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Problems of Pile Foundations Building

Damages to piles associated with excavation works in Bangkok soft clay

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DAMAGES TO PILES ASSOCIATED WITH EXCAVATION WORKS IN BANGKOK SOFT CLAY

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ABSTRACT

In Bangkok, Thailand, pile foundations are commonly used to support all type of structures. The excavation for construction of pile caps and mat foundations are carried out mostly in the soft clay layer. Sheet pile walls with temporary bracing systems are commonly used for excavation works (depth ranging form 4.0-11.3m) in the built-up areas of central and outskirts of Bangkok metropolis. Sometimes open cut excavation is adopted for shallow excavation (2.0-6.0m) in the areas where no buildings exist in the close vicinity of the site. Lateral movements of soils take place in such excavations causing pile deviation and cracks to the piles, especially located in the vicinity of boundary of excavation. Such defects have been found more frequently in smaller diameter piles than the larger diameter piles. These tension cracks in piles are commonly observed above the level of interface of soft and stiff clay layers where excavation induced bending moment in pile exceeds the pile's cracking moment capacity. Sonic integrity testing is usually employed to test the piles' integrity. High strain dynamic load test is sometimes employed to check the performance of piles with such defects. This paper presents four cases in which damages caused to piles by soil movement associated with excavation works. Pile damages, especially tension cracks indicated by integrity testing, analysis on stresses in pile due to the soil movements and behavior of retaining systems are also examined. Correlation between location of crack and bending moment in pile which exceeds the pile cracking moment capacity also made.

KEYWORDS

Pile deviation, Lateral movement, Sonic integrity test, Dynamic load test, Pile damage, Bending moment, Cracking moment

INTRODUCTION

Almost every structure in Bangkok sits on pile foundations. Excavation works for preparing the pile cap, footing and/or mat are usually within the soft clay commonly found in Bangkok. However for structures requiring many basement levels and underground facilities, the excavation works are undertaken to below the soft clay more than 20m from the ground. Various soil retaining systems are adopted in such excavation works to suit the site and soil conditions and depth of excavation. Analysis and design for the retaining systems sometimes are overlooked by the practicing engineers for the possible movements, both vertical and lateral, of soil adjacent to the excavation boundaries. Moreover monitoring of soil movements, with exception of existing structure near by, is often ignored. Such ignorance leads to damage the piles already constructed or installed in soft soil stratum. As a result secondary defects found in the piles after completion of piling work, including pile top deviations far from allowable tolerance become an argument between the piling contractor, excavation subcontractor and the employer or supervising engineer.

PILE FOUNDATIONS

Both bored and driven piles are commonly used for foundations of structures in Bangkok subsoil. The subsoil generally consist of a 12-18m thick very soft clay layer overlying medium to stiff clay layer. A sand layer occurs at depth of 20m to 35m below the stiff clay layer. A second layer of dense sand is generally ound below 50m where the toe of deep bored piles are founded for high rise or heavy structures. Stiff to hard clay layers occurs intermittently between the sand layers. Large diameter bored piles having diameter of 800mm to 1500mm are extended down to 35m to 60m respectively being embedded in the sand layers. For low rise buildings driven or small diameter bored pile of 35mm to 600mm are commonly used with footing for pile groups or for individual piles. The length of pile is generally to 20 to 28m embedded in stiff clay or first sand layer.

The working load capacity of bored piles is usually limited by the allowable stress of the concrete. Cutoff level of such piles generally varies from about 2.0m to 6.0m below ground surface. For the structures with deep basements, bored piles are trimmed down to 20.0m.

Generally bored piles are constructed with reinforcement of 0.5-1.2% of sectional area of pile and concrete having cube strength of 30-32 MPa. Wet process, using bentonite slurry is normally employed for drilling in water-bearing sand layers and concrete pouring is done under the slurry. Dry process normally used for construction of small diameter bored piles with depth not greater than 26m.

TYPES OF EXCAVATIONS

Common type of excavation found in Bangkok subsoil are tabulated as below,

Table 1. Common Types of Excavations in Bangkok Subsoil

Type of Excavation	Excavation below G.L. (m)	Site Conditions
Cut Slope	3.0-6.0	open area, no adjacent buildings
Sheet Piles Wall	4.0 to 11.3	adequate site clearance
Jet Grouted Wall	5.0 to 10.5	adequate site clearance
Secant or Contiguous Pile Wall	4.0 to 20.5m	in built-up area
Diaphragm Wall	7.0 to 23.0m	in built-up area

First two types of excavations are found to induce higher lateral and vertical soil movements compared to the remaining types (Ref. 2) and sometimes cause a localize failure of the soil mass retained due to improper construction practice. In this paper pile damage associated with the first two types in four cases are studied and presented.

INTEGRITY OF PILES

Sonic integrity test is usually employed to test the integrity of piles after piles have been trimmed to the design cutoff level. Generally a minimum of 10% to a maximum of 100% of piles are tested. A sonic integrity tester with built-in computer having high quality signal acquisition system has been commonly used for pile integrity testing. However, severity of the defect/crack or any irregularity in piles is usually determined comparatively based on magnitude of reflection amplitude of individual piles from such a defect/crack or irregularity, with reference to the input pulse. Figure shows the sonic test records of a good pile and piles with crack in different severity from Cases IV.

CASE I - CUT SLOPE (Bangna-Trad Highway KM. 26)

Subsoil Condition - A 17m thick soft clay layer occurs with unconfined average shear strength (Su), ranging from 0.69 t/m^2 at the top to 2.20 t/m^2 at the bottom of the layer. The field vane shear test indicates in-situ shear strength of that layer is 1.40t/m^2 to 3.80t/m^2 with sensitivity of 2.7 to 3.7. The natural water content of soft clay layer exceeds 100%. Below the soft clay layer is medium clay layer with Su value of 4.0 t/m^2 to 6.0t/m^2. Then a stiff clay layer having Su value of 13.0t/m^2 is found at the depth of 21m-22m overlying the first sand layer which extends to the depth of about 34m to 37m. The second sand layer occurs at the depths of about 52.0m - 61.0m. Between sand layers a thick hard clay layer is present, but sporadically.

Pile foundation - A total of 428 concrete bored piles of diameters 1.0m, 1.2m and 1.5m were installed with pile tip at 53m to 65m below the ground, being embedded in second dense sand layer to support a high rise structure. Cutoff level of piles ranges from 4.6m to 5.9m in depth. Entire length of piles were fully reinforced with steel reinforcement of 1% and 0.5% of pile sectional area in top 33m and lower section of pile shaft respectively.

Soil Retaining System - Cut slope excavation with two levels of 1:3 slope and a berm was adopted to achieve the maximum excavation to -5.9m below the existing ground level as the site is a large open space being located outside built-up area. Slope stability analysis using effective stress soil parameters indicated that a safety factor of 1.2 for temporary condition can be achieved by driving 6m long I-12 RC soldier piles at a spacing of 1.5m at the toe of the bottom slope. Moreover, the ground level around the perimeter of excavation was reduced down to 0.5m. Excavation was carried out on temporary working platforms supported by 24m long steel king posts (H300x300) driven into the ground.

Pile Damages - All piles were tested with sonic integrity test. Test results are summarized in the Table below;

Table 2. Summary of Pile Damage Detected by Sonic Integrity Test - Case I

Pile Dia. (m)	No. of Piles with			Defect Depth below GL(m)
	Least Prominent crack	Less Prominent Crack	Prominent Crack	
1.0	4	8	7	6.0-13.8
1.2		10	2	6.1-7.6
1.5		1	-	9.9

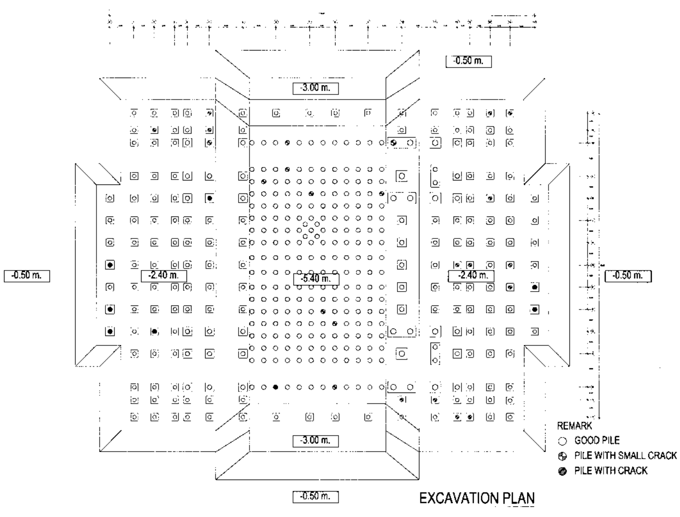

Figure 1. Excavation Plan and Location of Damaged Piles

Most piles with large crack detected were located in the outer row of foundation piles (Fig. 1) and located under the traffic ramps of temporary working platform. It was found that the crack in these piles were caused by localized soil sliding which was occurred by the heavy traffic load. Pile deviations in order of 50cm to 100cm towards excavation were observed.

An inspection after the soil sliding revealed that king posts were not installed to support parts of the ramps behind the slope on the ground. Apart from the traffic ramp area, a number of localized soil slidings up to 3m to 4m occurred in some areas. They are found to be caused by loose materials filled in bored hole above pile casting level during casting. Less Prominent crack detected in some piles, particularly within excavation zones are considered to be caused by improper pile trimming method. A backhoe was used to break off the over cast section by hitting the pile head after chipping of the concrete cover at the cutoff level around the pile shaft and separating the dowel bars form the overcast section.

Soil around the suspected pile with prominent crack were excavated down to detected crack level. These piles were trimmed down to below the crack and re-constructed to the cut off level. Tie beams were provided for the piles with crack and horizontal deviation more than allowable tolerance.

CASE II - SHEETPILE EXCAVATION SUPPORTED BY SOIL BERM (Huay Kwang Area)

Subsoil Condition - A 12m thick soft clay layer occurs with unconfined average shear strength (Su), ranging from 1.0 t/m^2 at the top to 2.50 t/m^2 at the bottom of the layer. The natural water content of soft clay layer is about 60-80%. Below the soft clay layer is medium clay layer with Su value of 2.5 t/m^2 to 3.5t/m^2. Then a stiff clay layer with traces of fine sand having SPT N value of 15 to 37 is found at the depth of about 18m-overlying sand layers which occur below 27m in depth.

Pile foundation - A total of 904 concrete bored piles of diameters 1.0m and 1.5m were installed with pile tip at about 59m below the ground, being embedded in dense sand layer to support a total of eight high rise buildings located at the particular size. Cutoff level of bored piles ranges from 5.1m to 8.1m in depth. Entire length of piles are fully reinforced with steel reinforcement of 0.72% of pile sectional area for the top and reduced gradually to 0.23% for bottom section of pile shaft. A total of 88 pre-cast concrete (I-30) piles with 21m in length was also driven to support the underground water tanks. The cutoff level of the pre-cast piles was 3.1m below the ground level.

Soil Retaining System - The foundation structure is about 10m to 20m away from the adjacent property boundaries. Initially excavation with cantilever sheet pile wall (FSP III with 14m in depth) supported by a soil berm or slope was adopted to achieve the maximum excavation to -8.10m below the existing ground level. However after excavation to some depths, due to sheet pile failure at some locations and excessive vertical and lateral soil movements, temporary raking struts were then immediately installed. Tension cracks wider than 300mm were observed on the ground about 4.0m away from the excavation zone. Minor damages also occurred to the adjacent properties due to soil movement.

Pile Damages - More than 50 % of piles were tested with sonic integrity test.

Table 3 Summary of Pile damage Detected by Sonic Integrity Test - Case II.

Pile Dia. (m)	No. of Piles with			Defect Depth below GL (m)
	Least Prominent crack	Less Prominent Crack	Prominent Crack	
I-30	-	49	14	6.2-8.0
1.0	1	23	4	13-16.6
1.5	-	1	1	15.6

Large numbers of piles with crack detected were located in the periphery of the excavation zone (within the soil berm) .

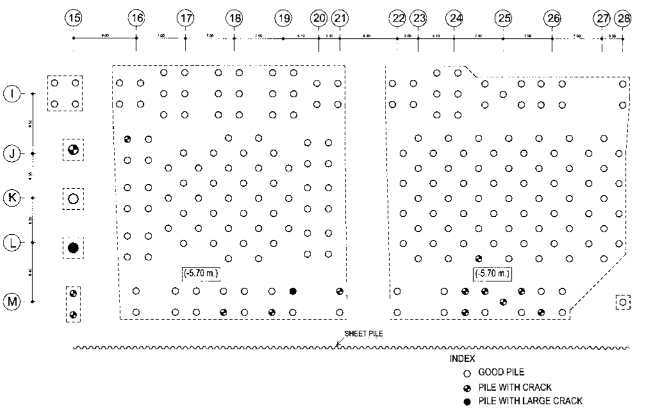

Figure 2. Location of Damaged Piles (only a quarter of Project Site shown here) Case II

Figure 2 shows a portion of the piling plan affected by soil movements. Pile deviations of up to 600mm, particularly in pile with prominent crack towards excavation were observed.

Bored piles with crack were cored to the depth below the crack and grouted. High strain dynamic load test was carried out on two piles suspected with crack and large horizontal deviation after remedial work. The dynamic test results indicate that these piles could be capable of carrying the design load with factor of safety higher than 1.5.

Figure 2.1. A Typical Scene showing excavation works Case II

CASE III SHEETPILE EXCAVATION WITH ONE LEVEL TEMPORARY SUPPORT (Yannawa)

Subsoil Condition - In this project site, a 14-15m thick soft clay layer occurs with unconfined shear strength (Su) ranging from 1.0 t/m^2 to 2.00 t/m^2 at the top and bottom of the layer respectively. Below is stiff to very stiff clay layers extend down to about 42m in depth. The subsoil condition below 36m from the ground level is variable, having a 13m thick sand layer sporadically. A stiff to hard dark grey clay is found at the depth between 40m and 49m. Generally a thick dense sand layer occurs below 50m in depth.

Pile foundation - A total of 402 concrete bored piles of diameters 1.0m and 1.5m were installed with pile tip at about 55m below the ground, being embedded in dense sand layer to support a building structure. Cutoff level of bored piles ranges from 0.75m to 7.80m in depth. Entire length of all piles are fully reinforced with steel reinforcement of 0.5% of pile sectional area.

Soil Retaining System - Due to different cutoff levels of piles, sheet pile (14m) with one level of temporary bracing at about 1m below the ground level was used for each excavation zone. Figure 3 shows a portion of pile layout which includes an excavation zone with braced sheet pile wall. Prior to installation of temporary struts, excavation was carried out to about 2.5 to 3m in depth. The over excavation without support caused excessive movements of soil and sheet pile wall along grid line C10 (Fig.3). Deflected sheet piles were re-aligned and struts were installed immediately with pre-loading.

Pile Damages - All piles were tested with sonic integrity test after pile were trimmed to the designed cutoff level. Piles with crack detected were mostly located in the vicinity of the excavation boundary (Fig. 3 and Ref. 6) . Moreover, lateral pile deviation in a range of 100-840mm towards excavation were also observed in those piles located in the vicinity of the sheet pile wall (Fig. 3).

Table 4. Summary of Pile damage Detected by Sonic Integrity Test - Case III.

Pile Dia. (m)	No. of Piles with			Defect Depth below GL (m)
	Least Prominent crack	Less Prominent Crack	Prominent Crack	
1.0	-	-	5	7.5-9.4
1.5	-	-	14	8.4-21.0

Damaged piles were cored to the depth below the crack and grouted. Modification of reinforcement for the mat was done for defect piles with large horizontal deviation.

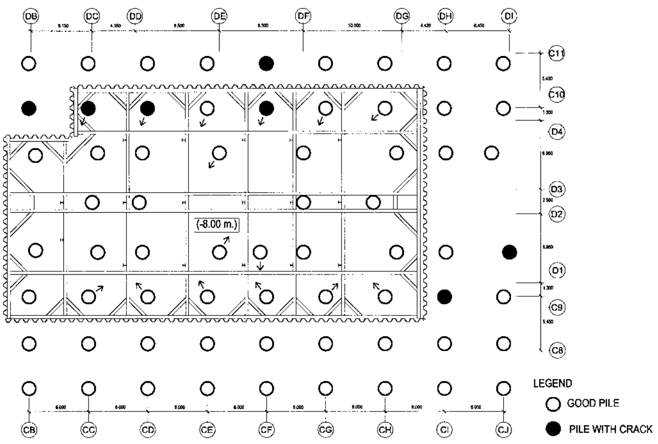

Figure 3. Plan of Excavation and Location of Damaged Piles and Pile Movements (a Portion of Project Area) Case III

CASE IV - SHEETPILE EXCAVATION WITH TWO LEVEL TEMPORARY SUPPORT (Sukhumvit Area)

Subsoil Condition - A 14-15m thick soft clay layer occurs with unconfined shear strength (Su), ranging from 1.0 t/m^2 at the top to 3.00 t/m^2 at the bottom of the layer. The natural water content of soft clay layer is generally about 37 - 87%. Below is very thick stiff to very hard clay layers inter-bedding with a 3m thick medium clay layer at the depth of 19m.

Pile foundation - A total of 143 concrete bored piles of 0.6m diameter were installed with pile tip at about 26m below the ground to support a residential apartment. Dry process was employed to construct the piles. Cutoff level of bored piles ranges from 0.85m to 5.95m in depth. Entire length of all piles are fully reinforced with steel reinforcement of 0.35% of pile sectional area.

Soil Retaining System - Type FSP III sheet pile (14m) with two level of temporary bracing at about 1.0m and 3.5m below the ground level was used. Figure 4 shows a portion of pile layout which includes an excavation zone with braced sheet pile wall.

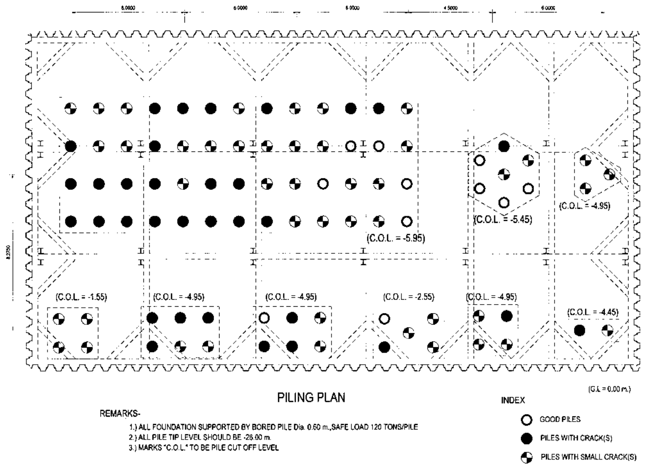

Figure 4. Plan of Excavation and Location of Damaged Piles (a Portion of Project Area) Case IV

Pile Damages - All piles were tested with sonic integrity test. In this particular project, 84% of piles within the excavation zone were found to be cracked (Fig. 4).

Table 5. Summary of Pile damage Detected by Sonic Integrity Test - Case IV.

Pile Dia. (m)	No. of Piles with			Defect Depth below GL (m)
	Least Prominent Crack	Less Prominent Crack	Prominent Crack	
0.6	-	38	33	6.5-13.8

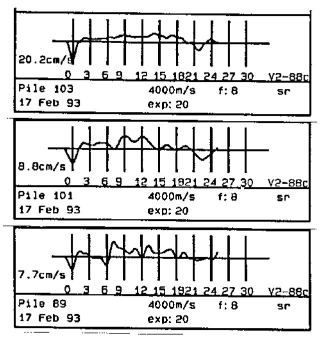

Figure 5. Sonic Integrity Test Records showing Good pile, Pile with less Prominent Crack and Prominent Crack respectively - Case IV.

Five bored piles with crack suspected were cored to verify the crack and grouted later. High strain dynamic load test was also carried on a total of 25 piles in which 24 piles with crack and 1 pile without crack. Summary of dynamic load test results is presented in the Table 5.

Table 6. Dynamic Load Test Results of Damaged Piles - Case IV

Mobilized Capacity/Design Ultimate Capacity of 240 ton	No. of Pile
less than 50%	1
less than 10%	2
More than 100%	22

From the results, only a few piles lead to low safety factor to carry the designed load and also connected by mat. Modification of reinforcement for the mat was done according to redistributed load.

FINITE ELEMENT ANALYSIS WITH COMPUTER MODEL SIMULATION

Two dimensional finite element computer modeling was carried out using PLAXIS computer program (ref. 7) for simulation of staged excavation process, pile/soil movements and to analyze the associated bending stress in the piles of the above projects. Stiffness of foundation piles per linear meter ($E.\Sigma I$/pile spacing in row) was used as a parameter for plate elements, where E and I is Young Modulus and moment inertia of pile respectively. The soil between piles in a row is ignored. Mohr-Coulomb constitutive model is adopted with soil parameters derived from the soil borehole data at the site. A plane-strain analysis approach was adopted with undrained soil condition.

Model profiles are presented in Figures 6 to 9. Figure no. 10 shows computed bending moments in pile and lateral deflection of pile in Case IV.

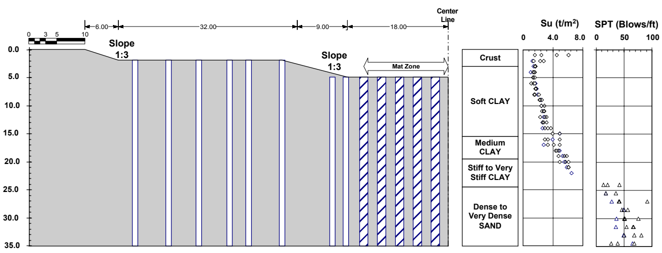

Figure 6. Model Profile of Case I

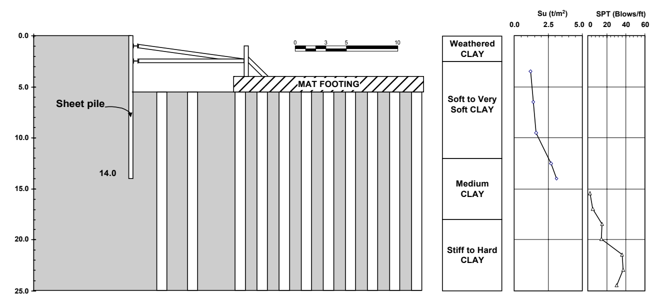

Figure 7. Model Profile of Case II

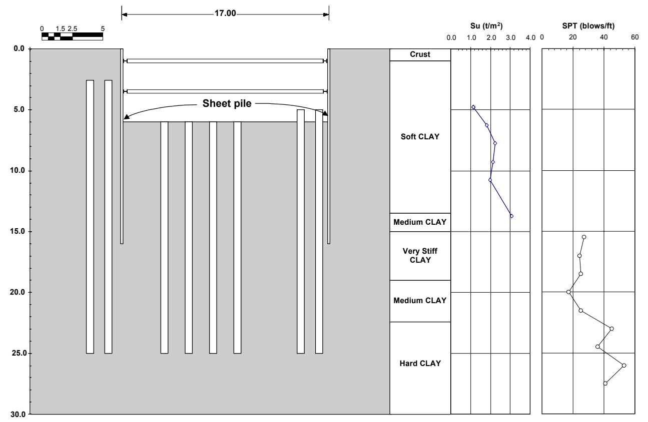

Figure 8. Model Profile of Case III

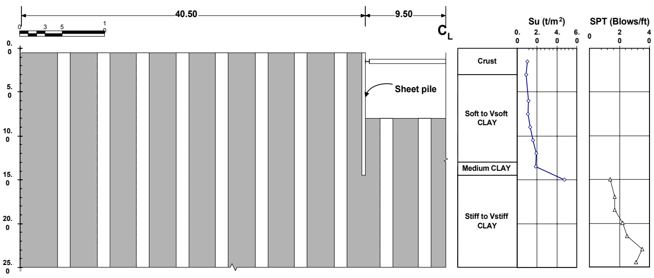

Figure 9. Model Profile of Case IV

DISCUSSION

The modeling results indicate that bending moments in piles induced by excavation are higher than the cracking moment capacity of the piles in all cases. Summary of analysis is presented in the Table below;

Table 6. Moment Capacity of Piles and Excavation Induced Moments in the Piles Closer to Excavation Boundary.

Case	Pile Size (m)	Rebar (%)	Cracking Moment (t.m)	Ultimate Moment (Whitney) (t.m)	Moment by FEM Model (t.m)
I	1.0	1.0	30	100	86.4 109.5*
II	1.0	0.75	30	79	149.7
III	1.5	0.5	102	188	117.2 255.7*
IV	0.6	0.35	6.5	9.2	13.3

Note: 1. (*) moment in pile located in active side of soil mass either outside of sheet pile wall or cut slope.

In Cases I and III, piles located in the active side of soil mass are found to be under the bending stress about 10% and 36% higher than the ultimate bending capacity of piles respectively.

In Case II, the computed bending moments in the pile closest to the sheet pile wall and piles in second row is 89% and 27% respectively higher than the ultimate bending capacity of piles. The sonic integrity test also detected presence of crack in 35% of the piles which are located in first two outer rows (see Fig. 2).

In Case IV, the modeling results show that excavation induced bending moments in pile exceed the ultimate moment capacity of piles. This is confirmed by the observed pile damages (see Fig. 5). Moreover the model results suggest that these piles are subject to some degrees of basal heave due to flexibility of and soil condition at embedment of sheet pile wall. Sonic integrity test results shows presence of more than one crack in some piles at depths, suggesting piles would have experienced combined stresses. Comparison between Case III and Case IV illustrates that cracks are found more frequently in small piles than large piles in a case of soil movements due to excavation.

The crack location in piles indicated by sonic integrity test generally is found to be consistent with the location of computed bending moment which exceeds the cracking moment capacity of piles for all cases.

Table 7. Locations of Crack and Computed Bending Moments in Piles in the Vicinity of Excavation Boundary

Case	Integrity Test Depth of Crack in Piles near Excavation Boundary (m)	Depth of Max. B.M by FEM (m)	Depth of B.M by FEM exceeding Pile's Cracking Moment (m)
I	6.0 & 13.8	19.5	13.5
II	12.7 & 13.7	18.0	11.0 & 13.0
III	12.4 &19.0	15.0	12.8 & 14.5
IV	11.5 & 12.0	15.5	13.0 &14.0

FEM analysis indicates the maximum bending moment in piles occurs at the level close to the interface between soft clay and stiff clay layers. For lateral movements of piles and soil, a direct comparison can not be made between model and observed data as the accurate field monitoring data are not available. Performance of soil retaining systems by model analysis are summarized in the Table below;

Table 8. Summary of Lateral Movements of Retaining System

Case	Type of Retaining (m)	Level of Strut	Excav. Depth (m)	Max. Lateral Movement (mm)
I	Cut Slope	-	5.4	117
II	Sheet Pile	1	5.7	175
III	Sheet Pile	1	8.0	56
IV	Sheet Pile	2	6.0	52

For Case III, model analysis also confirmed that without temporary bracing, sheet pile would fail when soil berm is removed for trimming pile adjacent to the wall.

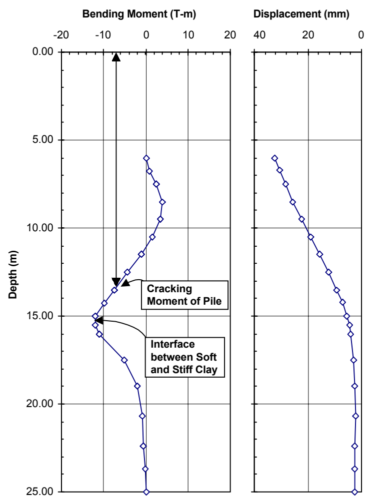

Figure 10. Computed Bending Moment in Pile and Pile's Deflection Closest to Sheet Pile Wall - Case IV

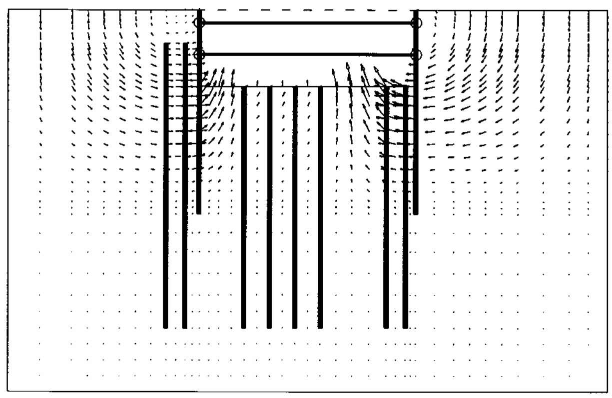

Figure 11. Section Showing Displacements of Soil - Case IV

Instrumentation such as installation of inclinometer and strain gauges in piles and active side of soil mass is suggested for the future projects to analyze behaviour and performance of piles subject to lateral loads induced by excavation.

CONCLUSION

This paper presents four case studies on bored piles damaged by excavation induced lateral soil movements in Bangkok soft clay layer. Performance and response of pile are studied by FEM modeling and confirmed with pile integrity test results. Causes of pile damages found are also discussed.

In addition to FEM analysis, the followings were found from the actual site construction activities,

1. Over excavation prior to installation of support
2. Inadequate retaining system which can effectively control soil movement.
3. Inadequate support for construction traffic load (Ref. 4)
4. Improper pile trimming method (Ref. 4)
5. Inadequate pile design for lateral load during construction
6. Inadequate reinforcement in piles to resist soil heave

In designing of bored piles, the above mentioned causes, including deviation of piles due to excavation induced soil movement are to be taken into account.

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