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Rigid Diaphragm Wall Response to Deep Excavation Works in Bangkok

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ABSTRACT

Deep excavation in soft clay may cause adverse effects on adjacent structures. Thus, it is crucial to understand the behavior and to estimate the magnitude of lateral wall displacement due to excavation works. This paper presents interpretation results from braced excavation works with rigid diaphragm wall in Bangkok. The data was collected from 30 projects with wall thickness ranging from 0.6 m to 1.0 m and excavation depth from 6 m to 21 m. Parameters investigated in this study are flexural stiffness of retaining wall, depth of maximum wall lateral displacement, system stiffness and excavation depth ratio. From the analyzed data, lateral wall displacements of 0.6 m and from 0.8 m to 1.0 m thick diaphragm wall are about 0.5% and 0.2% the excavation depth, respectively. In addition, there is no significant different of wall movement between bottom-up and top-down construction, unlike those reported in the literature. This is because the effects of wall thickness and construction method are not significant when the wall rigidity is sufficient.

Keywords: Diaphragm wall movement, Deep excavation, Soft clay, Bangkok

1 INTRODUCTION

Due to increase in demand of underground space, deep excavation for basement construction has been carried out extensively in urban area. The effects of deep excavation may cause adverse impact on adjacent structures. Thus, it is crucial to understand the ground and wall response due to deep excavation, especially when it is carried out in soft marine clay.

Phienwej et al. (1995) summarized wall lateral movement due to bottom-up and top-down construction in Bangkok and reported that they are about 0.4%H and 0.2% the excavation depth (H), respectively. This is because larger bracing system stiffness of the latter than the former. For estimation of impact of deep excavation on surrounding area, the method considering influence zone of excavation was proposed by Aye et al. 2006. To improve the accuracy of this method, collected data of ground movement due to excavation is analyzed and interpreted in this study. The data was collected from 30 projects of braced excavation with depth ranging from 6 to 21 m in Bangkok. All retaining walls in the analysis are diaphragm wall. Method of basement construction includes both bottom-up and top-down. Instrumentation adopted in those projects was mainly inclinometer.

Parameters investigated in this study are flexural stiffness of retaining wall, depth of maximum wall lateral displacement, system stiffness and excavation depth ratio. Measured results of wall lateral displacement are reported. Interpreted data related to effects of each parameter on wall movement is discussed and explained.

2 TYPICAL GEOTECHNICAL DATA

To understand the ground response due to excavation, typical geotechnical data of Bangkok is described below.

2.1 Typical soil profile

Bangkok typical soil profile is shown in Figure 1a. A thick Bangkok soft marine clay layer (about 12-18 m thick) locates at the top followed by thin layer of medium clay underlying by alternating layers of stiff clay and dense sand. Undrained shear strength of soft clay, is ranging between 10 and 25 kPa. In stiff and hard clay layers, undrained shear strengths are about 150 and 200 kPa, respectively. Angles of internal friction (ϕ') of dense sands are estimated to be from 31° to 33°.

2.2 Pore water pressure

Apart from the geotechnical parameters, distribution of measured pore water pressure and estimated trend line is given in Figure 1b. For Bangkok aquifers, there was a decrease in pore water pressure from 1960 to 2000 due to underground water pumping. A reduction of water pumping since 1997 caused a recovery in the pore water pressure. Current (in 2018) depth of ground water table is estimated to be 13 m. It is predicted that water level would reach the ground surface and pore water pressure would reach hydrostatic condition by 2032.

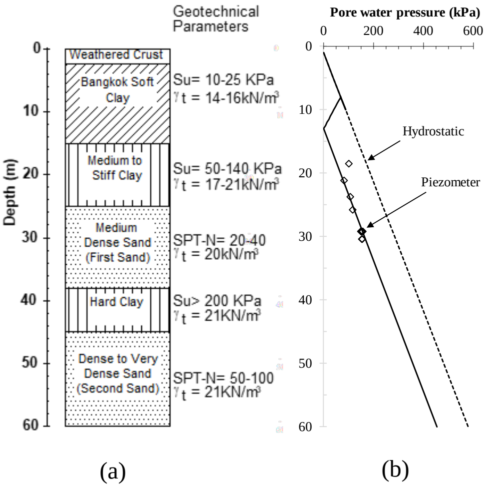

Fig. 1. Typical profile of (a) Soil layers; (b) Pore water pressure in Bangkok.

3 INTERPRETATION OF WALL MOVEMENT

Collected data of lateral movement of diaphragm wall is analyzed. Parameters that influenced the behavior of wall movement are interpreted as follows.

3.1 Summary of braced excavation database

Data analyzed in this study is obtained from excavation work with diaphragm wall thicknesses of 0.6 m, 0.8 m and 1.0 m as shown in Figure 2. Collected data was from 30 projects. The excavation depth is ranging from 6 m to 21 m. The excavation depth ratio (H/H_w) is defined as depth of basement excavation (H) divided by depth of retaining wall toe (H_w). In this study this ratio is between 0.2 and 0.8. The average depth of soft clay is 13 m (from the range of 11 to 15 m).

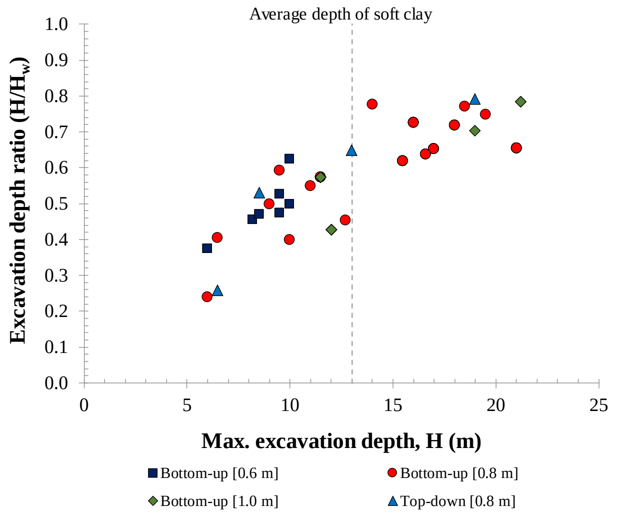

Fig. 2. Summary of excavation depth and excavation depth ratio of diaphragm wall in this study.

3.2 Measured wall lateral movement

Results of wall lateral movement with different wall thicknesses and excavation depths are shown in Figure 3. As expected, the average movement of 0.6 m thick diaphragm wall is 0.48% of excavation depth (H). This movement is larger than data of bottom-up excavation reported by Phienwej et al. (1995) as the wall thickness of latter is ranging from 0.8 m to 1.0 m. Average lateral movements of 0.8 m, 1.0 m thick wall with bottom-up construction and 0.8 m thick wall with top-down construction are 0.17%H, 0.19%H and 0.17%H, respectively. It can be seen that the effects of wall thickness and construction method are not significant when the wall rigidity is sufficient. The finding in this study is contradictory to that in Phienwej et al. (1995), where average wall movements induced by bottom-up and top-down construction are 0.4%H and 0.2%H, respectively. The possible reason for larger movement in the former than the latter in Phienwej et al. (1995) is bracing system in the past is not rigid enough and preloading system had not been widely adopted.

Relationship of wall movement where excavation depth is larger than the average depth of soft clay (13 m) suggests that wall movement is smaller than those with excavation shallower than depth of soft clay.

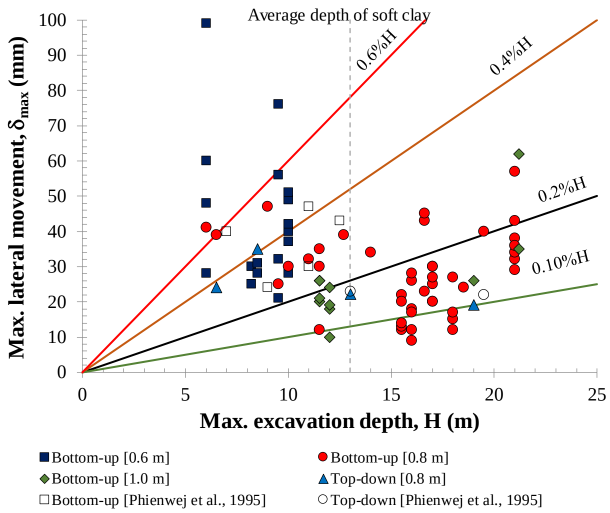

Fig. 3. Measured results of maximum lateral movement of diaphragm wall.

3.3 Depth of maximum lateral displacement

In order to verify the depth of maximum bending moment of retaining wall, depth of maximum lateral displacement should be identified as shown in Figure 4. The average depths of maximum lateral movement of wall with thickness of 0.6 m, 0.8 m (bottom-up), 0.8 m (top-down) and 1.0 m are 0.87H, 0.64H, 0.80H and 0.82H, respectively. In general, depth of maximum displacement is about 0.80H. It appears that both wall rigidity and construction do not have major influence on depth of maximum lateral displacement.

Moorman (2004) summarized that typical range of depth of maximum displacement is from 0.5H to 1.5H. For most cases, the wall lateral movement is in bulging mode. However, in this study, some data shows that depth of maximum lateral movement is smaller than 0.5H. This is because the removal the top bracing caused movement to be in cantilever mode, especially when the spacing between the top basement slab and the existing ground is relatively large (more than 3.5 m).

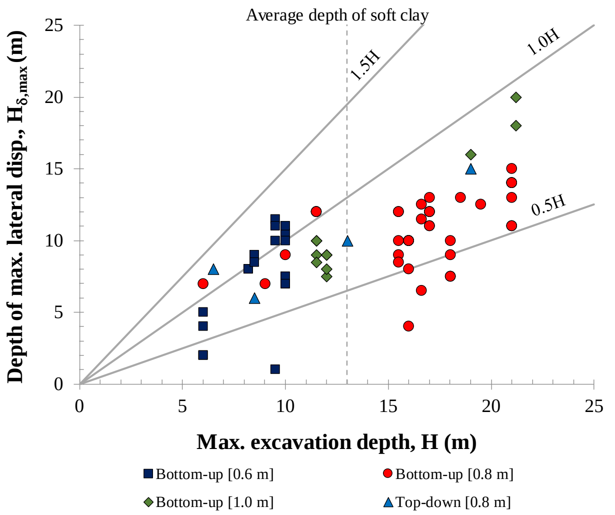

Fig. 4. Depth of maximum wall lateral displacement.

3.4 Effects of system stiffness

Relationship between system stiffness and normalized wall lateral movement is shown in Figure 5. Possible key factors that influence the wall movement are wall rigidity and stiffness of bracing. Clough et al. (1989) defined a parameter for system stiffness as $EI/\gamma_w s^4$, where E, I, γ_w and s are Young's modulus of retaining wall, a second moment of inertia, unit weight of water and average vertical spacing of strut, respectively. Clough and O'Rourke (1990) suggested factor of stability (FS) against basal heave as plotted in this figure.

The general trend suggests that normalized wall lateral displacement decreases with increasing system stiffness. Factor of stability (FS) of 0.6 m thick diaphragm wall are between FS of 1.4 and 2, whereas FS of thicker wall is larger than 2. It suggests that increasing wall thickness help increasing FS for basal heave.

For bottom-up and top-down construction, smaller system stiffness for the latter results in similar range of wall movement as the former. Thus, spacing of bracing in top-down method can be significantly larger than those using bottom-up method.

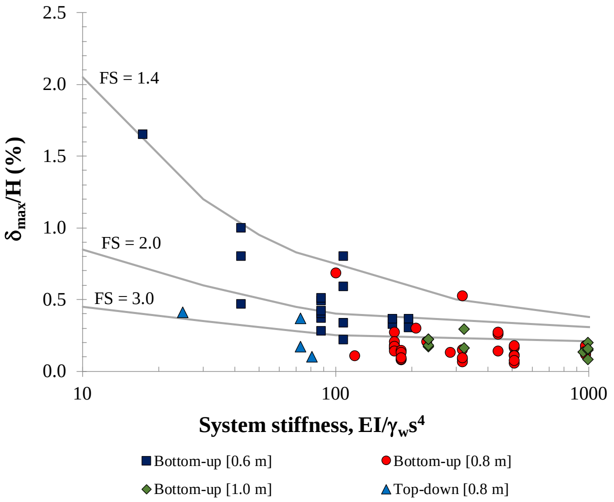

Fig. 5. Effects of system stiffness on wall movement.

3.5 Effects of excavation depth ratio

The relationship of excavation depth ratio and wall displacement is shown in Figure 6. From the results, there is no clear trend between excavation depth ratio and wall lateral movement. Moreover, wall lateral displacement at excavation depth ratio as large as 0.7 – 0.8 is only about 0.2%H. It suggests that, if the wall embedded depth is sufficient, increase depth of wall does not decrease the wall movement.

However, this extend embedded depth of retaining wall is still required for basal heave stability and water uplift stability. In many projects, maximum depth of excavation is larger than ground water table (13 m as shown in Fig. 1b). To minimize the risk of uplift instability, retaining wall is required to be embedded in sufficient thickness of stiff clay to provide resistance to uplift. Thus, excavation depth ratio should consider the basal heave and water uplift stability into account.

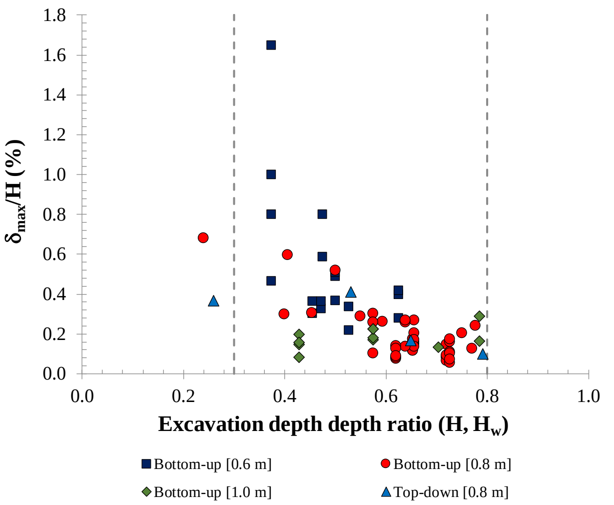

Fig. 6. Effects of excavation depth ratio on wall movement.

4 IMPLEMENTATION OF DATABASE

Aye et al. (2006) proposed a method to estimate wall and ground movement in clay due to excavation using diaphragm wall as shown in Figure 7. To adopt this method, database presented in this study e.g. estimated maximum wall lateral displacement and depth of maximum displacement can be used as the input data for prediction of horizontal ground movement at some distant away from the wall. In addition, this database can be used as a reference to compare with more detailed numerical analysis.

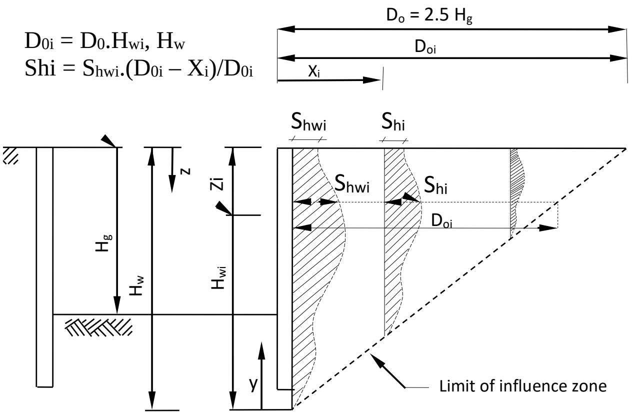

Fig. 7. Method for estimation of wall and ground movement due to diaphragm wall excavation (Aye et al., 2006).

5 SUMMARY AND CONCLUSIONS

Data from excavation work with diaphragm wall thicknesses of 0.6 m, 0.8 m and 1.0 m was collected and analyzed in this study. The data was obtained from 30 projects of braced excavation in Bangkok soft clay. The excavation depth is ranging from 6 m to 21 m. According to the interpretation of the results, following conclusions may be drawn:

(a) Lateral wall displacements of 0.6 m and from 0.8 m to 1.0 m thick diaphragm wall are about 0.5% and 0.2% the excavation depth (H), respectively. By comparing method of construction, there is no major different of wall movement between bottom-up and top-down construction. This is because the effects of wall thickness and construction method are not significant when the wall flexural rigidity is sufficient.

(b) The average depth of maximum lateral wall displacement is about 0.8H. It appears that both wall rigidity and construction method do not have major influence on depth of maximum lateral displacement. Only some data points show that depth of maximum lateral wall movement is smaller than 0.5H. This is because the removal the top bracing caused movement to be in cantilever mode, unlike most cases that mode of movement is in bulging mode.

(c) Increasing system stiffness significantly reduces wall lateral displacement. In addition, increasing wall thickness helps increasing factor of stability against basal heave. By comparing bottom-up and top-down construction, smaller system stiffness for the latter results in similar range of lateral displacement as the former. Thus, spacing of slab in top-down construction can be larger than those using bottom-up method that amount of wall movements in both cases are similar.

(d) Excavation ratio in this study is defined as excavation depth and depth of retaining wall tip. It appears that, there is no clear trend between excavation depth ratio and wall lateral displacement. This is because for deeper portion, soil properties change from soft clay to medium or stiff clay, resulting larger soil stiffness. Thus, if the wall embedded depth is sufficient, increase in depth of wall does not decrease the wall lateral displacement.

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