Recent development on deep basement construction in soft Bangkok clay next to British Embassy

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ABSTRACT

Basement construction has been developed for many years by using either top-down construction method or bottom-up technique. Recent, deep basement construction in Bangkok City becomes complicated as it may trigger damage to sensitive surrounding structure. Central Embassy department store project is the luxury department store and hotel located in the Central Business District (CBD). There are 5-6 basement floors which required excavation to 24.2 meter below ground level. The excavation is close to Bangkok Mass Transit System (BTS) sky train foundation at the front and the British Embassy at the back. Various depth and size of diaphragm wall were carefully analyzed and designed based on many obstruction. Fully instrument scheme including inclinometer, piezometer and stress transducer were installed in diaphragm wall and soil for monitoring of walls and their effect. The field measurement agrees with FEM prediction. The basement construction was completed without any effect to BTS sky train foundation and British Embassy.

Keywords: basement, FEM, deep excavation, diaphragm wall, instrumentation

1 INTRODUCTION

The demand of deep underground basement construction is increasing in Bangkok City especially in the inner zone due to the optimized land use for underground car park and retail of the department store. The design and construction of deep basement in the inner of Bangkok City have to take the impact of the nearby structure as well as public utilities in to account. The design of deep basement in Bangkok City done by the author are the Bai Yok II tower with 12 m. depth (Teparaksa, 1992), Library of Thammasart university with 14 m. depth (Teparaksa, 1999a), Millinium Sukhumvit hotel in the protection zone of Mass Rapid Transit (MRT) tunnel with 14 m. deep (Teparaksa, 2007) and Bank of Thailand with 16 m. depth closed to the palace (Teparaksa, 2013).

The Central Embassy department store is located in the Central Business District (CBD) of Bangkok city. The excavation is close to Bangkok Mass Transit System (BTS) Foundation at the front while the back of the project closed to British Embassy as shown in Figure 1. The design and construction of deep basement Central Embassy consists of five basements for underground car park with 24.2 m. deep. The analysis and diaphragm wall design as well as the impacted to BTS foundation and British Embassy were carried out by Finite Element Method (FEM) by simulating the full sequence of excavation in the model. The instrument was installed in the diaphragm wall to monitor the lateral wall movement. The behavior of diaphragm wall movement will also be discussed and compared with FEM prediction.

![Fig. 1 Layout of the central Embassy Project](http://doi.org/10.3208/jgssp.THA-02)
2 SOIL CONDITIONS

The soil condition at Central Embassy site based on 6 bored holes soil investigation consists of 9 m. thick soft dark grey clay and encountered by medium stiff clay to 13.5 m. depth then followed by stiff silty clay and hard clay until reach very dense silty sand layer at 48 m. depth. Table 1 presents the soil condition and the engineering properties.

Table 1 Soil Conditions and engineering properties

<table>
<thead>
<tr>
<th>Depth (m)</th>
<th>Soil profile</th>
<th>$\gamma_t$ (t/m$^3$)</th>
<th>$S_u$ (t/m$^2$)</th>
<th>Eu/So</th>
<th>E/N</th>
<th>SPT-N Value (Blows/ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0-0.9</td>
<td>Soft Clay</td>
<td>1.60</td>
<td>1.60</td>
<td>500</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>9.0-13.5</td>
<td>Medium Clay</td>
<td>1.65</td>
<td>2.50</td>
<td>500</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>13.5-15.0</td>
<td>Stiff Clay</td>
<td>1.80</td>
<td>5.50</td>
<td>1000</td>
<td>8</td>
<td>-</td>
</tr>
<tr>
<td>15.0-21.0</td>
<td>Very Stiff Silty Clay</td>
<td>1.90</td>
<td>12.0</td>
<td>1000</td>
<td>18</td>
<td>-</td>
</tr>
<tr>
<td>21.0-35.0</td>
<td>Hard Silty Clay</td>
<td>2.00</td>
<td>20.0</td>
<td>1000</td>
<td>30</td>
<td>-</td>
</tr>
<tr>
<td>35.0-48.0</td>
<td>Hard Silty Clay</td>
<td>2.00</td>
<td>27.0</td>
<td>1000</td>
<td>40</td>
<td>-</td>
</tr>
<tr>
<td>48.0-End</td>
<td>Very Dense Silty Sand</td>
<td>2.00</td>
<td></td>
<td>500</td>
<td></td>
<td>-</td>
</tr>
</tbody>
</table>

Note: $\gamma_t$ = Total Unit Weight  
$S_u$ = Undrained Shear Strength  
E/N = SPT N-Value  
Eu, $E_u$ = Undrained and Drained Young’s Modulus

3 PROJECT DESCRIPTION

The Central Embassy project is the luxury department store and hotel which was opened at the end of 2014 year. The project area is limited about 66x250 meter with approximately 12 m. away from BTS sky train foundation in the front and touch to fence of British Embassy in the back. Due to Limited land, the conventional bottom up construction technique was adopted as the basement construction procedure. Five basements consists of LG floor at -3.40 m, B1 floor at -7.30 m, B2 floor at -10.30 m, B3 floor at -13.30 m, and B4 floor at -16.30 m. and some area consists of B5 floor at -20.0 m. depth. The foundation was isolate footing with different thickness varied from 1.2 m. to 4.0 m. especially in the area of B5 basement floor and lead to create the maximum depth of excavation at -24.20 m. However, some area with only B4 floor with 1.20 m. thick of isolated footing, the depth of basement excavation was only -17.50 m. The different depth of basement excavation work was very high about 7.0 m. This lead to a design of different length and width of diaphragm wall (D-wall) and different layers of bracing struts.

The type of Diaphragm wall which consists of 6 types with different thickness from 800-1000 mm. and length from 25-30 m. (figure 1). The diaphragm wall on left and back side of project is the D-wall type 4 and 6 for ramp to the basement as shown by the typical section in Figure 2. The typical section of D-wall type 2 for 3.20 m. thick isolated footing is presented in Figure 3. It can be seem that at diaphragm wall type 2 (Figure 3), it consist of 4 temporary steel bracing struts at -2.0 m. -6.0 m. -11.50 m. and -15.50 m. depth for excavation depth of -19.65 m. to -22.40 m. depth. At this D-wall section, there was no third basement floor. At diaphragm wall type 6 (Figure 2), it is the zone of ramp to basement floor.

The location of main diaphragm wall was shifted from the boundary line for area of ramp of the project. The technique of construction using temporary flexible sheet pile wall type IV 18 m. long was adopted to be the local zone for construction of the ramp of -3.5 m. depth. This ramp was the main entrance of Central Embassy project to 1st basement floor at -3.50 m. depth. The sheet pile type IV 18 m. long was drived by Silent Piler tought to the British Embassy 2 m. high fence. The top elevation of sheet pile type IV was set at +4.0 m. above ground surface or 2m. higher than British Embassy fence.

Typical Section

Fig. 2. Section of D-wall type 6 at ramp area

Fig. 3. Section of D-wall type 2

The first steel bracing strut layer 1 at -2.0 m. depth, therefore, braced between flexible sheet pile type IV wall and rigid diaphragm wall. The unbalance force or reaction from flexible sheet pile wall and rigid diaphragm wall was solved by unbalance preloading technique in the first strut. To prevent the lateral
movement of sheet pile and increase stability of British Embassy fence behind the sheet pile wall, eight rows of soil cement column (SCC) 600 mm. diameter was provided between temporary sheet pile wall and permanent diaphragm wall as shown in Figure 2. The top and tip of SCC pile was set at -1.00 m. and -7.50 m. depth respectively.

4 ANALYSIS AND DESIGN OF DIAPHRAGM WALL

The analysis and design of the diaphragm wall was carried out by means of the Finite Element Method (FEM). The construction sequence was simulated in the FEM analysis. The sequence of basement construction for example at diaphragm wall type 6 or ramp zone consists of 15 steps as follows:
1. Excavating to -2.5 m. deep and install first bracing strut at -2.0 m. depth.
2. Excavating the ramp zone between temporary sheet pile wall and diaphragm wall to -4.20 m. depth on improved soil with SCC pile.
3. Casting Ramp slab and outer retaining wall.
4. Excavating to 7.0 m. depth and install second bracing strut at -6.0 m. depth.
5. Excavating to -12.5 m. depth and install third bracing strut at -11.50 m. depth.
6. Excavating to -16.5 m. depth and install fourth bracing strut at -15.50 m. depth.
7. Excavating to -19.5 m. depth and install fifth bracing strut at -18.50 m. depth.
8. Excavating to final depth of excavation at -24.20 m. and casting 0.20 m. thick lean concrete.
9. Casting footing F32 (4.0 m. thick) and remove the fifth strut.
10. Casting B4 basement floor and remove 4th bracing strut.
11. Casting B3 basement floor and remove 3rd bracing strut.
12. Casting B2 and B1 basement floors then remove 2nd bracing strut. At this sequence, the soil improvement zone by SCC pile is improve the stability of the D-wall system.
13. Casting LG basement floor at -3.40 m. depth and remove 1st strut.
14. Extend the retaining wall to ground surface.
15. Remove the temporary sheet pile wall.

The analysis and design of the diaphragm wall for 24.20 m. deep excavation were carried out by FEM. As the basement constructed in soft clay layer, the undrained concept based on bi-linear Mohr-Coulomb failure theory was used for FEM analysis. The Young’s modulus (Eu) was used in terms of an undrained shear strength (Su) of Eu/Su = 500 and 1000 for soft clay and stiff clay respectively (Teparaksa, 1999b), the value of Young’s modulus is also presented in Table 1.
The result of FEM analysis presents the envelope of lateral movement of D-wall at final stage of excavation in the order of 49.5 mm. and maximum ground surface settlement of 46.7 mm. This maximum ground surface settlement behind the D-wall and lateral movement of the D-wall was set as the trigger level to control the method of excavation as well as the stability of fence at British Embassy as well as foundation of BTS sky train.

The bending moment envelop to cover the 15 step of basement construction is presented in figure 7. The reinforcement of the D-wall was based on this bending moment envelop.

5 INSTRUMENTATION AND PERFORMANCE OF DIAPHRAGM WALL

The set of instrumentation was proposed to monitor the behavior of diaphragm wall and surrounding structure as presented in Figure 8. Totally 8 inclinometers and 4 strain gauge were installed in the D-wall to monitor lateral wall movement and bending moment developed in diaphragm wall. Apart from inclinometer and strain gauge, four piezometers were installed in clay layer and the results showed that ground water level was constant with hydrostatic pore pressure of ground surface water at 1.0 m. below ground surface.

The measurement of the lateral diaphragm wall movement at all step of excavation and basement floor casting at inclinometer No.I8 next to British Embassy is shown in Figure 9 together with the predicted maximum envelop of diaphragm wall movement estimated by FEM.

![Fig. 7. Moment envelop of D-wall type 6](image1)

![Fig. 8. Instrumentation location](image2)

![Fig. 9. Inclinometer and FEM result](image3)
It can be seen that the predicted wall movement by FEM agrees with field performance. The induced lateral diaphragm wall movement was not induced any disturbance to both British Embassy (Fence) as well as the BTS sky train foundation. The basement construction of Central Embassy was completed in 2014 Figure 10 presents the photograph of basement construction.

![Fig. 10a. Ramp construction beside British Embassy](image1)

![Fig. 10b. Project platform system](image2)

6 CONCLUSIONS

Central Embassy is the luxury premium department store and hotel located on Central Business District (CBD) area of Bangkok city. It consists of 5-6 basement floors with maximum depth of excavation - 24.20 m. The project is closed to the BTS sky train foundation and tought to the fence of British Embassy. The behavior of diaphragm wall was carried out by means of Finite Element Method with simulating construction sequence in the model. The full instrumentation was installed in the diaphragm wall to measure wall behavior, stability of wall system as well as their effect. The measured lateral movement of diaphragm wall by means of inclinometer is compared with FEM prediction. The FEM prediction agrees with measured values. The deep basement was completed in 2014 without any disturbance to both BTS sky train foundation and British embassy.

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