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Adhesion Factor (α) of Bored Piles in Clay Shale Derived From Static and Dynamic Load

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ABSTRACT Adhesion factor (α) is one of the significant parameters in calculating the bearing capacity of pile foundations, both for driven piles and bored piles in clay soils. In practice, the α value is usually estimated based on the available empirical correlations. The applicability of this correlation for bored pile installed in expansive soil and clay shale is questionable. Clay shale is known as one of the problematic soils, due to its physical properties that rapidly soften once exposed to water/moisture and loss of pressure. This physical sensitivity becomes crucial in bored pile constructions. Especially in the drilling and casting process as the soil is exposed to water and loss of horizontal pressure causing reduction in soil shear strength. This study investigates the load transfer behavior of a bored pile installed in clay shale formation. The pile, instrumented with vibrating wire strain gauges, was axially loaded through dynamic and static load test up to 700 tons. The strain gauges provide accurate strain measurement of each pile segment, proportional to the stress induced. Through the pile load-settlement, *t-z* and *q-z* curves, the load transfer mechanism and interaction between bored pile and the clay shale soil can be analyzed. By performing back analysis, the actual skin friction (*fs*), and adhesion factor (*α*), of bored piles in clay shale can be determined. The results show that in clay shale that have experienced slaking (30 < NSPT < 70), the adhesion factor (*α*) = 0.12~0.18. While for fresh clay shale (NSPT > 70), the adhesion factor (*α*) = 0.32~0.35. These values are significantly lower than α = 0.55 which is usually applied in practice; as well as some previous studies, including the value recommended by Reese and Wright (1979).

KEYWORDS Clay Shale; Bored Pile; Adhesion Factor; Skin Friction; Shaft Resistance

1 INTRODUCTION

Bored pile foundations are often the most suitable choice for projects requiring large bearing capacity. For bored pile in clay shale formations, determination of pile capacity becomes a challenge. Clay shale is known as one of the problematic soils. Mainly due to its physical properties that quickly deteriorate and become soft when exposed to water and moisture, as well as pressure loss. The sensitivity of this soil type is a major issue in bored pile construction, especially during the drilling process that involves water, the interval between drilling to casting, where the soil is exposed to air and water as well as loss of horizontal pressure. Depending on the duration of this time lag, the soil can experience a decrease in shear strength. As a result, the determination of the pile's bearing capacity becomes challenging.

The adhesion factor (*α*) is one of the significant parameters in calculating the bearing capacity of pile foundations in clay soils. Specifically, for bored piles in clay shale. This research aims to obtain the actual values of skin friction (*fs*) and adhesion factor (*α*) for bored pile installed in clay shale using static and dynamic load test.

2 CLAY SHALE CHARACTERISTICS AND SOIL CONDITIONS

Clay shale is formed by diagenesis process of sedimentation of soil into rock, where the material undergoes compaction and hardening and is fragmented layer by layer. Therefore, clay shale has anisotropic properties with its clay-sized constituent materials. Air and water exposure greatly affects the strength and compressibility of clay shale. Generally, clay shale is rapidly weathered when exposed to water or moisture. Therefore, it is necessary to minimize clay shale's contact with atmosphere during construction (Sudjatmiko, 2017; Wirmando et al., 2017).

This study was located in Citeureup, Bogor, West Java. Approximately 17 km northwest of the city of Bogor. Figure 1 shows the geological map of the area surrounding the research location. Geologically, the area is quite complex as it lies on the border of several geological formations. Referring to the regional geologic map (Turkandi et al., 1992), the study area is formed by three main formations i.e., Klapanunggal Formation (Tmk), Jatiluhur Formation (Tmj) and Aluvium deposits (Qa). Klapanunggal Formation (Tmk) is composed of coral limestone, sandy limestone insertion, marl, green glaconite quartz sandstone. Jatiluhur Formation (Tmj) consists of marl, shale, clay with quartz sandstone inserts, gray to black in color, easily crushed, and expands if exposed to water. This formation was formed in the middle to late Miocene. The upper part of the Jatiluhur formation overlies the Subang formation. In some places, the upper part of the Subang formation overlies unaligned Jatiluhur formation. Aluvium deposits (Qa) consists of clays, silts, pebbles, and gravel. Mainly river deposits, including sands and gravels from coastal deposits along the Pelabuhanratu bay. As for alluvial fan (Qav), it consists of silt, sandstone, gravel, and boulder deposits from Quaternary volcanic rocks that were redeposited as alluvial fans.

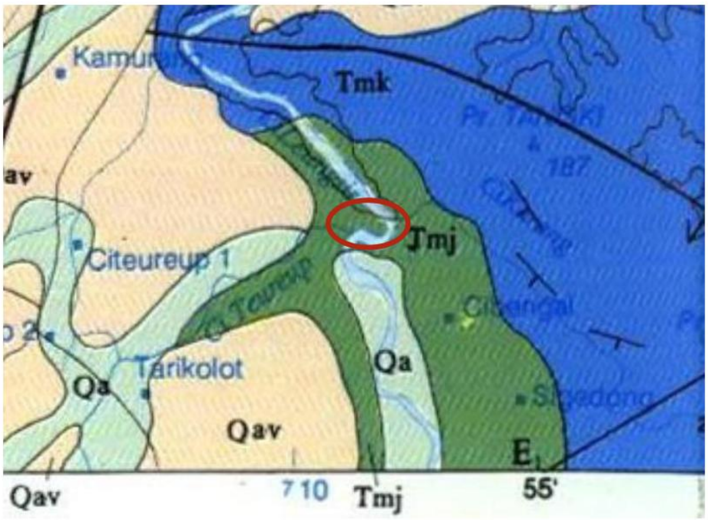

Figure 1. Research location on the geological map of Citeureup area

Oktaviani et al. (2018) reported the low durability of Jatiluhur formation's clay shale rock when exposed to air and water. Widjaja (2001) also examined the clay shale in this formation, specifically for clay shale layers at a depth of 1.0 to 10.5 m. He reported that the weathering process was capable of reducing the durability of the clay shale by 50%. Sudjatmiko (2017) showed that clay shale of Cikarang area can experience a shear strength reduction of 70–90% when the moisture content exceeds 35%.

To get an overview of soil stratigraphy and the physical properties of each layer, soil investigation program was conducted consisting of 37 core borings, including Standard Penetration Test (SPT) at 1.5 m intervals. At each point, drilling was carried out to a depth of 30 m. Figure 2 provides the boring log BH–31 and its interpretation of the soil stratigraphy. The SPT test results show that the consistency of this clay layer increases gradually with depth. From NSPT = 3 at 3 m depth, to the NSPT increases to 40 at 6 m depth and reaches NSPT 100 at 16~17 m depth. Drilling results of BH–22 and BH–31 show a consistent soil stratigraphy. The top soil layers are dominated by gray and brown clay with firm to very firm consistency. A layer of compacted sand and gravel at depth of 4 to ±7 m was found just above shale soil layer at a depth of ±7 m.

The soil investigation results showed that study area is dominated by clayey silt with fine sand interspersed. At the surface (up to a depth of ± 4.5 m), there are fine materials such as silt and clay from deformation of tuff, passive tuff with medium to firm consistency. At depths of more than ± 5.7 m, it is dominated by clayey silt with a very firm consistency. The yellow area shown on Figure 2, is a virtual stratification of soil layer to represent weathered clay shale with NSPT < 70 at 7~11 m depth, while the red area is to represent fresh clay shale with NSPT > 70 at 15~23 m depth. This stratification will be used for the pile analysis.

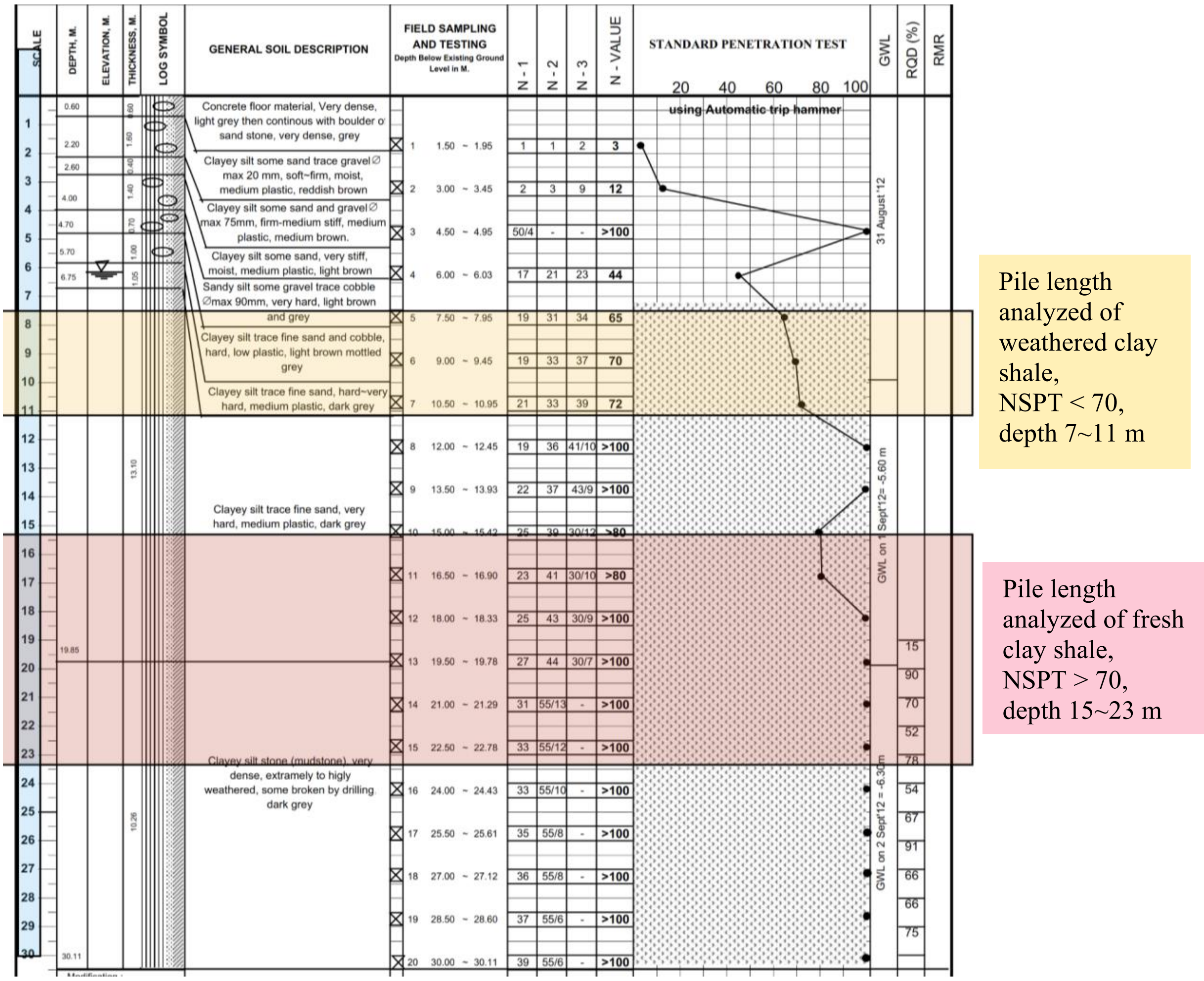

Figure 2. Boring log BH–31

3 BEARING CAPACITY OF BORED PILE

Drilled pile foundation, also known as bored pile, drilled shaft or caisson, have the distinct advantage that a variety of rational design methods have been developed for wide range of loadings and soil conditions. With the advancement of equipment technology, a wide range of bored pile dimensions can be implemented, from diameters of 40 cm up to 4 m. However, in the clay shale formation the application of bored piles must be executed cautiously. Particularly due to the construction process that unearth and deteriorate the original soil. Numerous factors must be taken into consideration such as: soil shear strength reduction due to drilling methods, the effect of water, and drilling technique. These factors affect the load bearing capacity at the pile base as well as distribution of skin resistance. Every step of construction methods should be adjusted to match the need of the local soil conditions. In some locations, temporary steel casing or bentonite is required as protection before the steel reinforcement and concrete can be poured (Reese and Wright, 1971; Rahardjo, 2017; Aurora & Reese, 1976).

The capacity of pile foundation can be divided as: (i) end bearing and (ii) shaft/skin friction.

$$Q_u = Q_p + Q_s - W_p \quad (1)$$

where Q_u = total ultimate capacity, Q_p = ultimate capacity of end/tip resistance, Q_s = ultimate capacity of shaft/skin friction and W_p = the weight of the pile.

The tip resistance capacity, Q_p is the multifaction of tip resistance per unit area, q_p, with the pile tip area, A_p.

$$Q_p = A_p \,.\, q_p \quad (2)$$

In cohesive soils, the ultimate tip resistance per unit area, q_p can be taken as 9 times soil shear strength (s_u) (Reese and Wright, 1977).

$$Q_p = A_p \,.\, (n_c{}^* \,.\, s_u) = A_p \,.\, (9 \,.\, s_u) \quad (3)$$

The shaft bearing capacity (Q_s) is the multiplication of the shaft area, A_s, to the friction capacity per unit area of the pile shaft (fs_i) for each segment (L_i).

$$Q_s = \Sigma fs_i \,.\, As_i \quad (4)$$

$$Q_s = \Sigma fs_i \,.\, L_i \,.\, p_i \quad (5)$$

For cohesive soils, Reese and Wright (1977) proposed the following equation for the friction per unit area (fs):

$$fs = \alpha \,.\, c_u \quad (6)$$

The adhesion factor (α) of bored piles is affected by various factors, including: soil type, consolidation history, degree of saturation, groundwater conditions, softening of the soil around the bored pile due to drilling, loss of circumferential stress due to drilling, water absorption of concrete slurry by the soil which results in softening of the surface soil along the pile, loss of horizontal pressure during casting, final texture of the drilled pile surface, duration of drilling, installation and casting of bored piles and so on.

Many researchers have argued that the adhesion factor (α) reduces with increasing undrained shear strength of the soil before pile installation. Sladen (1992) and Cherubini et al. (2007) evaluated and summarized the adhesion factor, α from several researchers as illustrated in Figure 3.

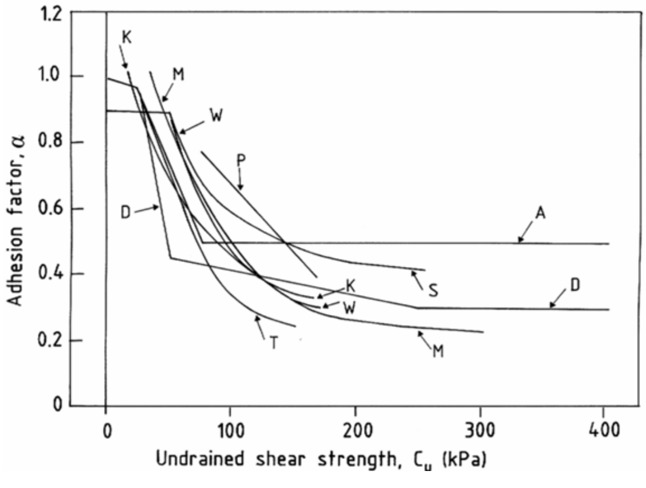

Figure 3. Trend of adhesion factors from several researchers: K = Kerisel (1965), T = Tomlinson (1957), W = Woodward and Boitano (1961), P = Peck (1958), D = Dennis and Olson (1983), A = API (1974), S = Sowers and Sowers (1970), M = McCarthy (1977)

Tomlinson (1957) proposed correlation for the adhesion factor (α) to the undrained cohesion (c_u), because the effect due to changes in stress in the soil due to the implementation of bored piles and driven piles. Reese and Wright (1977) proposed the value of α = 0.55. Kulhawi and Jackson (1989) reported various results of loading experiments and stated that the correction factor, α is not constant but varies with soil shear strength. Similarly, Coduto (1994), O'Neil and Reese also known as FHWA method (1999) and Woodward et al. (1972) proposed a reduction in shear strength for bored piles depending on soil properties such as moisture content, w_n, plasticity index, I_p, and undrained shear strength (s_u).

Specifically, for clay shale, Aurora and Resse (1976) emphasized the importance of the construction method of bored piles in clay shale soils and recommended the following formulae for calculating pile tip bearing capacity.

$$q_p = N_c \cdot c_q \quad (7)$$

With a value of N_c = 7 for bored piles constructed with wash boring method and N_c = 8 if constructed with the dry boring method. The soil shear strength (c_q) is obtained from the NSPT test results.

$$c_q = N60/55 \text{ (in tsf)} \quad (8)$$

For shaft resistance, f_s, Aurora and Resse (1976) proposed:

$$f_s = \alpha \cdot c_q \quad (9)$$

The adhesion factor (α) = 0.5 if the bored pile is made using the wash boring method, and α = 0.75 when the bored pile is constructed with the dry boring method.

In the construction of the foundation of Suramadu bridge, Irsyam et al. (2007) reported the presence of clay shale with montmorillonite content that is sensitive to the drilling process, resulting in reduction of lateral stress and cracking of the soil mass around the bore hole. Through instrumented loading tests, Irsyam, et. al. recommended a smaller adhesion factor (α) = 0.375 with a skin/shaft stress limit between 0.75–1 N (kPa) if no soil improvement is performed. Whereas if soil improvement by grouting is carried out, the shaft shear stress can be increased to 1.42 N (kPa). For end bearing capacity calculation, c_u can be taken as 6.5 N as long as the foundation base is clean.

4 METHODOLOGY

Since clay shale is a unique type of soil, this research aims to obtain the values of skin friction (*fs*) and adhesion factor (α) by studying the load transfer behavior of instrumented pile installed in clay shale. Through the instrumentation (strain gauges), the load transfer mechanism and the interaction between soil and the pile can be studied.

A static load (kentledge) test procedure was performed. The vibrating wire strain gauges (VWSG) were installed at five levels (detail shown in latter section). In addition, the bore pile was also equipped with a telltale to indicate shortening at the end of the pile. With accurate stress and strain data along the pile, the axial load distribution could be obtained. Through this data, a back analysis was performed to obtain the shaft resistance (*fs*). And by using the undrained shear strength, c_u, obtained from soil investigation, the adhesion factor (α) can be calculated.

In addition to the static load test, a dynamic load test i.e., Pile Driving Analyzer (PDA) test was also conducted. The results were computed and analyzed using CAPWAP® (case pile wave analysis program), the software used to analyze data from PDA tests, which is capable to estimate pile capacities and soil resistance distribution.

Tell tale extensometer is an instrument which is typically used for precise monitoring of ground surface settlement or heave. It consists of a galvanized steel bottom anchor to which a riser measuring rod is attached. The installation of this instrument was intended to measure the strain (shortening) of the drilled pile at a certain interval. Tell tale is pipe shaped, mounted to the pile reinforcement steel hence there is no friction between the steel reinforcements and concrete of the pile. The measurement was made using a dial gauge with an accuracy of 0.001 inches (0.025 mm). Pile shortening occurs during loading, with tell tale it is possible to measure the shortening (strain) that occurs between extensometer tell tale. By multiplying the strain to the concrete modulus, the stress in the respective segment can be determined.

Vibrating Wire Strain Gauge (VWSG) is used to measure strain in concrete/steel structures. The VW gauge consists of a fine wire that vibrates at a certain resonant frequency. As the wire is compressed due to stress of the concrete structure, the resonant frequency will change. The change in frequency is then measured electronically to determine the strain that occurs.

5 RESULTS

5.1 Pile Dynamic Load Test Results

PDA tests were carried out on pile BH–22 and BH–31. The pile geometry and hammer weight are shown in Table 1. The CAPWAP® analysis of PDA test results of BH–22 is shown in Figure 4, which shows the ultimate bearing capacity, Q_u = 980 tons, shaft resistance, Q_s = 562.9 tons and tip resistance, Q_p = 417.1 tons. The settlement recorded at 12.4 mm. By dividing the soil stratification and analyzing the resistance of each layer, load transfer by each layer can be calculated. Calculation of the adhesion factor (α) based on PDA for BH–22 test data were carried out on 2 (two) segments of the clay shale layers, namely: soil layer with NSPT < 70 and soil layer with NSPT > 70 in accordance with the shale weathering criteria. Table 2 summarizes the calculation results of adhesion factor value (α) for both piles.

Table 1. PDA test profile data

Pile No	Pile Type	Diameter (cm)	Pile Length (m)	Embedment (m)	Penetration (m)	Drop Hammer
BH 22	Bored Pile	ϕ 120	22.25	20.6	20.3	18.5 Ton
TP–2/BH 31	Bored Pile	ϕ 60	31.80	20.6	30.0	18.5 Ton

BORE F D 120,DROP H 18.5T; Blow: 10 CAPWAP(R) 2006-2
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CAPWAP SUMMARY RESULTS

Total CAPWAP Capacity: 980.0; along Shaft 562.9; at Toe 417.1 tons

Soil Sgmnt No.	Dist. Below Gages m	Depth Below Grade m	Ru tons	Force in Pile tons	Sum of Ru tons	Unit Resist. (Depth) tons/m	Unit Resist. (Area) tons/m²	Smith Damping Factor s/m
				980.0				
1	2.1	1.8	5.0	975.0	5.0	2.83	0.75	1.313
2	4.1	3.8	26.3	948.7	31.3	12.75	3.38	1.313
3	6.2	5.9	41.2	907.5	72.5	19.94	5.29	1.313
4	8.3	8.0	52.7	854.8	125.2	25.53	6.77	1.313
5	10.3	10.0	59.5	795.3	184.7	28.79	7.64	1.313
6	12.4	12.1	62.6	732.7	247.3	30.31	8.04	1.313
7	14.5	14.2	65.7	667.0	313.0	31.83	8.44	1.313
8	16.5	16.2	70.3	596.7	383.3	34.05	9.03	1.313
9	18.6	18.3	84.5	512.2	467.8	40.94	10.86	1.313
10	20.6	20.3	95.1	417.1	562.9	46.04	12.21	1.313
Avg. Shaft			56.3			27.66	7.34	1.313
Toe			417.1				368.82	0.138

Yellow: Weathered clay shale, NSPT < 70.

Red: Fresh clay shale, NSPT > 70.

Figure 4. CAPWAP results of BH–22

Table 2. Determination of adhesion factor (α) based on PDA test results

Test type	PDA				Unit
Drilled Pile No.	BH–22		TP–2/BH–31		
Layer Depth (m)	9.0–17.0	17.0–20.0	7.0–11.0	15.0–23.0	
NSPT Classification	NSPT < 70	NSPT > 70	NSPT < 70	NSPT > 70	blow
Pile Length Analyzed	8	3	4	8	m
Diameter	1.2	1.2	0.6	0.6	m
Circumference	3.77	3.77	1.88	1.88	m
Friction Area	30.16	11.31	7.54	15.08	m^2
Friction Resistance	270.60	137.35	39.50	366.00	ton
$fs = \boldsymbol{\alpha} . c_u$ $fs =$	8,97	12,14	5,24	24,27	ton/m^2
$NSPT_{average}$	59	105	69	113	blow
$c_u = 6.(NSPT)_{av.}$ $c_u =$	354	630	414	680	kPa
$c_u =$	36.10	64.24	42.22	69.34	ton/m^2
$\boldsymbol{\alpha} =$	**0.25**	**0.19**	**0.12**	**0.35**	-

5.2 Static Load Test Results

Instrumented static load (Kentledge) test was conducted on test pile TP–2 (BH–31). Figure 5 shows the raw data obtained from static loading test. Figure 6a shows the location of the VW strain gauges and tell tale along the soil stratigraphy and SPT data. The figure also shows the division of pile segments for ease of analysis. The yellow-colored section represents the soil layer with NSPT < 70, while the red-colored section represents the soil layer with NSPT > 70.

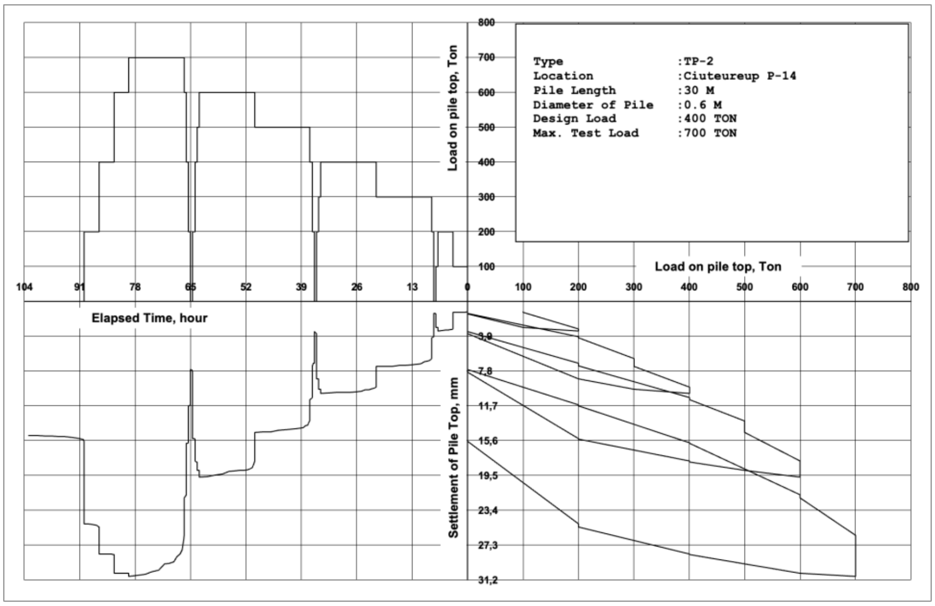

Figure 5. Static loading test result of TP–2/BH–31 pile

TP–2 drilled pile was designed to support a working load of 400 tons. Hence the maximum load test was planned up to 1000 tons, (250% of the allowable load). The test was conducted referring to ASTM D1143, with 4 (four) loading cycles. However, on the 4th cycle, the test was stopped at a working load of 700 Tons (175% allowable load), as the settlement has exceeded 25.4 mm or 1 inch. The recorded pile head settlement for each load cycle was 3.3 mm, 10.3 mm, 19.6 mm, and 30.8 mm. The residual settlement measured at unloading to no-load conditions were 1.36 mm, 3.37 mm, 7.61 mm, and 15.0 mm. Figure 6b plots the load-settlement curve.

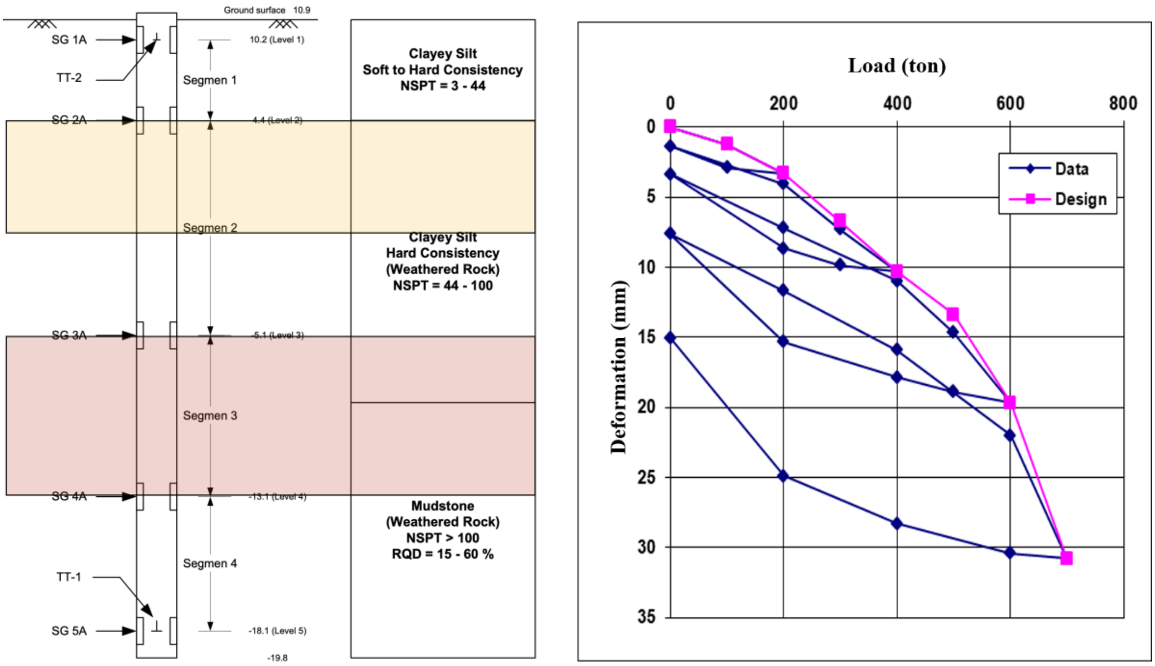

Figure 6. (a) Position of load cells, strain gauges, tell tale, and soil layering; (b) Static loading curves

5.3 Determination of Bored Pile Concrete Modulus

The modulus of elasticity (E) is a measure of material's stiffness and its resistance to elastic deformation under a certain stress/load. It is the ratio of stress (σ) to strain (ε). In practice, the concrete modulus is generally approximated by the empirical equation, $E = 4700 \cdot (f_{c'})^{0.5}$. For concrete of grade K-350 ($f_c' = 35$ MPa), as used for this bored pile, $E = 28$ GPa. It is also common to assume that this value is valid for all ranges of applied loads/stresses. Theoretically however, the value of modulus, E, will vary depending on the magnitude of the stress acting on the material. The presence of load cells (measuring the stress) and strain gauges (measuring the strain) mounted on the studied bored piles allows us to determine the pile modulus (E) of the pile at each working stress-strain.

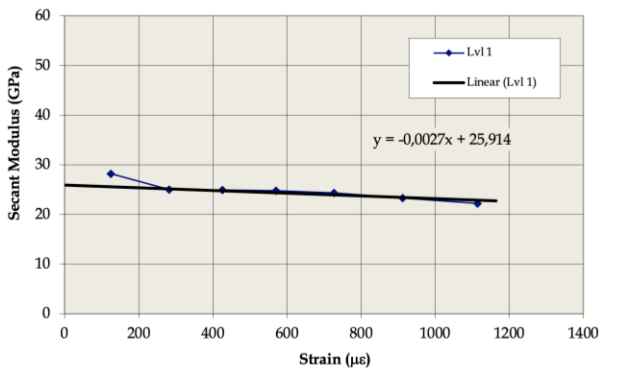

Figure 7. Concrete modulus distribution of Test Pile TP 2 (BH–31) based on strain gauges measurement

Figure 7 shows the calculated pile modulus for the strain range that occurred during the loading test. As the working stress increases (the higher the strain), the pile concrete modulus (E) decreases. To simplify further calculations, this study used the concrete modulus obtained from the first level strain gauge (SG 1A), located at 0.7 m depth. This is to minimize the effect of shaft resistance on strain measured for deeper strain gage levels.

The calculation results for strain gauges at level 1 (0.7 m depth) indicated that at low stresses (small strains), the modulus of the pile can reach $E = 28$ GPa, as predicted for concrete $f_c' = 35$ MPa.

However, as the load (stress) and strain increase, the concrete modulus (E) decreases up to 22 GPa. This concrete modulus, E = 22 GPa is the value used for elastic settlement calculation when the pile is at high stresses/loads.

5.4 Analysis of Load Transfer Curve

A load transfer curve is a curve that reflects the extent of load transmitted to the ground by pile segments either by the shaft along the pile as well at the tip of the pile according to the interaction of the pile and soil interface. On clay soil under small loads and/or long piles foundation, the load distribution at the pile head generally does not reach the tip of the pile as all the load has been transferred to the ground along the pile shafts.

Figure 8 shows the load transfer curves based on the stress and strain data collected by the strain gauges collected during the loading test. It shows that most of load is transferred to the ground through shaft/skin friction. This is characterized by the gentle slope of the load distribution curve, indicating high frictional resistance. The friction acting on the pile shaft varies between 7.5–22 tons/m^2. The red color block in Figure 8 shows the segment 3 area, which is the reference segment of this study to obtain the value of the adhesion factor (α) of clay shale.

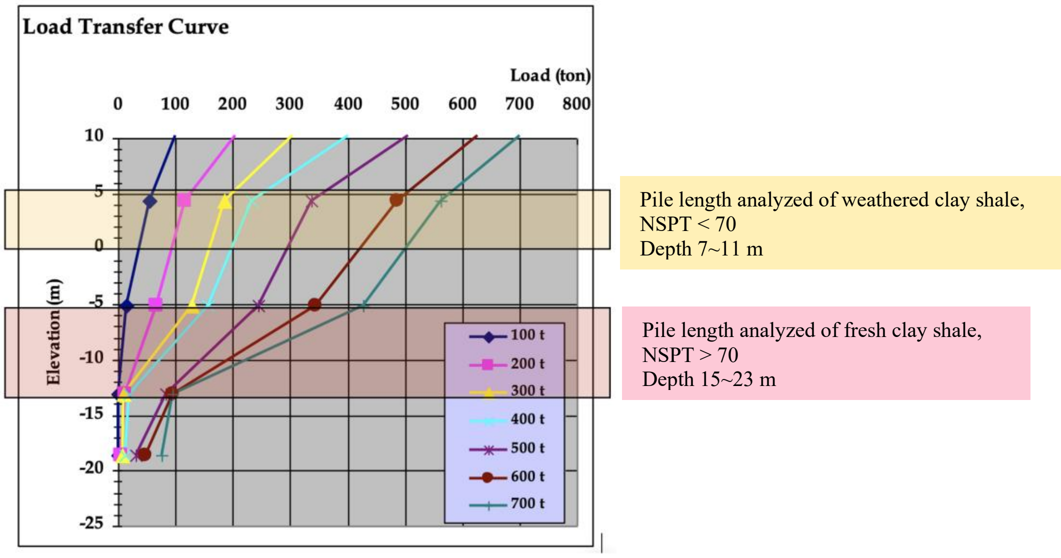

Figure 8 Load transfer curve from strain gauge measurement results

5.5 Analysis of *t-z* and *q-z* Curves

The load transfer mechanism in a pile-soil system is a quite complex, involving parameters that are difficult to evaluate numerically. Nevertheless, the extend of load transfer by the pile skin friction and pile tip is proportionally dependent on the soil's shear strength and elasticity. To further understand this load transfer behavior between the soil along the pile, the *t-z* and *q-z* curve can be used. The *t-z* curve is intended to describe one-dimensional magnitude of pile shear stress (τ) vs vertical displacement (z) of the pile segment. This curve is developed from the readings of load cell and strain gauges installed along the pile. As for the *q-z* curve, it is used to describe the vertical stress (q) vs vertical displacement (z) at the tip of the pile. The data is obtained from the strain gauges and tell-tale installed at the end of the pile.

Figure 9a shows the interpretation of the *t-z* data on the 4 (four) segments of pile from the 5 (five) strain gauges installed (refer to figure 6). At a load of 700 tons, the shaft resistance of the upper two segments of the of the pile (segments 1 and 2) was fully mobilized at a displacement of 5.9 mm at segment 1 and 7.4 mm in segment 2. The full mobilization can be interpreted by reduction of shear stress, indicating strain softening. On the segment 3, of the pile shows elastic behavior, in the sense that the shaft resistance has not reach its maximum friction resistance as it only moved by 3.3 mm.

While at segment 4, the displacement did not reach 1 mm, which can be interpreted that the friction resistance was not yet mobilized.

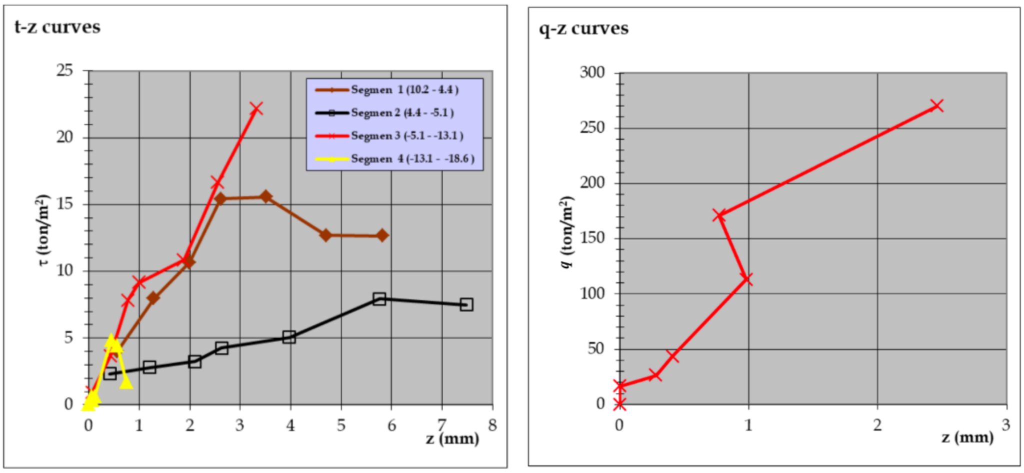

Figure 9. (a) The *t-z* curves and (b) *q-z* curve.

5.6 Adhesion Factor (α) Calculation Based on Strain Gauges

Using the results of load and strain transfer data recorded from the VWSG above, the adhesion factor of each pile segment can be determined. Table 3 shows the results of these calculations. The calculation was done specifically to estimate the adhesion factor for clay shale soil layers with NSPT < 70 and NSPT > 70. It should be noted that these calculations were performed for shaft resistance only.

Table 3. Adhesion factor (α) calculation based on static load test

Test type		Static Loading & VWSG		Unit
Drilled Pile No.		TP–2/BH–31		
Layer Depth (m)		7.0–11.0	15.0–23.0	
NSPT Classification		NSPT < 70	NSPT > 70	blow
Pile Length Analyzed		4	8	m
Diameter		0.6	0.6	m
Circumference		1.88	1.88	m
Friction Area		7.54	15.08	m^2
Friction Resistance		56.42	334.00	Ton
$fs = \boldsymbol{\alpha} \cdot c_u$	$fs =$	7.48	22.15	Ton/m^2
$(NSPT)_{average}$		69	113	blow
$c_u = 6.(NSPT)_{av.}$	$c_u =$	414	680	kPa
	$c_u =$	42.22	69.34	Ton/m^2
	$\boldsymbol{\alpha} =$	**0.18**	**0.32**	-

6 DISCUSSION

Referring to the length and diameter of the two drilled piles, specifically TP–2/BH–31, where L/D = 50, this pile should behave as friction pile. This behavior is clearly observed on the load transfer curve at Figure 8.

The total settlement of the TP–2 test pile (BH–31) with a diameter of 600 mm with a pile length of 30 m at a maximum load of 700 tons was 30.80 mm. The residual settlement on this pile is 15.00 mm. The designed ultimate load on the TP–2 pile test should be 1.000 tons, but this static test was stopped prematurely at a load of 175% of the working load as the pile head settlement already exceeded 25 mm.

At its maximum applied load (700 Ton), the end bearing resistance reached 270 tons/m² at NSPT > 70. However, this value cannot be used as a reference for the end bearing capacity as the base resistance has yet to be mobilized. Theoretically, tip resistance capacity can be mobilized when tip settlement exceeds 10 ~ 25% of the pile diameter. In this case, 10% × 600 mm = 60 mm.

Based on the two types of loading tests at TP–2/BH–31, kentledge/static load test and PDA dynamic test, the shaft resistance, *fs* mobilized for clay shale soil for NSPT < 70 is 5.24 tons/m²~7.48 tons/m². For NSPT > 70, the shaft resistance, *fs* can reach 22.15~24.247 tons/m². Applying estimated undrained shear strength of cohesive soils, $c_u = 0.6 \cdot$ NSPT (Terzaghi, 1943), the adhesion factor (α) of drilled pile on clay shale are estimated. Table 4 compiled results of the adhesion factor (α) analysis from the static loading (kentledge) tests and dynamic testing (PDA). Comparing the PDA test results for both piles in the NSPT > 70 layer, adhesion factor obtained from BH–22 is much lower than BH–31 (0.19 vs. 0.35). This is because the load was insufficient to mobilize its friction capacity.

Table 4. Comparison of adhesion factor, α based on dynamic (PDA) and static (Kentledge) load test

Test type	Pile Dynamic Analysis				Static Loading & VWSG		Unit
Drilled Pile No.	BH–22		TP–2/BH–31		TP–2/BH–31		
Layer Depth (m)	9.0–17.0	17.0–20.0	7.0–11.0	15.0–23.0	7.0–11,0	15.0–23.0	
NSPT Classification	NSPT < 70	NSPT > 70	NSPT < 70	NSPT > 70	NSPT < 70	NSPT > 70	blow
Pile Length	8	3	4	8	4	8	m
Diameter	1.2	1.2	0.6	0.6	0.6	0.6	m
Circumference	3.77	3.77	1.88	1.88	1.88	1.88	m
Friction Area	30.16	11.31	7.54	15.08	7.54	15.08	m²
Friction Resistance	270.60	137.35	39.50	366.00	56.42	334.00	ton
$fs = \boldsymbol{\alpha} \,.\, c_u$ $fs =$	8.97	12.14	5.24	24.27	7.48	22.15	ton/m²
$(\text{NSPT})_{average}$	59	105	69	113	69	113	blow
$c_u = 6.(\text{NSPT})_{av.}$ $c_u =$	354	630	414	680	414	680	kPa
$c_u =$	36.10	64.24	42.22	69.34	42.22	69.34	ton/m²
$\boldsymbol{\alpha} =$	**0.25**	**0.19**	**0.12**	**0.35**	**0.18**	**0.32**	-

7 CONCLUSION

The interaction of bored pile installed in clay shale soil layers is studied by conducting dynamic and static loading tests on instrumented pile. Through the loading tests, the axial load distribution on the pile is obtained, and the interaction between the pile and clay shale are studied.

Using the estimated undrained shear strength, $c_u = 6 \cdot$ NSPT (Terzaghi, 1943), the results show that the adhesion factor of bored piles in clay shale soils with NSPT > 70 are ranged from $\alpha = 0.32$ to 0.35. While for NSPT < 70 ranged from $\alpha = 0.12$ to 0.18. These results are significantly lower compared to the estimation proposed of Reese & Wright (1977) or Kulhawy & Jackosn (1989) who gave a rough estimate of $\alpha = 0.55$ for cohesive soils as well as Aurora & Reese (1976) for clay shale soils who gave a value of $\alpha = 0.5$~0.75 depending on the drilling method. However, these results are very close to the adhesion factor (α) recommended by Irsyam et. al. (2007), especially for fresh clay shale with NSPT > 70, where $\alpha = 0.375$.

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