Evaluation of strut and ground anchor system for deep excavations – A case history in Vietnam

Manh Truong Quang [2] and N.C. Lan[1]

[1] Geotechnical Department, University of Transport and Communications, Hanoi, Vietnam
[2] Technical Department, DELTA Corporation, Hanoi, Vietnam

ABSTRACT

Recently, accompanied by the speed of urbanization, deep excavation is rising as a common and avoidable part of infrastructure development. It is more critical for buildings in high populated cities or crowded areas. Therefore, problem for engineers or experts nowadays is able to access an appropriate method among various options for deep excavations. A right selection that is controlled by support systems could prevent displacement as well as corruption of nearby structures.

In this paper, two support systems chosen for analyses in a real project in Vietnam are Strut and Ground Anchor. The deep excavation project is modelling by finite element program (Plaxis 2D version 2010) for both two methods. The excavation is L-shape, one length is around 180m and the other is approximate 150m, the maximum depth of excavation is -21.9m. Bottom up method would be chosen for the project. In the first scenario, the excavation have been reinforced by 39m-high diaphragm wall accompanied with seven rows of ground anchor (15m bonded and 13~18m unbonded length for the rows and both are anchored in sand layer). In the second case, anchors are replaced by five rows of H400-struts system. The results of displacement as well as bending moment of the diaphragm wall would be compared, then the more reasonable one would be proposed for practice.

Keywords: Deep excavation, Strut system, Ground Anchor, Finite element method.

1 INTRODUCTION

Nowadays, earth retaining systems using ground anchors are commonly used in basement construction in urban area due to improvement in construction techniques, design methods as well as anchor materials. ground anchors have been applied successfully in deep excavation with different geological conditions. along with upgrade techniques, thick soft clay layer is no longer an obstacle. meanwhile, strutted excavation could be set up inside of the pit and independent of soil profiles. strutting system consist of h-beam always be the first choice for long and narrow pits. the most disadvantage of the strut system is the difficulty in excavation work. each of them has own pros and cons in specific circumstances. statistically, struts are by far the predominant method for wall support. however, the large working space inside the excavation provided by a ground anchor system has a significant construction advantage. the behaviors of the two kinds of diaphragm wall support systems are compared and discussed briefly through a case history in hanoi, vietnam. finite element analysis plays an important role in the design of excavations in urban environments because of the necessity of ensuring the protection of adjacent buildings. to simulate the case study, a finite element based computer program plaxis 2d version 2010 was used. the soil was modeled as mohr-coulomb model while the elastic perfectly-plastic was chosen to model for design of the diaphragm wall and the supports (liao and hsieh (2002); vermer and brinkgreeve (2002)).

2 PROJECT OVERVIEW AND SOIL INVESTIGATIONS

Case study is an underground parking in Hanoi, Vietnam. The project is expected to build underground with 5 floors, capacity of 2,500 cars and 5,000 motorcycles. The excavation is L-shape, one length is around 180m and the other is approximate 150m, the maximum depth of excavation is -21.9m. Bottom up method would be chosen for the project. Plan view of the project as well as the distribution of boreholes in the area are shown in Figure 1.

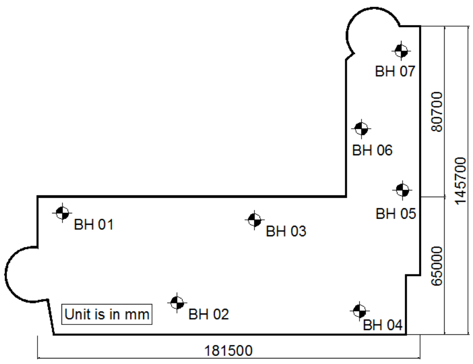

Fig. 1 Plan view of the project

Ground anchor would be designed with five rows, average length for each is around 30m and spacing is 2 m. Meanwhile, other calculation will be performed with H-400 strutting system. In details, five levels of the struts with spacing of 10m. The section view of the strutting system and the anchor system are shown in Figures 2 and 3, respectively.

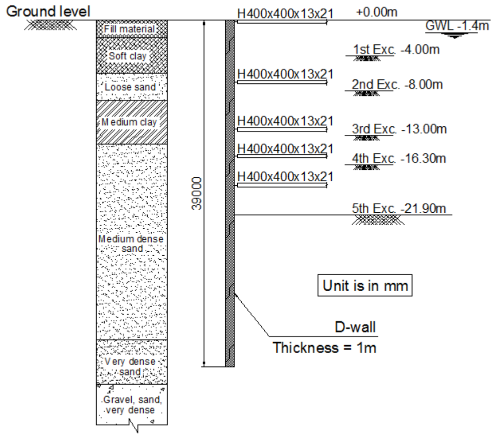

Fig.2 Section view of strut system

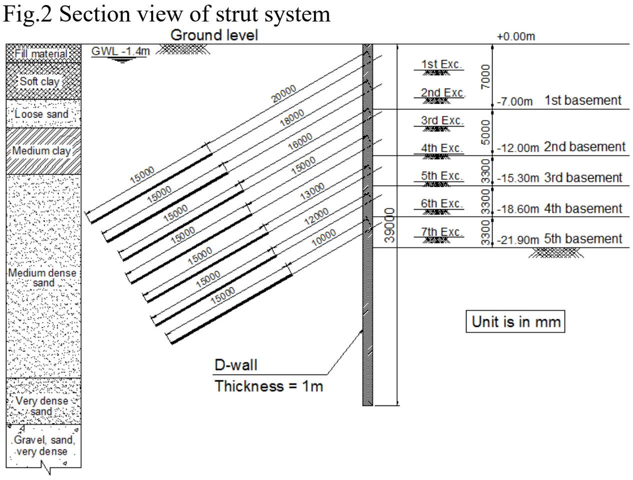

Fig. 3 Section view of the anchor system

Soil investigation is performed in this case with 7 boreholes and the profile could be drawn (Figure 4) as follows: Weathered layer on the top with thickness of 2~3m. Following by that is a soft to medium clay or clayey soils. It is proven by fine content is more than 80% and low values of SPT and Su (minimum SPT value is 2 and Su value from vane shear test is 20 kPa) (Fig. 4 a,c,d). Since strength of underlying layer is larger along with decreasing of fine content, it is evidences of the sandy soil with thickness varies from 2 to 3 m and N value range from 4 to 6. Next, with increasing of fine content as well as SPT and Su values (N value varies from 5 to 15, Su value varies from 40 to 50 kPa), underlying the sandy soil could be medium to stiff clay layer. And last, with the sand content is almost 90% and rapidly increase in strength, the soil at bottom of excavation is medium to dense sand and the N value are more than 20 blows/30 cm. The ground water table is recorded at 1.4m depth.

3 SELECTION OF PARAMETERS AND NUMERICAL ANALYSES

Normally, shear strength will be adopted from laboratory (triaxial test, direct shear test…) or field test (vane shear test), meanwhile, stiffness parameter is evaluated base on empirical correlations. In which, SPT value is convenient and useful for shear strength estimation. It is proven and applied in various design standards and codes worldwide, for example Architectural Institute of Japan. Many previous papers have also mentioned the empirical equation for excavation modeling base on own experiences and geological data, (D'Appolonia and Brisetle (1970), Schmertmann (1970), Poulos (1975)), in this paper, the most common equations are introduced. Undrained shear strength of clay can be obtained using Stroud's correlation (Fig. 5). The estimated values are then compared to undrained shear strength of undisturbed sample acquired from vane shear tests, then conservative numbers are chosen and shown in table 1b. Meanwhile, the value of stiffness might be estimated using the empirical correlation proposed by Duncan and Buchignani (1976) (Fig. 6). Soil input parameters of MC model are summarized in Tables 1a and Table 1b. Tables 2 and 3 list the input parameters of the diaphragm wall and steel struts used in the analysis. Poisson's ratio of the structural elements was taken to be 0.15 for both. The Young's modulus of the diaphragm wall was calculated by the formula of ACI Committee 318 as follows:

$$E = 4700\sqrt{f_c'}\ \text{(MPa)} \qquad (1)$$

where f'c (MPa) is 28-day uniaxial compressive strength of the concrete.

The Young's modulus of the steel struts was assigned to be $2.1\text{x}10^5$ (MPa). As suggested by Ou (2006) the stiffness of the diaphragm wall should be reduced by 20% due to the occurrence of cracks caused by bending of the diaphragm wall. Meanwhile, strut stiffness would also be suggested to reduce 30% and 40% from their nominal values to consider improper strut installation as well as repeated use. As suggested by Khoiri and Ou (2012) and the default value suggested by PLAXIS 2D, the interface reduction parameter between the wall and the soil is assumed as $R_{inter} = 0.67$.

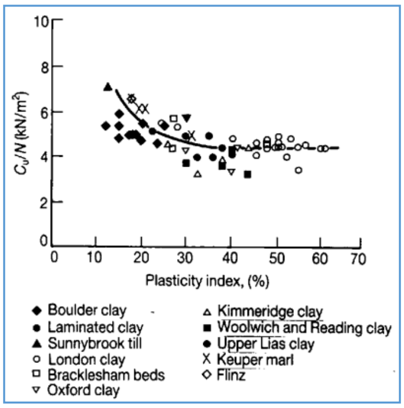

Fig. 5 Correlation between N value and undrained shear strength for sensitive clay (after Stroud and Butler, 1975)

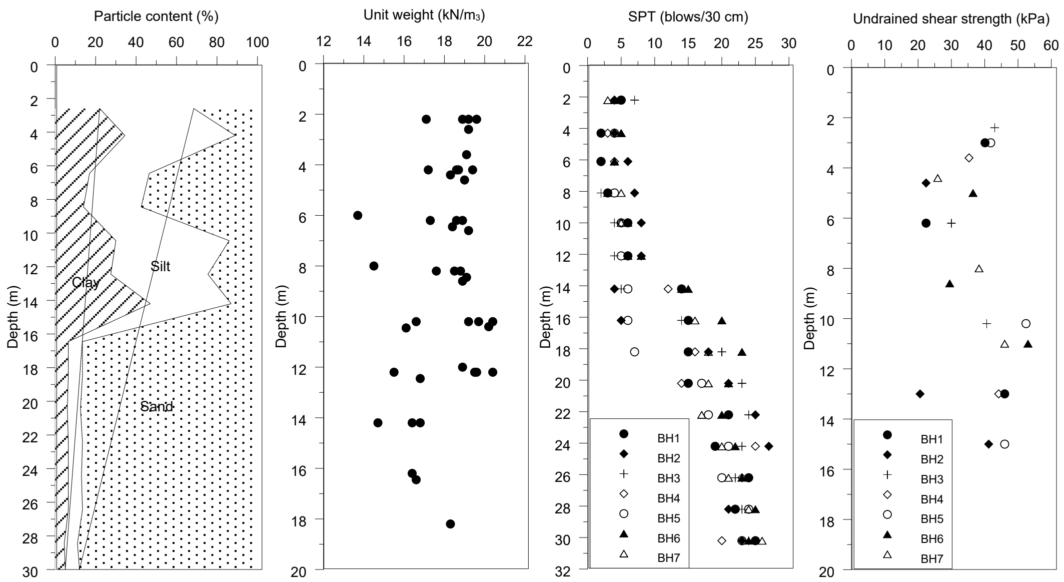

Fig 4. Information from borehole logs: (a) Particle content; (b) Unit weight; (c) SPT values; (d) Undrained shear strength from vane shear tests.

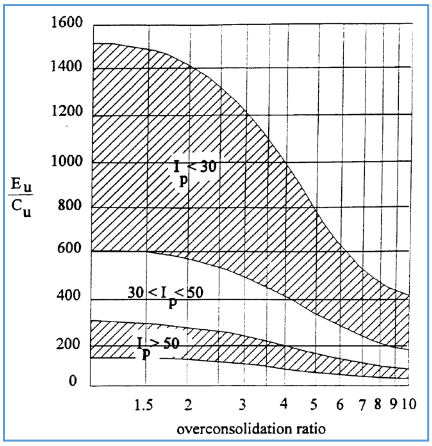

Fig. 6 Relationship between stiffness and shear strength parameter of clay (Duncan and Buchignani, 1976)

Table 1b. Input parameters for clay layers

Layer	Depth (m)	Type of undrained	γ (kN/m^3)	Su (kPa)	E' (kPa)	ν
1	2.0-6.0	UD (B)	17	25	6,000	0.35
2	9.0-14.0	UD (B)	18	42	21,000	0.35

Table 2. Input parameters for diaphragm wall

Parameter	Name	Value	Unit
Compressive strength of concrete	f'c	38.53	MPa
Thickness	d	1.0	m
Young's modulus	E	29,174	kPa
80% of Young's modulus	80%E	23,339	kPa
Unit weight	w	7.0	kN/m3
Poisson's ratio	ν	0.15	-

Table 3. Input parameters for steel struts

Strut level	Section	EA (kN/m)	60%EA (kN/m)
1 to 5	H400x400x13x21	4.15E6	2.49E6

Table 1a. Input parameters for sand layers

Layer	Depth (m)	γ (kN/m3)	N average	Ø' (°)	c' (kPa)	E' (kPa)	ν
3	6.0-9.0	18.5	6	29.5	1	15,000	0.3
5	14-36	19	15	32	1	32,000	0.3
6	36-41	19.2	>50	33	1	70,000	0.3
7	41-51	19	>50	35	1	100,000	0.3

4 RESULTS

Lateral wall displacement with two kinds of support system are presented in Figure 9(a) and 9(b). The predicted values in case of using strut system seems to be smaller than the other case. Generally, it could be concluded that the strutting has higher stiffness than the anchor system. In details, maximum displacement using strut system is about 10 cm (δ_{max}/H = 0.47%), meanwhile, it is approximately 19cm (δ_{max}/H = 0.85%), when using anchor system (Figure 9c). Last but not least, at final step of excavation, the maximum movement in strutting case could be seen at 24m depth, while in anchoring system, it is located at 14m depth (middle of anchor block). It could be explained by that in the first case with high stiffness, the wall moves at lower part since the absence of strut while in the second case, in spite of using 7 levels of anchors, each of them has less stiffness and distributed along the excavation depth, earth pressure tends to push them all, led to the maximum movement at the middle of the anchor block.

The envelope of bending moment diagram induced in the diaphragm wall with all excavation steps until casting the foundation in both two cases are shown in figure 9(d). the advantage of strut once again is proven with the internal force of diaphragm wall. however, the value as using ground anchor is larger but the discrepancy is not as large as displacement.

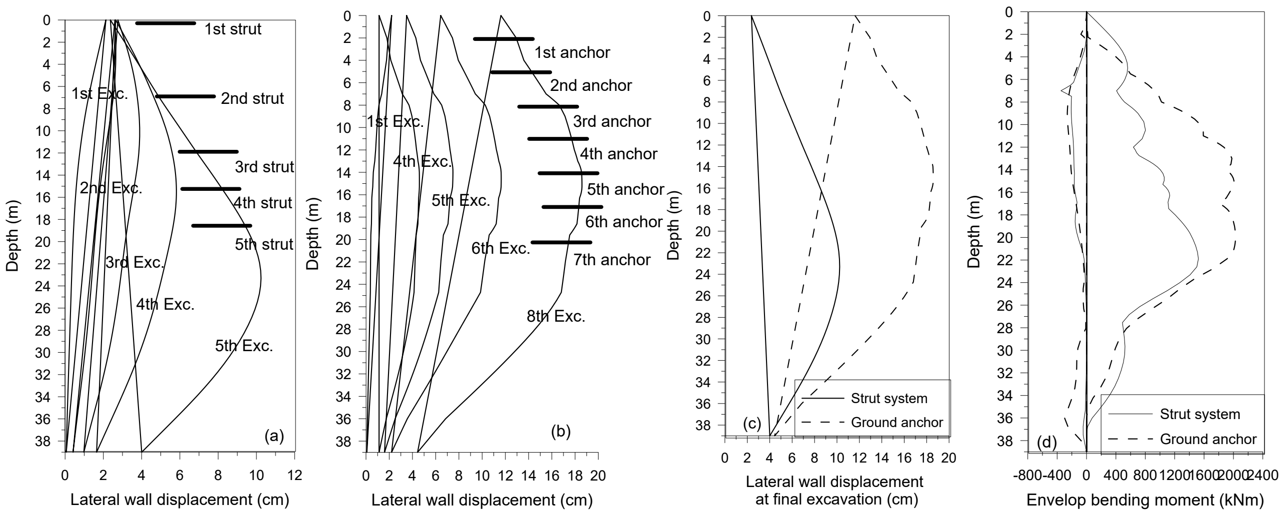

Fig. 9 Analysis results: (a) Wall displacement using strut system; (b) Wall displacement using Ground anchor; (c) Wall displacement at final excavation for both cases; (d) Envelop bending moment for both cases.

5 CONCLUSION

Deep excavation with two kinds of support systems are presented in this paper. Generally, it is reasonable to conclude that the strut system is more rigid than the anchor system. In other words, with a similar arrangement of configurations, a strut system is better in controlling ground movement caused by deep excavation. However, strut system also has disadvantage. It is the limitation of space therefore, hampering the construction works and led to significant increasing in time and construction cost. While, ground anchor system offers practically no obstruction within the excavation, that is much easier and convenient for construction work. For project management, with wide excavation, ground anchor system is considered as the most economical option. Selection of stiffness and strength parameters for deep excavation are also mentioned in this project.

In order to verify the behavior of the support systems in the area, monitoring system needs to be set up during and after the construction. That would give better modeling of construction work in the area in future.

6 REFERENCES

ACI Committee, American Concrete Institute, & International Organization for Standardization. (2008). Building code requirements for structural concrete (ACI 318-08) and commentary. American Concrete Institute.

Architectural Institute of Japan. Recommendations of design of building foundation. Japan. (Interface [Japanese] 2001).

D'Appolonia DJ et al. Discussion of ''Settlement of spread footings in sands''. J Soil Mech Found Div ASCE 1970;96:754–61.

Duncan, J. M., & Buchignani, A. L. (1976). An engineering manual for slope stability analysis. Department of Civil Engineering, University of California.

Khoiri, M., & Ou, C. Y. (2013). Evaluation of deformation parameter for deep excavation in sand through case histories. Computers and Geotechnics, 47, 57-67.

Liao HJ, and Hsieh PG (2002). Tied-Back Excavations in Alluvial Soil of Taipei, Journal of Geotechnical and Geoenvironmental Engineering.Vol. 128.No. 5.pp. 435 441.

Ou C-Y. Deep excavation: theory and practice. Taylor & Francis/Balkema; 2006

PLAXIS. Reference manual. Amsterdam, The Netherlands: Plaxis BV; 2013

Poulos HG. Settlement of isolated foundations. In: Valliappan S, Hain, Lee IK, editors. Soil mechanics – recent developments. Zetland: William H. Sellen Pty.; 1975. p. 181–212.

Schmertmann JH. Static cone to compute static settlement over sand. J Soil Mech Found Div ASCE 1970;96:1011–43.

Stroud, M. A., & Butler, F. G. (1975). The standard penetration test and the engineering properties of glacial materials. In Symposium on Engineering Properties of Glacial Materials, Midland Geotechnical Society.

Vermer PA, and Brinkgreeve RBJ (2002). Manual of PLAXIS Finite Element Code for Soil and Rock Analysis Version 8.x,.Balkema, Rotterdam, Netherland.