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Stability of diaphragm wall for deep basement excavation in central business district of Bangkok

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ABSTRACT

Recently, the demand for deep underground basement is increasing in the Central Business District of Bangkok city to optimizer land use. This paper present diaphragm wall performance and analysis of the high-rise building project located in the Bangkok city center. There are three basement floors with -14.80m maximum depth of excavation. Three layers of steel bracing strut was employed to brace 0.80m thick diaphragm wall with the tip penetrated in the very stiff clay later at -23.50m. Finite Element Method (FEM) was used to analyzed retaining wall behavior and displacement with Mohr-Coulomb soil modeling. Lateral diaphragm wall's displacement was monitored and compared with that computed by FEM. The stability of surrounding houses was also recorded by instruments such as ground surface settlement, building settlement and tiltmeter. The monitoring results were compared and discussed with field performance. The predicted diaphragm wall displacement agreed well with the recorded data.

Keywords: diaphragm wall; finite element; deep excavation; basement; trigger level

1 INTRODUCTION

As a developing city, demand for deep basement construction is increasing in the inner zone of Bangkok to optimum land use. Although there are many theoretical methods studied the stability of braced excavation (Bjerrum and Eide, 1956; Khatri and Kumar, 2010) and ground movement induced by excavation (Terzagi, 1943; Eide et al., 1972; O'Rourke, 1993), the number of research on an actual construction work is still limited. The examples of deep basement excavation in Bangkok are Bai Yok II Tower with 12m deep (Teparaksa, 1992), The library of Thammasat University with 14m deep (Teparaksa et al., 1999), Millennium Sukhumvit Hotel next to Bangkok Mass Rapid Transit (MRT) subway tunnel (Teparaksa, 2007), the impact assessment of deep basement construction in MRT Protection Zone (Teparaksa et al., 2015), the deep basement construction next to British Embassy (Teparaksa, 2015), deep excavation closed to historical palaces (Teparaksa, 2013) and the hotel in Bangkok city center (Teparaksa, 2018). This paper present another deep basement construction performance and analysis of high-rise building in Bangkok city center.

2 PROJECT DESCRIPTION

The building consisted of three basement floors at -3.80m, -7.80m and -12.00m deep below ground surface. The final excavation depth was -14.80m which intended for Mat foundation. The diaphragm wall (D-Wall) of 80cm thick was employed as a soil retaining wall during excavation and at final stage. During excavation, three steel bracing layers were employed at elevation of -2.00m, -6.00m. and -10.50m. below ground surface. The tip of d-Wall was penetrated in the very stiff silty clay layer at -23.50m. Typical section of the excavation works and temporary bracing detail is presented in Fig. 1.

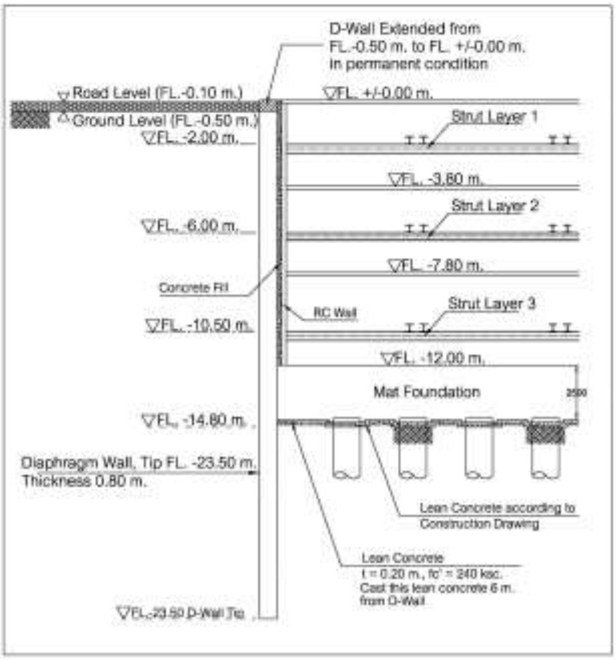

Fig. 1. Typical cross section of the basement construction

Fig. 2. Soil Profile and engineering properties

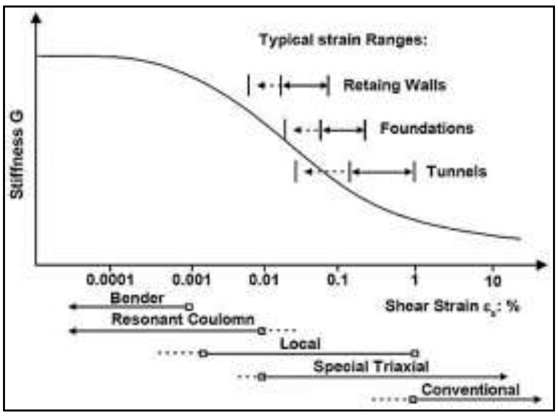

Fig. 3. The relationship between modulus and shear strain level (Mair, 1992)

3 GEOLOGICAL CONDITIONS

Five boreholes of 65-70m were carried out to investigate the soil conditions. It consisted of a 13.5 m. thick soft to medium stiff clay layer followed by stiff to very stiff clay at -20.50 m. Hard silty clay and dense silty sand layer are encountered below the very stiff clay layer. The soil condition as well as its engineering properties is shown in Fig. 2.

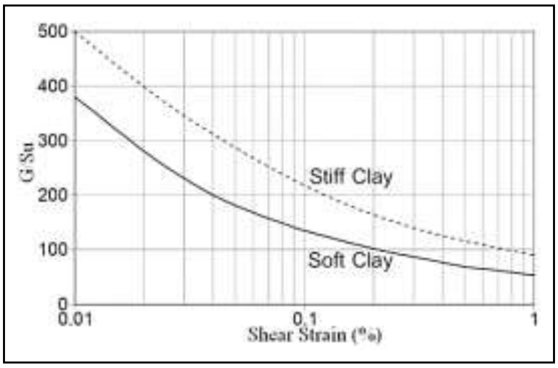

Fig. 4. Relationship between modulus and shear strain level of soft and stiff Bangkok clay (Teparaksa, 2007)

4 ANALYSIS OF DIAPHRAGM WALL BY FINITE ELEMENT METHOD

4.1 Deisgn Criteria of Diaphragm Wall

The behavior of diaphragm wall can be predicted by numerical analysis by mean of Finite Element Method (FEM). The result of FEM analysis of diaphragm wall behavior is presented in term of bending moment and shear force induced in the diaphragm wall. The lateral displacement of diaphragm wall is also presented. Soil modeling is one of the main parameter for FEM analysis. Steps of soil excavation, bracing installation, as well as preloading in the strut system were simulated in the FEM analysis. Moreover, casting of base slab, basement floor and the step of removal of strut system have to be designed and combined in the FEM analysis of diaphragm wall. In this project, PLAXIS 2D program (Brinkgreve, 2002) is used as the FEM program analysis to predict the diaphragm wall behavior.

Mohr-Coulomb soil modeling is used for FEM analysis. Undrained Young's modulus (Eu) of layer was correlated with undrained shear strength (Su). In the sand layer, the drained modulus (E') was correlated with the Standard Penetration Test, SPT N-Value.

The correlation of Eu and Su as well as E' and N-value can be conducted as follows.

- For soft to medium clay layer, Undrained Young's modulus (Eu) = 500 – 700 Su (Undrained Shear Strength)
- For Stiff to very stiff silty clay layer

Eu = 1000 Su

- For Sand layer

E' = 2000(N) SPT-N-Value (kN/m^2)

Young's Modulus or shear modulus (G) of clay depends on shear strain of system type as proposed by Mair (1992) (see Figure 3). The above correlation for Bangkok clay between Eu-Su, and E'-N(value) is based on the back analysis from various basement excavation project by means of FEM analysis compared with field measurement proposed by Teparaksa (2001). Figure 4 shows the relationship of soft and stiff Bangkok clay based on self-boring pressuremeter tests of MRT project (Teparaksa, 2007).

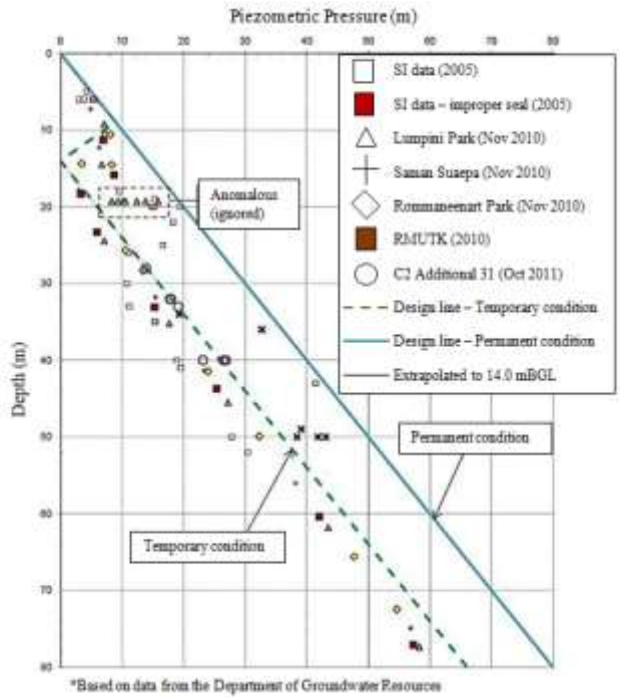

Fig. 5. Piezometer level of Bangkok subsoil (Teparaksa, 2018)

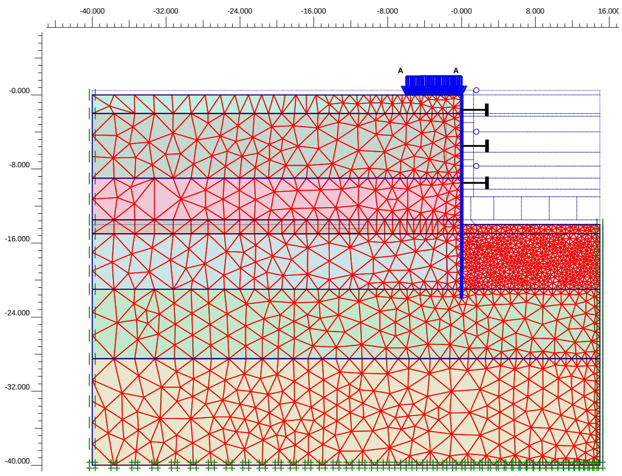

Fig. 6. FEM deformed mesh at final excavation

4.2 Surcharge on Diaphragm Wall

Ground surface surcharge behind the diaphragm wall during construction was assumed at 10kN/m^2. This surcharge was applied throughout excavation and construction process; in other words, during excavation, basement casting and completion of the basement work.

4.3 Ground Water Table

Ground water in Bangkok subsoil condition is in draw down condition due to deep well pumping. In the past, ground water table was at -24 m. from ground surface. However, recently, the deep well pumping was not allowed. As a result, the recent ground water table is elevated to -13 m. below ground surface as shown in Fig. 5 (Teparaksa, 2018).

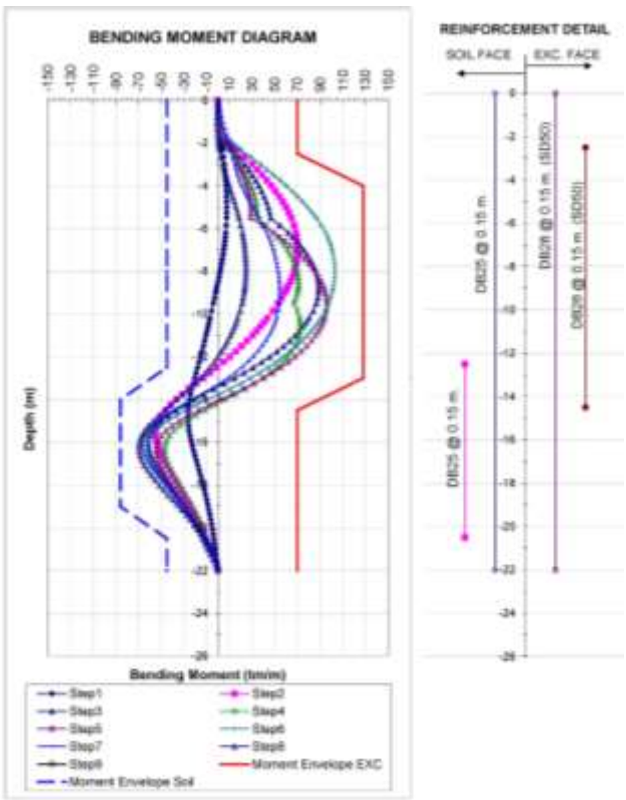

Fig. 7. Envelop of bending moment diagram induced in the diaphragm wall and reinforcement design

5 RESULT OF FEM ANALYSIS

The FEM analysis was carried out based on Mohr-Coulomb soil failure criteria by simulating all the construction sequences in the analysis. Fig. 6 presents the deformed mesh of FEM at final excavation depth. The maximum lateral displacement of diaphragm wall was 26.76 mm which was used to set as a trigger level (see table 1) for monitoring field performance during construction.

Fig. 7 shows the envelop of bending moment diagram induced in the diaphragm wall with all excavation steps including soil excavation, installing and removing of bracing strut as well as basement casting. The outer line of the bending moment envelop is the bending resistance of diaphragm wall steel reinforcement.

Table 1. Trigger level for safety control.

Trigger level	Inclinometer Movement (mm.)	Safety Criteria
Alarm level (70% of DV)	18.73	Inform designer to review construction sequences
Alert level (80% of DV)	21.41	Inform all parties to review construction sequences
Action level (90% of DV)	24.08	Stop construction and revise the construction sequences
Maximum	26.76	

DV = Design value

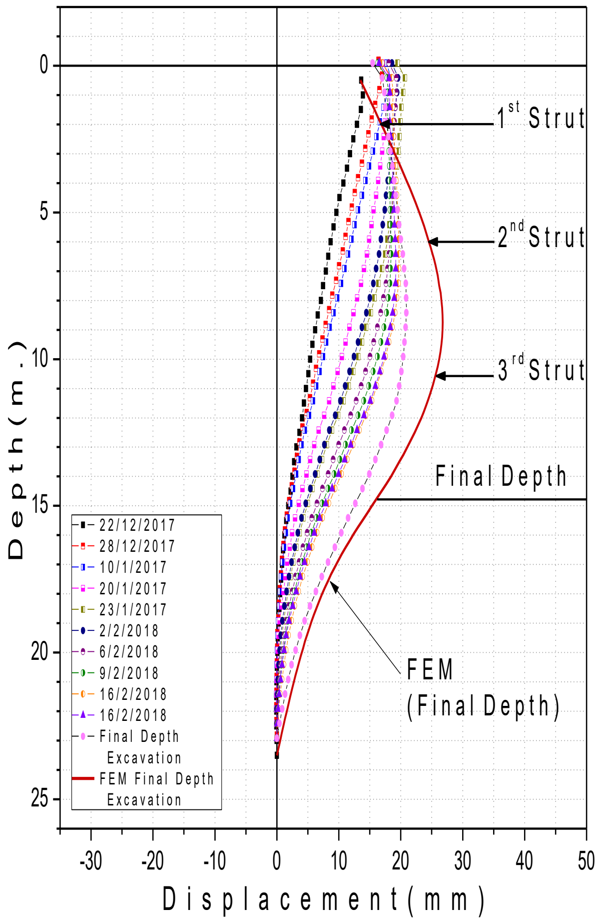

Fig. 8. Inclinometer monitoring data and FEM results

6 FIELD MEASUREMENT OF D-WALL DISPLACEMENT

The stability of diaphragm wall was monitored during excavation, casting basement slab and removal of strut by means of inclinomter. Fig. 8 shows the lateral disphragm wall displacement by means of inclinometer reading. At initial stages, D-wall is in the mode of cantilever. After that, the movement of D-wall changed to a beam support as steel bracing struts acted as a rigid support for D-wall. The maximum deflection was 20.91 mm at the final depth of excavation. Even though measured wall deflection was lower than the prediction by FEM (26.76 mm.), the shape of wall deflection was similar. The FEM prediction agreed well with the field performance. The behavior was stable and can be used as a part of permanent wall. The stability of the surrounding houses measured by means of tiltmeter showed very low tilt value.

7 CONCLUSIONS

The high-rise building consists of three basement floors was constructed using D-wall as a soil retaining structure with three steel bracing strut layers. The maximum depth of excavation was -14.80 from the ground surface. Bottom-up technique was employed in the construction project. The D-wall behavior was analyzed and designed using FEM with Mohr-Coulomb failure criteria. All the construction sequences were taken into the analysis. During construction, movement of D-wall was monitored by installed inclinometer. The recorded data showed well agreement in D-wall deflection shape.

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