Polymer Base Bored Pile in Bangkok Subsoils

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SYNOPSIS: The bentonite slurry has been used as the stabilize suspension for wet process bored pile construction in Thailand. The bentonite suspension has benefit on filtration in the sand layer, but it creates thick cake film along pile shaft and loose sedimentation at pile toe. The base grouting technique was widely used to rectify the soft base or loose sedimentation problem of bored pile. The base grouting technique was not increased only end bearing capacity, but was also more increase in skin friction capacity of the bored piles. The comprehensive researches on base grouting was carried out by installing PVC casing inside the shaft to allow the drilling through the pile base in order to collect the soil sample below the pile tip. The polymer based slurry recently was used to replace the bentonite slurry to overcome the thick cake film along pile shaft as well as loose sedimentation at pile toe. The extent research on polymer slurry by physical model was performed to verify the real behavior of polymer. The appropriate mixing ratio of polymer was proposed. The design skin friction coefficient, β and end bearing coefficient, Nq, for sand layer base on fully instrumented tested pile were proposed. The application on remedial of the lose capacity bored pile with large displacement in Bangladesh was proposed and discussed.

Key words: Bentonite Slurry, Polymer Slurry, Bored Pile, Base Grouted Pile, Pile Capacity, Remedial Work

1. Introduction

The method of construction wet process bored piles under bentonite slurry as hole stabilized agent has become well established in Thailand for along time. It is particularly used for large diameter pile, where powerful rings can be used by auger and bucket drilling technique through otherwise unstable water bearing strata. It is always used with a temporally steel casing to support the top most 14 meter thick Bangkok soft clay. Construction problems are general effecting integrity and performance of the bored pile. A pile without sound toe leads to cause higher order of detrimental settlement. The known causes of ending up with a defective pile toe, are the loosened materials during boring operation are accumulation of sediments from bentonite column at the base of the borehole. The bentonite slurry has benefit in forming a cake film in the sand layer and prevent the hole collapse. This cake film leads to reduce the skin friction capacity of pile in sand layer. The technology of flowable concrete and tremie placing are well known to avoid these cake film and sediments at pile toe problems up to certain extent. It is already a standard procedure to use a bucket technique, a cleaning bucket and an airlift to clear the borehole shaft and base. However, this standard procedure of bucket technique is still not able to solve the thick cake film along the pile shaft and loosening with sedimentation at pile toe. This soft base and thick cake film problem can be effectively solved by means of base grouted techniques at proposed and reported by Teparaksa (1991, 1992, and 1994) . During year 1991-2000, the base grouting is widely used in Thailand to rectify the soft toe problem.

Nowadays, the polymer slurry drilling technique has been used to replace the bentonite slurry. The polymer slurry shows the benefit in environment issue that can be drained to the city drainage system and safe energy that does not required desander equipment. The researches on using polymer slurry as a hole stabilizing slurry for constructing wet process bored pile were carried by Teparaksa (2000 and 2001). The pile performance using polymer slurry shows an excellent performance as same as or better than base grouting bored pile using bentonite slurry.

This paper presents the performance of wet process bored pile in Bangkok subsoils based on using bentonite slurry with and without base grouting, and the polymer slurry. The application of polymer slurry with grouting technique to remedial on the loss pile capacity with large displacement in Bangladesh is also presented and discussed.

2. Bangkok Subsoil Conditions

The Bangkok subsoils consist of 13-16m 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 basements, 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 the subway tunnels. The first dense silty sand layer located below stiff silty clay layer at 21-28m 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 45.0-60.0m depth (Figure 1). Generally, for high rise building, expressway and heavy structure, pile tip of the bored pile is fixed in second dense silty 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 deep aquifers has led to the under drainage of the soft clay and stiff clay as well as deeper soil layer. The piezometric level or the pheratic surface of the Bangkok aquifer is, therefore, reduced and quite constant at about 23m below ground surface (Teparaksa, 1999) as shown in Figure 2. This low piezometric level contributes to increase in effective stress, causing ground subsidence. However, the benefit of this lower piezometric level is easy to construct bored piles having pile tip in the first stiff clay using dry process. Deep excavation pattern is also very convenient by using dry excavation method for basement construction up to the silty clay level without any dewatering or pumping system.

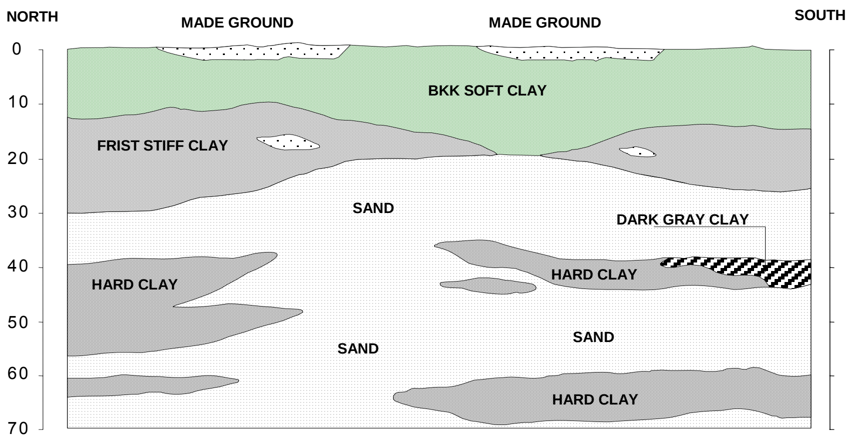


Figure 1 Bangkok Subsoils Conditions (Teparaksa, 1999)

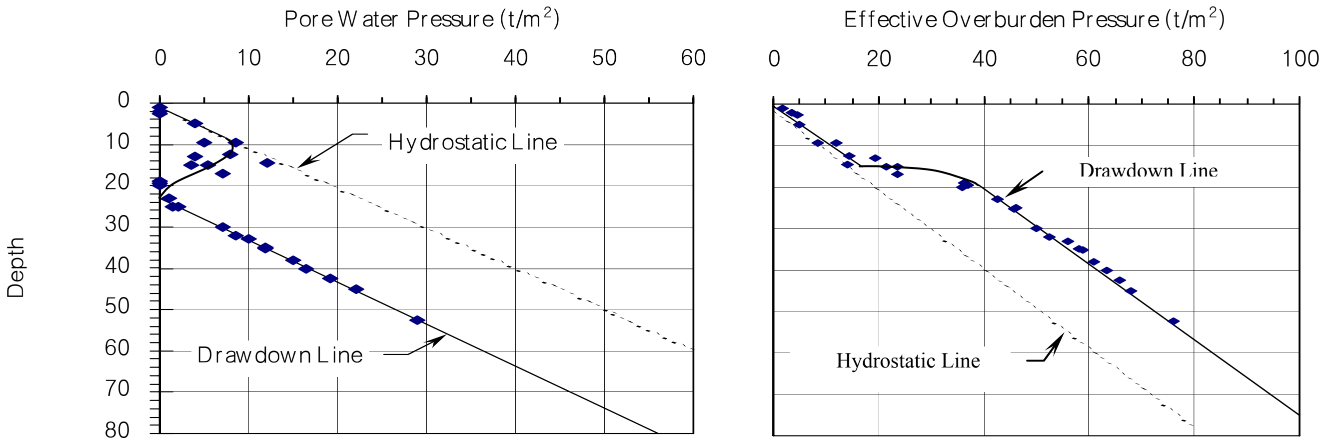


Figure 2 Ground Water Level and Vertical Effective Stress of Bangkok Subsoils (Taparaksa, 1999)

3. Properties of Bentonite and Base Grouting Pile

3.1 Properties of Bentonite Slurry

The bentonite slurry mixed between clay particle (bentonite powder) and water. It was used in the ratio of 5% by weight to the slurry volume of drill hole. This clay particle is expanded when mixed with water and forming a cake film along the shaft of bored pile in sand layer and can stabilize the drill hole. The bentonite slurry performs as colloid and can be settled to the base of the drilled hole. The sedimentation of the bentonite occurred during installation of the reinforcement cage which was taken about 2 hours after completion of the hole drilling of 50 – 60 meter depth. This sedimentation is too soft and has to be cleaned by airlift technique which required very long period between 4 hours to 10 hours. If sediment is too thick and cannot be absolutely removed, the soft base behavior is still occurred.

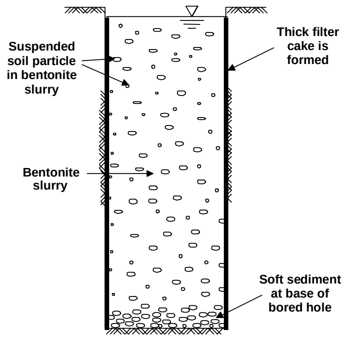


Figure. 3. Behavior of bentonite slurry as drilling slurry.

3.2 Base Grouting Pile

This soft base problem of the large and wet process bored pile can be solved by base grouting technique. Two U-loop grouting circuit or tube-a-machette technique was used by installed two manchette with covering at pile base less than 20 centimeter. Grouting is applied only one U-loop grouting circuit while the other loop is prepared as a spare circuit. The grouting volume is applied between 500 – 2000 liters with maximum pressure up to 40 bar. Recently, the code of practice in Thailand (EIT, 2003) propose the applied grouting pressure ranging from 20 – 40 bars and grouting volume between 500 to 1000 liters with injection rate vary from 5 – 35 liters/min.

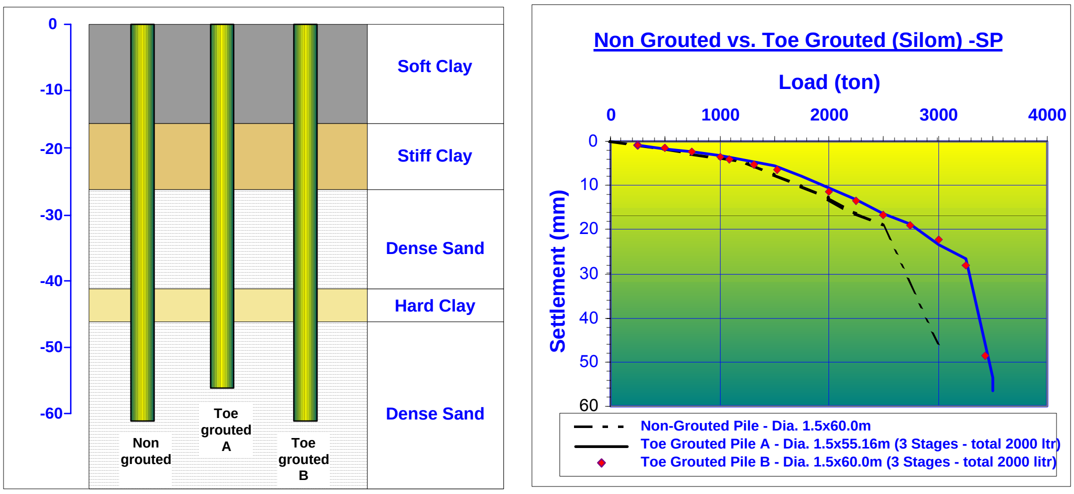


Figure. 4. The comparison of pile performance between non grouting pile 1.5 m. in diameter and 60 m. long and base grouted pile with pile tip in the dense sand layer.

It can be seen that base grouting technique can solve the soft base problem. Teparaksa (1994) and Wachiraprakarnpong (1993) reported the construction and performance of base-grouted bored pile in Bangkok subsoils based on the fully instrumented tested piles, as shown in Table 1.

Table 1. Improvements made by base grouting (Teparaksa, 1994).

Layer of Pile tip	Increase in failure load (%)	Increase in skin friction (%)	Increase in end bearing (%)	Displacement at fully mobilized skin friction (% of Pile Dia.)	
				NGB	GB
1st Sand	26-66	24-66	28-61	0.49 – 0.51	1.34-1.35
2nd Clay	27	51	1	0.37	0.74
2nd Sand	12-24	9-27	11-21	1.04	1.59-1.86

NGB: Non Grouted Base, GB: Grouted Base

It was found that base grouting not only helps to improve the end bearing capacity but skin friction as well. The increasing of the skin friction of pile made more doubt to geotechnical engineer why skin friction capacity was increased more than end bearing capacity.

3.3 Mechanism of Base Grouting Pile

In order to investigate the mechanism of grout spreading beneath and in the surrounding soil of pile tip, Teparaksa et al (1999) performed the real test and collected grouted sample beneath pile tip. PVC – casings were placed in the prototype bored piles as shown in Figure 5 and 6 to allow for the passage of drilling tool down to the pile base. Three piles, 1.0 m. and 1.5 m. in diameter and length 50 to 55 m. were constructed with the provision of 7.5 cm. diameter PVC – casings. Position of PVC – casings were staggered with respect to the manchettes as depicted in figure 5. Portland cement Type I grout with w/c ratio equal to 0.55 was used. Nominal grout volume used for each pile was about 550 liters. After 15 to 20 days of base grouting, the diamond bit rotary drilling with double tube sampler was used to core through concrete present below the base of PVC – casing. Right after reaching the pile tip, Standard Penetration Test (SPT) was started. Steel liner was used inside the split spoon sampler to collect sandy soil samples. All the concrete and soil samples retrieved, carefully examined on site to determine the grout content present. Additionally, in order to determine the lateral spreading of grout into the surrounding soil of pile tip, additional boreholes were drilled 30 cm away from the pile periphery.

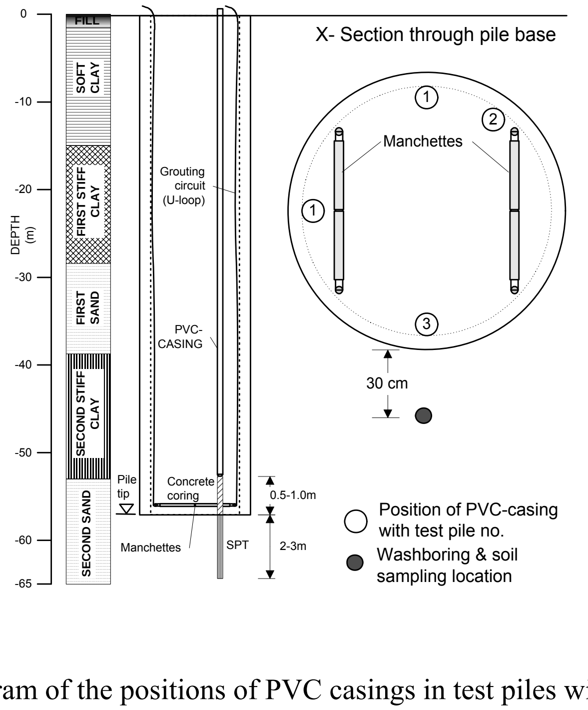
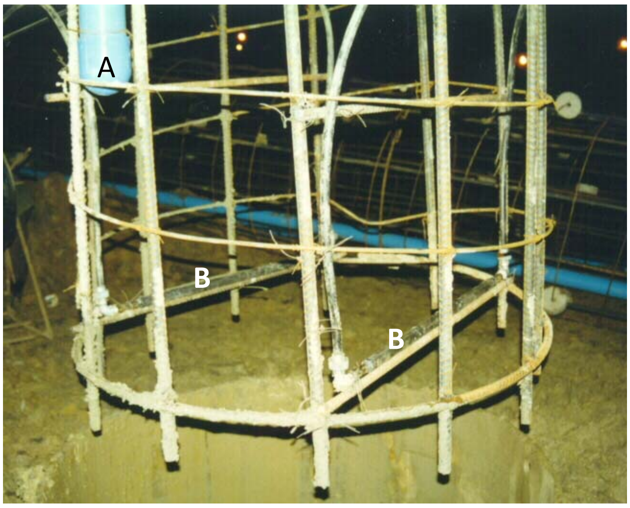


Figure. 5. Schematic diagram of the positions of PVC casings in test piles with typical soil profile at the site.



A: Base of PVC-casing, B: Manchettes

Figure 6. PVC casing attached to the rebar-cage, before lowering in to the borehole.

3.4 Penetration of grout into the sand

From the concrete cores recovered no trace of grout was found. Below the grout core recovered no traces grout were found in sand sample recovered by SPT. The SPT – N values obtained right below the pile tip and 30 cm. away from the pile are compared with the values from nearest bore holes performed at the time of soil investigation as shown in Figure 7. It is quite clear that the density of the sand surrounding the pile tip after grouting has been increased.

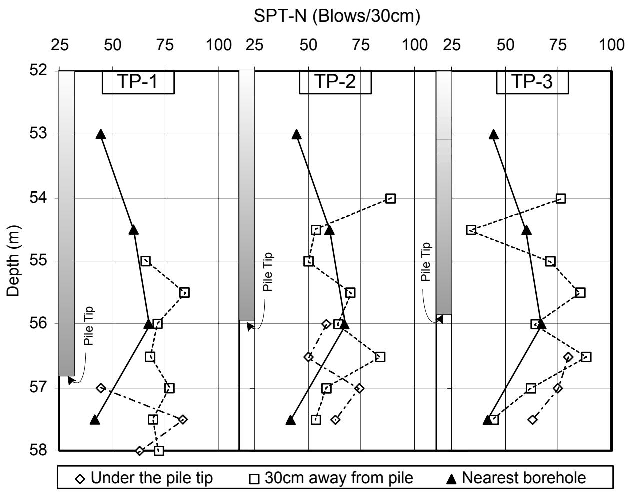


Figure 7. Comparison of SPT-N values around the grouted pile tip and the nearest borehole from soil investigation.

Most of the grout injected during base grouting rises up along the pile/soil interface and does not permeate into the surrounding sand layer. So the improvement made by base grouting is mainly contributed by increase in skin friction by stabilizing the cake film along the pile shaft or to form of rock – socket effect. The increase of end bearing capacity is mainly from the increase of density of sand beneath pile toe due to the pressure of base grouting.

3.5 Performance of Base Grouted Pile

The performance and behavior of base grouted bored pile were investigated by Teparaksa (1999, 2000, and 2002) based on instrumented tested piles. The pile shaft friction (fs) of pile generally can be curtained from

- For clay layer

$$f_s = \alpha S_u \quad (1)$$

- For sand layer

$$f_s = \beta \sigma'_v = k_s \tan\delta (\sigma'_v) \quad (2)$$

Where,

f_s	=	Unit pile shaft friction (kN/m^2)
Su	=	Undrained shear strength of clay (kN/m^2)
σ'_v	=	Effective overburden pressure in drawdown condition (kN/m^2)
α	=	Adhesion factor for clay
β	=	Friction factor for sand

The bearing capacity of the bored pile with pile tip in the sand layer generally derived from the followed approach

$$q_b = N_q \sigma'_v \quad (3)$$

Where

q_b	=	Unit end bearing capacity (kN/m^2)
N_q	=	Bearing coefficient
σ'_v	=	Effective overburden pressure in drawdown condition (kN/m^2)

The β - value and N_q value based on the pile test results on the fully instrumented bored pile were proposed as shown in Figure 8 and Figure 9, respectively

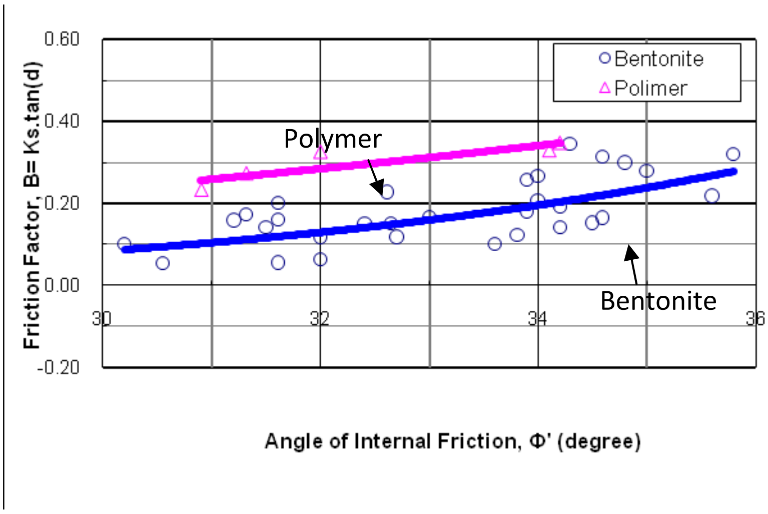


Figure 8 β - value for Base Grouted and Non Grouted Bored Pile

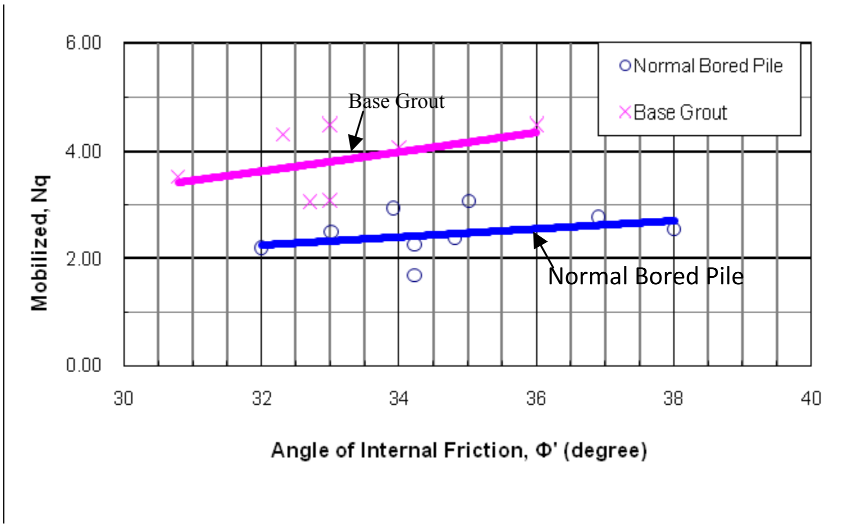


Figure. 9. N_q-parameter for Base and Non Based Grouted Bored Pile

4. Properties of Polymer Slurry and Model Test

4.1 Properties of Polymer Slurry

Polymer slurry is the mixing slurry between polymer powder and water. The polymer is the synthetic agent, partially hydrolyzed polyacrylamide (PHPA) type. The structure of polymer is the chain structure, as defined as the high molecular weight polymer. The polymer slurry, however, cannot perform the cake film, therefore, only pure polymer slurry cannot be used as hole-stabilizing agent. In practice, a small ratio of bentonite slurry will form a very thin cake film, while the polymer slurry will form chain structure along the drilled hole. The high molecular weight polymer will flocculate the soil or sand particle suspended in the slurry and sediment to the bored hole base as shown in Figure 10. This sedimentation is quite dense because it is strengthened by polymer chain structure and easily excavated by bucket drilling method.

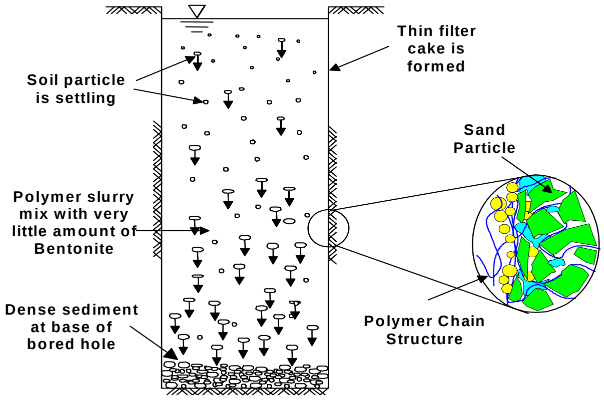


Figure. 10. The sediment to the bored hole base

4.2 Model Test on Bentonite and Polymer Slurry

The bentonite slurry of 5% of the slurry volume can create the thick cake film along pile shaft and create the loose sedimentation at pile toe. The research on using polymer slurry as the hole stabilizing slurry was investigated by Teparaksa & Boonyarak (2001) by mixing bentonite slurry and polymer slurry. The model test on the behavior of bentonite and polymer slurry has been carried out in order to clarify the interested issues of the ratio of bentonite slurry to polymer slurry to perform filtration in sand layer and strength increasing in the sand layer. The model was designed to simulate the borehole by using the cylinder mold of 190 mm. in diameter as shown in Figure 11

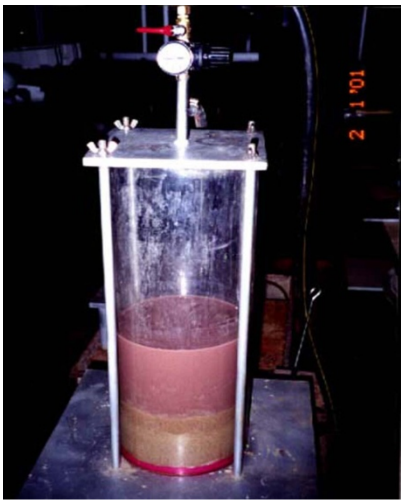


Figure. 11. The model was designed to simulate the borehole

The pressurize system was applied on Bangkok sand to simulate the real In-situ stress of the second sand layer at about 55 m. depth. After sample preparation and starting the pressurizing system, the slurry will flow through the sand layer which is so-called the filtrate volume of the slurry. Various mixes of slurry such as pure bentonite, bentonite mixed with polymer slurry and pure polymer slurry were tested. Figure 12 presents the filtrate volume of various mixing slurry passed through the sand layer.

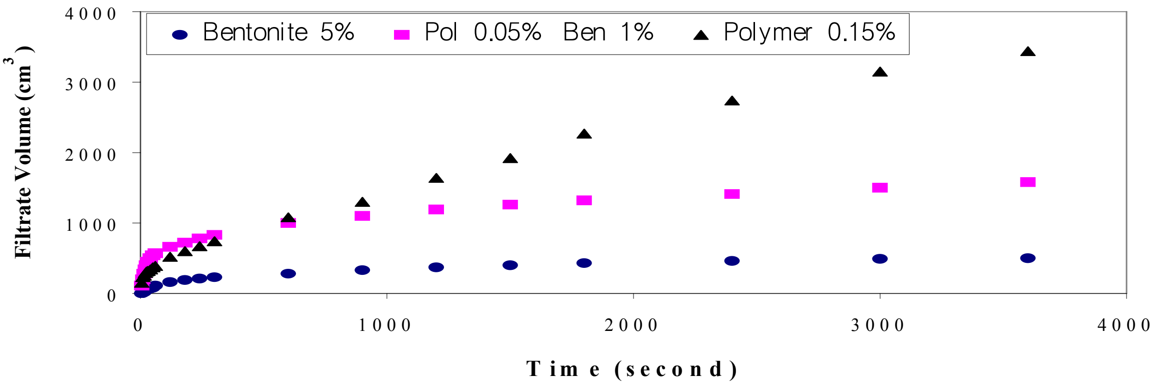


Figure 12 presents the filtrate volume of various mixing slurry pass through the sand layer.

It can be seen that in case of pure bentonite slurry, the filtrate volume is very low and become constant at very short period. This is because the cake film is formed at the surface of sand layer. In case of pure polymer, because of no cake film, there is no constant period of filtrate volume. In case of mixing only 1% of bentonite slurry and 0.05% of polymer by weight of slurry, it can be seen that there is a constant filtrate volume. It means that at 1% mixed of bentonite slurry, the cake film is formed on the surface of sand layer. The behavior of pure polymer without any bentonite, cake film cannot observe as shown by photograph in Figure 13.

Figure. 13. The cake film cannot observed.

The sand layer after the test shows no bonding and mostly no shear strength on their surface. In case of mixing between bentonite slurry 1% with polymer slurry, the sand particles are bond together by thin cake film from bentonite slurry and fiber from polymer slurry as shown in Figure 14.

Figure. 14. The thin cake film from bentonite slurry and fiber from polymer slurry.

Teparaksa & Boonyarak (2001) reported that appropriate mixing ratio of slurry was 1% by weight of bentonite mixed with 0.08% of polymer slurry.

5. Performance of Bored Pile with Polymer Slurry

The bentonite slurry only 1% by weight can be performed the thin cake film and it strength is increased due to the strengthen of fiber from polymer slurry of 0.08%. The high molecular weight polymer is flocculated the soil and sand particle and sediment to the bottom of the drill hole. Figure 15 presents the thickness of sedimentation at the bottom of the dill hole at various times after completion of the hole drilling for bored pile construction in Bangkok subsoils (Thasananiphan et al 1998). It can be seen that at about 100 minutes, all suspension is already settled and can be cleaned up. This benefit lead to improve the performance of wet process bored pile. Because of a very thin cake film in case of using 1% of bentonite slurry mixing with polymer slurry, the skin friction capacity in the sand layer is improved.

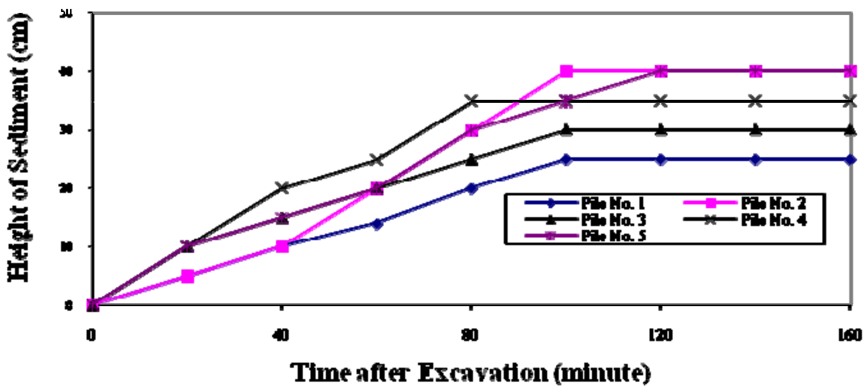


Figure. 15. Sedimentation of soil at bottom of drill hole

Teparaksa and Chuenhirun (2008) research the performance of bored pile using polymer based slurry based on the fully instrumented tests piles with pile tip seated in the second silty sand layer at about 50 -60 m. depth. The ultimate skin friction of pile for each soil layer was presented against the vertical strain of pile as shown in Figure 16. The stress strain relation of skin friction pile capacity was separated included soil properties for each soil layers from ground surface to deeper layer as presented in Table 2

Table. 2. Soil properties and each layers from ground surface.

Typical Soil Profile					
Pile	**Layer**	**Soil**	**Unit Weigth, γ_t(ton/m^3)**	**Water Content, w_n(%)**	**SPT-N Value (blows/ft)**
	1	Soft Clay	1.5 - 1.6	> 70	-
	2	Medium Stiff Silty Clay	1.6 - 1.7	60 - 50	6
	3	Stiff Clay to 1st Very Stiff Clay	1.8 - 2.0	40 - 30	14 - 19
	4	1st Dense Sand to 1st Very Dense Sand	2.0	-	20 - 30
	5	2nd Very Stiff Clay	2.0	20 - 16	25 - 35
	6	Hard Clay	2.0	-	43 - 59
	7	2nd Dense Sand	2.0	-	50 - 60
	8	2nd Very Dense Sand	2.0	-	> 60

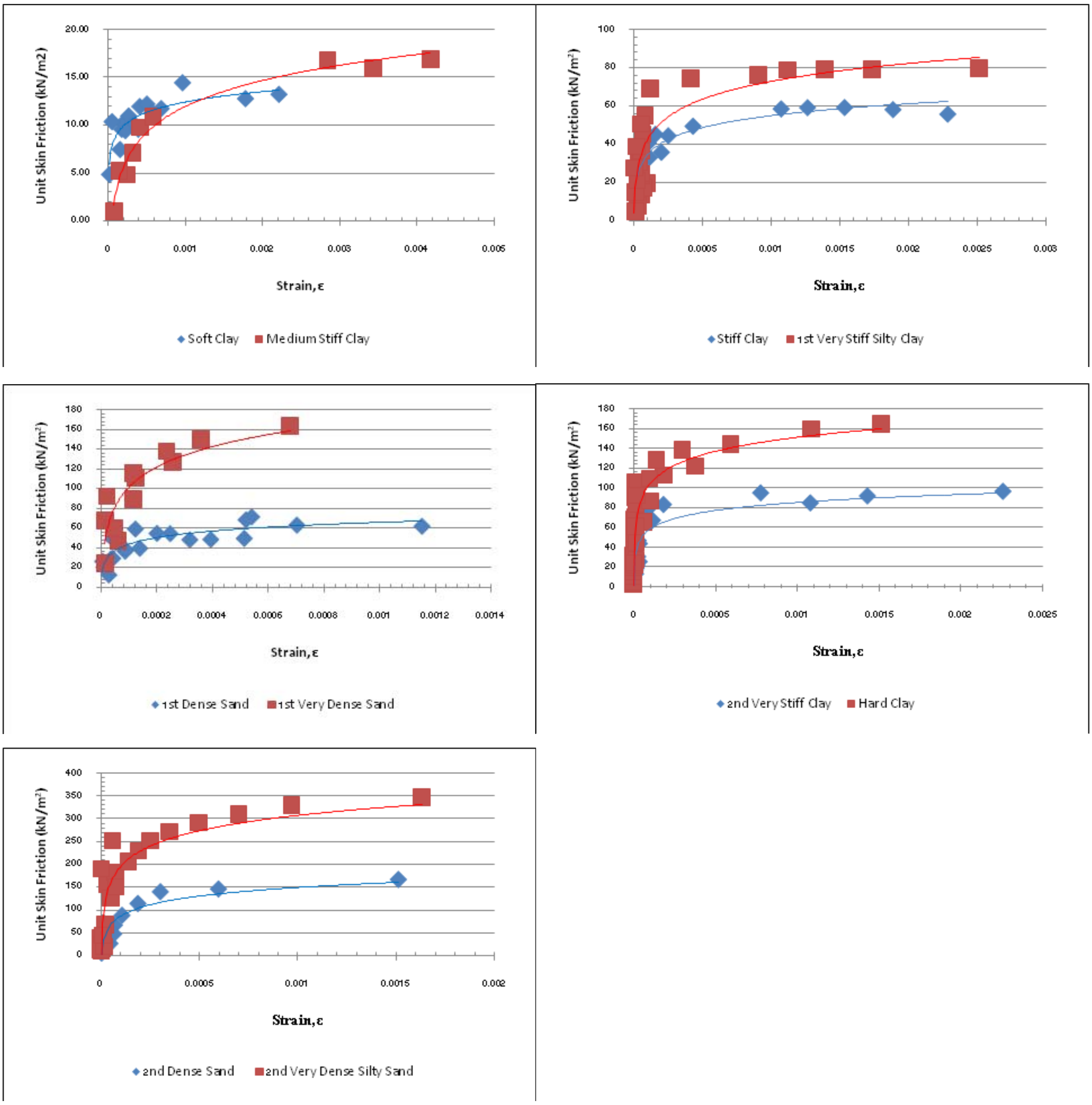


Figure 16 The ultimate skin friction of pile and strain at each soil layers.

The design friction factor β - value and end bearing factor N_q- value for bored using bentonite slurry and polymer slurry were presented in Figure 17 and 18.

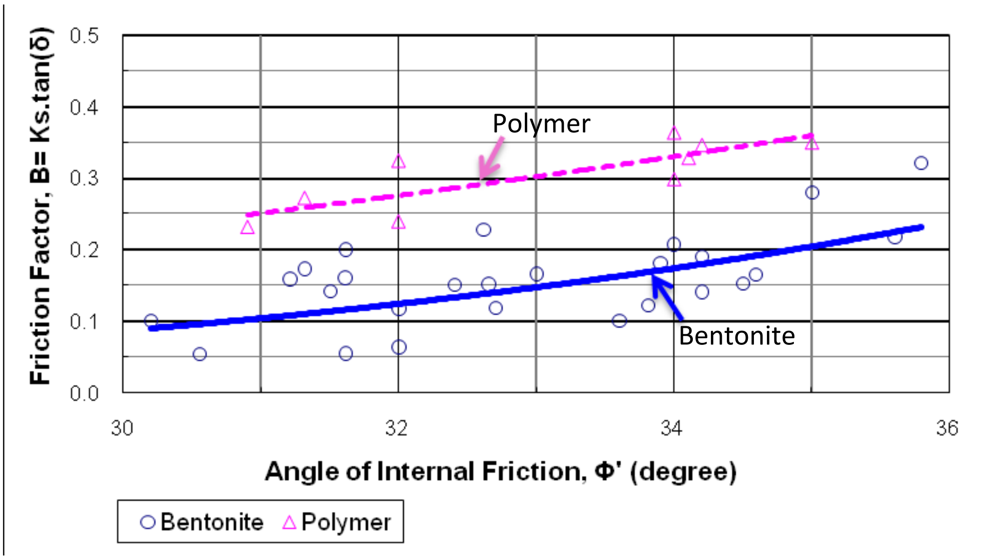


Figure 17. β - value with friction angle for Bored Pile tip in Sand

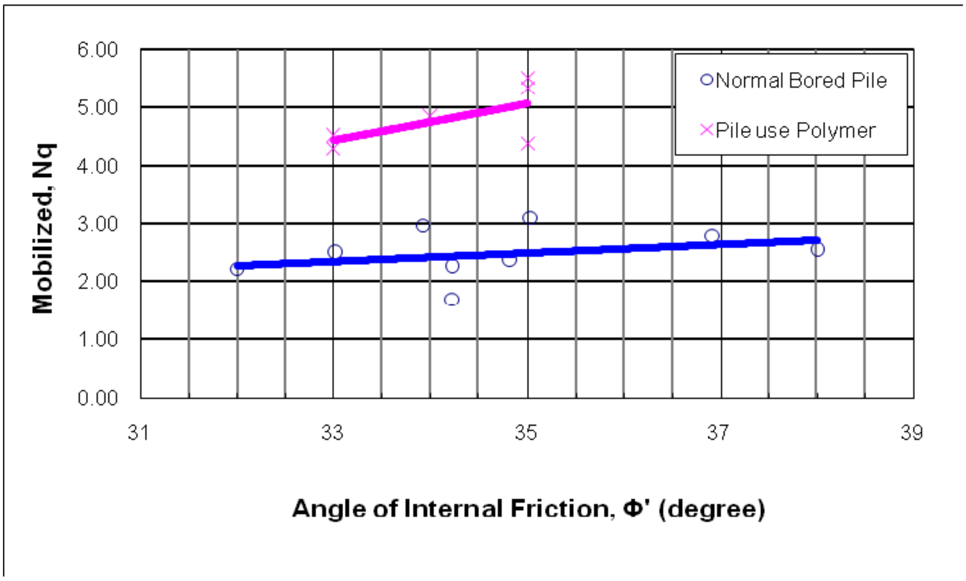


Figure 18. N_q- value and friction angle

It can be seen that the β - value for bored pile using polymer slurry show a significant higher resistance than normal bored pile using bentonite slurry.

6. Application on Remedial Work on loose Pile Capacity with large Deformation in Bangladesh

6.1 Project Description and Bored Pile Performace

The Rupsa Bridge is the bridge across the Rupsa river linked to bay of Bengal in the Khulna Province of Bangladesh. The bridge was totally 640 m. long supported by pile foundation of 2.6 m. in diameter and 75 - 83 m. long to carry safe load of 22,000 kN. The limit of pile settlement was allowed only 14 mm. at 1.5 times of design load. (33,000 kN) Before starting the bored piled construction, the first tested pile (TP1) was carried out without any instrumentation installation. The result of TP1 tested pile showed large pile movement more than 250 mm at the design load of 22000KN and settlement was maximum at 630 mm at 1.5time of design load 33000 KN as shown in Figure 19.

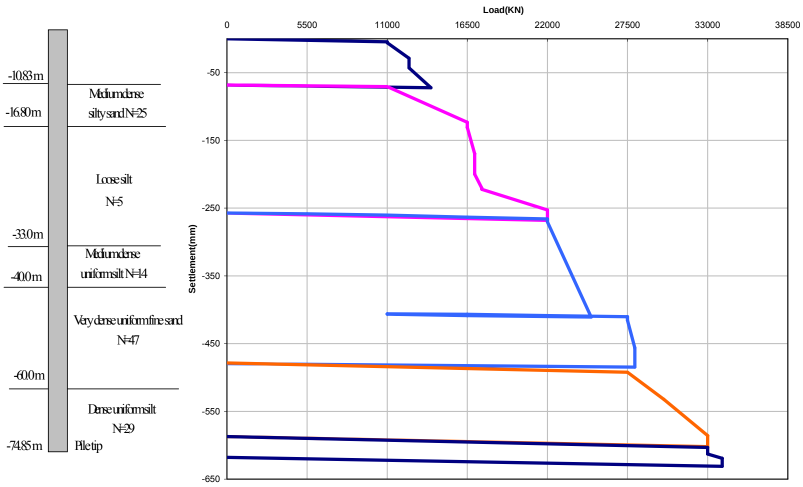


Fig. 19. Load-Settlement of the first tested pile TP1.

The specification was allowed the tested pile induced the settlement not more than 14 mm at 33000 KN or 1.5 times of design load. The TP1 tested bored piled was constructed using bentonite slurry of about 5 % of total slurry volume and bored by means of reverse circulation technique. Total constructed time of TP1 tested bored piled was about 106 hours and caused the problem of thick cake film along the shaft of the hole and created the low shaft friction as well as soft base behavior (Teparaksa, 1991 and 1992). The engineers found that the bentonite should be a major cause of this excessive pile movement, therefore the bored pile constructed by means of polymer slurry was used to solve this situation. The polymer based slurry consists of 5% of bentonite slurry with 0.08% of polymer of total slurry volume. The second tested pile (TP2) was constructed together with 6 no. of real piles. The second tested pile was tested without any instrumentation installation. The test result on TP2 pile showed worse result than the TP1 tested pile by having pile settlement of about 320 mm. at design load of 22,000 KN as shown in Figure 20. The bored pile construction of the project was, therefore, stopped and remedial the excessive pile displacement. The author was invited to solve two major problems as to remedial the second test pile TP2 and can applied to remedy real 6 piles those were constructed together with TP2 tested pile. The second issue was to create a new solution for construction all new bored piles of the project.

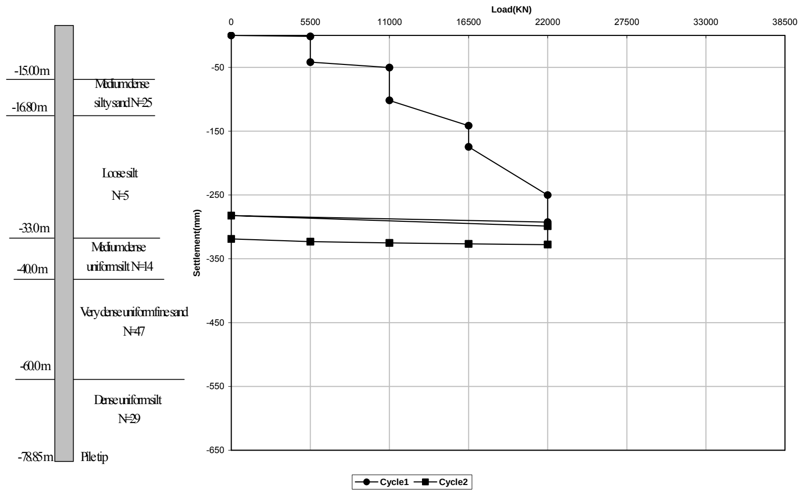


Fig. 20. Load-Settlement of the second tested pile TP2.

The soil condition of the Rupsa Bridge project can be summarized in Table 3. It can be seen that the pile tip of the bored piles is seated in the dense fine sand layer.

Table 3.. Soil condition and engineering properties.

Depth (m)	Soil Description	γ_t (t/m^3)	N (Blow/ft)	ϕ' (degree)	S_u t/m^2
-12.7 to -16.8	Medium dense Silty sand	1.9	25	32.8	-
-16.8 to -33.0	Loose Silt	1.8	5	27	-
-33.0 to -40.0	Medium dense uniform Silt	1.9	14	29	-
-40.0 to -60.0	Dense uniform Silt	1.9	29	31.2	-
-60.0 to -95.7	Very dense uniform fine Sand	2.0	47	33	-

6.2 Remedial Measure on Loss Pile Capacity

The major cause of the excessive settlement of both tested bored piles TP1 and TP2 are due to

- The thick cake film and reduce the shaft friction of pile.
- Soft base or loose sedimentation of bentonite at pile toe and lead to loss both friction and end bearing of pile.

The remedial method was divided into 2 categories as

6.2.1 Remedial work on thick cake film with soft base

The TP2 tested pile was pointed out by the author based on experience in deep and large bored pile in Bangkok subsoil (Teparaksa, 1999 and 2001) that it was due to the thick cake film and sedimentation of bentonite at pile toe. The remedial technique was proposed by

- Improve end bearing capacity by toe grouting technique through six existing logging tubes to about 3.30 m. depth below pile tip.

- Improve shaft friction capacity by skin grouting technique eight points surrounding outside of the pile as shown in Figure 21.

The skin grouting was applied only from 50 m. depth to pile tip (75 m. depth). Geotechnical instrumentation by installation of 6 gauges was fixed into sonic logging tube and 5 strain gauges in the skin grouting pipe. The conventional load test on the remedial second tested pile (TP2) was performed after one month bored pile completion. The result showed the settlement at design load of 22,000 KN only at 8 mm. and 14 mm. at 1.5 times of design load (33,000 KN) as presented in Figure 22. This technique, then was used to remedy six numbers of real piles.

6.2.2 New solution for construction new bored piles

The new solution was proposed by the following techniques

- Use base grouting by installation of the tube-a-manchette at pile toe by installation together with reinforcement cage. This base grouting will improve not only soft base problem but also improve shaft friction of pile (Teparaksa et. al, 1999)
- Use shaft grouting technique by installation 8 tubes of manchette and apply horizontal grouting surrounding the pile from 50 m. depth to pile toe.

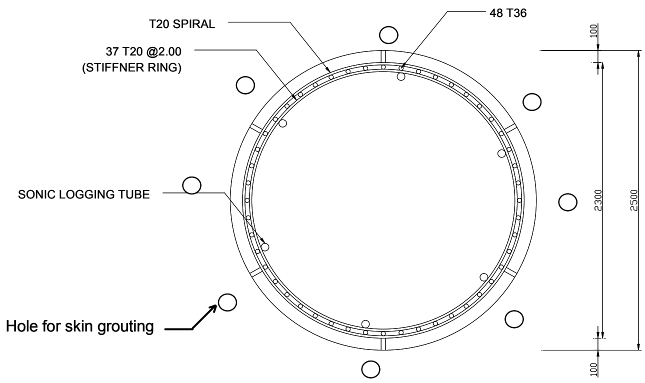


Fig. 21. Location of toe grout through sonic logging tube and hole of skin grout.

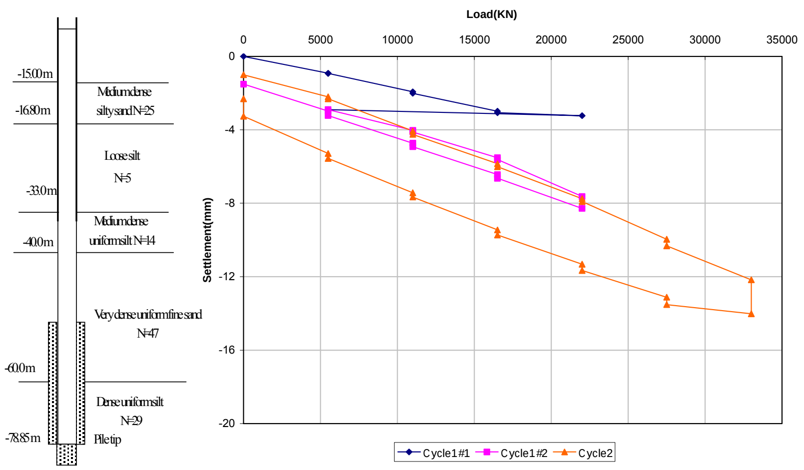


Fig. 22. Load-Settlement of remedial second tested pile TP2r.

The fully instrumentation was installed in this new third pile (TP3). For comparison with remedial test pile (TP2r), the pile load test by means of Osterberg Cell testing method was proposed by installation 2 load cells at close to pile tip (85 m. depth) and other one at middle of pile at -66 m. depth. Figure 23 and 24 presented the results of pile load test for stage 1 loading at lower load cell, and for stage 2 loading at middle load cell, respectively. The settlement of the third tested pile was very small and much less than the specification.

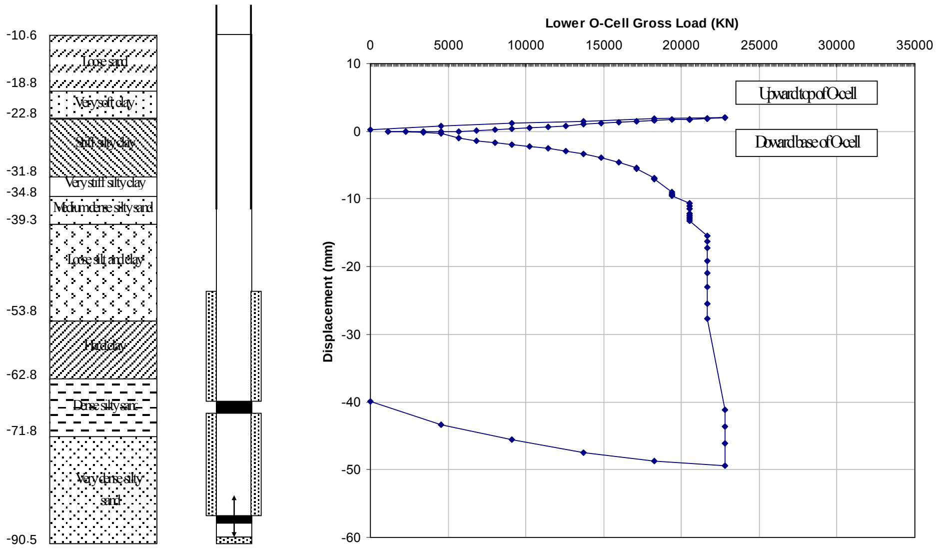


Fig. 23. Load-Settlement of third tested pile TP3 at stage 1.

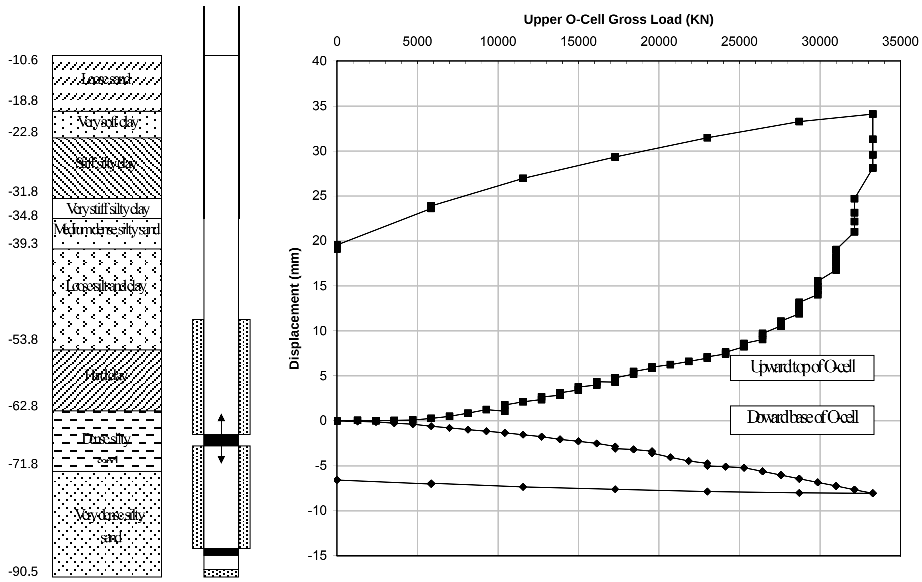


Fig.24. Load-Settlement of third tested pile TP3 at stage 2.

7. Conclusion

The benefit of bentonite slurry as stabilize suspension of drill hole is well known for bored pile construction. The bentonite slurry creates the cake film along the pile shaft in the sand layer and settles as loose sedimentation at pile toe. This soft base of the bored pile was solved by cement base grouting technique. The mechanism of base grouted bored pile was investigated by direct collected sample beneath the pile tip. The polymer slurry recently widely used to replace the bentonite slurry. The polymer slurry can not create the cake film and can made the soil particle in the drill hole settle to pile toe and can be absolutely clean out. The model test on polymer can be simulated the polymer mechanism and its increasing strength. The polymer slurry can improve the pile capacity both skin friction and end bearing capacity. The application on remedial work of loss capacity pile in Bangladesh by using polymer slurry and base grouting technique was presented.

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