Invited paper

PERFORMANCE OF CONTIGUOUS PILE WALL FOR DEEP EXCAVATION ON CHAO PHRAYA RIVER BANK

Wanchai Teparaksa

Department of Civil Engineering, Faculty of Engineering, Chulalongkorn University, Bangkok,
Thailand, Tel: + 662 252 7178, e-mail: wanchai.te@chula.ac.th

Received Date: July 19, 2011

Abstract

The excellent medical center in Asia, Siriraj Hospital is the largest medical center in Asia is constructed with three basement floors on Chao Phraya River bank and close to the preserved building seated on shallow foundation. The excavation is about -10.85 m. depth below ground surface. The contiguous pile wall was used as the temporary soil protection system and permanent wall with two layers of temporary steel bracing system. The behavior of contiguous pile wall was predicted by Finite Element Method (FEM) with simulation of all construction sequences. The instrument including inclinometer, tiltmeter, piezometer and ground surface settlement were installed in the contiguous pile, preserved building and in the ground, respectively. The performance of the contiguous pile wall was evaluated by instrumentation monitoring compared with FEM analysis and trigger level.

Keywords: Contiguous pile wall, Deep excavation, FEM analysis, Instrumentation, Trigger level

Introduction

The high-rise buildings and infrastructure is increasing in the Bangkok city. The foundation of the heavy infrastructure in Bangkok such as MRT subway station and elevated station of the Airport Rail Link are supported by deep bored pile and barrette system. The foundations of the high-rise building in Bangkok city mostly consists of deep piles foundation with deep excavation. The technology on deep bored pile construction was developed by using polymer based slurry to eliminate soft toe problem and thick cake film along the pile shaft [1,2]. The technique of deep excavation in soft Bangkok clay is recently improved by strengthening the soft clay with SCC pile (Soil Cement Column (SCC) pile) to minimize the horizontal diaphragm wall movement [3]. The application of temporary earth supported wall such as sheet pile wall system by apply preloading system is also become the normal practice for deep excavation work in Bangkok.

The diaphragm wall is normally used as the permanent rigid wall for deep excavation over than 10 m. deep in Bangkok subsoil. The diaphragm wall construction, however, more complicate and required special technique and experience such as trench stability, quality of bentonite slurry and construction sequences. Recently, the use of contiguous pile wall as the permanent rigid wall is increasing. This is because the construction technique is simpler, less construction time, and cheaper than diaphragm wall. However, the limitation is not applied for very deep excavation greater than -14 m. depth due to the limited resisting moment of the pile section.

This paper presents the performance of contiguous pile wall as the permanent basement wall for deep excavation on to Chao Phraya River bank for a very large area —Case of Siriraj Hospital."

The behavior of the contiguous pile wall during excavation is presented and discussed based on the instrumentation monitoring.

Soil Conditions

The general subsoil conditions are presented in Figure 1. The subsoil consists of 13-16 m. thick soft marine clay on top. This clay is sensitive, anisotropic and creep (time dependent stress-strain-strength behavior) susceptible. These characteristics have made the design and construction of deep basement, filled embankments, and tunneling in soft clay difficult. The first stiff to very stiff silty clay layer is encountered below soft clay and medium clay varying from 21 to 28 m. depth. This first stiff silty clay having low sensitivity and high stiffness is appropriate to be the bearing layer for subway tunnels. The first dense silty sand layer located below stiff silty clay layer at 21-28 m. depth contributes to variations in skin friction and mobilization of end bearing resistance of pile foundations constructed with different piling methods (dry and wet processes). The similar variations are also contributed by the second dense and coarse silty sand found at about 45-55 m. depth (Figure 1).

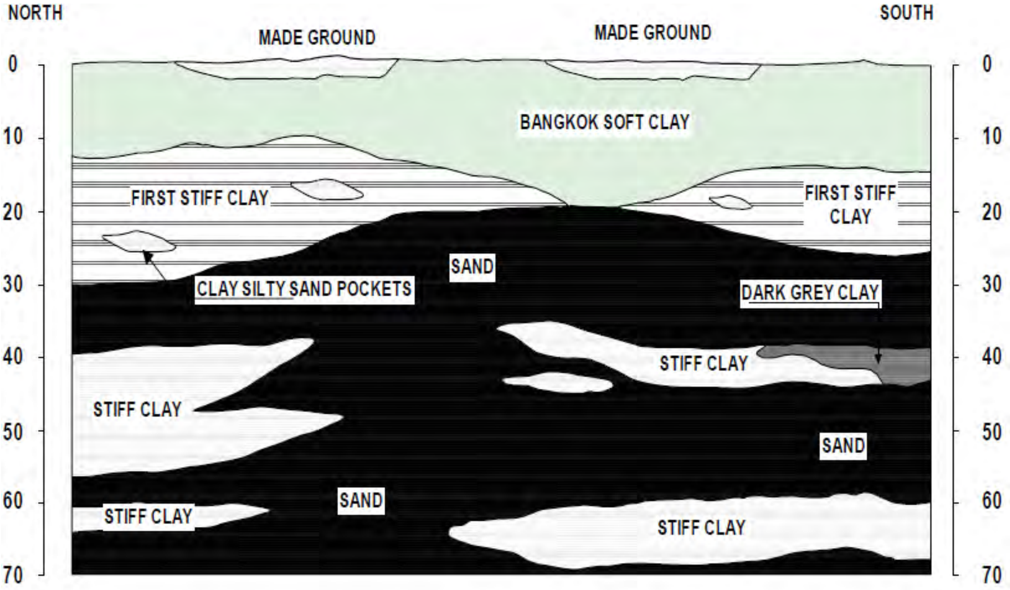


Figure 1. The general subsoil condition [4]

Ten bored holes soil investigation was carried out to 80 m. depth during the foundation design period. The soil conditions consist of 12 m. thick soft dark grey clay layer. This soft clay layer is homogenous without loose sand seam layer which is very important for deep excavation that will create the water leakage and flow linking from Chao Phraya River to the site. The dark grey medium stiff clay is encountered below soft clay to about 15 m. depths. The light brown stiff and very stiff clay layer is found beneath the medium stiff silty clay to about 30 m. depth and reach the first silty sand layer. The typical soil condition and engineering properties is presented in Table 1.

Table 1. Typical Soil Condition and Its Engineering Properties

Soil Layer	Depth (m)	γ_t (kN/m^3)	S_u (kN/m^2)	SPT N-Value (Blows/ft)	E_u , E' (kN/m^2)
Soft Clay	0 - 12	16	17	-	5,950
Medium Stiff Clay	12 - 15	16.5	29	-	10,150

Stiff Silty Clay	15 - 18	20	82	-	82,000
Very Stiff Silty Clay	18 - 30	20	137	-	137,000
Dense Sand	> 30	20	-	25	50,000

Note : γ_t = Total Unit Weight

S_u = Undrained Shear Strength
SPT N-Value = Standard Penetration (SPT) N-Value
E_u = Undrained Young Modulus in Clay Layer
E' = Drained Modulus in Sand Layer

The groundwater condition of the Soft Bangkok Clay is hydrostatic starting from 1.0 m. below ground level. Deep well pumping from the aquifers has led to the under drainage of the soft clay and first stiff clay. The piezometric level of the Bangkok aquifer is reduced and quite constant at about 23 m. below ground surface as shown in Figure 2. This low piezometer level contributes to increase in effective stress, causing ground subsidence. However, the benefit of this lower piezometer level is easy to construct bored pile 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.

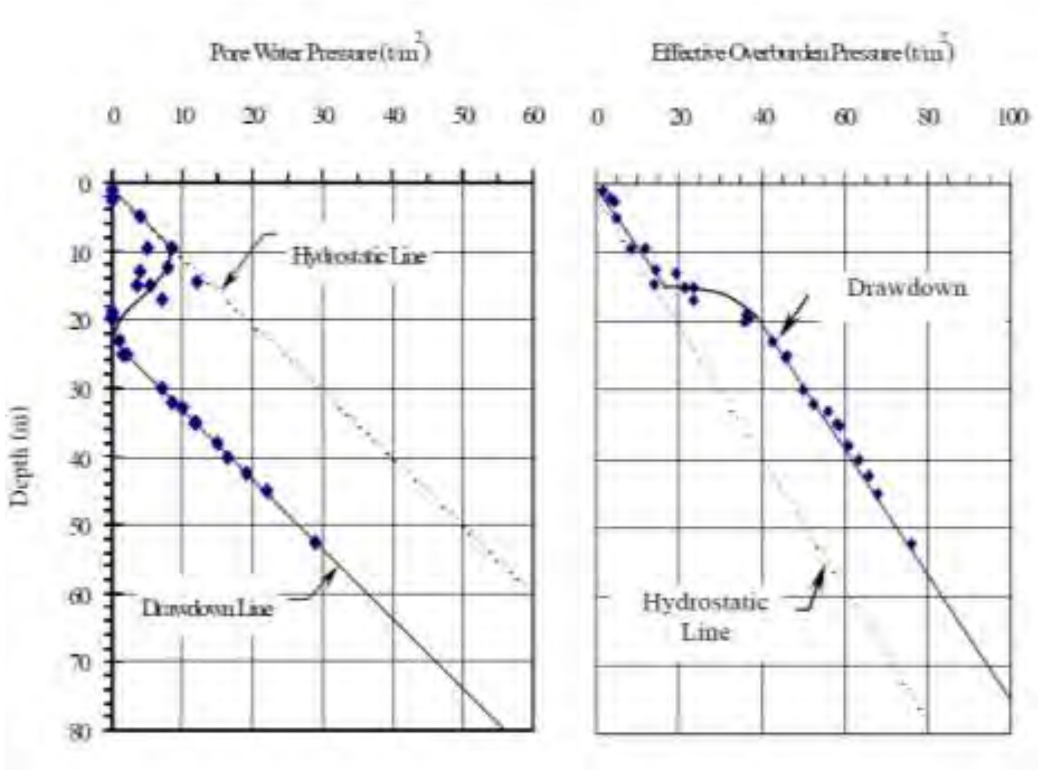


Figure 2. Piezometric level of Bangkok subsoils

Project Description

The excellent medical center in Asia, Siriraj Hospital is the largest medical center in Asia constructed next to the existing Siriraj Hospital, Mahidol University, Prannok area. The Siriraj excellent medical center covers the area of 130 m. wide and 225 m. long and is constructed adjacent to Chao Phraya River and Klong Bangkok Noi. The nearest basement wall is about 8 m. away from Klong Bangkok Noi as shown in Figure 3.

On the southern side of the project, it is next to the car park building, medical student dormitory and medical supplies buildings. These buildings are seated on driven pile foundation seated in the first sand layer. On the east side, there are two preserved buildings seated on the shallow spread footing. On the north side, there are two old wooden buildings seated on shallow spread footing. There are three basement floors at -2.55 m., -5.35 m. and -8.15 m. depth, respectively as shown in Figure 4. The excavation for pile foundation of the building is up to -10.85 m. below ground surface.

The contract information was proposed to use the sheet pile bracing system as the temporary soil supported system. The preliminary design showed that the sheet pile system required largest type of sheet pile (FSV Type IV system) with four layers of full cross bracing. The cost of temporary soil supporting system is too expensive in this very wide excavated area. The newly developed contiguous pile wall as a rigid wall was proposed with only two bracing layers. In order to minimize the cost of steel bracing system, the raking strut at the second bracing layer was proposed as shown in Figure 5. This excavation system is so call the "Island" method by first excavation at the central area and leaving the soil berm on the outer surrounding area and starting construction the foundation and base slab at the center.

Contiguous Pile Wall System and Excavation Work

The contiguous pile wall is the rigid retaining wall system, can be acted as the temporary earth retaining wall during excavation, and can be used as the permanent basement wall of the building. The contiguous pile wall consists of the row of bored pile constructed with its clearance about 100 mm. The joint between each bored pile is the natural soft clay. The natural soft clay will act as the natural impervious water sealant both during excavation and at the permanent stage. Due to the drawdown piezometric level of Bangkok subsoil, the existing real ground water level is at about -23 m. below ground surface as presented in Figure 2 [4]. The natural soft Bangkok clay, therefore, is the saturated soft clay without piezometric level. The contiguous pile wall for the Siriraj excellent medical center consists of the row of 1.0 m. diameter bored pile with clearance of 100 mm. between each bored pile as shown in Figure 6. Each bored pile acted as the individual pile for resisting lateral earth pressure of 1.1 m. width. The contiguous pile wall was constructed as same as normal bored pile but using dry process technique without polymer slurry. This is because the contiguous pile wall was designed with 20 m. long in which is higher than real piezometric level of -23 m. depth. The construction of contiguous pile started with driving steel casing with inner diameter equal to 1.00 m. and 14 m. long to protect the holes collapse in upper soft clay. The casing is normally about 30 m. thick and driven by vibro-hammer technique. The casing have to be driven continuously for 5 – 6 numbers, then the bored pile is excavated not continuous by excavating one and waive for 2 piles and the construction return back again. The bored pile excavation is normally excavated by auger method in soft clay and bucket method in stiff clay. The reinforcement cage is installed before casting the concrete without tremie. The steel casing is then removed. After removal of the steel casing, the diameter of the bored pile in the steel casing zone is larger than 1.0 m. to be 1.06 m. and will be touch to the next contiguous pile as shown in Figure 6. In the final stage, the contiguous pile at the upper portion 14 m. long is touched together look like a contiguous row of the bored pile. Figure 7 presents the photograph during excavation and construction as well as after completion.

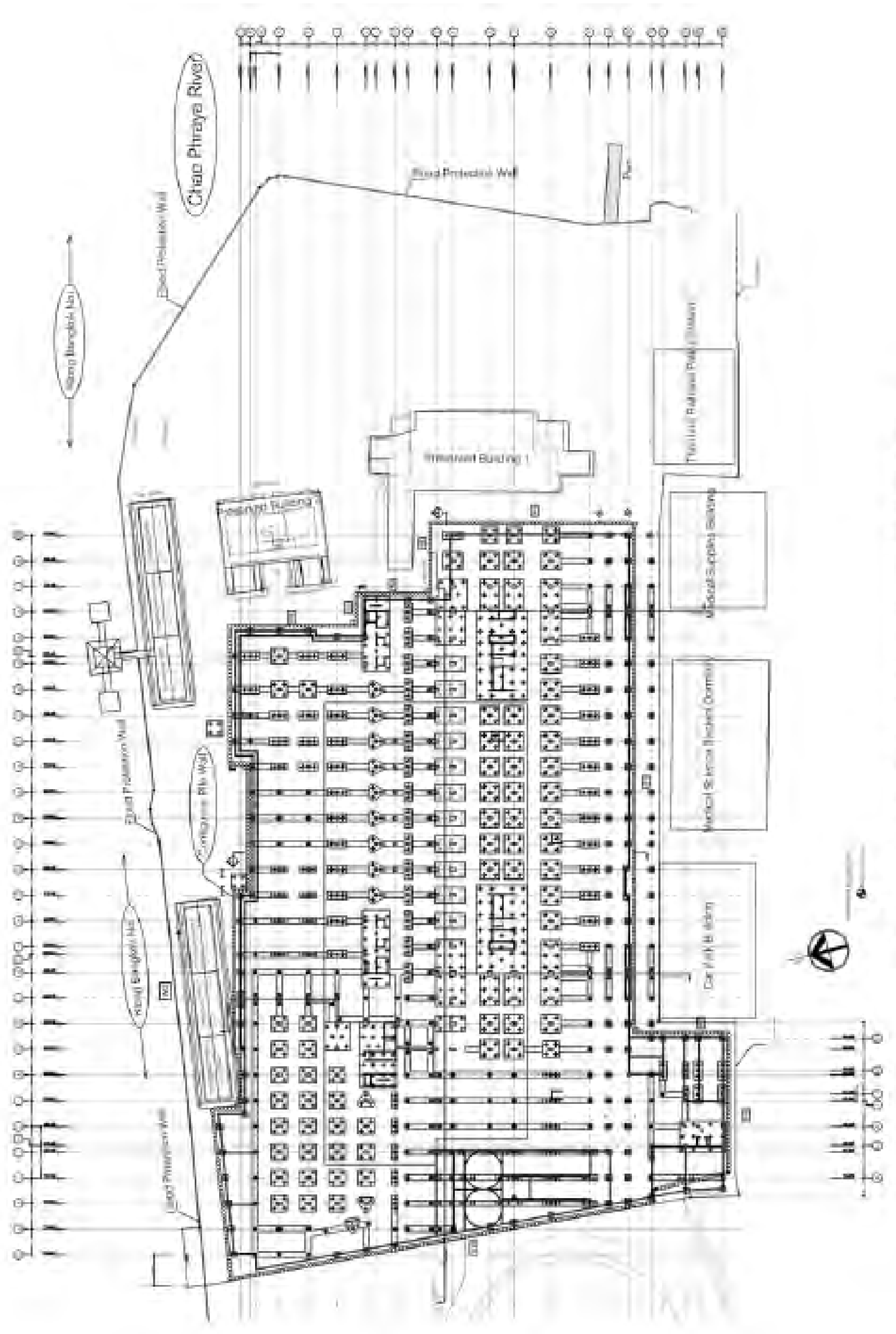


Figure 3. Layout of Siriraj Excellent Medical Center.

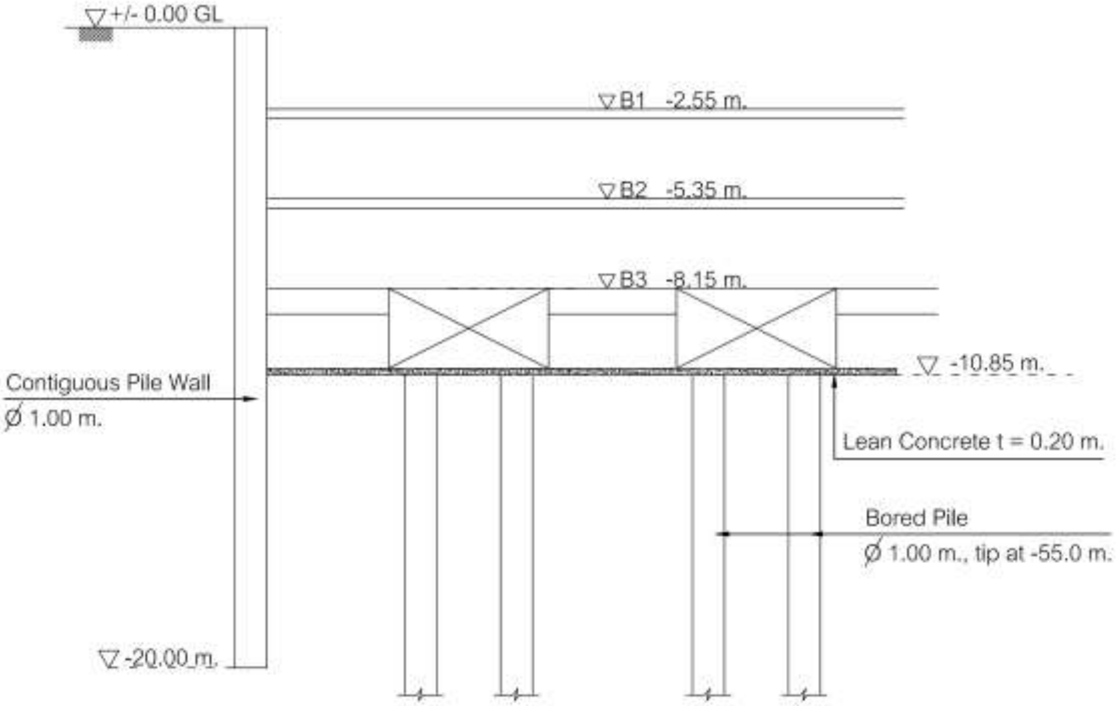


Figure 4. Typical section of basement floor

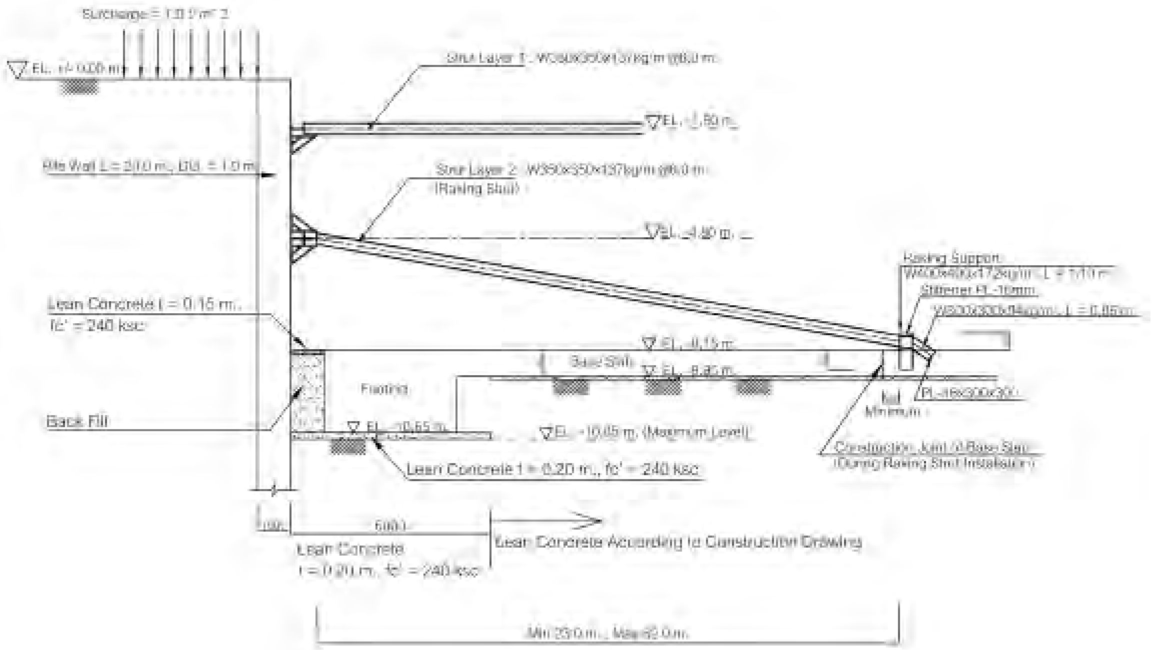
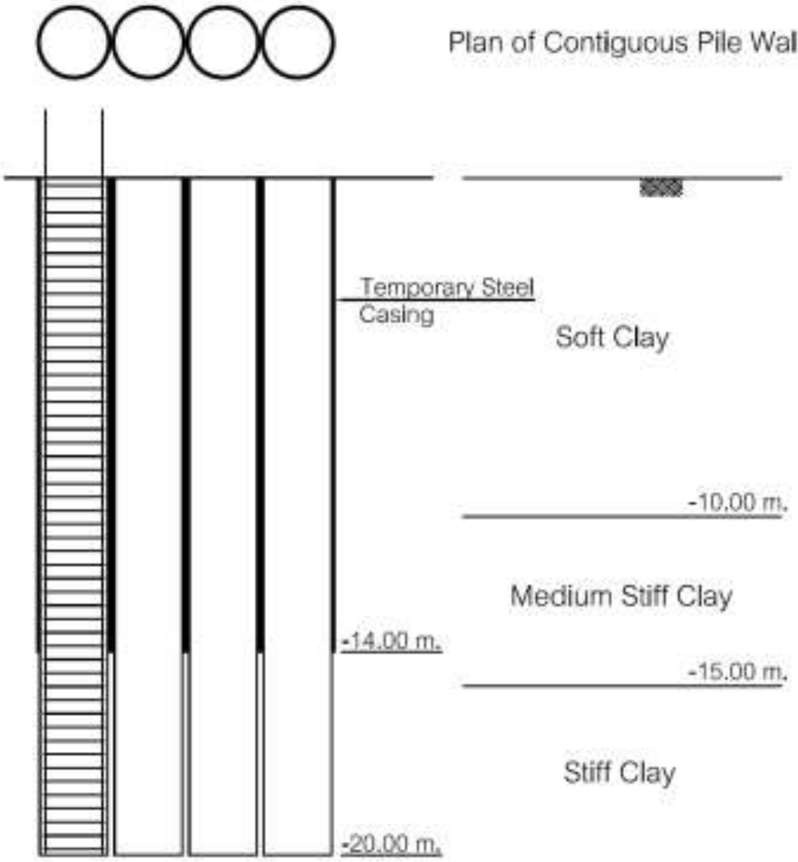
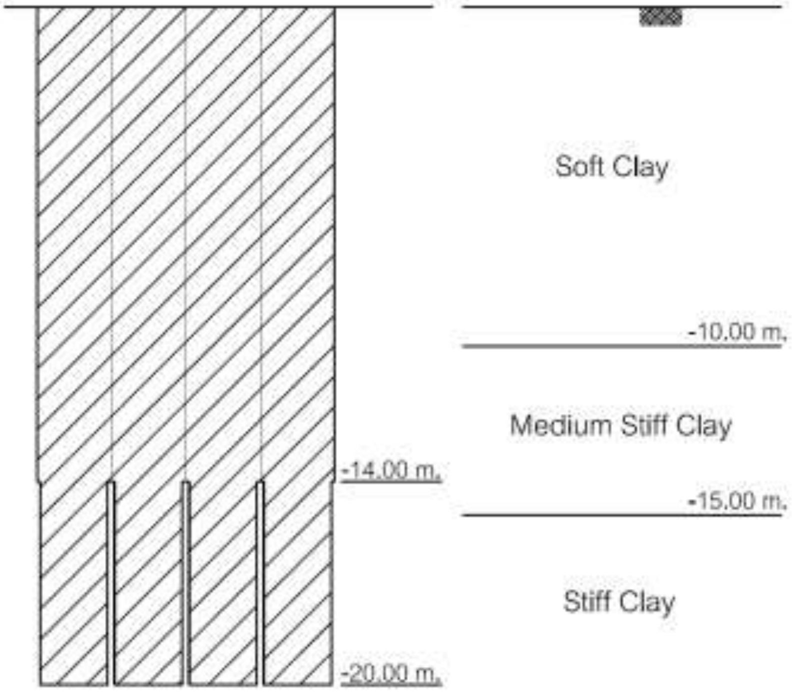


Figure 5. Typical cross section of pile wall and bracing system



Section of Contiguous Pile during Construction



Section of Completed Contiguous Pile Wall

Figure 6. Contiguous pile wall for Siriraj medical center

Figure 7. Photograph of pile wall construction

The contiguous pile wall is the very simple bored pile constructed by dry process technique. The difficulty is how to control the position of the pile. Because of there is no guide wall to control the position. The position of pile wall is controlled by installing the continuous casings. The location of the reinforcement is also quite difficult to control, because it might be rotated or twisted during withdrawal of the steel casing.

Analysis of Contiguous Pile Wall and Design of Excavation System

The basement construction cover the area of 130 x 225 m. required an excellent planning not only efficiency of the excavation system, but also the budget. There are two constraints which are excavation next to Chao Phraya River and the wide area of excavation work. The contiguous pile wall is proved to be the cheapest rigid wall because the construction of contiguous pile is so simple and faster. Therefore, the contiguous pile wall was designed to use as temporary basement wall for the Siriraj excellent medical center. The critical issue is concerning the leakage of the water from Chao Phraya River which is about 8 m. away from contiguous pile wall. The natural soft clay between each contiguous pile wall is acted as the impervious clay layer with coefficient of permeability less than 1 x 10^{-7} cm/sec. The shear resistance of soft clay and arching effect of each contiguous pile are the main reason to whole the contiguous pile becomes the rigid wall.

The bracing system is the first requirement of the rigid wall during excavation. The contractor tried to create the idea of open cut to -10.85 m. without temporary bracing. After fully considering the rigid wall system and lateral movement of soil and contiguous pile wall, the simple open cut system can not be performed. In order to control the budget and engineering performance of the system, two bracing layers were designed with upper layer be full cross bracing while the lower layer be raking bracing system as presented in schematic in Figure 5. This excavation is so call ―the island system‖

The bracing system of this approach can be save cost of bracing about 40% compared to cross bracing system. This island excavation system can be accelerated the excavation work below the upper bracing as same as the open cut system. After completion of the foundation and base slab in the central area, the raking strut system can be carried out. During excavation and installation of the raking strut, the upper basement construction and main building of about 80% of the area can be constructed in advance.

The analysis and design of the contiguous pile wall for 10.85 m. deep excavation was carried out by Finite Element Method (FEM). The construction sequence was also simulated in the FEM analysis. 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 = 350 and 1000 for soft clay and stiff clay, respectively [4]. The relationship of the Eu/Su and strain level presented in Figure 8 was based on the results of self boring pressuremeter test during construction of MRT Subway Blue Line which is similar to the relationship proposed by Menzies [5]. Figure 9 presents deformed mesh of the FEM analysis. The results of the analysis at each step of excavation, bracing, casting base slab, removing strut, casting basement floor is presented in Table2. It can be seen that the maximum lateral deflection of the contiguous pile wall will be about 49.4 mm. This value is set as the trigger level to control contiguous pile wall movement as well as for the construction supervision as presented in Table 3.

Figure 10 presents the bending moment diagram of each contiguous pile at all steps of construction as well as the reinforcement envelope. Based on the bending moment envelope, the contiguous pile can be arranged according to actual bending moment as shown in Figure 11. It can be seen that the reinforcement of the contiguous pile is unsymmetry according to the real bending moment envelope.

Figure 8. The relationship of the Eu/Su and strain level

Table 2. Results of FEM Analysis of Contiguous Pile Wall

Construction Step	Pile Wall			Strut Force (t/m)	
	Lateral Movement (mm)	Bending Moment (t-m/m)	Shear Force (t/m)	F1 EL -1.5	F2 EL -4.8
1. Excavation to EL. -2.00 m.	38.90	35.96	12.47	-	-
2. Install cross strut F1 (EL. -1.5) and preload 30 % then excavate with embankment to EL. -6.5 m.	33.72	65.54	22.20	23.06	-
3. Excavation with embankment to EL. -10.85 m. (for inner area)	36.31	71.13	25.02	26.32	-
4. Casting base slab (top EL. -8.15) for inner area & install raking strut F2 from top of base slab to EL. -4.80 m.	40.17	95.92	30.01	27.59	2.13
5. Excavate soil and leave embankment adjacent to pile wall	44.91	114.26	38.71	26.34	11.07
6. Remove embankment and casting lean concrete thickness = 0.2 m. fc‘ = 240 ksc at EL. -10.85 adjacent to pile wall	45.47	115.18	40.00	24.74	20.38
7. Casting base slab (top EL. -8.15) & retaining wall to EL. -5.35 & casting slab B2 (top EL. -5.35) then remove raking strut F2 (EL. -4.8)	49.41	109.87	37.42	30.08	-
8. Casting retaining wall EL. -2.00 & casting slab B1 (top EL. -2.55) then remove cross strut F1 (EL. -1.5)	49.05	89.75	36.23	-	-

Table 3. Trigger Level and Safety Control for Contiguous Pile Wall

Trigger Level	Lateral Movement (mm)	Ground Surface Settlement (mm)	Inclination of Preserved Building	Safety Control
Alarm	34.6	25.1	1:510	Report to designer for rechecking construction sequences.
Alert	39.5	28.7	1:450	Meeting between designer and project owner to inspect and revise construction sequences.
Action	44.5	32.2	1:400	Stop the construction and set a meeting with every parties involved in the project to revise construction sequences.
Maximum	49.41	35.83	1:360	

Instrumentation and Performance of Contiguous Pile Wall

The Siriraj Excellent medical center is constructed next to the preserved building seated on the shallow spread foundation and next to the Chao Phraya River. The instrumentation was designed to check the performance and behavior of the contiguous pile wall as well as the status of the surrounding buildings. The detail and the plan of instrumentation are presented in Table 4 and Figure 13, respectively.

Table 4. Instrumentation in Siriraj Excellent Medical Center Project

Instrumentation	Purpose	Location
Inclinometer	Measure pile wall lateral movement.	In the contiguous pile.
Ground surface settlement point	Ground surface settlement	Ground surface behind the contiguous pile wall.
Tiltmeter	Tilt of the preserved building.	Preserved building.
Piezometer	Pore water pressure	In soil behind the contiguous pile wall.

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 loading on pressure gauges to measure the strut force were also installed in the first layer of strut as shown in Figure 13. The pressure gauge reading showed that the axial force in the strut were in the order of 35-65 tons/ line of strut. The inclinometer readings throughout all basement construction sequences at inclinometer No. I2, I3 and I4 are presented in Figure 14. It can be seen that the lateral wall movement is in the order of 39 – 53 mm. which is a little higher than the predicted trigger level. The tiltmeter reading of the preserved building is presented in Figure 15. It can be seen that the tilt of the preserved building is still in the allowable limit of 1/500. Figure 16 presents the photograph of the basement construction by means of the contiguous pile wall.

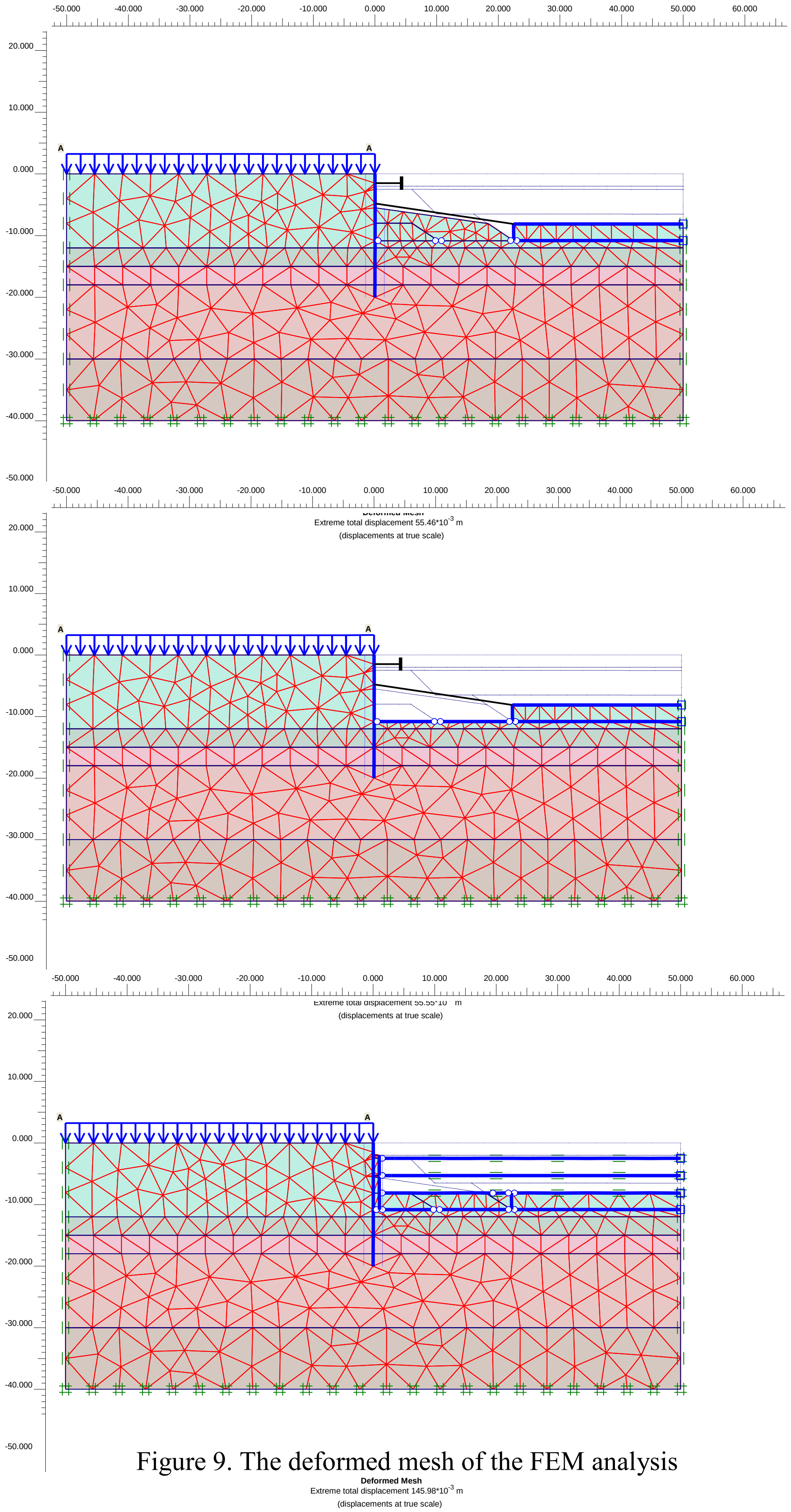


Figure 9. The deformed mesh of the FEM analysis

Pile Wall Diameter 1000 mm.
Internal Force Induced in Pile Wall

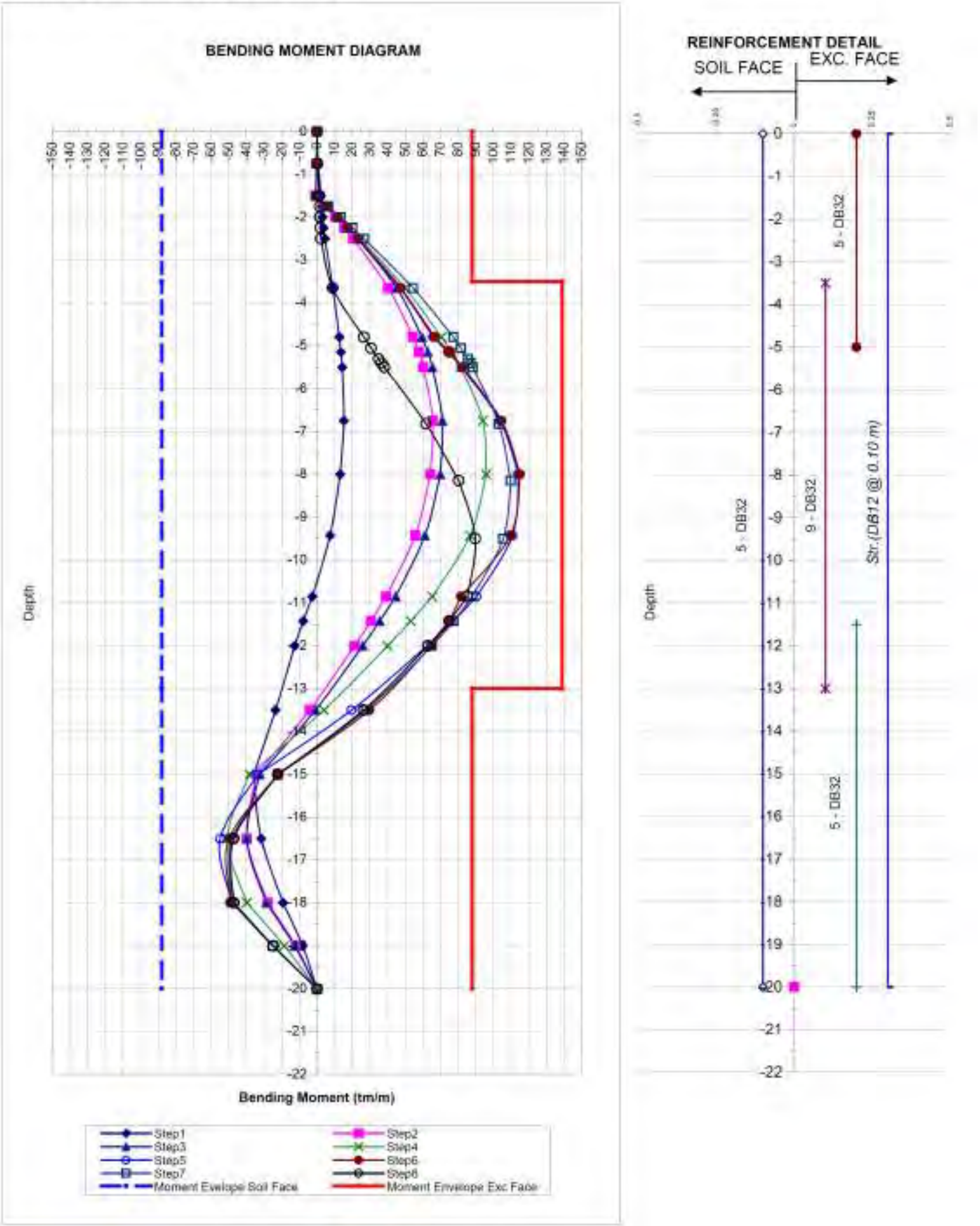


Figure 10. The bending moment diagram and moment envelope of contiguous pile

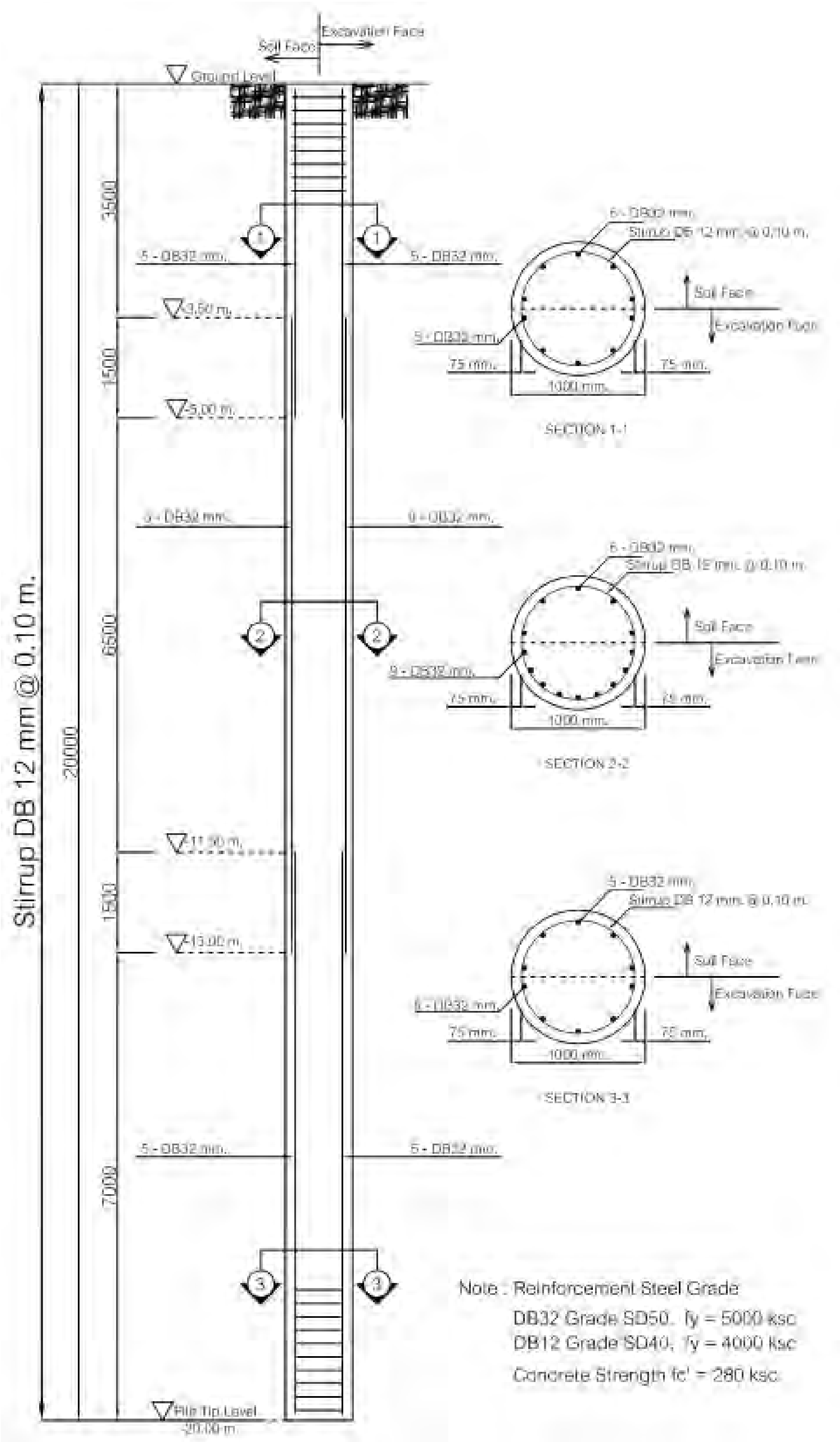


Figure 11. The reinforcement of contiguous pile

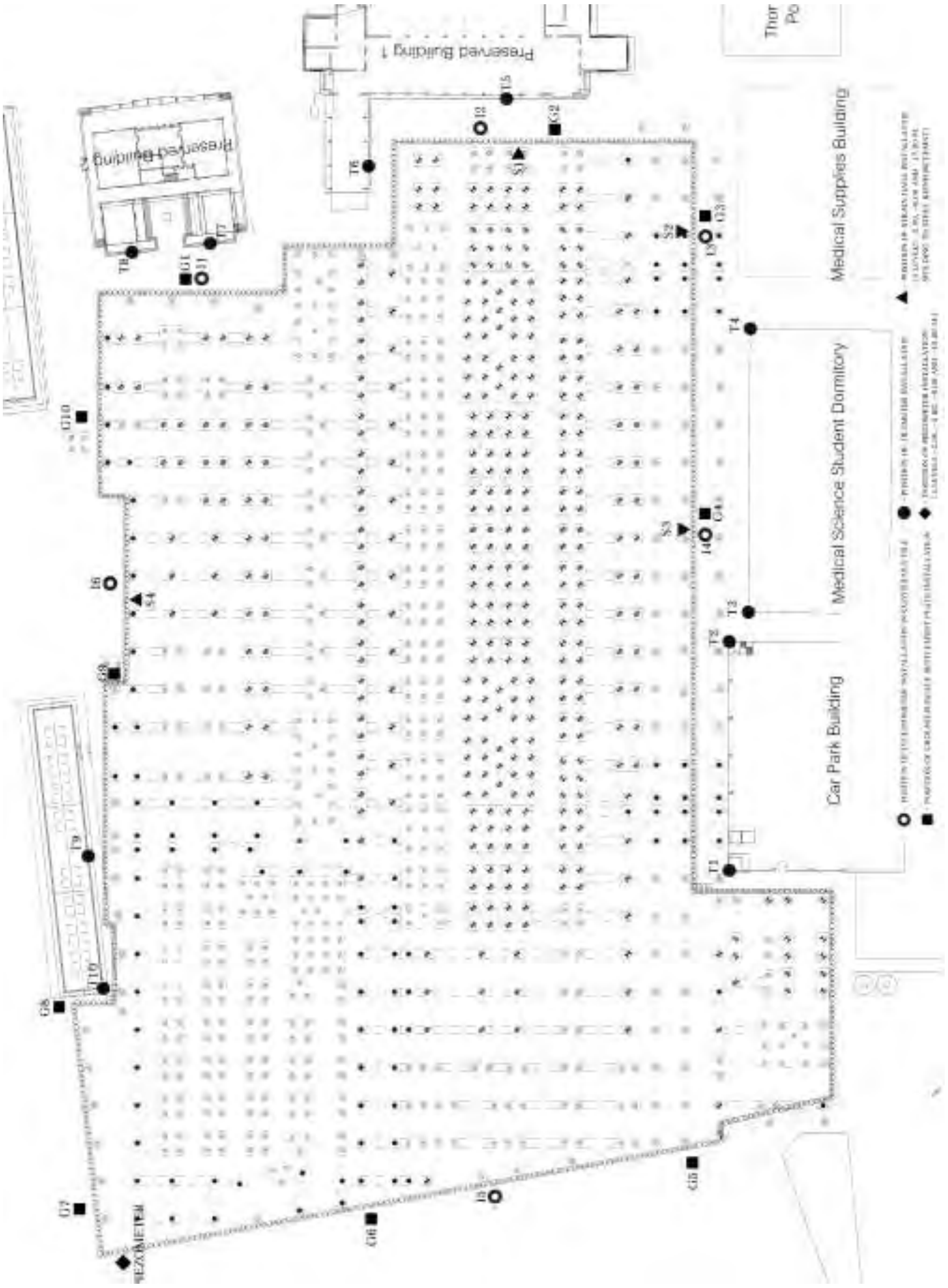


Figure 12 (a). Plan of instrumentation

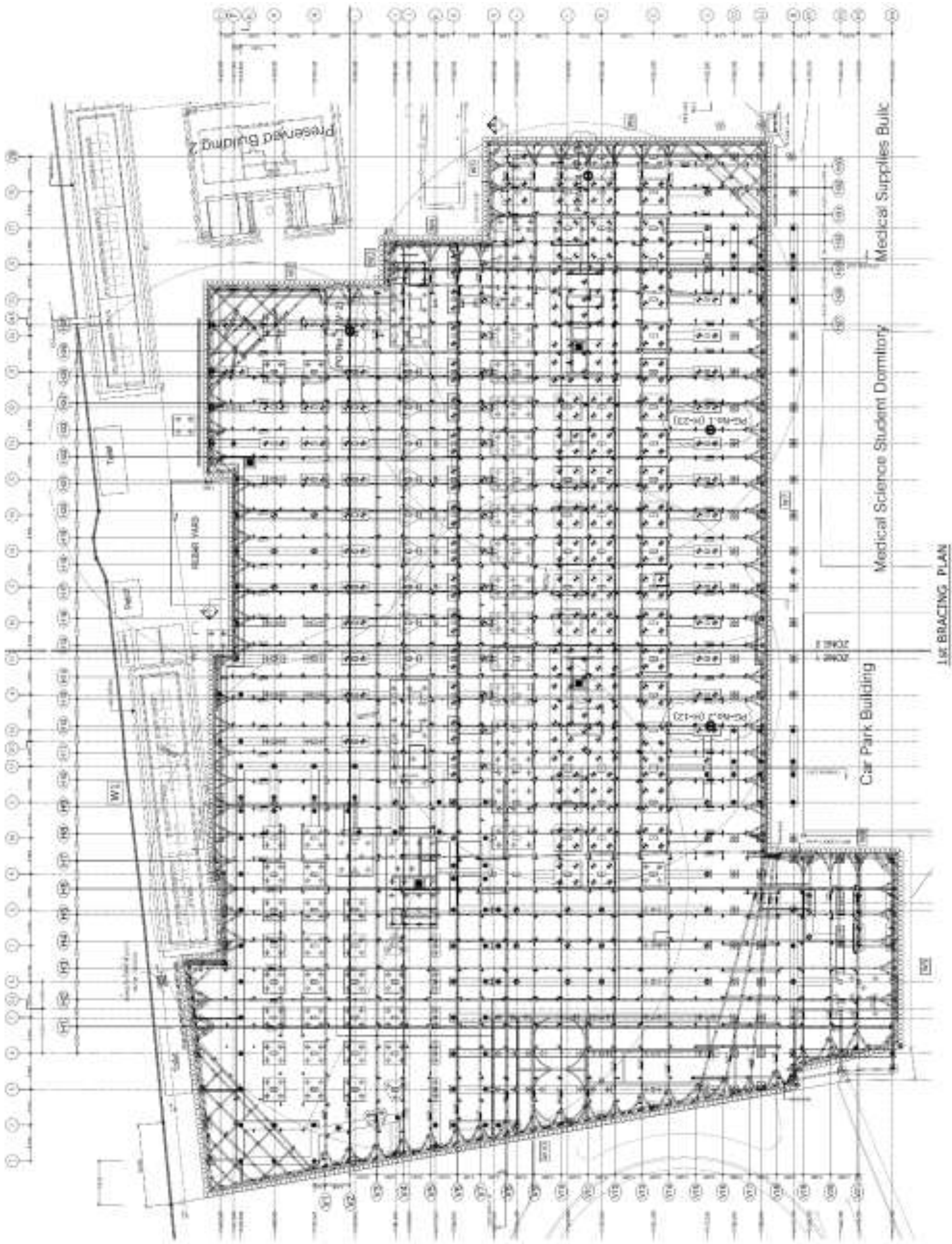


Figure 12 (b). Plan of pressure gauge

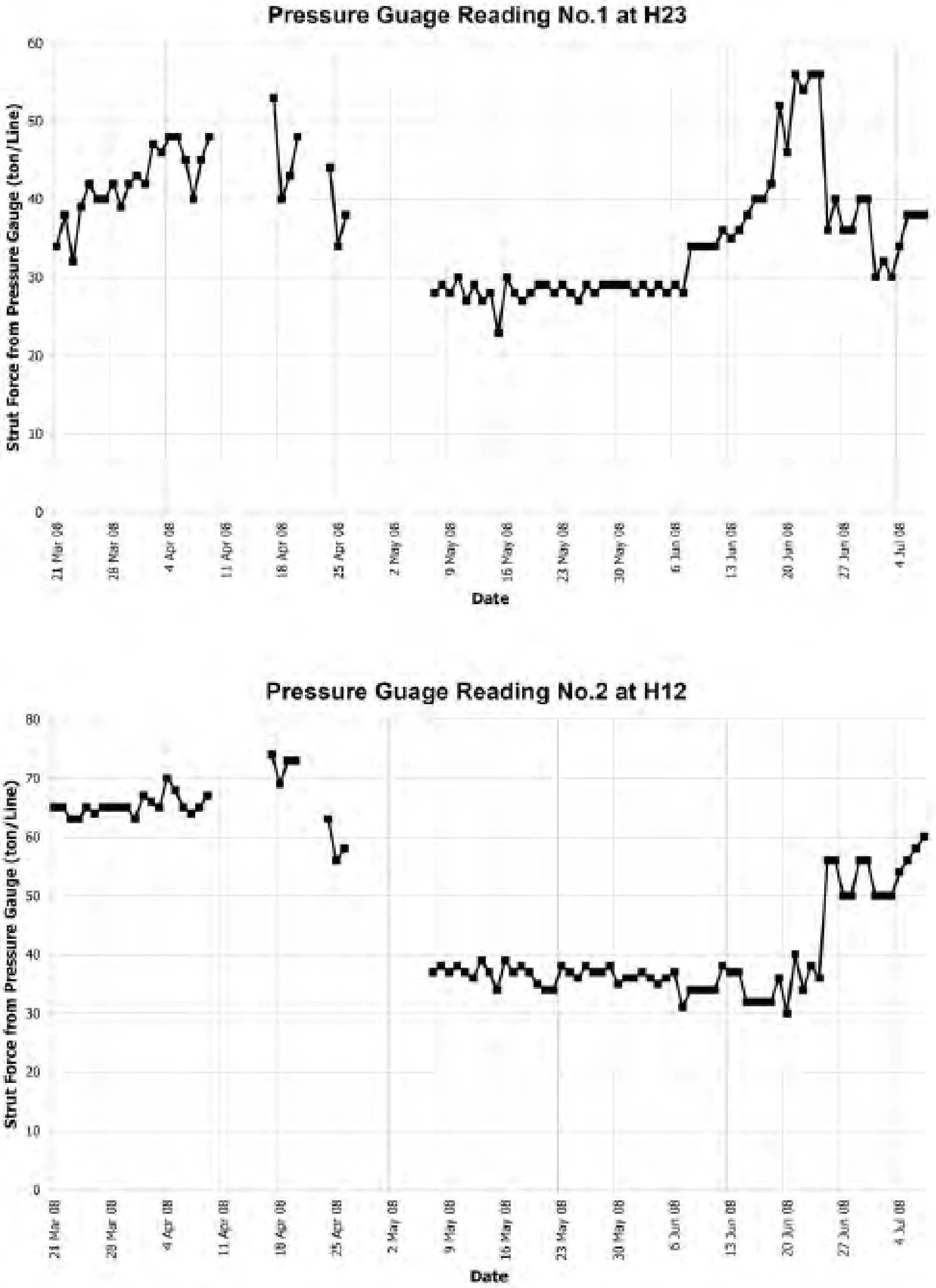
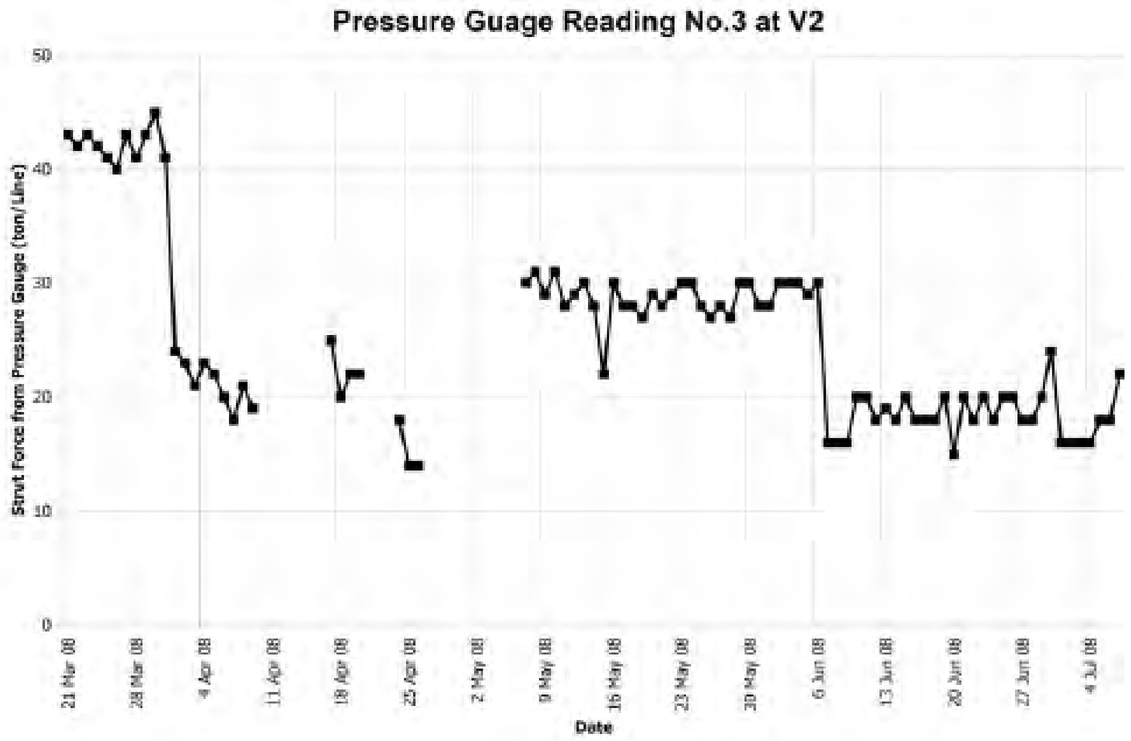


Figure 13 (a). The Pressure Gauge Monitoring Result of Pressure Gauge No.1 (H-23) and No.2 (H-12)


Pressure Guage Reading No.3 at V2

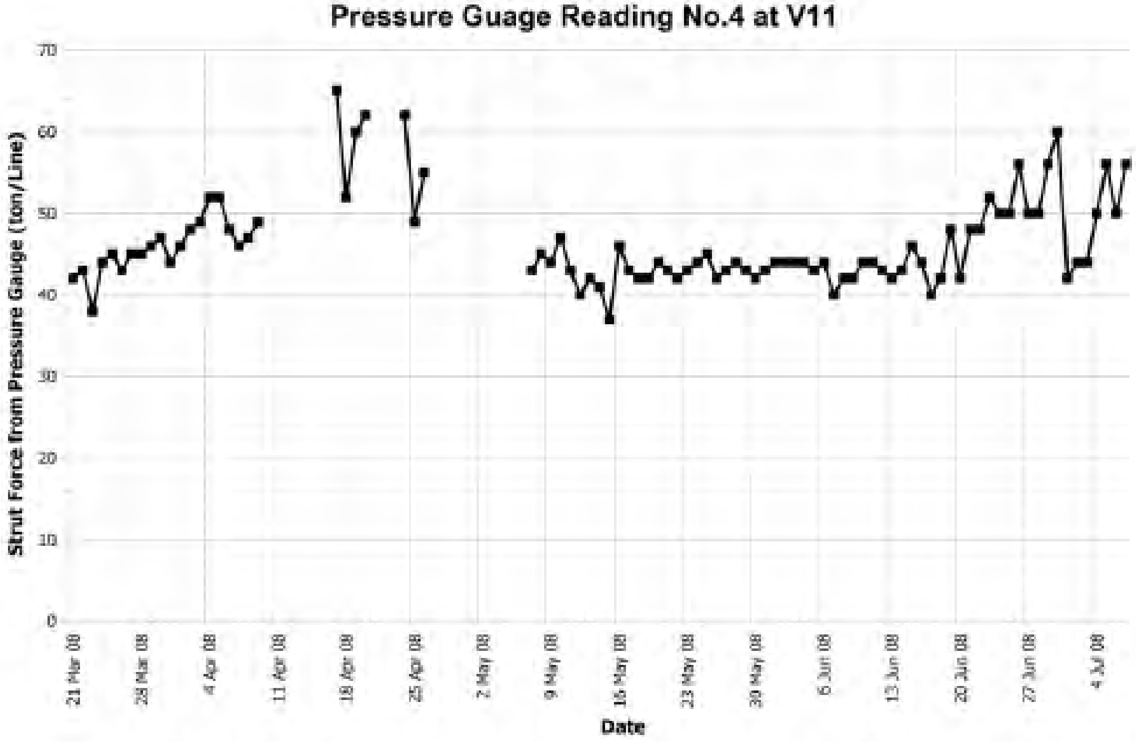

Pressure Guage Reading No.4 at V11

Figure 13 (b). The Pressure Gauge Monitoring Result of Pressure Gauge No.3 (V-2) and No.4 (V-11)

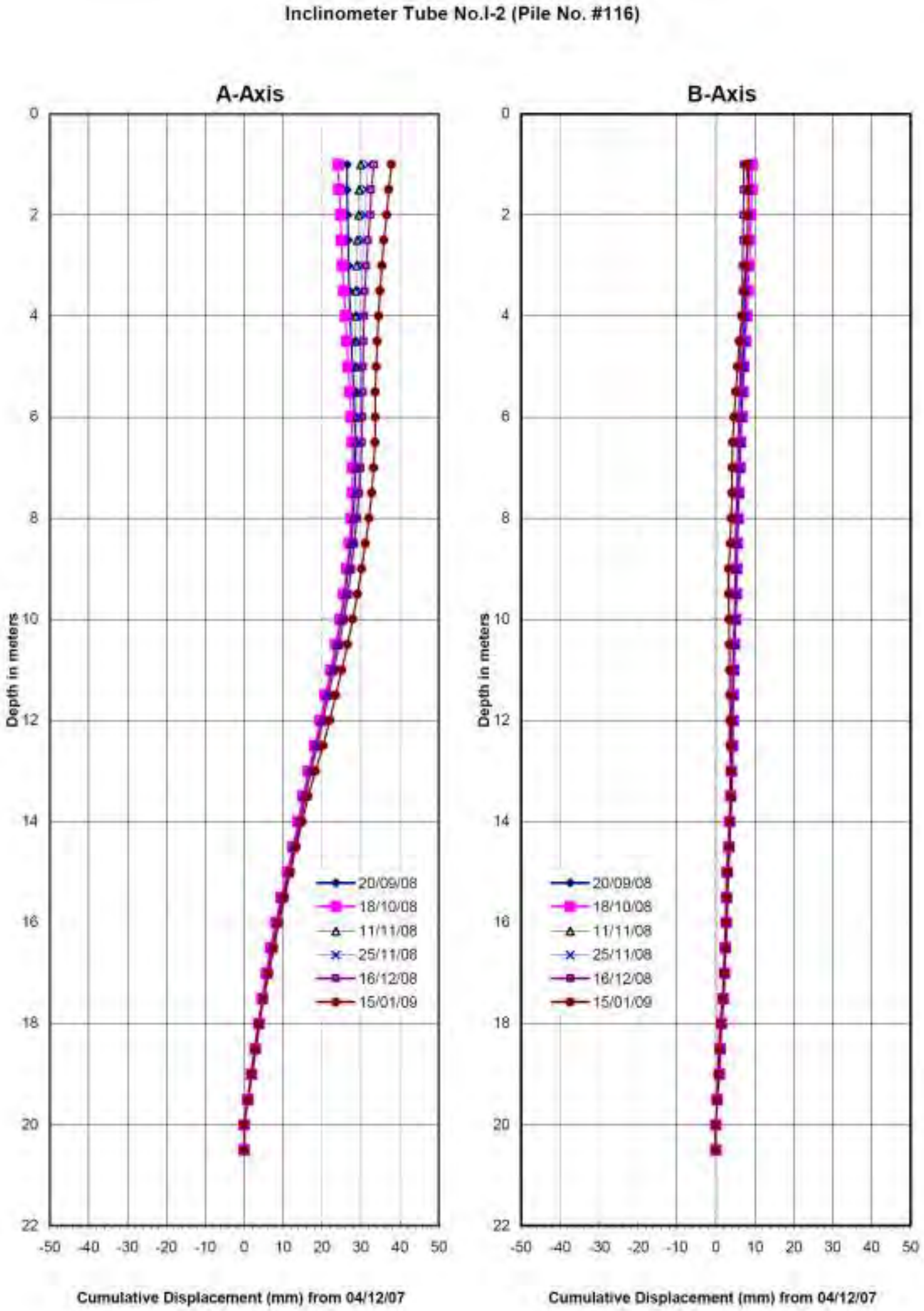


Figure 14 (a). The inclinometer monitoring result of inclinometer No. I-2

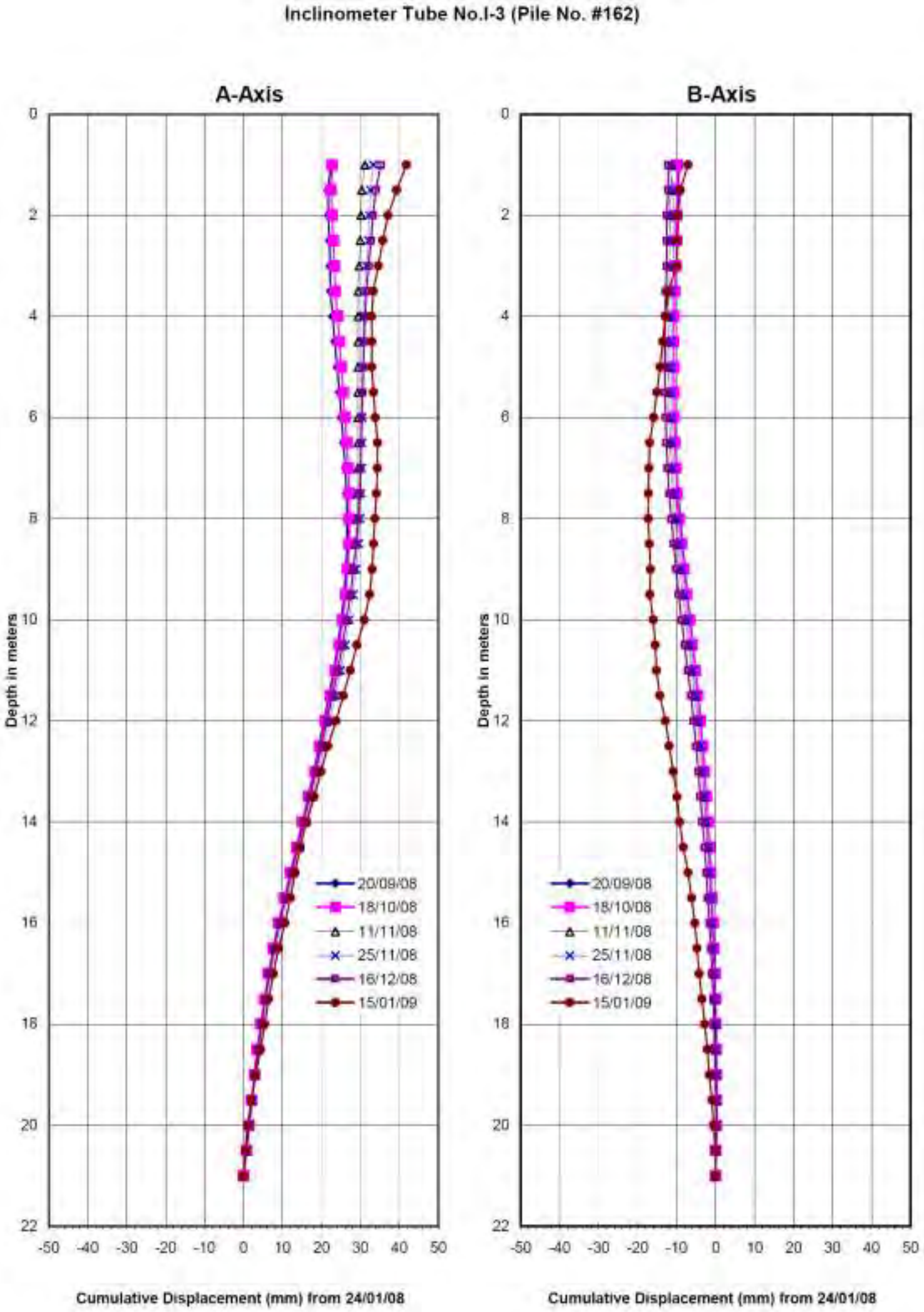


Figure 14 (b). The inclinometer monitoring result of inclinometer No. I-3

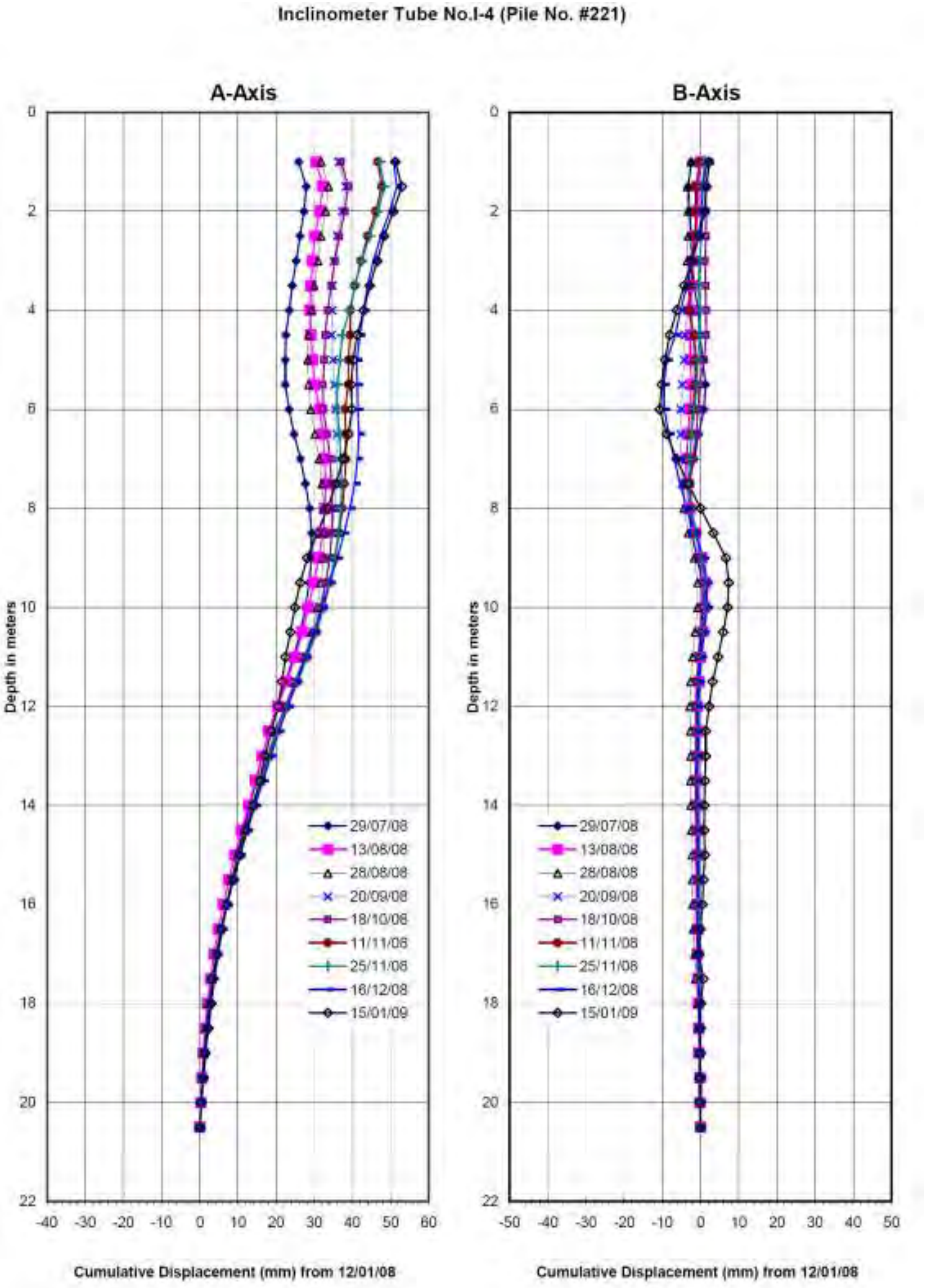


Figure 14 (c). The inclinometer monitoring result of inclinometer No. I-4

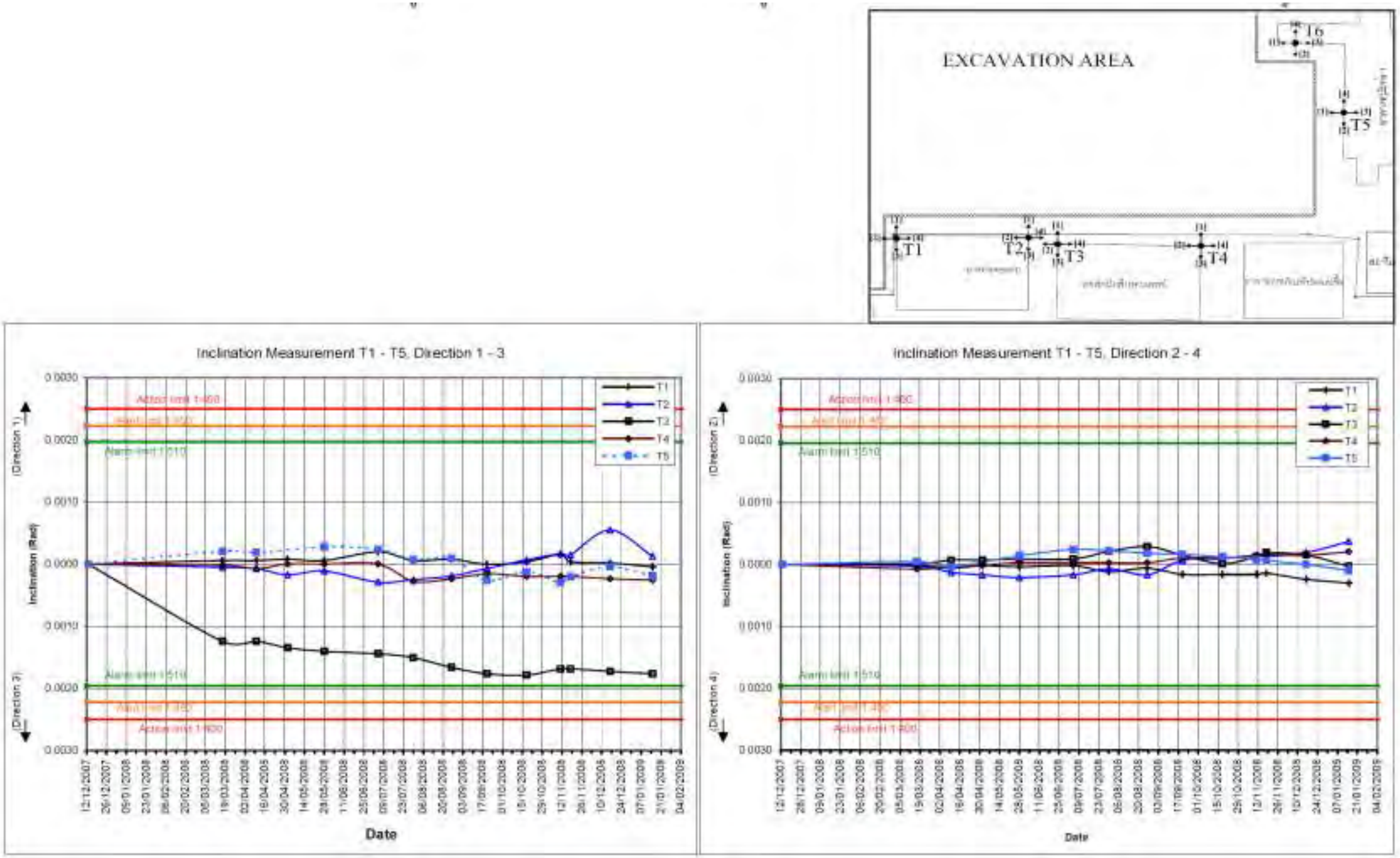


Figure 15 (a). The tiltmeter monitoring result of tiltmeter No. T1 – T5

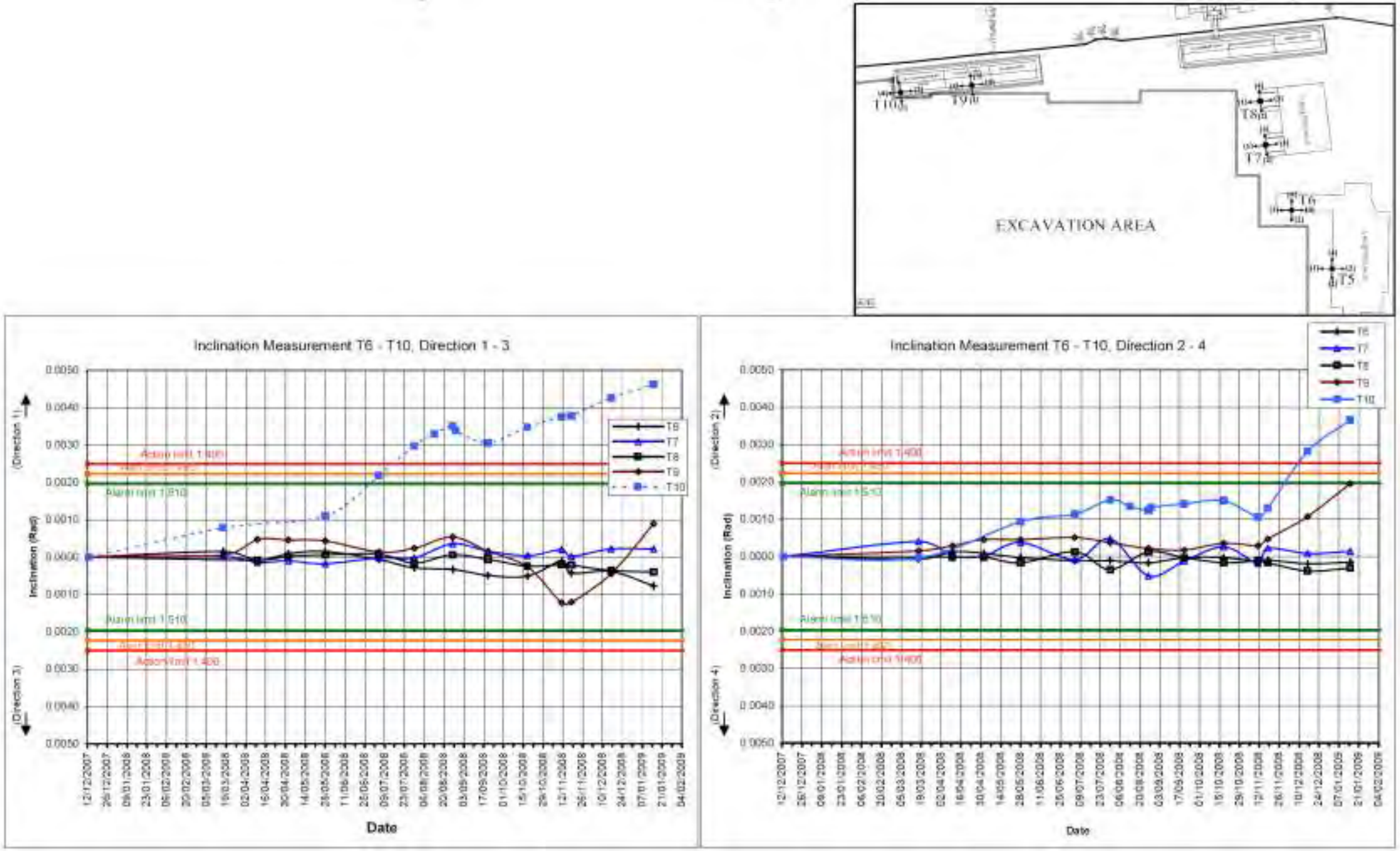


Figure 15 (b). The tiltmeter monitoring result of tiltmeter No. T6 – T10

Figure 16 (a). The photographs of the basement construction by means of the contiguous pile wall

Figure 16 (b). The photographs of the basement construction by means of the contiguous pile wall

Conclusions

The contiguous pile all was applied to be the temporary wall for basement construction of the excellent medical center in Asia, Siriraj Hospital. Three basement floors with 10.85 m. depth were excavated next to the Chao Phraya River closed to the preserved buildings seated on shallow foundation. Two temporary bracings with one upper layer full cross bracing and one lower raking strut were constructed. The analysis and design of the contiguous pile wall was carried out by Finite Element Method (FEM) based on Mohr-Coulomb failure theory. All construction sequences were simulated in the FEM analysis. The trigger level was set based on FEM analysis and set as the safety criteria to control basement construction. The instrumentation including inclinometer, settlement point, tiltmeter and piezometer were installed to measure the performance of contiguous pile wall system through out the excavation process. The results of instrumentation monitoring agree with the FEM prediction.

References

[1] W. Teparaksa, ―Polymer base bored pile in Bangkok subsoil,” *KGS National Conference*, Korean Geotechnical Society, Gwangju, Korea, 2008 [Guest speaker].

[2] W. Teparaksa, ―Behavior and performance of deepest barrette pile along Chao Phraya River on Bangkok,” *The 2nd Asian Workshop on ATC 18 Mega Foundations*, Korean Geotechnical Society, Seoul, Korea, 2008 [Guest speaker].

[3] W. Teparaksa, ―Deformation of subway tunnel induced by deep basement excavation in MRT protection zone, Bangkok,” *The 13th Asian Regional Conference in Soil mechanics & Geotechnical Engineering*, Kolkata, India, 2007 [Theme lecture].

[4] W. Teparaksa, ―Principal and application of instrumentation for the first MRTA subway project in Bangkok,” *The 5th International Symposium on Field Measurement in Geomechanics*, Symposium conducted in Singapore, December 1999.

[5] B. Menzies, ―Applying modern measures,” *Ground Engineering*, Vol. 30, No. 6, 1997.