

CHALLENGE IN DEEP FOUNDATION AND UNDERGROUND STRUCTURE IN THAILAND

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Abstract. *In recent years, there has been an increase in urban development in Thailand. The development initiated by government sector included roads, railways, mass rapid transit and airports. For private sector, the major development focuses in Bangkok, the capital city. Challenge of construction of these mega projects in Bangkok is very soft and unstable ground conditions. Ground condition in Bangkok consist of soft marine clay with thickness up to 20 m. Problems of foundation and retaining wall in this type of soil consist of large settlement of buildings, instability and damage of structure due to tilting and differential settlement. To tackle these problems, deep foundation and rigid retaining structures such as large diameter bored pile, barrette and diaphragm wall are adopted to support the structures. In this paper, master plan of mega infrastructure projects in Thailand. Challenges and major issues relevant to geotechnical problems for the mega projects are highlighted. Solution to each problem encountered is described and explained. Innovation in design and construction to overcome those challenges are discussed.*

1 INTRODUCTION

Mega projects in Thailand includes large scale infrastructures for public sector and tall buildings for private sector. To support those heavy structures, deep foundation is required. In urban area, there is an increasing demand in underground space. Thus, deep excavation works are carried out for construction of subway stations, underground car park for buildings and shafts for utilities. Those deep foundations and deep excavation works are constructed in very ground conditions that encounter many challenges. The challenges include difficulties in working area, understanding the behavior of very deep foundation, bleeding and channeling in tremie concrete, increasing demand in deep excavation and rising in underground water table. This paper reports details relevant to the above issues. Solutions to tackle those problems are presented and discussed.

2 MEGA PROJECTS IN THAILAND

Thailand has gradually modernized itself for past decades. To boost up the speed of urbanization, several plans of mega projects have been launched to substantially improve the transportation system of the country. Four modes of transport are included in this plan. Example of the mega projects are Eastern Economic Corridor Development (EEC), double track railways, high speed railways, motorways, Bangkok Rail Transit Network, sea port and air ports expansion. For private sector, high rise buildings with height ranging from 100 to 450 m are under construction. To keep the paper short, a summary of only two mega projects are given below.

2.1 Double track railways, high speed railways and motorways

Railways and motorways are key projects to enhance the economic growth of the country. Figure 1a shows the plan network of Double track railways, which will improve the rail transport and decrease the logistic cost significantly. Similar to Double track railways, high speed railways and motorways are planned to improve the transportation system substantially. It is expected that the enhancement of the roads and railways systems would increase the rate of urbanization for major cities not just focus on in Greater Bangkok area.

2.2 Bangkok Rail Transit Network

Bangkok Rail Transit Network Plan (including currently under operation, under construction and planned) is shown in Figure 1b. The network consists of elevated train system operated by Bangkok Mass Transit System Public Company Limited (BTS), Airport Link service provided by State Railway of Thailand (SRT) and subway and elevated train operated by Mass Rapid Transit Authority of Thailand (MRTA). The total length of the entire network in the Master Plan shall be about 567 km, which will be one of the longest mass transit system in the world.

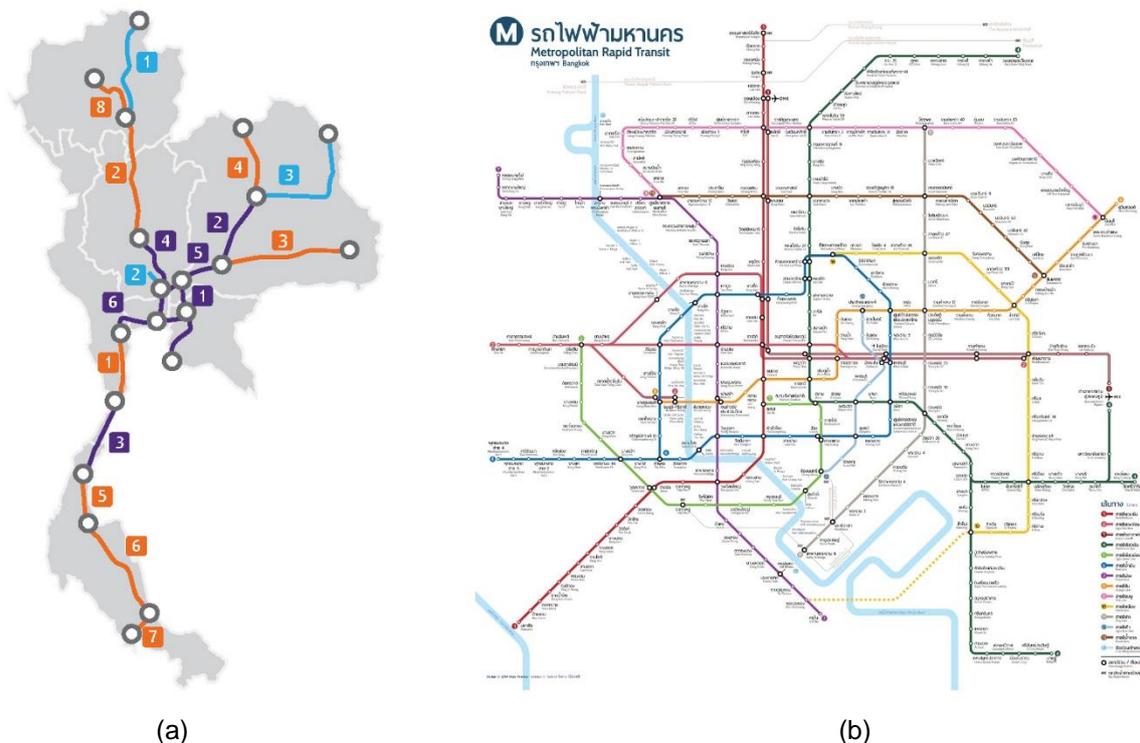


Figure 1: (a) Planned network of Double track railways system (www.railway.co.th); (b) Bangkok Rail Transit Network Plan (www.mrta.co.th)

3 GENERAL GEOLOGICAL AND GEOTECHNICAL INFORMATION IN THAILAND

Figure 2a shows Geological map of Thailand¹ (Department of Mineral Resources, 1999). Major urban development has taken place in Greater Bangkok area, where soil conditions consist of soft marine deposit at the top 10-20 m follow by alternating layers of sand and clay. Igneous rocks are mainly located in the North, East and South. The most common rock encountered during bored pile construction in these regions is granite. Typical unconfined compressive strength (UCS) of granite from several projects the authors have collected is ranging from 40-150 MPa. Common rocks in the Northeast are sedimentary type such as siltstone, sandstone, claystone and shale. These are considered as soft rocks, having their UCS between 10 and 50 MPa.

Figure 2b shows location of soft marine clay in Southeast Asia² (Brand & Premchitt, 1989). In Thailand, soft soil can be found in the Chaopraya Basin where the thickness of soft clay layer is from 14 to 20 m. Undrained shear strength of soft clay is ranging between 10-25 kN/m², which is too soft for supporting high rise building without deep foundation.

Common problems associated with soft clay for construction of infrastructure such as roads, embankment on soft clay are instability and large settlement as shown in Figure 3a. This type of instability can be triggered by changing in adjacent water level of river, additional surcharge, or poor soil protection system. For serviceability problem as shown in Figure 3b, differential settlement occurs on structures supported by different foundation types or at different depths. These differential settlement problems generally occur on transition structures such as bridge abutment, linkage between existing buildings and building extension.

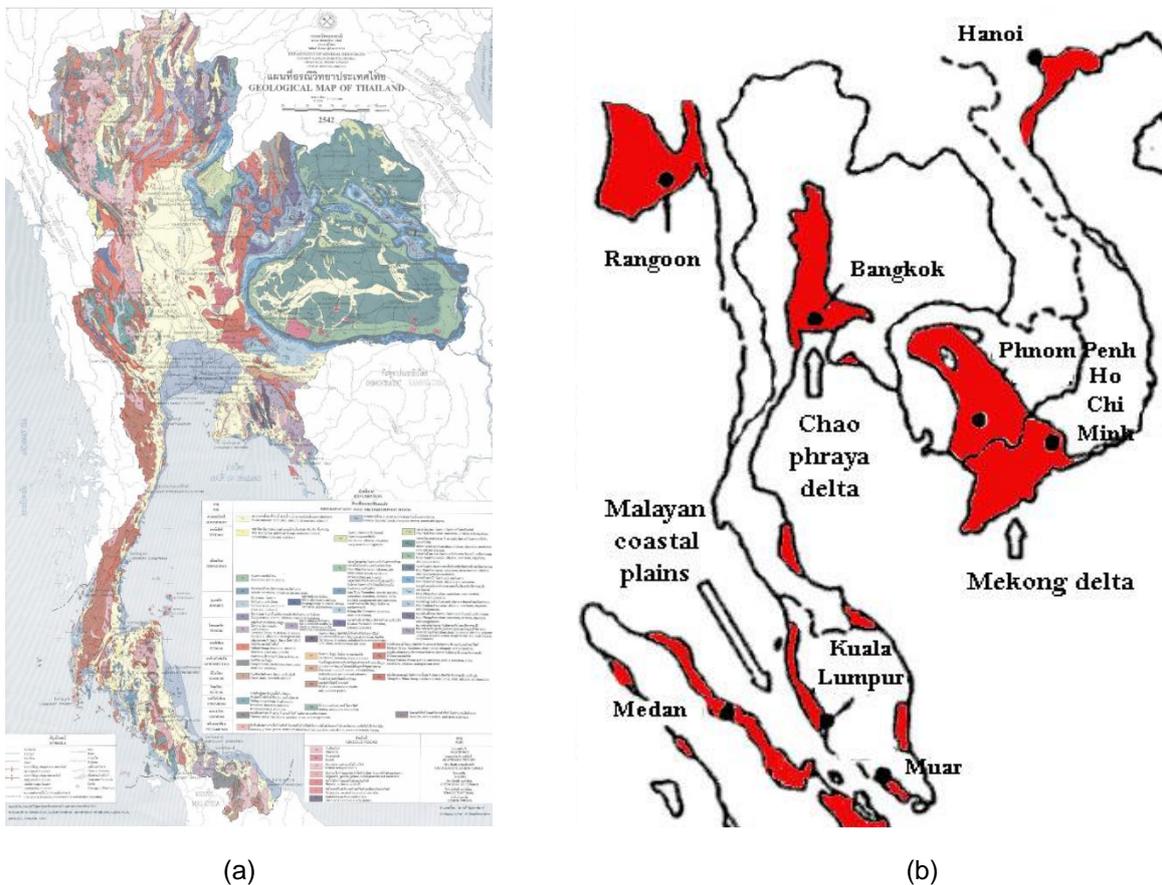


Figure 2: (a) Geological map of Thailand (Department of Mineral Resources, 1999); (b) Location of soft marine clay in Southeast Asia (Brand & Premchitt, 1989)



Figure 3: (a) Instability problem of Bangkok soft clay; (b) Long-term differential settlement between structures on different types of foundations

4 DEEP FOUNDATION

To provide stable foundation for massive structures in soft soil, wet process bored pile and barrette were utilized. Following details describe main features of each type of deep foundation. Major challenges and difficulties of deep foundation are discussed in this section.

4.1 Type of deep foundation

Figure 4a shows a drilling rig of circular bored pile. This type of pile can be constructed in almost all soil conditions ranging from very soft clay to hard rock. In Bangkok, depth of circular bored pile can be deeper than 100 m.

In some cases, barrette (rectangular bored pile) is used due to its versatility and larger load bearing capacity given the same amount of concrete. The equipment of barrette construction is shown in Figure 4b. For working conditions under limited head room, the equipment of barrette construction can be shortened and modified as shown in Figure 4c. This modification provides the advantage of barrette over circular bored pile that cannot work under the low headroom conditions.



Figure 4: Machine for construction (a) Rotary auger and bucket type; (b) Hydraulic grab for normal conditions; (c) Mechanical grab for limited headroom conditions.

For circular bored pile section (as shown in Figure 5a). the advantage is the borehole is stable during excavation due to hoop stress effects. The rate of construction is faster than those of barrette piles. Unlike circular bored pile, the lateral load resistance of rectangular barrette (see Fig. 5b) in

the major axis is larger than in the minor axis. Thus, if the lateral force is majority in one direction, barrette can be a good option for design compared with bored pile. For a special loading case, T-shape barrette and X-shape barrette as shown in Figures 5c and 5d, respectively are used to resist large vertical load and lateral load.

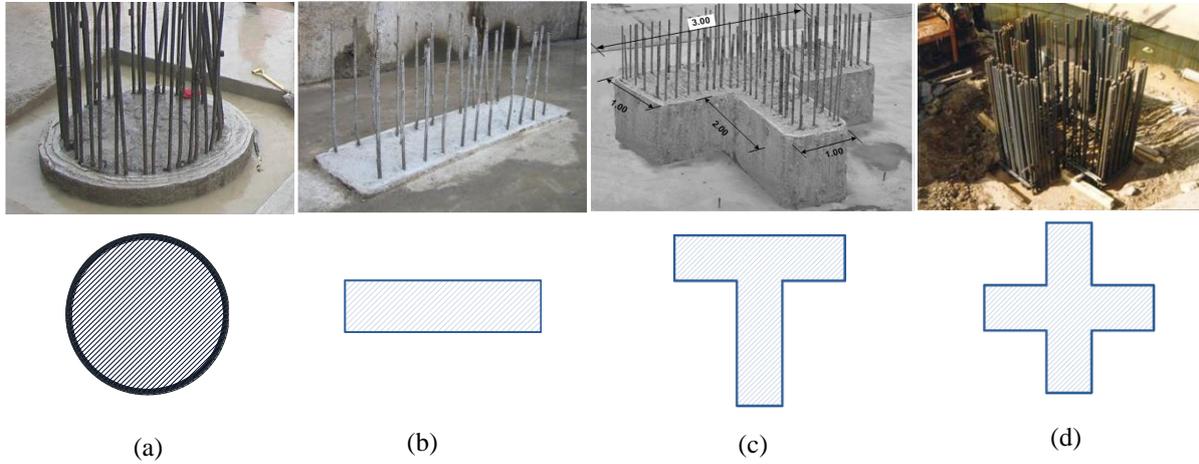


Figure 5: Exposed deep foundations; (a) Circular bored pile; (b) Rectangular barrette; T-shape barrette; (d) X-shape barrette

4.2 Understanding the behavior of very deep foundation

The major issue for design and construction of deep foundation is the understanding of their behavior. Figures 6a and 6b show load settlement curves of bored pile and barrette, respectively³ (Boonyarak et al., 2016). To compare results from piles with different sizes and depth of pile tip, the applied load is normalized with shaft area and pile settlement is normalized with its diameter. Factors affecting the behavior of deep foundation in Bangkok soil including type of drilling slurry, type of foundation, soil type at the pile tip were analyzed and interpreted. It appears that there is no major difference in behavior between circular bored pile and rectangular barrette given the same slurry and soil type at the pile tip. Thus, the interpreted data from circular bored pile can be used for rectangular barrette. For brevity of paper, details behavior and mechanism are not discussed.

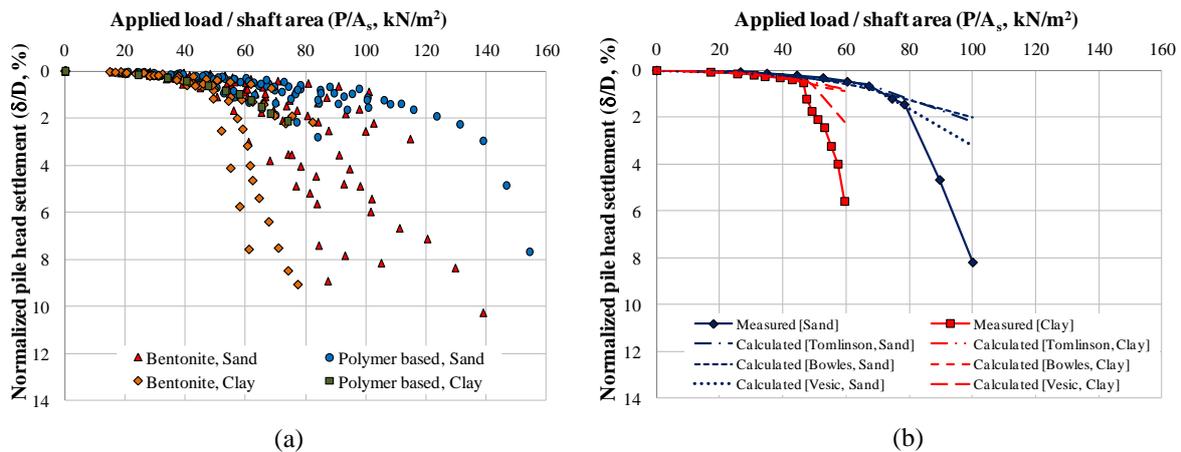


Figure 6: Normalized load-settlement behavior of (a) Circular bored pile; (b) Rectangular barrette (Boonyarak et al., 2016)

4.3 Enhancing quality of tremie concrete

Concrete pouring through tremie pipe is one of the most important procedure for deep foundation. Integrity problem for the hardened concrete was reported to be resulted from bleeding and channeling of fresh concrete. Evidence of channeling or upward water flow in fresh concrete⁴ is shown in Figure 7a. Records of water flow duration was ranging from 10 to 30 minutes, depends on pile depth. The location of bleeding or channeling was at the center of the pile, where tremie pipe is placed. When the pile head is exposed (see Figure 7b), unsound and damp concrete was found. To further investigate the concrete quality, cored samples of concrete were taken as shown in Figure 7c. Evidence of imperfect concrete was found up to 5 m from the pile cut-off level. If mix design of concrete is inappropriate or tremie concreting procedures are not well-controlled, weak spot or channeling may occur. From the literature, fresh concrete with fly ash content of more than 20% and water to binder ratio of more than 0.5 is likely to cause bleeding and channeling.

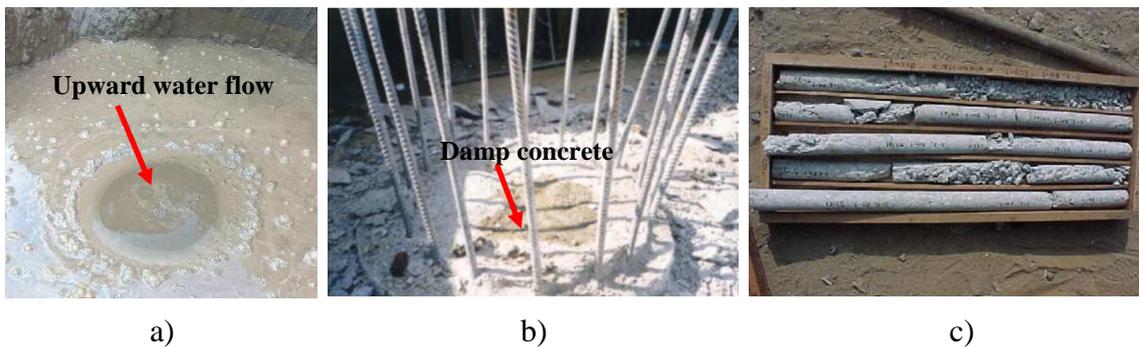


Figure 7: a) Water flow up to concrete surface in fresh state; b) Unsound and damp concrete at pile head; c) Cored samples of unsound concrete. (Thasnanipan et al., 2017)

To tackle bleeding and channeling of very deep bored pile (i.e., depth from 80 m to 100 m) filtration test⁵ should be carried out as shown in Figure 8a. This is because the water pressure from outside the borehole and inside the fresh concrete can be very high. Thus, water retention ability should be tested. For comparison between normal concrete and special mix concrete, a standard filtration apparatus for drilling fluid can be used for testing of fresh concrete (see Figure 8b).



Figure 8: a) Filtration test for concrete (EFFC/DFI, 2018); b) Filtration test for drilling fluid adopted for fresh concrete.

An example of concrete mix design to minimize bleeding and channeling is given in this section. A cast-in-situ bored pile with diameter of 1.8 m and depth of 100 m was constructed as a test pile for a sky scraper in Bangkok. This pile was subjected to vertical compression static load test up to 70,400 kN. The required compressive strength, slump and initial setting time of concrete were 45 MPa, 175 mm and 10 hours, respectively. To achieve these properties, mix design was adjusted as follows. Total binder was 500 kg/cu.m. and pulverized fly ash content was limited to 20%. Water

to binder ratio (W/B) was 0.35 by adding superplasticizer (Type F admixture). This W/B was lower than typical range of 0.45-0.48 of normal tremie concrete. Retarder (Type D admixture) was incorporated into the concrete to prolong the setting time up to 10 hours.

During casting of concrete, no sign of bleeding and channeling was observed. Based on the result of integrity testing using cross-hole sonic logging, no anomaly was encountered. Average unconfined compressive strength at 28 days was 63 MPa (cylinder), exceeding the required strength of 45 MPa.

5 DEEP BASEMENT AND RIGID RETAINING WALL

As the land price is continuously increasing, the underground space is required to accommodate these issues. In addition, the regulations control only the height of building by using set-back concept. However, there is still no regulations for controlling depth of basement. For deep excavation, rigid retaining wall is used to minimize excessive soil movement underneath the adjacent buildings. Major issues relevant to deep excavation in soft ground are discussed in this section.

5.1 Increase in depth of excavation

The demand of underground space has been increasing for decades. Figure 9a shows an example section of a subway station in Bangkok with excavation depth of 35 m. To provide stability and water uplift control, the depth of the retaining wall extended from 60 to 68 m. For commercial buildings, excavation depths are generally ranging from 15 to 22 m. Figure 9b shows, relationships between maximum excavation depth and excavation depth ratio. This excavation depth ratio is the depth of excavation over the depth of retaining wall, suggesting that the deeper excavation requires less penetration depth below the basement excavation. This is because the soil at the deeper depth has larger strength than the upper part, where major part of soil is soft clay.

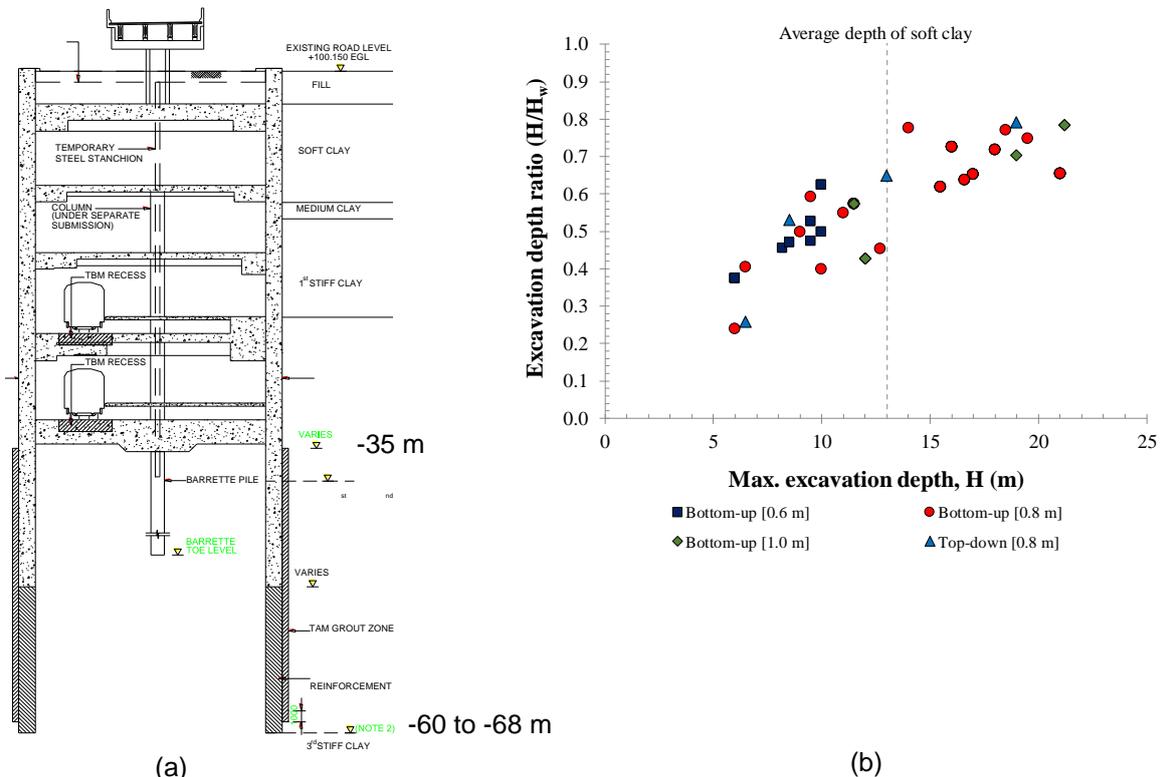


Figure 9. a) An example of section of subway station in Bangkok; b) Summary of excavation depth and excavation depth ratio of diaphragm wall.

5.2 Assessment of excavation induced soil movement

Ground movement prediction and building risk damage assessment for the deep excavation works can be found in the works of Aye et. al., 2006⁶ as shown in Figure 10a. With demonstration

of the procedure used in staged assessment on risk of damage by excavation induced ground movement, a simple method was proposed to predict both vertical and horizontal surface and subsurface ground movement based on the deflection profile of diaphragm wall.

To adopt this method, database to estimate maximum wall lateral displacement and depth of maximum displacement can be used as the input data for prediction of horizontal ground movement at some distance away from the wall. Results of measured wall lateral movement with different wall thicknesses and excavation depths⁷ are shown in Figure 10b. From the records, the average movement of 0.6 m thick diaphragm wall is 0.48% of excavation depth (H). 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. 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. The previous research by Phienwej et al. (1995)⁸ shows major difference in wall movement between bottom-up and top-down constructions. However, there is no significant behavior between the two methods in Aye et al. (2019) study⁷. The possible reason for large discrepancy in the former than the latter is bracing system in the past is not rigid enough and preloading system had not been widely utilized.

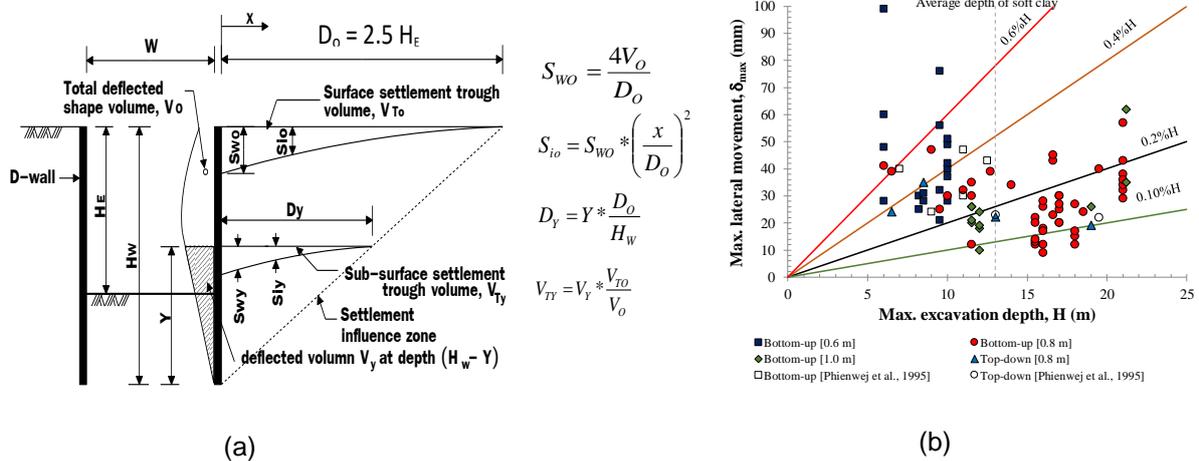


Figure 10: a) Method to estimate ground movement due to excavation of rigid wall in Bangkok (Aye et al., 2006) b) Relationship of lateral wall movement due to excavation of diaphragm wall in Bangkok (Aye et al., 2019).

5.3 Rising in underground water table

Apart from the geotechnical parameters, distribution of measured pore water pressure and estimated trend line is given⁹ in Figure 11a. For Bangkok aquifers, there was a decrease in pore water pressure from 1960 to 2000 due to excessive underground water pumping. A reduction of water pumping since 1997 caused a recovery in the pore water pressure. Current (in 2019) depth of ground water table is estimated to be 12 m. It is predicted that water level would reach the ground surface and pore water pressure distribution would reach hydrostatic condition by 2032. In recent years, Bangkok has suffered from the rise of ground water table when deep well pumping is prohibited since 1997. This results in uplift pressure or buoyance pressure of underground structure especially diaphragm wall and tunneling work. With high underground water pressure, the underground structures are vulnerable to water leakage. This causes the underground structures more challenging and costly on water-stopping techniques.

An example of rising in water table is shown in Figure 11b. Deep excavations of 20.0m in Bangkok subsoil encountered presence of groundwater after reaching about 17.5m. Subsoil information obtained by soil boring in the project indicated a series of stiff silty and sandy clay between 15m and 24m, overlying a dense sand layer. Construction progress was significantly affected by presence of groundwater in silty clay. Fully saturated silty clay turned liquid when disturbed by excavation activities, causing difficulties in casting a concrete blinding layer for foundations construction. Dewatering and ground improvement to the subgrade layer below

foundation mat and footings needed to be carried out. Bearing capacity of disturbed silty clay with high water content is very low so that cobble size concrete blocks and crushed rocks to be compacted in to the soil for improving the subgrade. Then a lean concrete blinding layer was cast on the subgrade part by part while dewatering.

To minimize the risk of water uplift, the retaining wall should be embedded in hard clay layer (refer to Figure 9a). In addition, the stability calculation against the uplift and retaining wall joint sealing system should be provided. However, if the thickness of clay at the base of excavation is not sufficient to provide the stability, ground improvement such as jet grouting or chemical grouting may be required.

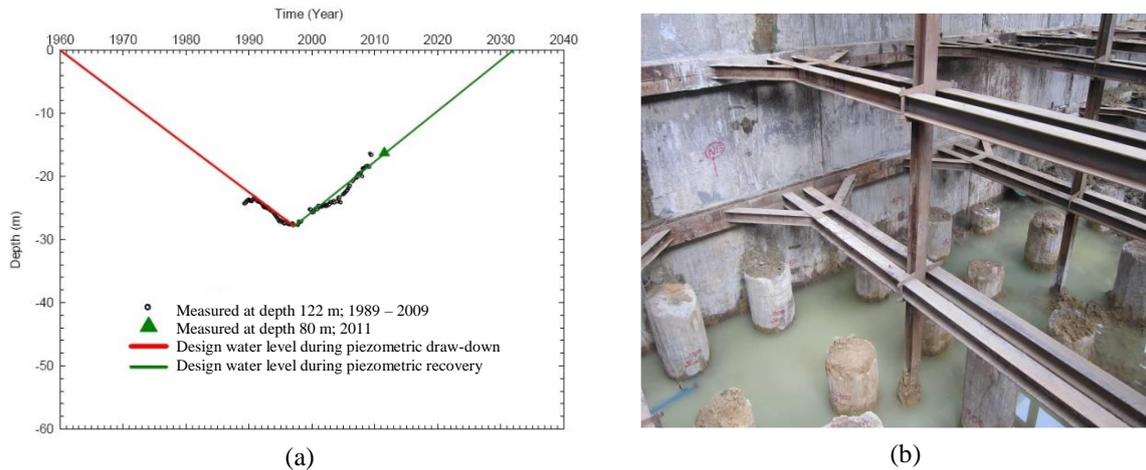


Figure 11: a) Changing in depth of water table in Bangkok (modified from Paveenchana & Saowiang, 2012); b) Water uplift through base of excavation.

6 SUMMARY AND CONCLUSIONS

Geotechnical challenges of deep foundation and deep excavation works in Thailand are summarized in this paper. There is a clear trend that foundation is going to be deeper, larger and has higher performance to support buildings and mega infrastructures with very high load. For deep excavation, there is an increasing demand in underground space for mass transit, deep basement and service. According to the given information, following conclusions may be drawn:

- Deep foundation construction in difficulties in working area: In case of working under the limited headroom or working on the median of the road, barrette is a better option over circular bored pile due to its versatility and larger load bearing capacity. In addition, the machine for barrette construction can be modified to work under the limited headroom.
- Understanding the behavior of very deep foundation: For design and construction of very deep foundation, interpreted data of pile testing with instrumentation from previous projects is very useful. Optimization of the design can be carried out by testing the pile prior to the working pile to verify the practicality of the design and to monitor the performance of the contractor.
- Bleeding and channeling in tremie concrete: It is found that concrete with fly ash content of more than 20% and water to binder ratio of more than 0.5 is likely to cause bleeding and channeling in fresh concrete. Conventional testing method for bleeding may not be able to capture the bleeding and channeling in deep foundation. To overcome this limitation, filtration test of concrete should be carried out to simulate underground water pressure acting on fresh concrete.
- Increasing demand in deep excavation: Deep excavation in Thailand can be deeper than 35 m. Thus, approach to assess the effect of excavation on adjacent building is required. The proposed method in this paper combined with supporting database can be adopted to evaluate the impact of excavation on nearby structures.
- Rising in underground water table: A reduction in underground water pumping since 1997 caused a recovery in water table. It resulted in instability of water uplift at the base

of excavation works. To minimize the risk of water uplift, toe of retaining wall should be embedded in hard clay. Alternatively, ground improvement such as jet grouting or chemical grouting can be used to increase the stability of excavation.

7 ACKNOWLEDGEMENT

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