double jet grouting method.
3. The maximum deflection measured during excavation is only 11 mm. It is smaller than the analysis value.

REFERENCES

Hsieh Pio-Go, Use of finite element analysis in bermed excavation and its associated problems, Sino-Geotechnics: 93, 43–52, Oct., 2002.

Ho Tai-Yuan & Chen Tsung-Hai, Case study of demolishing the existing structure and then rebuilding MRT entrance, Sino-Geotechnics: 111, 15–26, March 2007.

Yin Y.L. & Huang N.C. & Huang C.S. & Lin Y.K. & Lu F.C. & Kuo C.J., Case study for renewal of an old building with two-story basement and prepack pile walls, Sino-Geotechnics:111, 39–46 , March 2007.

C &M Hi-tech Engineering Co., 2011, Site Geological Survey Report.

Construction and Planning Agency Ministry of the Interior (CPAMI), 2011, Building foundation construction design specifications.

Kuo C.J. & Lin Y.K. & Lu F.C. & Chen C.H., Case study of slurry wall construction for renewal of an old mansion with three-story basement and slurry wall, ISAFE 2013, Singapore.