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DISPLACEMENT OF DIAPHRAGM WALL FOR VERY DEEP BASEMENT EXCAVATION IN SOFT BANGKOK CLAY

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ABSTRACT: Rosewood Hotel Project consists of 6 basements by using a diaphragm wall as a soil protection system. Elevations of Rosewood Hotel basements are -2.9, -6.5 -9.25, -11.95, -14.65 and -18.9 m. depth from the ground surface. Final excavation depth of this project is -24.2 m. from the ground surface which is area intended for a lift pit. Due to the fact that the final depth of this project is very deep, the effect of water pressure was also considered. Finite Element Method (FEM) was carried out to predict behavior and displacement of the diaphragm wall which is used as a soil protection system. In addition, the Mohr-Coulomb soil modeling was used as failure criteria of the FEM analysis. Measured lateral movement of the diaphragm wall by means of inclinometer at all stages of construction was compared with analytical results from FEM prediction. The predicted diaphragm wall displacement by FEM agrees well with field performance.

Keywords: Deep basement, FEM analysis, Diaphragm wall, Lateral wall movement

1. INTRODUCTION

As a developing city, the demand for underground basement construction is increasing in the city especially in the inner zone due to optimum land use such as underground car park and retails of the department store. Although there are a large number of theoretical methods studied the stability of braced excavation [1]-[3] and ground movement induced from excavation [4]-[6], the number of research on an actual construction work is still limited. The examples of deep excavation projects in Bangkok designed by the first author are Bai Yok II tower with 12 m. deep [7], Library of Thammasat University with 14 m. deep [8], Central World department store with 9 - 14 m. deep [9], Millennium Sukhumvit hotel next to Bangkok Rapid Mass Transit (MRT) Tunnel with 14 m. deep [10], the impact assessment of deep basement construction in the MRT Protection Zone [11], the deep basement construction next to British Embassy [12], the deep excavation in the safety zone of Bangkok subway [13]-[14] and the deep excavation closed to palaces [15]

Rosewood hotel consists of six basement floors at -2.90 m,-6.50 m, -9.25 m, -11.95 m, -14.65 m, and -18.90 m. deep below the ground surface. The final excavation depth of -24.2 m. is intended for lift pit of the project. The diaphragm wall is used as the temporary wall during excavation and is used as a permanent wall at the final stage. During excavation, four temporary steel bracing layers were used at an elevation of -1.50 m, -7.45 m, -12.75 m. and -17.50 m. below ground surface. The diaphragm wall is 1.0 m. thick with tip penetrated in the very stiff silty clay layer at -28.0 m. depth below ground surface. Typical section of basement floor is presented in Figure 1 while the detail of temporary bracing system is presented in Figure 2.

The research works for behavior and performance of diaphragm wall for basement construction in Bangkok subsoil with various conditions were presented in [9], [11] and [16].

This paper presents the performance and behavior of the diaphragm wall. Lateral displacement of the diaphragm wall is predicted by FEM analysis by simulating the construction sequence in the analysis. The lateral wall displacement is monitored during excavation and casting the basement floor. The FEM prediction was compared and discussed with the field performance.

2. GEOLOGICAL CONDITIONS

Three bored holes of 70 m. depth were carried out to investigate the geological conditions of the project. The soil condition consists of soft to medium Bangkok clay from the ground surface to 14 m. depth. The stiff silty to hard clay was encountered below soft to medium clay up to -45 m. depth. The dense second silty sand layer was found below 45 m. depth below ground surface. At this project site, the first layer of silty sand was not found as normal Bangkok soil condition which is normally found at approximately 27 – 30 m. depth. The soil conditions, as well as soil engineering properties, are presented in Figure 3.

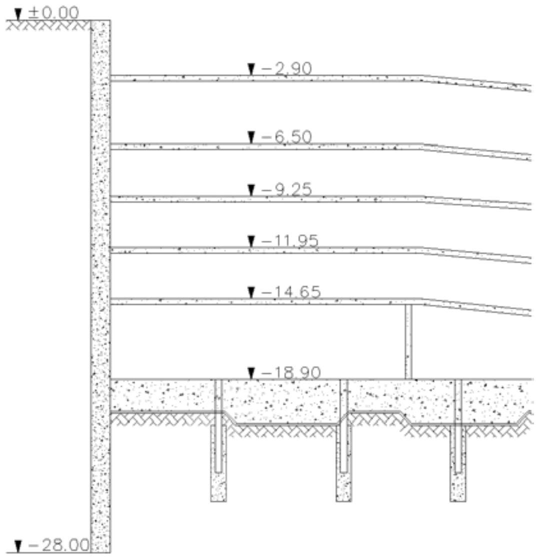


Fig.1 Typical section of Rosewood Hotel basement

3. ANALYSIS OF DIAPHRAGM WALL BEHAVIOR BY FINITE ELEMENT METHOD

3.1 Design Criteria for 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 parameters 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 [17] program 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 clay 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)

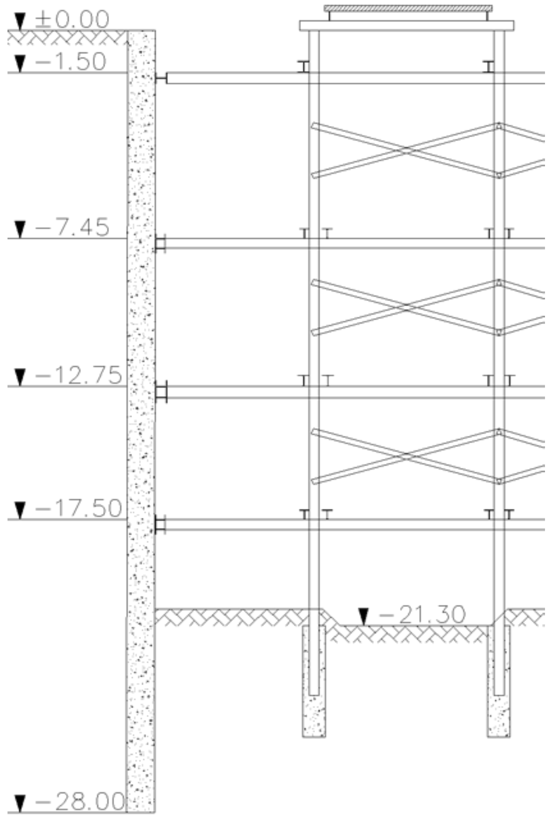


Fig.2 Detail of temporary bracing system

Young’s Modulus or shear modulus (G) of clay depends on shear strain of system type as proposed in [18] (see Figure 4). 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 in [19]. Figure 5 shows the relationship of soft and stiff Bangkok clay based on self-boring pressuremeter test of MRT project [10].

3.2 Surcharge on Diaphragm Wall

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

3.3 Ground Water Table

Groundwater in Bangkok subsoil condition is in drawdown condition due to deep well pumping. In the past, groundwater table was at -24 m. from the ground surface. However, recently, the deep well pumping was not allowed. As a result, the recent groundwater table is elevated to -13 m. below ground surface as shown in Figure 6.

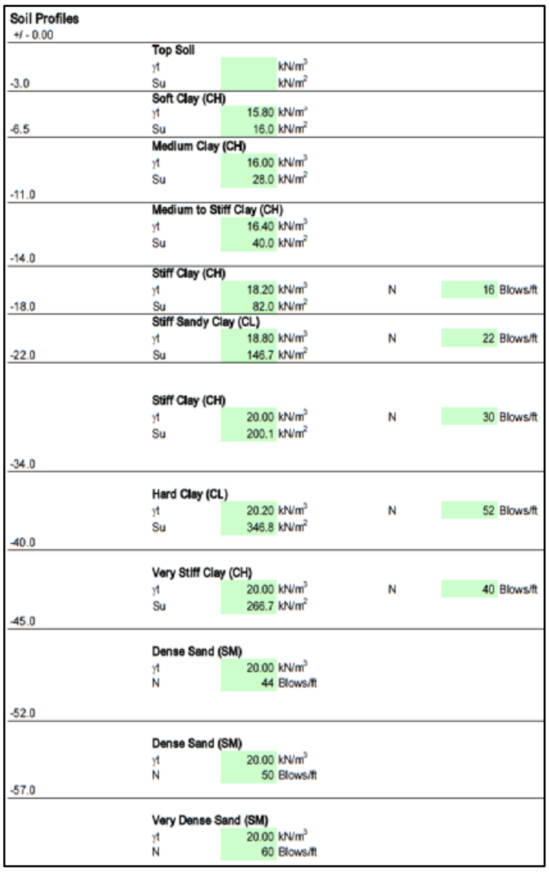


Fig.3 Detail of temporary bracing system

4. RESULT OF FEM ANALYSIS

The FEM analysis was carried out base on Mohr-Coulomb soil failure criteria by simulating the construction sequence in the FEM analysis. Figure 7 presents the deformed mesh of FEM analysis at final excavation depth -21.30 m. with 4 bracing layers. Figure 8 presents the deformed mesh of FEM analysis at the stage of all 6 basement floor is cast. The maximum lateral diaphragm wall deflection is found at 43.34 mm. This maximum diaphragm wall deflection is used as the Trigger Level for monitoring D-wall deflection as the safety control of the project.

Figure 9(a) presents the envelope of bending moment diagram induced in the diaphragm wall with all excavation steps including soil excavation and bracing installation until casting the foundation. The upward construction including casting base slab, removing of bracing as well as basement casting is also included in the envelope.

The dotted line outside of the bending moment envelop is the bending moment resistance of the reinforcement. This dotted line of reinforcement is calculated from reinforcement detail presented in Figure 9(b).

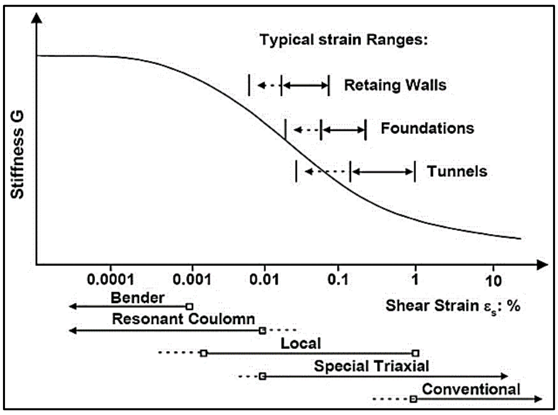


Fig.4 The relationship between modulus and shear strain level [18]

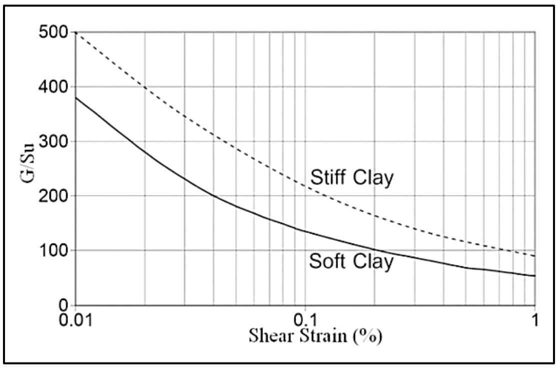


Fig.5 Relationship between modulus and shear strain level of soft and stiff Bangkok clay [10]

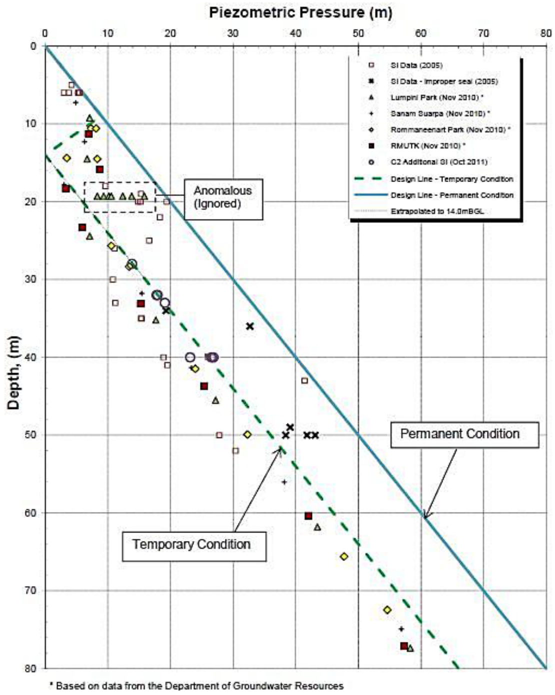


Fig.6 Piezometer level of Bangkok subsoil [15]

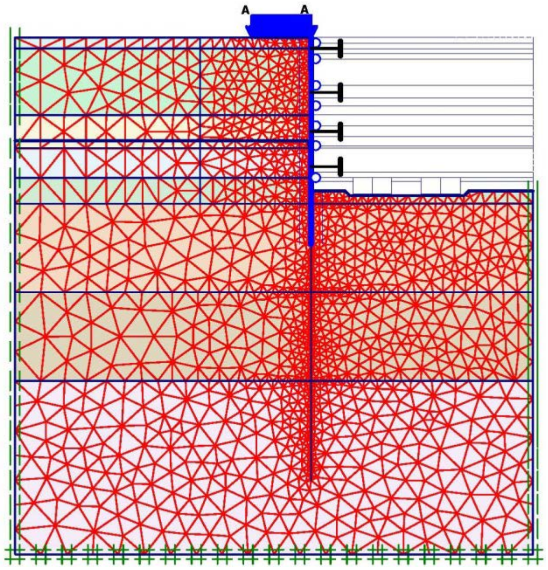


Fig.7 Deformed mesh from FEM analysis during final depth excavation

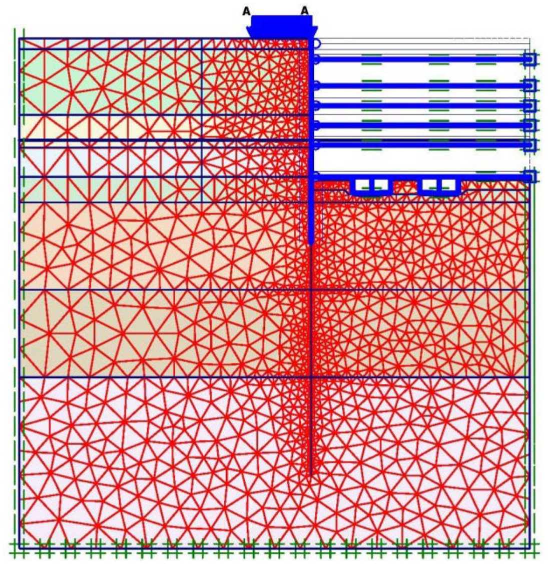
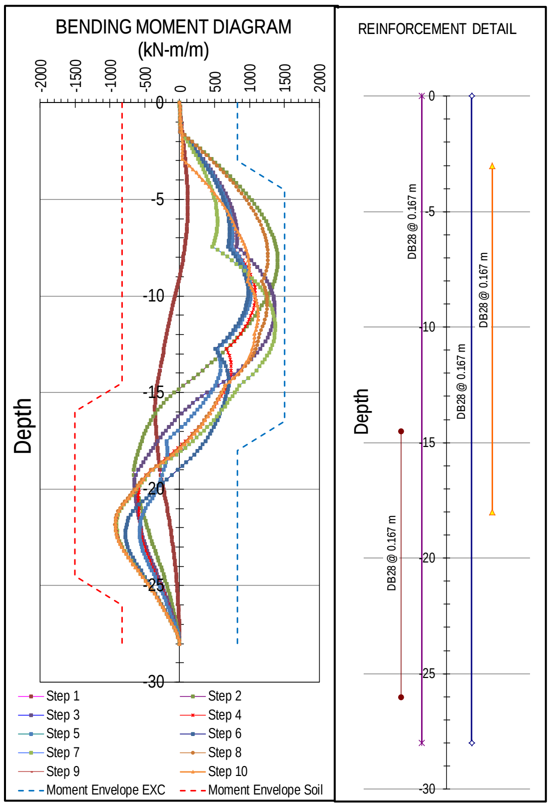


Fig.8 Deformed mesh from FEM analysis during B1 Floor construction at EL. -2.90 m.

5. TRIGGER LEVEL AND SAFETY CONTROL

The instrumentation for monitoring the diaphragm wall deflection is proposed as inclinometer by installing inside the diaphragm wall panel. The safety control and monitoring criterion are proposed in terms of trigger level as presented in Table 1. The lateral diaphragm wall deflection is monitored at all construction sequence as simulated in the FEM analysis. The safety criterion is only one method to control the behavior and performance of diaphragm wall during construction.



(a) (b)

Fig.9 (a) Envelop of bending moment diagram induced in the diaphragm wall and (b) reinforcement design

Table 1 Trigger level and safety control

Trigger level	Inclinometer Movement (mm.)	Safety Instruction
Alarm Level (70 % of design value)	30.34	Inform designer to review construction sequence
Alert Level (80 % of design value)	34.67	Inform all parties to review construction sequence
Action Level (90 % of design value)	39.01	Stop construction and revise the construction sequence.
Maximum	43.34	

6. FIELD MEASUREMENT OF D-WALL DISPLACEMENT

Figure 10 presents the lateral diaphragm wall displacement by mean of inclinometer reading. At initial stage during first excavation and first strut installation, the D-wall movement is in cantilever mode. At later stages, the movement of D-wall is changed to be beam on supported shape. This is because the bracing strut is acted as the rigid support of the diaphragm wall. The maximum wall deflection is only 28.41 mm. at final depth excavation. The maximum measured diaphragm wall deflection is less than the prediction of 42 mm. This is because the basement construction period is very fast and can be completed within 4 months. Even the order of maximum measured wall deflection is less than prediction; however, the shape of wall deflection is similar. The FEM prediction of diaphragm wall agreed well with field inclinometer measurement.

7. SAFETY AGAINST UPLIFT

The deepest basement of Rosewood Hotel is at -24.20 m. below ground surface. Uplift at the final depth excavation is predicted by checking safety factor against uplift which can be estimated as the ratio between the weight of overburden stress of soil from the final depth to sand layer and uplift pressure as shown in Figure 11. The overburden pressure is estimated of about 410 kN/m^2 while uplift pressure is at 320 kN/m^2. The safety factor against uplift is 1.28.

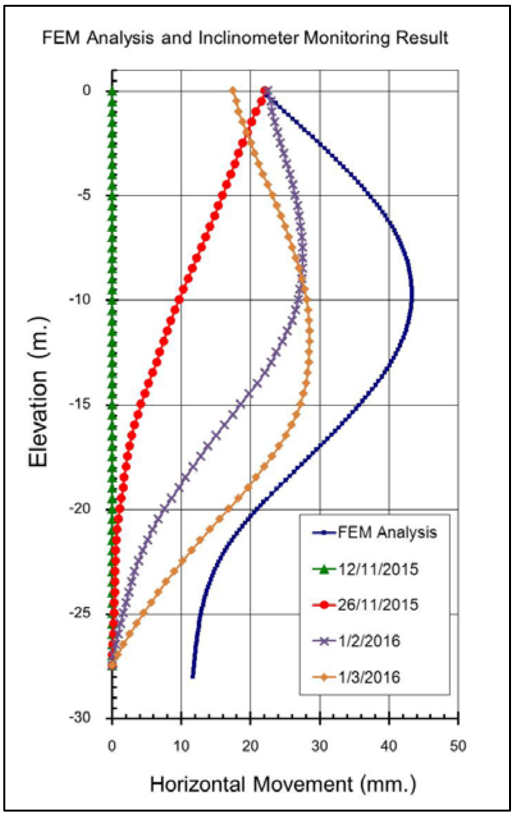


Fig.10 The lateral diaphragm wall displacement

8. CONCLUSIONS

The Rosewood hotel consists of six basement floors and constructed by means of diaphragm wall. The maximum depth of excavation is at -24 m. depth below ground surface. The diaphragm wall is 1.0 m. thick with tip penetrated in very stiff clay at -28 m. below ground surface. Four temporary steel bracing at -1.5 m, -7.45 m, -12.75 m and -17.5 m. is used for excavation work with bottom-up construction technique. The behavior of diaphragm wall is predicted by means of FEM analysis. The Mohr-Coulomb soil modeling is used for FEM analysis with simulating construction sequence in the FEM analysis. The diaphragm wall displacement is predicted. The measurement of D-wall displacement by inclinometer agreed well with FEM analysis.

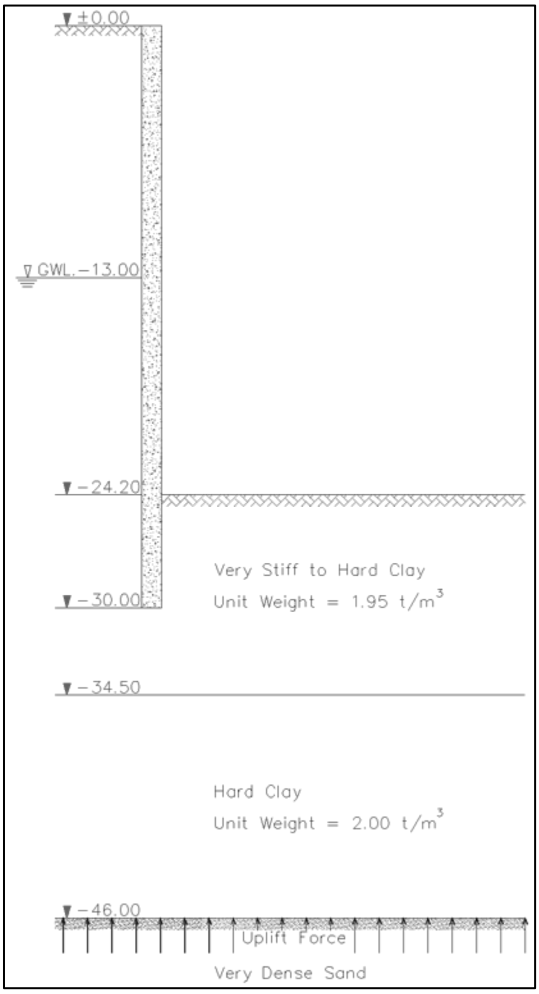


Fig.11 Layer of soil for uplift estimation

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