Pile Capacity Behavior of Very Long Bored Piles in Bangkok Soil

Siam Aunmongkonmit[1,*] Thayanan Boonyarak[2] and Zaw Zaw Aye[3]

1, 2 EDE Company Limited, Bangkok 10510, Thailand
3 Seafco Public Company Limited, Bangkok 10510, Thailand
**Corresponding author; E-mail address: siam_aunmongkonmit@hotmail.com*

Abstract

Urbanization in Bangkok necessitates large-scale construction that often conflicts with the city's limited space. To address this challenge, very long bored piles (exceeding 60 meters) have emerged as a more suitable geotechnical solution for supporting high-rise buildings, deep excavations, and large infrastructure projects. These piles offer potential benefits such as reduced construction time, lower costs, and a smaller carbon footprint. This study investigates the effects of pile length, diameter, and ultimate bearing capacity by analyzing monitoring data from numerous projects in Bangkok, focusing on factors such as skin friction, and end-bearing resistance. Static pile load test results for piles ranging from 60 to 100 meters in length demonstrate that extended pile lengths significantly enhance load capacity, primarily due to increased shaft friction at greater depths, represented by higher friction factors (β). These findings suggest that longer piles can replace or reduce the number of conventional bored piles, resulting in a 50% increase in load capacity per unit volume of concrete. This also leads to a reduction in total concrete consumption. Additionally, while traditional pile designs required a safety factor of 2.5, static pile load tests allow for a reduced safety factor of 2.0, potentially cutting the carbon footprint by 25%. Moreover, the substitution of bentonite slurry with polymer slurry further improves the ultimate bearing capacity and settlement performance of bored piles, making them more efficient and sustainable for urban geotechnical applications. piles.

Keywords: Very long bored piles, Ultimate bearing capacity, Friction factor (β), Static pile load test, Carbon footprint reduction

1. Introduction

Due to the limited space within the city and mega projects in Bangkok, which include large scale infrastructures to support those heavy structures, deep foundation is required, a foundation with higher efficiency. In particular, the soil beneath Bangkok, which has a thick layer (up to 20 m.) of clay with low shear strength and stiffness but high compressibility, is known as Bangkok clay. Previously, there was a change to use piles with a much larger diameter. However, this research will present another solution: using deep piles (exceeding 60 meters). It is well known that piles' bearing capacity increases with the soil layer's depth. The deeper the soil, the higher the soil stiffness, including the friction and end-bearing values of the piles. This research focused on the performance of deep-seated long bored piles based on pile load test results. The design parameters became so well established that wet-process cast-in-place foundations became regarded as reliable foundations for practitioners involved in the construction industry in Bangkok

2. Geotechnical information

2.1 Subsoil and existing piezometric profile

Geologically, Bangkok subsoil consisted of alternating clay and sand layers of thick Quaternary deposits extending shown to about 550 m. depth where bedrock generally exists, (Balasubramaniun, 1991) [3]. Verry soft to Soft clay, highly compressible dark gray marine clay lies beneath weathered crust layer of 2 m. thick. Depending on the location, this layer is extended up 12 m. to 18 m.

About 2 m. thick Medium Clay layer can be observed between Soft Clay and underlying Stiff Clay. Generally Stiff Clay layer occurs directly underneath Medium Clay and its depth goes up to 22 m. Below Stiff Clay layer, First Sand layer 5-8 m. in thickness can be found. This First Sand layer, however, is absent in some areas. Stiff to Hard Clay layer underlies First Sand and it is found to be about 5 m. thick. Second Sand layer generally occurs at depths between 45 to 65 m. Existing pore water pressure conditions in upper part of Bangkok Soft Clay are hydrostatic from nearly 1 m. below the ground level. Then the hydrostatic conditions change to piezometric drawdown near bottom level of Bangkok Soft Clay. Typical Bangkok subsoil and piezometric profile are shown in Figure 1.

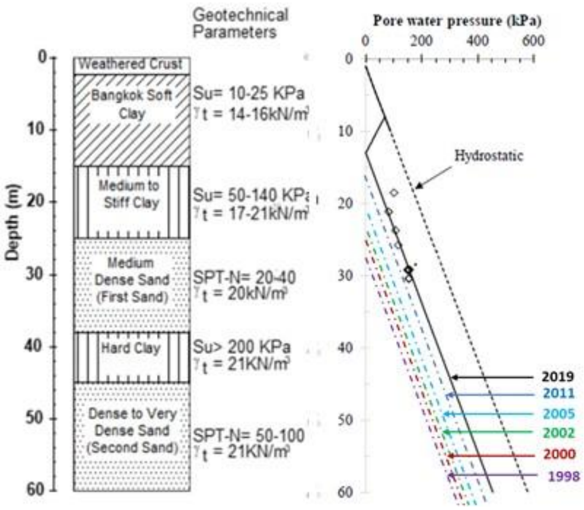

Figure 1. Typical soil profile of Bangkok with piezometric drawdown condition (Zaw Zaw Aye, et. al., 2024)

3. Overview of Bored pile construction sequences and quality control

3.1 Type of deep foundation

Figure 2 shows a drilling rig of circular bored pile. This type of pile can be constructed in almost all soil conditions, depth of circular bored pile can be deeper than 100 m.

Figure 2: Drilling Machine (a) Rotary auger and bucket type; (b) Hydraulic grab for normal conditions; (c) Mechanical grab for limited headroom conditions. (Thasnanipan, et. al., 2002)

3.2 Construction sequences of bored pile

The construction sequences of wet bored piles are shown in Figure 3, as follows:

(1) Pre-boring of hard soil at the surface is carried out

(2) Install temporary steel casings using low vibration method to protect borehole collapse in soft soil

(3) Excavation the soil in the clay layer with a drilling rig.

(4) Prior to encounter unstable soil layer beneath the depth of the casing, bentonite slurry or polymer slurry is poured into the borehole for stabilization. Slurry circulation using pump and desander is used for cleaning of slurry.

(5) Reinforcement cages are lowered into the borehole, insert the Tremie pipe and pour the concrete.

(6) When the concrete is poured, remove the steel casing before the concrete sets.

One of concerns for bored pile construction is vibration in construction. To minimize the vibration in sensitive area, double-casing method using short-casing and long-casing is adopted.

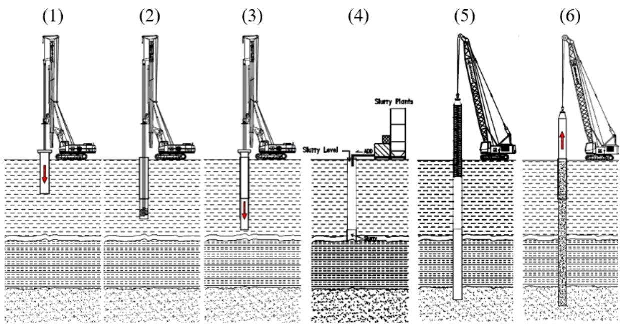

Figure 3. Construction sequences of wet bored piles (Zaw Zaw Aye, et. al., 2018)

3.3 Quality control in bored pile construction

Deviation and inclination of the borehole are controlled to be within 75 mm. at ground level and 1:100, respectively. The methods for controlling deviation and inclination of borehole are conventional survey technique, visual inspection and drilling monitor apparatus. To ensure the quality of the drilling fluid, routine testing is carried out prior to exaction and concreting (FHWA, 2010) [12]. Reinforcement cage lowering, rock samples at the pile base are identified and sediment measurement using sounding method by measuring tape is carried out. Concrete slump and setting time for wet-process bored pile are 150-200 mm. and 4-6 hours, respectively. For Tremie concrete, apart from flow ability, stability to prevent bleeding and channeling is also required (EFFC/DFI, 2018) [11].

4. Overview on design concept and parameters

4.1 Load Transfer Characteristics of Bored pile

Tomlinson (1995) approach considers proportion of load carry between shaft resistance and end bearing. In this analysis, proportion of load carry was obtained from measured axial force distribution in the pile. Vibrating wire strain gauges (VWSG) were installed at the major soil boundaries for each pile. The measured data from strain gauge, load distribution curves along the test pile shaft at various applied load are shown in figure 4, found that there was a tendency to follow the Tomlinson's theory, which is the skin friction load is a first part of pile capacity at 100% and gradually decreased along the shaft to tip and remaining load will transfer load and support by end bearing as a second part of pile capacity. Using Tomlinson's method (1995) for pile settlement as follow at working load and ultimate load transfer to pile toe was 0.1% and 5.0%, respectively in this study.

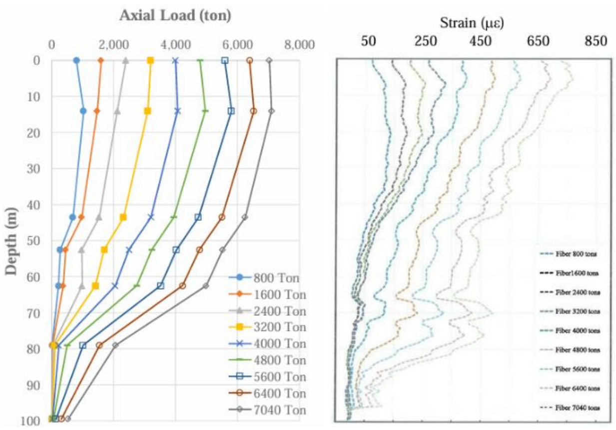

Figure 4: Example of load transfer and strain curves of pile (Aye, Z. Z., et al., 2024)

4.2 Static pile load test

Installed four anchor piles and the reference beams to find the settlement of the test piles. Hydraulic Jack is used to create axial compression or dead load on kentledge is adopted as the reaction system to the test piles and measure the pile settlement by dial gauges with measurement range of 0 to 50 mm. and a resolution of 0.01 mm. according to ASTM D1143 standard are carried out on working piles of the project. Maintained loading procedures from the design working load to the ultimate load (up to 3.25 times) are adopted. Using static load test method to determine the settlement and verify the capacity of each pile and each project in this paper.

Table 1. Results of Static pile load test of each project.

Project	Pile length (m.)	Diameter of pile (m.)	Load (kN)	Settlement (mm.)
1. Rama 3 Road	90.0	1.80	24,000	9.29
			42,000	23.05
			60,000	40.94
2. Rama 3 Road	90.0	1.80	24,000	10.59
			42,000	24.58
			60,000	43.30
3. Rama 4 Road	84.0	1.80	20,000	8.09
			50,000	32.30
			65,000	53.16
4. Ratchadamri Road	92.0	1.80	28,000	13.04
			49,000	27.01
			56,000	47.07
5. Rama 4 Road (pile tip in clay layer)	80.0	1.80	23,000	9.97
			34,500	18.84
			46,000	31.23
6. Rama 4 Road (pile tip in clay layer)	75.5	1.50	13,500	6.37
			33,750	29.39
			43,875	44.54

4.3 Load versus settlement

In the initial stage of introducing bored piles in Bangkok, Thailand, the design concept and parameters were mainly based on the available literature from research carried out in other parts of the world such as Bowles (1968, 1996) [7, 8], Broms (1966) [9], Meyerhof (1976) [13] and Tomlinson (1957) [24]. The work of Chiruppapa (1968) [10] was believed to be the first research data available for design parameters of bored piles in Bangkok soft clay. With the passage of time, design method and selection of parameters for local subsoil were improved as a result of research carried out in 1980s. It should be noted that the design parameters obtained from the research of 1980s were mainly based on the estimation of shaft friction loads from plain static pile load test results with numbers of assumptions, since instrumented pile load test results were limited. With the peak of construction boom in Thailand, particularly in Bangkok, large numbers of instrumented full-scale static load tests on bored piles were conducted throughout the 1990's which provided a better understanding of the behavior of these deep-seated foundations. Researches focused on the design parameters and methods were published based on these test data. With more confidence on soil parameters selection and better understanding on behavior of these deep foundations, the designer designed higher load capacity bored piles and barrettes in late 1990s than those in the 1980s. Thasnanipan et. al., (1999) [16] reported the failure mechanism of long bored piles in layered soil of Bangkok. The major issue for the design and construction of deep foundations is the understanding of their behavior. Figure 5 shows that using deeper piles can significantly increase the pile load-bearing capacity, while construction area is limited, the problem of differential settlement can be reduced.

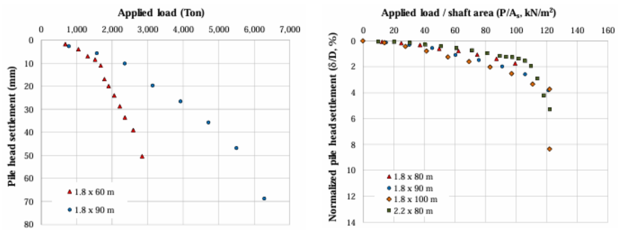

Figure 5: Comparison Load-settlement curves of circular bored pile with different depth of pile tip
(Thasnanipan, 2003)

Results of load-settlement relationship of circular bored pile are shown in Figure 6. For comparison of different soil types at embedded pile tip and types of slurry, applied load is divided by shaft area (P/As) and settlement at pile head is normalized by its pile diameter (δ/D) show the trend same as previous research that the efficiency of pile capacity can improve with pile tip embedded in sand layer rather than in clay layer and bored pile construction with polymer slurry instead of bentonite slurry can provided high bearing pile capacity and reduced pile settlement also. It suggests that the shaft friction of bored pile using bentonite slurry is smaller than those with polymer slurry. Bentonite slurry former a thicker filter cake layer between the pile surface and the soil than the polymer slurry, this layer directly affects the reduction of friction between the surfaces, resulting in bentonite slurry can create smaller shaft friction than polymer slurry which is consistent with research by Thasnanipan et al., (2003) [19].

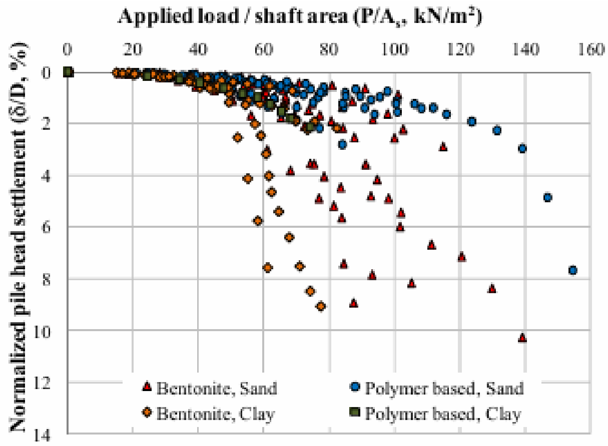

Figure 6: Load-settlement curves with different soil types
(Aye, Z. Z., and Boonyarak, T. 2017)

General trend of load-settlement curves can be described by bi-linear relationship. The first part of linear is where normalized settlement is within 2%. After that, load-settlement relationship becomes curved or called transition zone. The second part of linear is the zone of higher settlement rate than the first part of linear as shown in Figure 7.

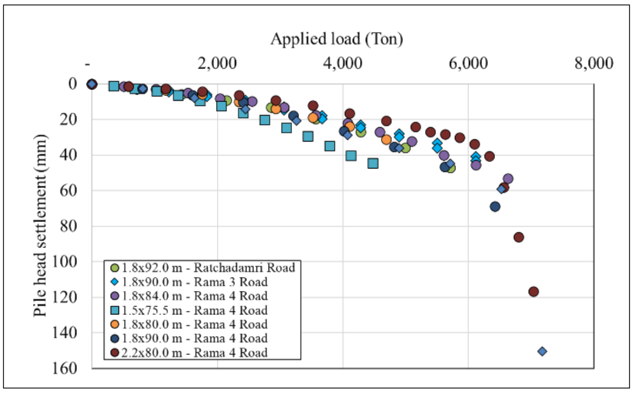

Figure 7: Load-settlement curves of very long bored pile in Bangkok from different project.

Note that only one set of data from pile using polymer shows a bi-linear behavior as axial load did not transfer to the toe of most of piles of this type. Considering type of soil at pile base, it is found that pile with tip in sand had smaller settlement than those having tip in clay (given the same type of drilling slurry). This is because soil stiffness (e.g. Young's modulus) of sand (at depth of more than 40 m.) is substantially larger than clay as stiffness proportionally increases with depth for sand. In addition, the type of soil at the pile tip also affects settlement, found that the settlement of pile tip in clay is larger than sand, as can be seen from the trends in Figures 8 and Figures 9.

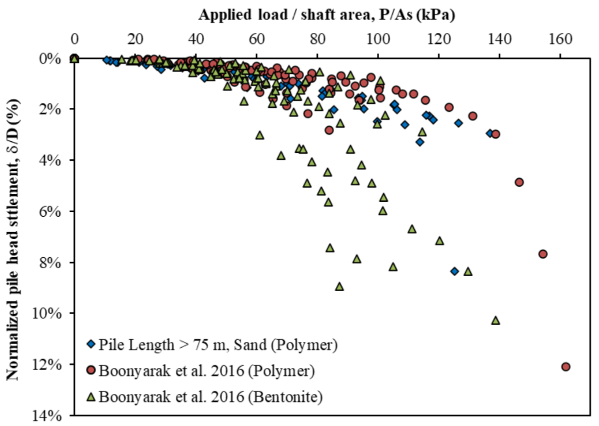

Figure 8: Load-settlement curves of pile tip in Sand (Boonyarak et al., 2016)

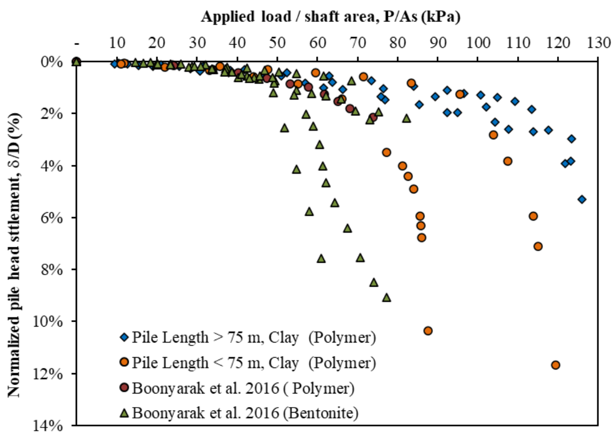

Figure 9: Load-settlement curves of pile tip in Clay (Boonyarak et al., 2016)

Support the results of Thasnanipan et al., 2003 that shaft friction of bored pile using bentonite slurry is smaller than polymer slurry because bentonite slurry is a cause of thicker filter cake than polymer slurry. Therefore, types of drilling slurry is another important factor for the shaft friction and settlement.

4.4 Estimation of settlement

From previous design and research found that Tomlinson's equation provides a reasonable estimation of pile settlement. In this research, Tomlinson's equation was chosen to calculate for estimate of pile settlement. Figure 10 shows the comparison between measured and calculated normalized very long pile head settlement (δ/D, %) at working load and ultimate load of each test (only δ/D not exceeding 5%). Pile settlement can be calculated using Equation (1) proposed by Tomlinson (1995) [24] as shown below.

$$\delta = \frac{(W_s+2W_b)L}{2A_sE_p} + \frac{\pi W_b B(1-v^2)I_p}{4A_bE_s} \quad (1)$$

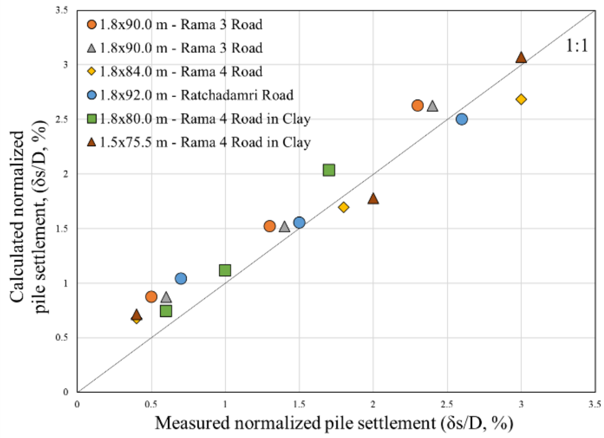

Figure 10: Comparison of measured normalized pile settlement and calculated normalized pile settlement prediction by Tomlinson

Results show that Tomlinson's equation still provides a reasonable estimate of pile settlement for very long bored pile compared to the actual pile settlement from field monitoring.

4.5 Back-calculated β values

Introduction of polymer-based slurry for wet-process bored piles marked a major breakthrough for both construction and design engineers. Thansnanipan et al., (2002) [17], reported that bored piles constructed with polymer-based slurry have higher capacity than those constructed with bentonite slurry. Figure 11 shows the shaft friction factors β of sand layers for polymer-based bored piles compared with the design line of bentonite bored piles and Figure 12 verifies that polymer slurry provided the friction parameter (β) higher than using bentonite slurry. The higher load capacity of bored piles constructed with polymer-based slurry allows the use of a single deep-seated bored pile in place of a group of smaller-sized shallow-seated bored piles or driven piles.

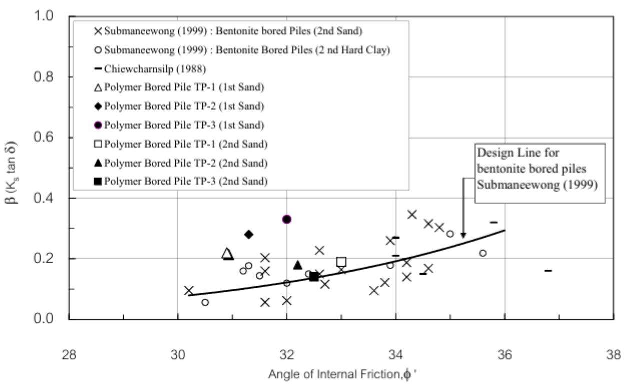

Figure 11: Back-calculated β values in Bangkok subsoil (Thansnanipan et. al 2002)

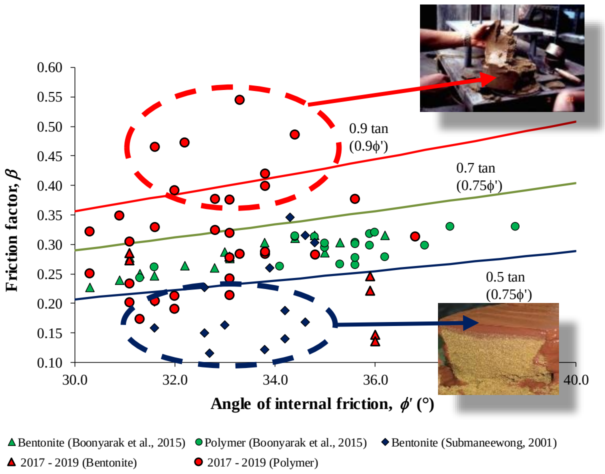

Figure 12: Comparison of the friction parameter (β) between bentonite and polymer slurry from projects in Bangkok (Aye, Z. Z., and Boonyarak, T. 2017)

4.6 Carbon Reduction Initiatives

Reducing carbon emissions is a challenging and critical step towards achieving sustainability goals. In deep foundation construction, applying value engineering options to reduce materials such as concrete and steel is one of the key components in carbon reduction initiatives. According to the announcement from the Ministry of Interior from Thailand on the determination of the foundation of the building and the ground that supports the building, specified that if the static pile load test is also included, the maximum test load can be reduced by at least 2 times from the safe load (reduced from 2.5 times) [28], which is considered to reduce the amount of construction materials by at least 25%. From the projects that this research considered, it can be seen that many projects have reduced the maximum load test to only 2 times, even though the piles are still tested to the point of failure.

5. Recommendations and Conclusions

Based on field monitoring, numerical back-analysis and parametric study results from projects in Bangkok. As well as comparisons with previous research, the results clearly show the same trend that foundation is going to be deeper and has higher performance to support buildings. According to the given information, conclusions as follows:

(a.) Bored pile constructed using the same type of slurry, bored piles embedded in clay have larger pile settlement than those embedded in sand due to smaller soil stiffness.

(b.) For deep foundation embedded in the same soil type, the settlement of bored pile constructed using bentonite slurry is substantially larger than that constructed with polymer slurry. This is because of a thicker filter cake in the former than the latter, causing a reduction in shaft friction. Which significantly affects the parameter (β) from Figure 12.

(c.) Calculation of pile settlement using analytical equations such as Tomlinson's provides reasonable estimation for Bangkok soil for this research.

(d.) Very long piles can replace or reduce the number of conventional bored piles with resulting in a 50% increase in load capacity per unit volume of concrete whereas can also reduce pile settlement also.

(e.) Very long bored piles also lead to a reduction in total construction materials consumption (concrete material). Additionally, while the safety factor of static pile load tests allows for a reduction from 2.5 to 2.0, potentially cutting the carbon footprint by 25%.

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