FINITE ELEMENT ANALYSIS OF DEEP BASEMENT CONSTRUCTION OF BANK OF THAILAND ALONG CHAO PHRAYA RIVER CLOSED TO HISTORICAL PALACES

Wanchai Teparaksa

Department of Civil Engineering, Faculty of Engineering, Chulalongkorn University, Bangkok, Thailand

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Abstract

The Bank of Thailand headquarter (BOT) is a large building located in the inner Rattanakosin Island where high-rise building more than 4 storey is not permitted. This building consists of 3 story and 5 basements with excavation depth of 15.8 m. The head office was constructed along Chao Phraya river, the main river of Bangkok. The basement of the building was constructed only 5m and 10m away from two historical palaces, Tewavej and Bangkhunphrom. Hence, protection policy has been set for the construction and damage assessment by means of Finite Element Method (FEM) with simulation of basement construction method was carried out to predict any potential damage to both palaces. At last, the top down construction method was employed for basement construction using 1m thick and 20m long of diaphragm wall combined with 50m long of bored pile. The instrumentation was installed at the palaces, diaphragm and ground settlement to observe field performance both during and after construction. Furthermore, the field measurement data is compared and discussed with prediction data from FEM analysis and the time dependent of lateral wall movement will be presented. Currently, the construction of Bank of Thailand head office is finished without damage to both palaces

Keywords: Deep basement, Deep excavation, FEM analysis, Historical palace, Top-down construction,

Introduction

In Bangkok city, the construction of deep basement construction is currently increasing especially in the inner zone, Rattanakosin Island, because of several reasons such as the optimization of land use for underground car park and retail of department store. However, the impact to the nearby structure as well as public utilities have to be taken into the account due to high potential movement. Examples of deep basement construction in Bangkok subsoil are the Bai Yok II tower with 12 m. deep (Teparaksa, 1992) [2], Libraray of Thammasat university with 14 m. deep (Teparaksa et al, 1999a) [3], Central World with 9 - 14 m. deep and Millennium Sukhumvit hotel next to Bangkok Mass Rapid Transit (MRT) Tunnel with 14 m. deep (Teparaksa, 2007) [5].

The head office, Bank of Thailand (BOT) is located in the inner Ratanakosin Island where is not allow to construct high-rise building more than 3 storey. The new head office of BOT is constructed along Chao Phraya riverbank and closed to two historical palaces, Tewavej Palace and Bangkhunphrom Palace, as shown in Figure 1.

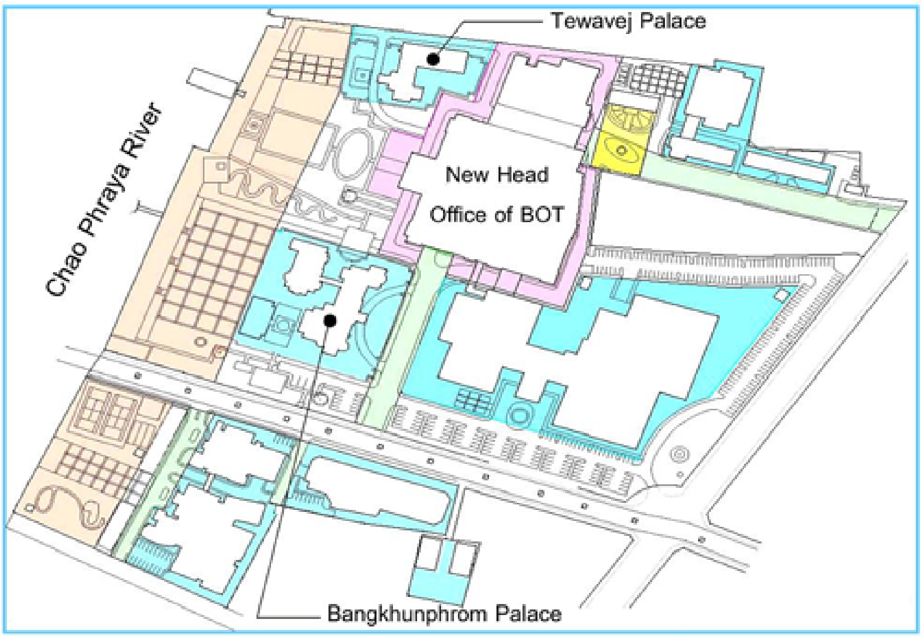

Figure 1. The location of new head office, Bank of Thailand (BOT) and surrounding palace

New headquarter building of BOT consists of 15.8m deep excavation of 5 basement floors which is to be used as underground parking and 3 floor of superstructure. The analysis and the design of diaphragm wall and the impact assessment of two palaces were conducted by Finite Element Method (FEM) analysis. Full method of excavation and construction was simulated in the model. Measuring instrumentation was installed in both diaphragm wall and the palace to monitor the safety and stability of the palaces. Finally, the observed behavior of diaphragm wall was compared with FEM analysis.

Soil Conditions

The investigated soil conditions are illustrated in Figure 2. There was a 13-16m thick soft marine clay layer on top which is sensitive, anisotropic and creep (time dependent stress-strain-strength behavior) susceptible. This behavior promotes difficulty to the design and construction not only in deep basement but also filled embankments and tunneling. The first stiff to very stiff clay layer was found below soft clay and medium clay at about 21-28m deep. The further test showed that this stiff clay has low sensitivity and high stiffness. The first dense silty sand layer is located below the first stiff to very stiff clay layer providing skin friction and end bearing resistance of pile foundations. The similar variations are also contributed by the second dense and coarse silty sand found at about 45-55 m depth where the pile tip of the building is seated. Table 1 presents the detailed soil condition with the engineering properties.

Bangkok ground water condition is hydrostatic starting from 1.0m below ground surface. As a result of deep well pumping from the aquifers, the piezometric head of Bangkok aquifer reduced and stays constant at about 23m below ground level, as presented in Figure 3, leading to an increase in effective stress and ground subsidance. Despite the drawbacks, this lower piezometric level also results in an easy in bored pile construction having pile tip in the first stiff clay using dry process and dry excavation for basement construction up to the silty clay level without any dewatering or pumping system.

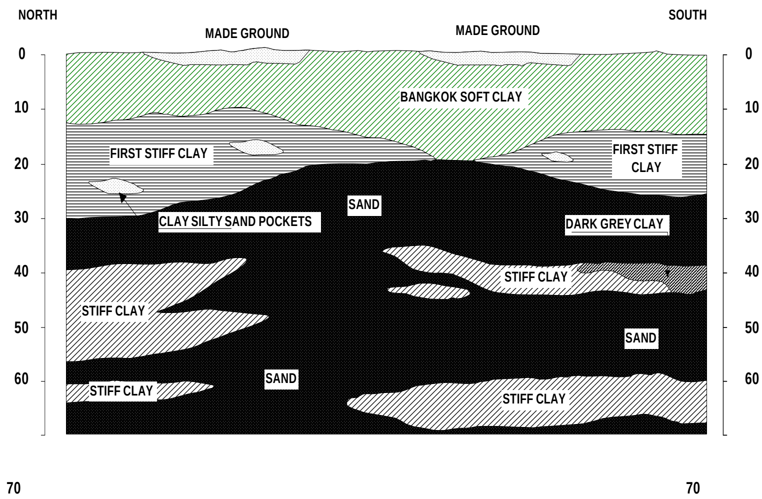

Figure 2. The general subsoils condition (Teparaksa, 1999b) [4]

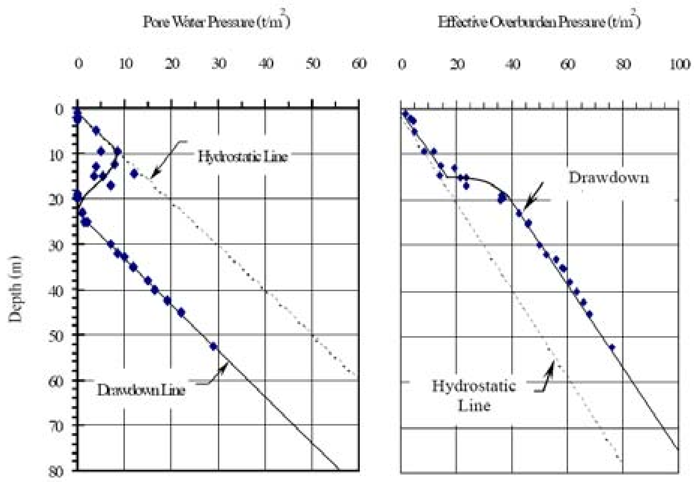

Figure 3. The piezometer level of Bangkok subsoils

Table 1 Soil Conditions and Engineering Properties

Depth (m.)	Soil Description	γt	Su	N	E	E'
0 - 12.5	Soft Clay	16.0	15	-	8750	-
12.5 - 15.0	Medium Stiff Clay	16.5	40	-	18000	-
15.0 - 20.0	Stiff to Very Stiff Silty Clay	19.0	-	12	85000	-
20.0 - 28.5	Hard Clay	20.0	-	35	300000	-
28.5 – 39.0	Dense Silty Sand	20.0	-	40		80000
39.0 – 46.0	Hard Silty Clay	20.0	-	45	-	-
46.0 – 65.0	Very Dense Silty Sand	20.0	-	>50	-	-

Note: γt = Total Unit Weight (kN/m^3)
Su = Undrained Shear Strength (kN/m^2)
N = SPT N-Value (Blows/ft)
E, E' = Undrained and Drained Young's Modulus (kN/m^2)

Project Description

The new basement construction of BOT project is to be a solution to limited car park. The area of excavation is 10790 m^2 approximately with 5m and 10m far from historical palaces, Tewavej palace and Bangkhunphrom palace, accordingly as presented in Figure 4. Both palaces were constructed with brick and bearing wall seated on shallow foundation. Top-down construction method was employed in order to minimize the effect of basement construction to the historical palaces. Due to high construction cost, this method is only used in the restrict area such as subway station of Bangkok MRT project.

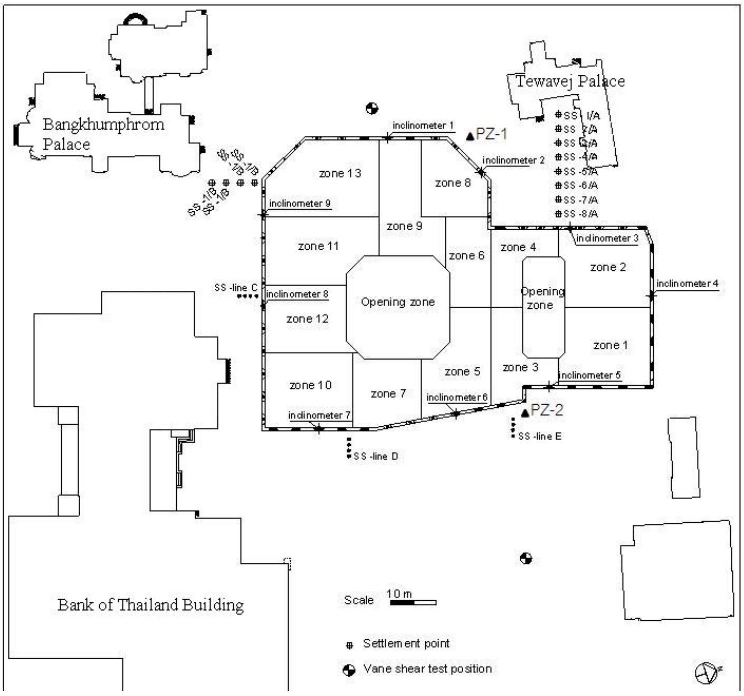

Figure 4. Site of the BOT project

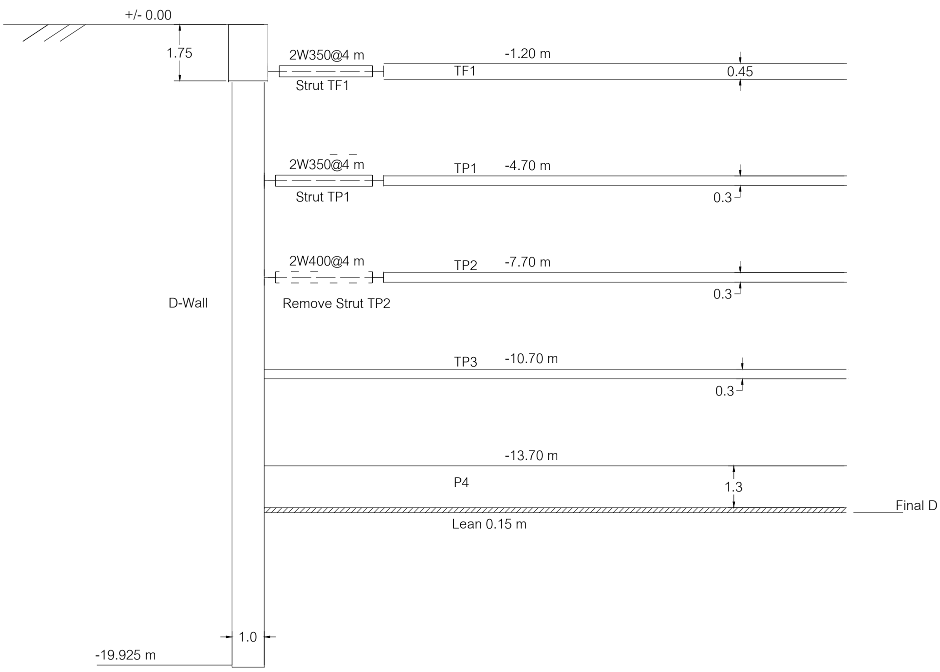

Figure 5. Typical section of underground basement

The diaphragm wall (D-Wall) of 1.0 m. thick and 20 m. deep was designed as the temporary wall for -15.8 m. deep excavation and used as permanent wall at the final stage. Five basement floors consist of F_1 ,P_1 ,P_2 ,P_3 and P_4 floor at -1.20 m., -4.70 m., -7.70 m., -10.70 m., and -13.70 m. depth respectively as shown in Figure 5.

In this case, top-down construction method was started by casting the first basement F_1 at -1.20m, third basement floor at -7.70m, fifth basement floor at -13.70m and mat foundation at -13.70m depth as shown in Figure 5. Loading of the permanent basement floor during construction was transferred through the stanchion at the centerline of the column which was installed into the bored pile during construction of the bored pile. Figure 6 shown the photograph of stanchion installation in the bored pile of 50 m. long seated in the 2nd very dense silty sand layer.

Figure 6. Photograph of stanchion installation in the bored pile

Instrumentation

The head office of BOT was constructed in the large area of more than 10790 m^2; therefore, the excavation area for top-down construction was divided into 13 zones as presented in Figure 4. Two large zone were left opened for excavation works. The excavation at the deeper basement is required to excavate step by step from far corner to the opening zone where the excavated soil was move out of the project area. There was an installation of full set of instrumentation at the palaces on ground surface and at the diaphragm wall to monitor their behavior and for safety reason as shown in Figure 4 and Table 2. The photograph of tiltmeter, inclinometer and vibration sensor installed at the palace and diaphragm wall are presented in Figure 7.

Table 2 Instrumentation at the Palaces and Diaphragm Wall.

Instrumentation	Location	Purpose
Vibration Sensor	At Tewavej palace and Bangkhunphrom palace.	Vibration at the palace
Tiltmeter	At Tewavej palace and Bangkhunphrom palace.	Tilt of the palaces
Ground Surface Settlement point	Ground Surface	Ground Surface Settlement
Inclinometer	In the Diaphragm Wall	Lateral D-Wall movement
Piezometer	Outside the D-Wall	Ground water level

Figure 7(a). Photograph of tiltmeter measuring at Tewavej palace

Figure 7(b). Photograph of inclinometer

Figure 7(c). Photograph of vibrating sensor

Figure 7. Photograph of Instrumentation

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 consists of 8 steps as follows:

1. Excavating to -1.75 m. deep and casting lean concrete.
2. Casting the first permanent basement floor at -1.20 m. (thickness 0.45 m.)
3. Excavating to the third basement floor at -8.10 m. deep and casting lean concrete.
4. Casting the third permanent basement floor at -7.70 m. (thickness 0.30 m.)
5. Excavating to the fifth basement floor (base slab) at -15.60 m. deep and casting lean concrete.
6. Casting the fifth basement floor (base slab) at -13.70 m. (thickness 1.30 m.)
7. Casting the permanent fourth basement floor at -10.70 m. (thickness 0.30 m.)
8. Casting the permanent second basement floor at -4.70 m. (thickness 0.30 m.)

The detail of construction sequence is presented in Figure 8.

The analysis and design of the diaphragm wall for -15.6 m. deep excavation was carried out by Finite Element Method (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) [4]. The value of Young's modulus is also presented in Table 2.

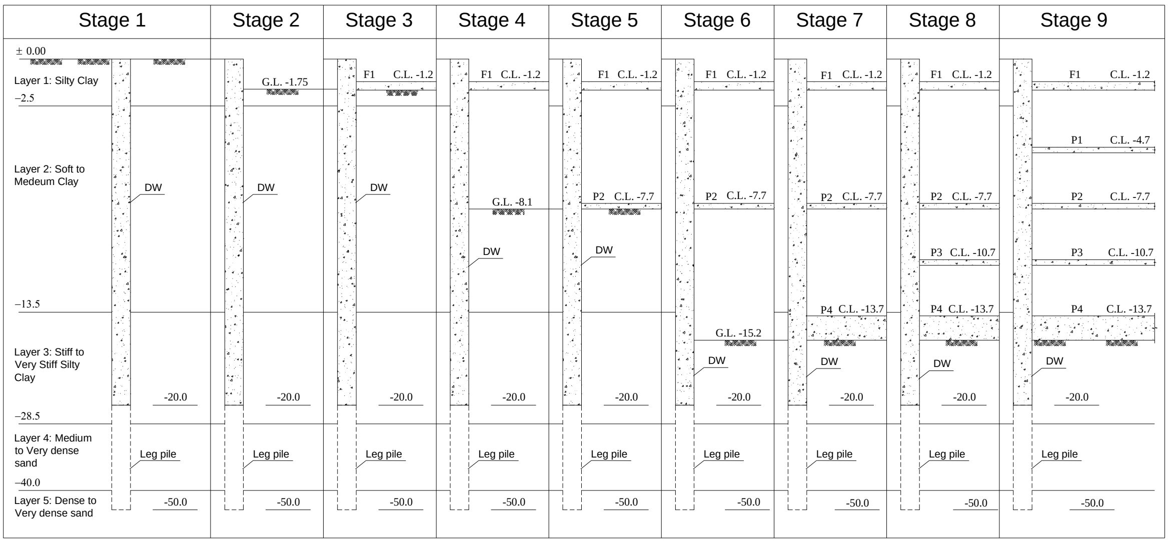

Figure 8. Deatil of construction sequences

The Young's modulus of the clay is depended on the shear strain of the system as shown in Figure 9 (Mair, 1993) [1]. The relationship of the Eu/Su and strain level presented in Figure 10 was the modulus of soft and stiff Bangkok clay based on the results of selfboring pressuremeter test during construction of MRT Subway Blue Line in Bangkok city. Figure 11 and 12 present deformed mesh of the FEM analysis at the final stage of excavation at -15.6 m. deep and after casting the full basement floor respectively.

The result of FEM analysis presents the envelope lateral movement of diaphragm wall (D-wall) at final stage of excavation in the order of 28.2 mm. and maximum ground surface settlement of 23.7 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 Tewavej palace as shown in Table 3. The safety control criteria are also proposed in Table 3.

Table 3 Trigger Level and Safety Control for D-Wall and Tewavej Palace.

Trigger Level	Lateral Movement (mm)	Ground Surface Settlement (mm)	Inclination of Preserved Building	Safety Control
Alarm	19.8	16.6	1:510	Report to designer for rechecking construction sequences.
Alert	22.6	19.0	1:450	Meeting between designer and project owner to in spect and revise construction sequences.
Action	25.4	21.3	1:400	Stop the construction and set a meeting with every parties involved in the project to revise construction sequences.
Maximum	28.2	23.7	1:360	

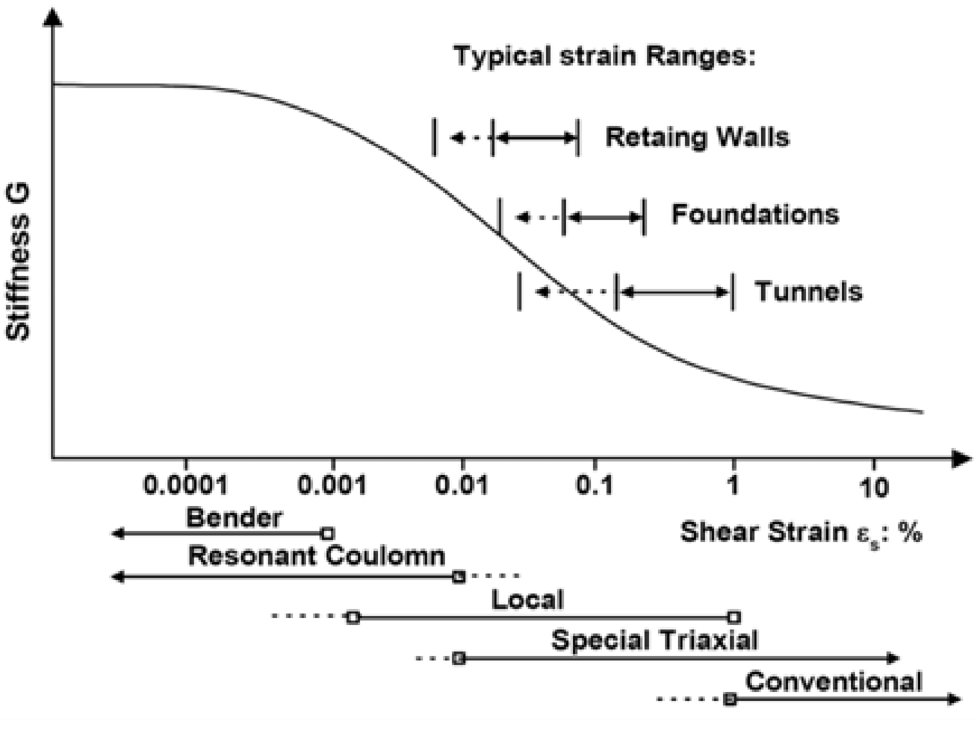

Figure 9. The relationship between modulus and shear strain level

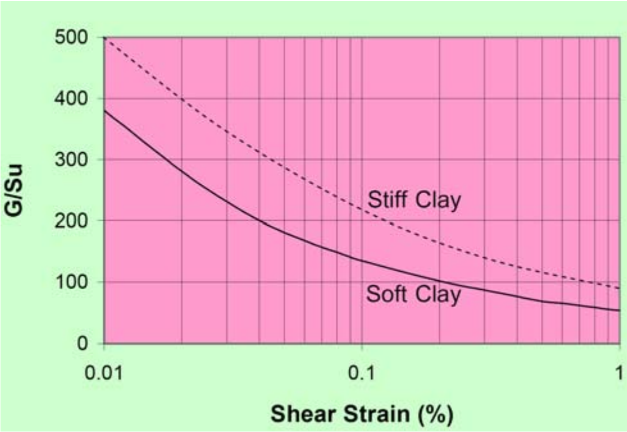

Figure 10. The relationship between modulus and shear strain level of soft and stiff Bangkok clay

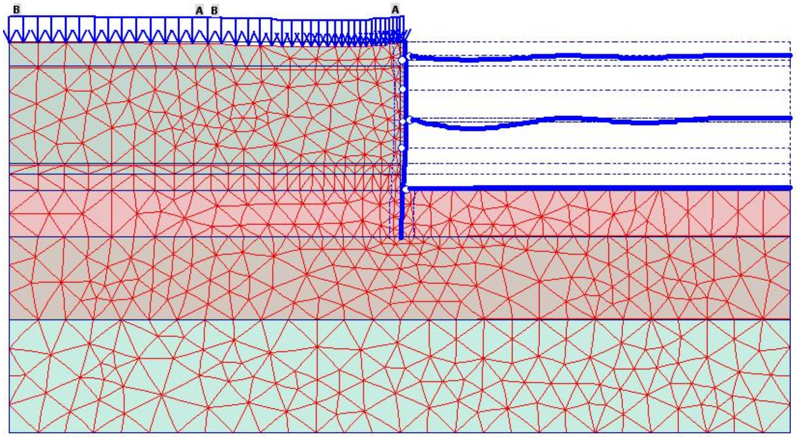

Figure 11. Deformed mesh of FEM analysis at the final stage excavation -15.6 m. depth

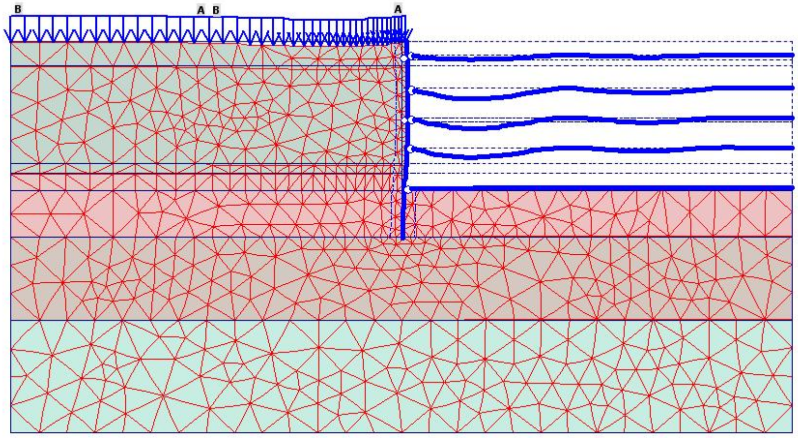

Figure 12. Deformed mesh of FEM analysis after casting the full basement floor

Instrumentation and Performance of Diaphragm Wall

The full set of the instrumentation was proposed to monitor the behavior of the diaphragm wall and surrounding palaces as presented in Table 2 and Figure 4. The results of the piezometer monitoring by pneumatic type in soft clay was constant with hydrostatic pore water pressure of ground surface water at -1.00 m. below ground surface.

The lateral movement of diaphragm wall at all steps of excavation and basement floor casting at inclinometer no. I-3 next to Tewavej Palace has been monitored and is presented in Figure 13. There is also the predicted lateral wall movement analyzed by FEM method in Figure 13. It can be seen that the predicted wall movement by FEM agrees well with field performance. The tiltmeter number T1 and T2 measured at the Tewavej palace is also less than the alarm trigger level as shown in Figure 14. Figure 15 - 19 show the basement construction, Bank of Thailand project. The basement construction of the new head office, Bank of Thailand was completed without any disturbance to both Bangkhunphrom and Tewavej palaces.

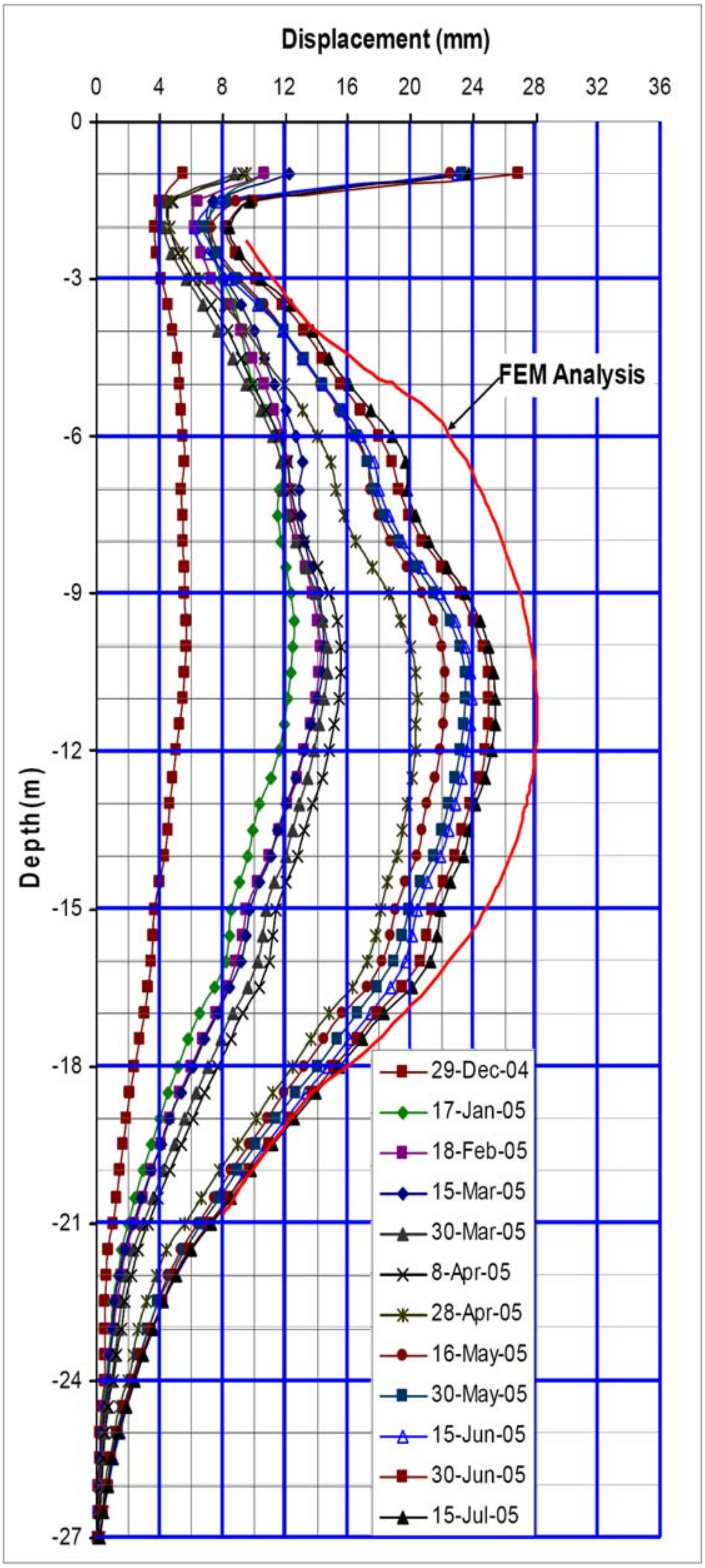

Figure 13. The inclinometer I-3 monitoring result with the predicted maximum movement by FEM analysis

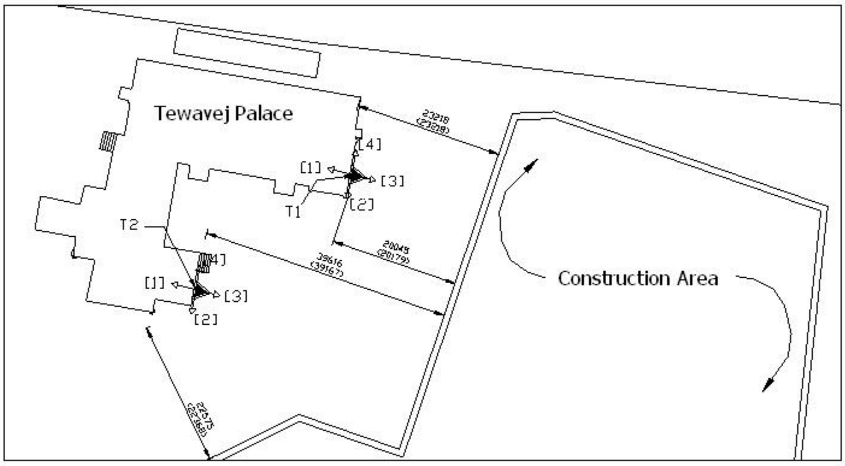

Figure 14(a). Plan of tiltmeter number T1 and T2

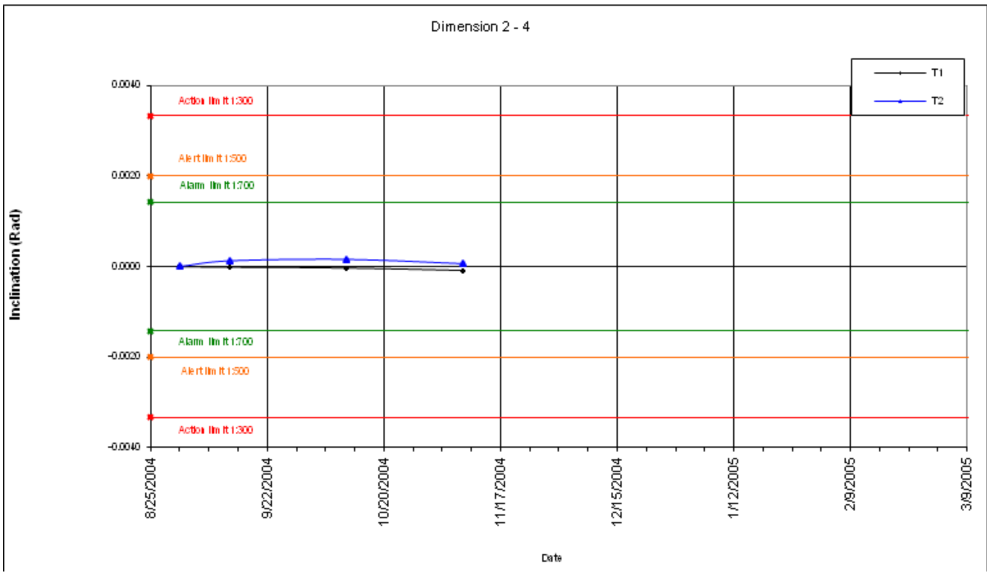

Figure 14(b). Monitoring data of tiltmeter (T1)

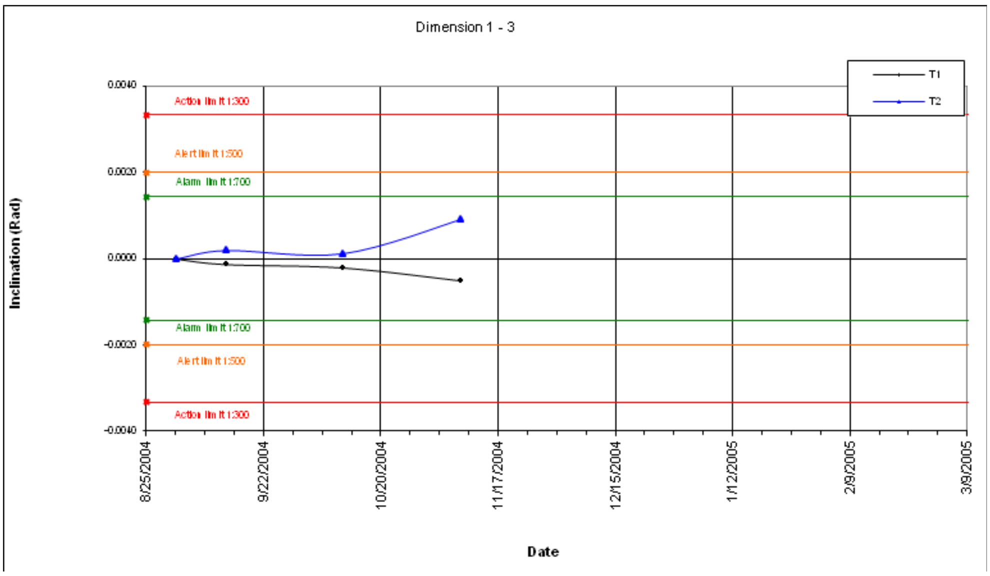

Figure 14(c). Monitoring data of tiltmeter (T2)

Figure 14. Monitoring data and plan of tiltmeter, T1 and T2

Figure 15. Photograph concreting of diaphragm wall

Figure 16. Photograph opening Zone and Tewavej Palace

Figure 17. Photograph of excavated soil at opening area

Figure 18. Photograph of D-wall after excavation

Figure 19. Photograph of base slab construction (fifth basement floor)

Conclusions

The basement of -15.6 m. deep excavation was constructed at the new head office of Bank of Thailand. The deep basement consists of 5 basement floors at -1.20 m., -4.70 m., -7.70 m., -10.70 m. and -13.70 m. depth. The basement constructed area is closed to two palaces, Bangkhunphrom palace and Tewavej palace which is the historical buildings and also located on the Chao Phraya river bank. The top down construction method was used for basement construction. The prediction of diaphragm wall movement and its effect to the palace was carried out by FEM analysis. The fully instrumentation was installed in D-wall, ground surface and the palace to measure the wall behaviour and their effect. The lateral movement of D-wall by means of inclinometer at all stages of construction is compared with FEM prediction. The FEM prediction agrees well with measured values. The deep basement was completed without any disturbance to both palaces.

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