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Research Paper

# Uplift of very sensitive soft clay due to pile driving

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**A R T I C L E   I N F O R M A T I O N**

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**A B S T R A C T**

The subsoil of Samutprakarn province in Thailand consists of thick sensitive very soft clay layer. The construction, such as pile driving and excavation work would lead to reduce the shear strength of very soft clay or induce the excess pore pressure on very soft clay. This paper presents the results of pile driving around the press pit reinforced concrete structure which was excavated and constructed on the very soft sensitive clay. The pile driving effect surrounding the press pit caused the uplift of press pit. The uplift of press pit was investigated by additional soil investigation, piezometer installation as well as coring the base slab of press pit. The investigation result was analyzed for clarifying the uplift behaviors before remedial work. At present, the remedial work was already completed.

## 1. Introduction

Samutprakarn province is located in the South of Bangkok, Thailand, by the sea in the area of sea delta. The soil in the area was deposited soil. Therefore, the underground construction and design in Samutprakarn province should be thoughtfully and carefully carried out because the Samutprakarn subsoil consists of a thick layer of very soft clay which has high water content and very low shear strength. This paper presents the results of pile driving around the press pit reinforced concrete structure which was excavated and constructed on the very soft sensitive clay in a factory construction project in Samutprakarn. In the factory, there were four press pits as TRF#1 for 2500 tons, TRF#2 for 2500 tons, BL for 1000 tons and TDM for 5400 tons. The locations of these press pits are shown in **Fig. 1**. The columns and floor slabs of the factory as well as the press pits were supported by deep pile foundations seated in dense sand. The deep piles were I-shape prestress concrete (PC) piles of about 27-28 m. long with section of 300x300mm, 350x350mm. and 400x400mm. The piling construction sequence started by driving the PC pile in the floor slab areas which were far from the press pit area. Then, the PC piles were driven in the press pits areas. Consequently, the excavation and construction of press pit was carried out by sheet pile braced excavation method. The excavation depth was about 8.05 m. from the ground surface level. The base slab and the retaining wall of four press pits was completed before removing the sheet pile. After the press pit construction was completed, the PC piles of the factory were driven in the areas around the press pits. After the completion of the pile driving surrounding the press pit, the uplifts of four press pits were found. As a result, the details of soil investigation were re-investigated as well as measured water pressure by piezometer, and cored the base slab of press pits as a precaution. According to general foundation engineering books, such as Bowles JE. (2001) or NAVFAC DM 7.2 (1982) there are no

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description regarding the causes of uplift that uncommonly occurred after the press pit completion.

Previously, there are many research works that studied the impact of pile driving; for instance, Massarsch at el. (2008), Wiss. (1967), Woods. (1997), Hwang et al. (2001) and Head and Jardine (1992) or the effects of foundation construction nearby structures; for example, D'Appolonia. (1971). Most of researches assumed that energy transfers between hammer and pile when a hammer hits the pile head and the P-wave and S-wave that propagated in surrounding soil. Deckner. (2013) presented the summary of ground vibrations due to pile driving. The most important findings and conclusions of his work are the main factors influencing vibrations due to pile driving such as the geotechnical conditions at the site and the distance from the source. In addition, there are many case studies where the ground heave effects were observed such as the works of Hagerty and Peck. (1971), Chandra and Hossain (1993), Wersäll and Massarsch (2013) and McCabe et al. (2013). The aim of this paper is to illustrate the causes of the uplift which occurred in the pit and surrounding area around the pit.

## 2. Soil conditions

Six bored holes soil investigation was carried out up to 30-40 m. deep below ground surface. The soil condition consists of a 12 m. thick very soft dark grey clay layer with very high natural water contents between 109% to 158%. Below the very soft dark grey clay layer, a soft to medium dark gray clay layer was encountered to about 16.5m. depth. Stiff to very stiff silty clay layer was found below soft to medium clay to about 27m. depth. The first Samutprakarn dense sand was encountered below the very stiff clay layer to about 36m. deep then followed by a hard silty clay layer. The summary of soil conditions and its properties are presented in **Table 1**. It can be seen that undrained shear strengths of very soft clay and soft to medium clay were very low. Compared to soil condition of Bangkok which located in the north of Samutprakarn, the soil layer of these two city was quite similar (Teparaksa., 2007). However, shear strengths of soft and medium clay of Bangkok subsoil was much higher with the lower water content ranging between 70%-90% for the very soft clay and in the range of 47%-58% for medium clay.

The very soft dark grey clay layer was the sensitive clay with very high water contents in the range of 109-158%. This very soft clay layer seems to be the most sensitive clay with highest water content of Bangkok clay. The ground water table measured at 24 hours after completion of soil boring was at about -1.0 m. below the ground surface level.

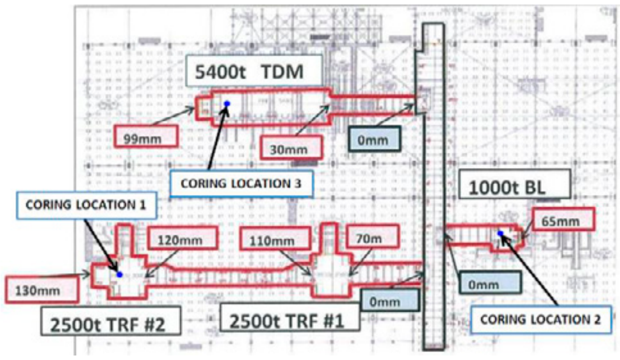


**Fig. 1.** Locations of four press pit.

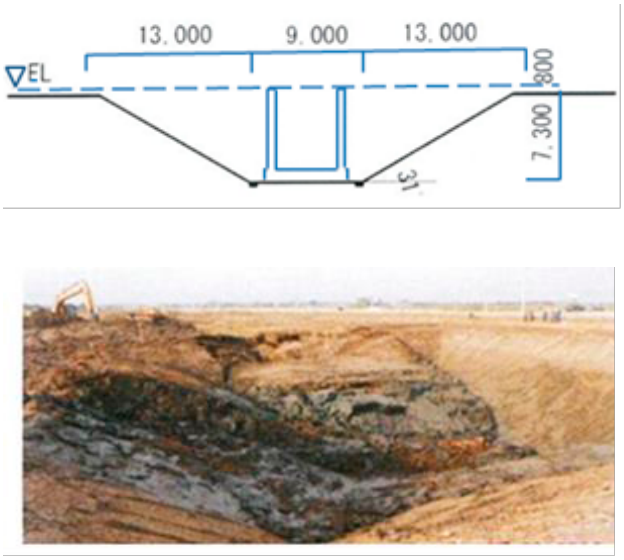


**Fig. 2.** Trial excavation work.

**Table 1.** Summary of soil conditions and properties.

| Depth (m.) | Soil Description | $w_n$ (%) | $\gamma_t$ (t/m$^3$) | $S_u$ (t/m$^2$) | N (Blows/ ft) |
|---|---|---|---|---|---|
| 0–12.0 | Very Soft dark gray Clay | 109–158 | 1.3-1.4 | 0.4–1.0 | – |
| 12.0–16.5 | Soft to Medium dark gray Clay | 70–90 | 1.5-1.6 | 1.2–2.3 | – |
| 16.5– 22.0 | Stiff Silty Clay | 41–45 | 1.7-1.9 | – | 10 – 18 |
| 22.0–27.0 | Very Stiff Silty Clay | 23–25 | 2.0 | – | 16 – 31 |
| 27.0–36.0 | Dense Silty sand | – | 2.0 | – | 27 – 39 |
| 36.0– 40.0 | Hard Silty Clay | 16–19 | 2.0 | – | > 30 |

**Note:** Wn = Natural water content, Su = Undrained shear strength , $\gamma t$ = Total unit weight, N-value = SPT N-value

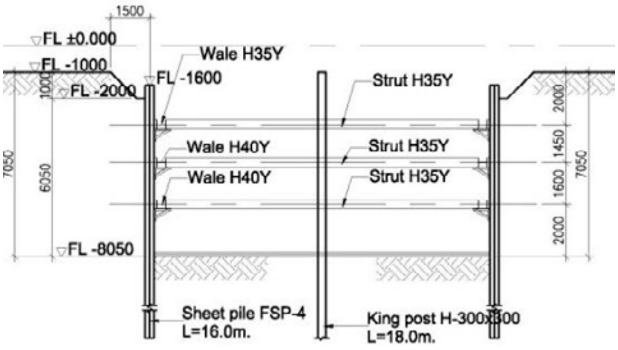


**Fig. 3.** The detail of sheet pile bracing system.

**Fig. 4.** Sheet pile braced excavation system.

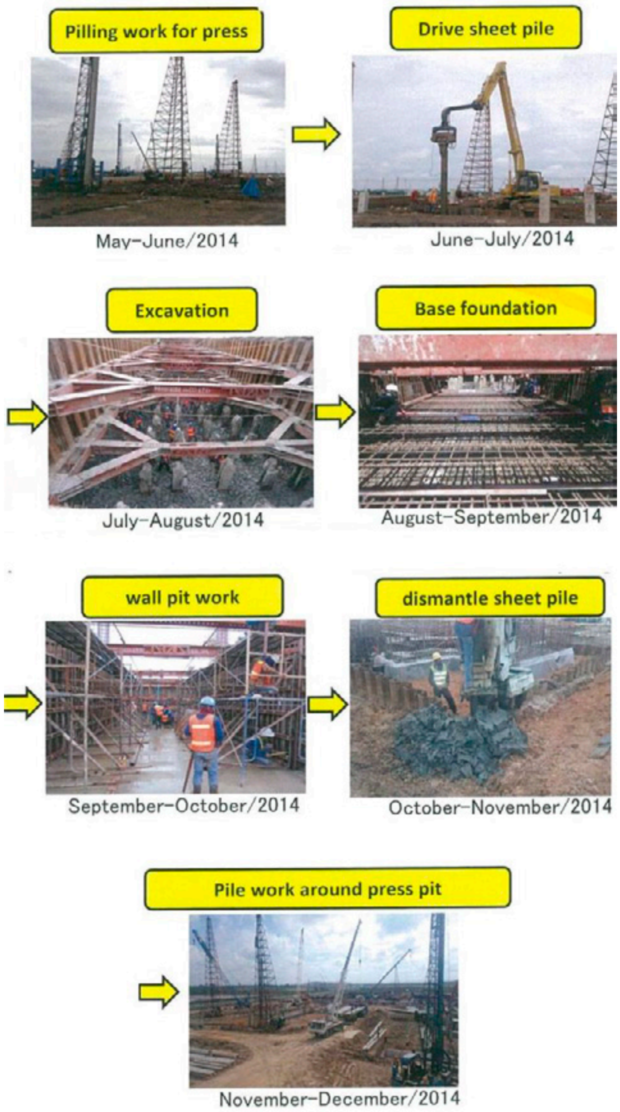


**Fig. 5.** The schedule of piling pile.

## 3. Construction sequence and observed uplift on press pit

The building of this factory project was designed by using I-shape driven pre-stressed concrete piles as a pile foundation to support the columns, floor slabs and press pits structures. The pile capacity and layout was designed based on soil investigation. There were many driven piles in the project. Since the soil conditions consists of thick very sensitive soft clay of about 12 m, before starting the construction of press pit, the trail open excavation was carried out on April 2014 to verify the possibility of open excavation as shown in **Fig. 2**. There was no ground water during excavation. The result of excavation showed the collapse of excavation slope and the soil was flow as also shown in **Fig 2**.


**Fig. 6.** Piles driven in the surrounding area of the press pit.

**Fig. 7.** Concrete coring at location 1.

Due to the collapse during open excavation as shown in **Fig. 2**, it can be seen that the trial open excavation was very dangerous to construct the press pit. Therefore, in order to avoid any possible risks, the sheet pile braced excavation method was preferred as a soil protection system instead of open excavation method. Generally, during excavation by sheet pile braced cut system in the very soft sensitive clay, the pile deviation and pile crack normally occur both inside and outside of the pit. Thus, the contractor proposed the excavation method by sheet pile bracing system without pile installation outside of the sheet pile wall as shown in **Fig 3 and 4.** There were, in total three steel bracing layers at the level of -2.0 m., -3.45 m. and -5.05 m. from the ground surface level. Sheet pile was 18 m. long. In addition, the contractor proposed the pile driven sequence into 3 phases as well as construction of press pit as shown in **Fig. 5** with detailed as follows:

**Fig. 8 .** Concrete coring at location 2.


. **Fig. 9.** Concrete coring at location 3.

**Table 2**. Summary of uplift at four press pit area

| Press Pit Area | Uplift (mm.) |
|---|---|
| 2500 tons TRF#1 | -70 to -110 |
| 2500 tons TRF#2 | -120 to -130 |
| 1000 tons BL | 0 to -65 |
| 5400 tons TDM | -30 to -99 |

Zone1: Piles driving started on the outside of the areas, that the press pit would be constructed, by waiving the surrounding area of the press pit. The piles surrounding the press pit area were not driven because the piles outside the excavation pit would be normally deviated and cracked during deep excavation in the very soft clay area. Thus, the area of zone1 was far away from press pit areas. Some piles in zone1 were driven at the same time with the excavation of the press pit or the construction of the press pit slab and the retaining wall because zone1 was huge area. In zone1, the piles were used to support the floor slab and column of the factory.

Zone2: Pile driving started only inside the press pits area by waiving the surrounding area of the press pit. After completion of pile driving, the steel sheet pile braced excavation was carried out in order to construct the press pits. This method was modified from the trial excavation work.

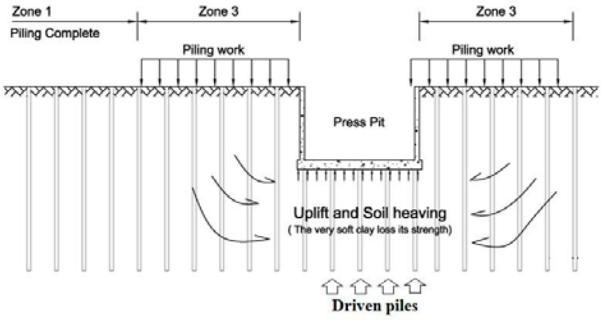


**Fig. 10.** The uplift and soil heaving at press pit area.

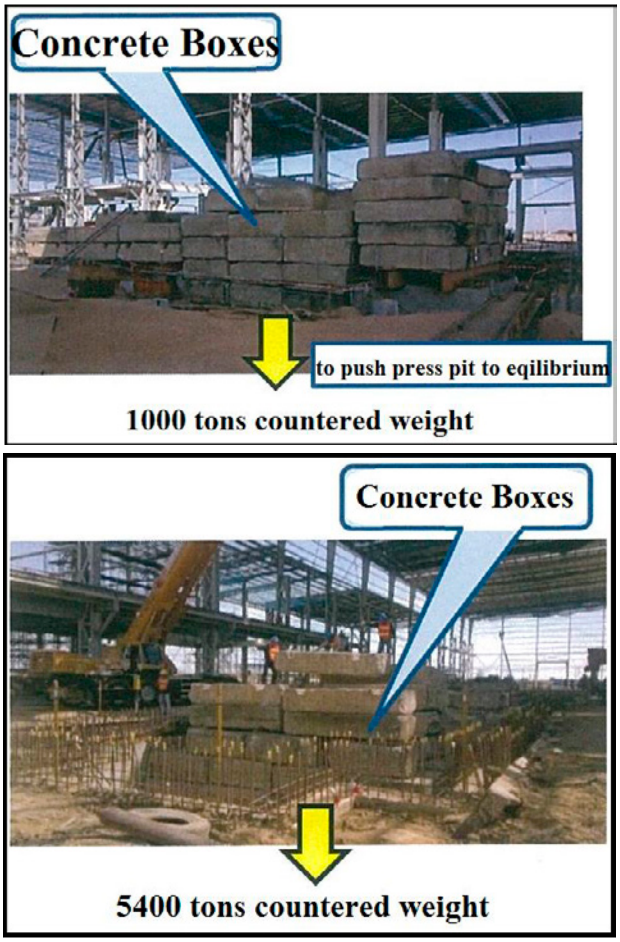


**Fig. 11.** Countered weight balance on press pit.

Steel Sheet pile was 18 m. long with embedded length of 9.95 m. Three bracing layers at -2.0 m., -3.45 m. and -5.05 m. Construction work started by soil excavating to the depth below the first bracing layer and installing the first layer of bracing system at -2.0 m. The process repeated until installation of the third bracing layer at -5.05 m. before excavation up to the final depth of -8.05m. below the ground surface level as shown in **Figs 3** and **Fig 4**. During excavation, there was no groundwater and soil heaving found in the pit as well as pile inside the pit. The sheet pile was removed after the base slab and

**Fig. 12.** The piling work of micro spun pile.

retaining wall of all press pits was constructed completely. Any disturbances to the surrounding pile were not found because the surrounding piles were not yet driven.

Zone3: After completion of press pit structure and piling in zone 1, the piles surrounding the press pits were driven as shown in **Fig. 6.** The piling in zone3 was carried out between November to December 2014. After completion of piling in zone3, the uplifts of press pits were observed. The uplift of the press pit is the unforeseen behavior.

The uplift of press pits were observed and measured on 14 December 2014 as presented in **Fig. 1.** as summarized in **Table 2**. After uplift of press pits were observed, concrete coring on base slab of the press pits were carried out at 3 locations as shown in **Fig. 1** as location1 at press pit 2500 tons TRF#2 on 16 December 2014, location2 at press pit 1000 tons BL on 16 December 2014, and location3 at 5400 tons TDM on 19 December 2014.

At location1: After coring of base slab, water flow up was found and pile head was separated from base slab. The water flow was stopped after 30 minutes as shown in **Fig 7.**

At location2: The concrete coring was pushed up to about 30 cm. by the uplift pressure and the flowing of water was stopped after 10 minutes. The pile head was not separated from base slab as shown in **Fig. 8**.

At location 3: After coring concrete of base slab, no water flow was found and pile head was not separated from base slab as shown in **Fig. 9**.

The water flow up at location 1 was strong and had high pressure because it was the first coring hole and uplift pressure beneath the base slab was still very high. For location 2, the water flow was less than location1 because the uplift pressure was already partly relieved. At location 3, the coring was about 3 days later from execution at location 1 and location 2. There was no uplift water pressure

## 4. Causes of uplift on press pit

The press pit construction was completed by sheet pile braced excavation system. During excavation, there was no ground water and soil heaving observed at the final excavated depth (-8.05 m.). Additionally, there was no pile crack and pile deviation inside of the press pit. After base slab and retaining wall of press pit were casted in October 2014, and sheet pile was re-moved in November 2014, there was no uplift on press pits. During these time period, the piling work was carried out on the surrounding area of the press pit or zone 3 as shown in **Fig. 6**. The uplift of press pit was found on 14 December 2014. Over this period, only the activity of piling work around the press pit area was carried out. That means the piling works at surrounding the press pit created the uplift on the press pits. In addition, only piling work in zone 3 was carried out near the press pit area.

The piling work induces the excess pore pressure in the very soft clay layer. The 12 m. thick very soft clay in this project is very sensitive clay with very high water content of 109-158%. Driving of pile would strongly compress soil, and would lead to a buildup of excess pore water pressure. The soil pressure from piling work also induced soil heaving. As the very soft clay located at the first layer (0-12 m.) was the very sensitive clay, the vibration due to pile driving in surrounding area of press pit (zone 3) created disturbance to very soft clay and leaded to a reduction or loss of the shear strength of the very soft clay. This also promoted reduction in pile capacity. Decrease in friction capacity induced by soil disturbance was well observed and studied; for example, Bozozuk et al. (1978). This decrease would recover with time (Broms, 1981). In addition, the detail regarding the vibration due to pile driving can be learnt more in Design of Structures and Foundation for Vibration Machine by Arya et al. (1979). The excess pore pressure, loss of shear strength as well as soil heaving created uplift at the press pit area because the overburden pressure at press pit area was lower than the surrounding area as presented in **Fig. 10**.

After uplift occurred at the press pit area, the additional soil investigations with 3 bored holes were carried out during January 2015 with field vane shear test and installation of piezometer at 10m. and 18m. deep below ground surface. The results showed that the very soft clay was about 16.5 m. thick with very high natural water content. Typically, the sensitive value of very soft clay should be generally about 3-4. However, the sensitivity ($S_t$) of the very soft clay from field vane shear test of an additional soil investigation data was about 3-6 and it was about 10 based on an unconfined compression test on undisturbed and remold samples. This very soft clay layer can be classified as extra sensitive clay (St > 8) (Blowes, 1996 and Skempton and Northey, 1952). The ground water monitored by installed piezometers from additional soil investigation shows the high water level of 1 m. above the ground surface. Therefore, based on the soil re-investigation, it can be concluded that the piling work in extra sensitive clay can easily disturb the underground structure if the piles are driven in nearby area.

## 5. Remedial works

The countered weight balance by concrete box was loaded to the press pit as shown in **Fig. 11**. The countered weight can effectively success to push the press pits to the equilibrium state because all excess pore pressure and soil heaving was already flow out during concrete coring of the press pit base slab. However, the press pits were pressed down between 50-90% of its uplift. After equilibrium or relief of excess pore pressure, the press pit was under the compressive loading of the concrete structure.

The additional piles were redesigned to support the pedestal of the press pit and the press pit itself by neglect the original driven I-shape PC pile. **Fig. 12** shows piling work of micro spun pile driving both beneath the pedestal of the press pit and the press pit itself. The piling system of micro spun pile is very light with driving spun pile portion at every 1.5 m. long for totally 27m. long pile. The design load of micro spun pile diameter 0.25 m. with 27 m. long is 40 tons with safety of 2.5 or ultimate pile capacity of 100 tons. The dynamic pile load test on additional micro spun pile was also carried out to verify its design load as shown in **Fig.13**. The ultimate pile capacity from dynamic pile load test is about 131.7 tons. If compared to design load of 40 tons., the safety factor is in the order of 3.29 which is more than the requirement of 2.5. After completion of the press pit, the loading on the press pit is under compression without any uplift.

**Fig. 13.** The dynamic pile load test on micro spun pile.

## 6. Conclusions

This paper presents the cause of uplift at the floor of press pit that occurs while pile driving of a factory project in Samutprakarn province was constructing. Since Samutprakarn is located in the South of Bangkok by the sea, soil was deposited by sea which gives difficulty in geotechnical construction. The first soil layer is 12 m. thick of highly sensitive very soft dark grey clay layer with high water content between 109-158% and very low shear strength of 3.9-9.9 kN/m$^2$. Foundation of this factory was design using I-shape driven pile. The pile driven works were separated into 3 zones which were the press pit zone, the very far from press pit zone, and the surrounding press pit zone. Based on the observation, after piles in the surrounding press pit zone were driven, the uplift occurred on the floor of the press pit. The disturbance from the piling work on the very soft and very sensitive clay created the excess pore pressure, loss of shear strength of soft clay and induced the uplift on the press pit structure. The additional soil investigation and piezometer installation was carried out with coring on press pit slab to verify the uplift behavior. Finally, the remedial work was carried out by adding the new micro spun piles on the press pit structure without consideration of the existing driven I- shape PC piles.

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