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Development Study Of T-Z Curve Generated From Kentledge System And Bidirectional Test

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ABSTRACT

A pile loading test is generally proposed to examine the bearing capacity to support the big loads. It can also be used to measure its deflection under lateral load. There are two tests: axial static pile load test (Kentledge) and two-directional static pile load test (Bidirectional). T-Z curve as the result analysis based on the instrumented pile test data describes the load distribution and mobilized skin friction along with the pile. There are numbers of Vibrating Wire Strain Gauge (VWSG) mounted in several depths of the bored pile and two tell-tale on top and toe of the pile used as primary data in this research. This research is meant to determine the different distribution of mobilized skin friction, and the pile from two different pile load test methods from the calculated t-z curve as the study developed from both methods of pile test. The research results that the kentledge system has bigger mobilized skin friction than in the bidirectional test.

1. Introduction

Invalidating the High-Rise Building Project's design in Jakarta, performed two different static instrumented loading test. As shown in the following figure, the area of study is surrounded by other high-rise buildings and located at the road's side. This project will accommodate all data to fulfill the analysis of this research.

The two different pile load tests performed in this project are Head-Down Static Load Test and Bidirectional Test. Head-Down Load Test as known as Kentledge accommodates loads from the top of the pile directly towards the pile toe. Meanwhile, Bidirectional accommodates loads in two directions, upward and downward through the hydraulic jack placed in a certain depth of pile called Osterberg cell. Therefore, these upward loads will give tension forces through the pile in the upward direction.

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These pile load tests are instrumented with vibrating wire strain gauges at a certain depth along with the pile. According to Fellenius (2018), data from strain gauges provides records of load movement or shear stress and represents the data of a pile element, which can be described in the t-z function [1][2]. The t-z curve may be derived from the pile movement's soil behavior under the axial load during the pile load test.

This research is meant to investigate the pile's behavior under load using Kentledge and Bidirectional test results based on the load distribution. The t-z curve portrays the load distribution and determines the maximum mobilized skin friction after the load test is conducted [3].



Source : Google Earth. (2020).

Figure 1. Area of Study.

2. Literature Review

The t-z curve suggested by Seed and Reese (1957) is an analysis method to determine the axial movement of the pile under axial load. The t-z curve procedure is to generate the relationship of mobilized skin friction and the movement of the pile along with the bored pile during stages of loading. Empirically, the t-z curve is obtained based on the load distribution from load transfer curve analysis. The t-z curve behavior is much affected by most of the pile parameters such as diameter, stiffness, length, and strength [4].

Finite difference equations are employed to achieve compatibility between pile displacement and the load transfer along with the pile and between displacement and resistance at the tip of the pile. This method was used by Seed and Reese (1957). The t-z difference method assumes the Winkler concept, that is, the load transfer at a certain pile section, and the pile tip resistance are independent of the pile displacement elsewhere [5].

Load distribution is developed from strain data obtained by strain gauge record during pile load test [6][7]. Head-Down Load Test generates load in one direction from the top of the pile until it reaches the pile toe, which results in compression that causes a bigger stress zone around the pile [8]. In contrast to a conventional head-down test, a bidirectional test establishes load into two upward and downward directions. The load provided by the hydraulic jack called Osterberg cell at a certain pile depth causes the pile to produce two different stress zones in the upper and lower segments of the pile, as shown in Figure 2. The lower segment of the pile develops compression force and tension in the upper segment [9].



Source : *Instrumentation Final Report of BP 38. (2013).*

Figure 2. Hydraulic Jack Osterberg Cell.

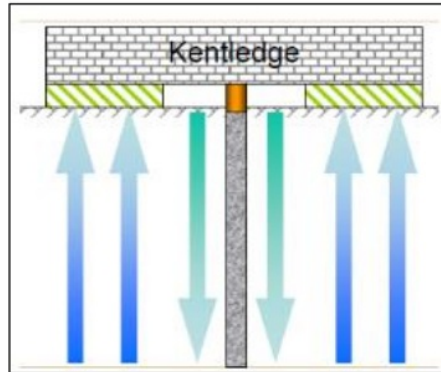
As there is tension force going upwards the upper segment of the pile, this may cause the smaller amount of mobilized skin friction along the upper segment caused by the smaller stress zone affected by the upward loads[10]. Unlike the head-down test, to develop the t-z curve from bidirectional test data, the upward-downward movement must be delivered in one equivalent top load curve, which generates the load and movement in one direction to be calculated into load transfer analysis[11].

3. Research Method

This research is conducted through several steps such as soil investigation to examine the soil condition, primary data collection from pile load tests performed, data analysis, and conclusion.

The tests conducted were pile loading test with kentledge system and bidirectional test. In this project, both Kentledge and bidirectional tests are conducted in two different locations with similar soil conditions and performed these two methods on two 1.5 m diameter bored piles. Conducted kentledge system in a bored pile in BP 24 (depth of 64.5 m) while performing the bidirectional test in a boring pile in BP 38 (depth of 59.20 m).

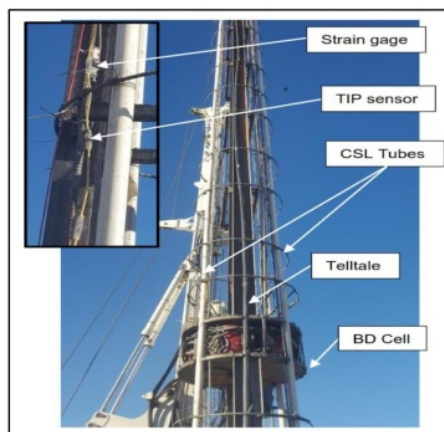
During the pile load test using the kentledge system, the pile is gradually compressed by the axial load with enough time within the load. Pile settlement is recorded using a dial gauge. The load used for each step depends on the building around the area. In this project, the pile is being compressed under 200% axial load [12]. Then it is gradually decreasing, which is usually known as unloading. The illustration of the static load test is shown in the following figure.



Source : England, 2010.

Figure 3. Illustration of Static Loading Test (Kentledge).

The bidirectional test consists of a jacking system on both piles with a head-down position where the pile is pushed down against counterweight or reaction [13]. Jacking cylinder is in between the two-bearing plate forming bidirectional cell and located in a very strategic place between friction pile where the pile resistance above and below the pile can be compared. The following figure shows the illustration of the bidirectional test.



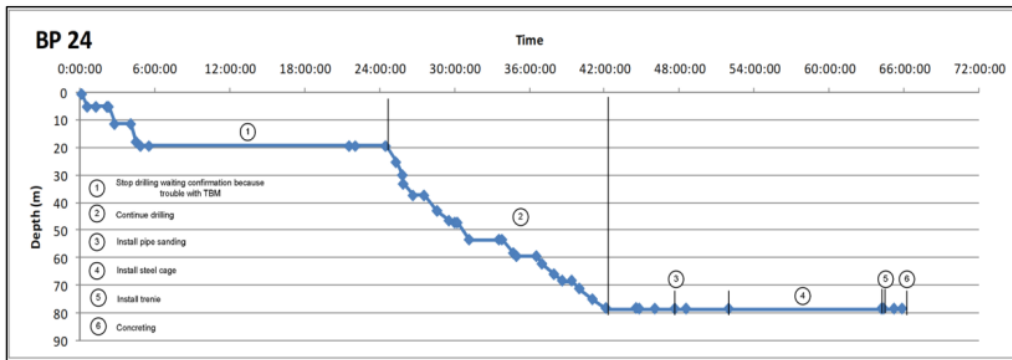
Source : Fellenius & Salem, 2017.

Figure 4. Illustration of Bidirectional Test.

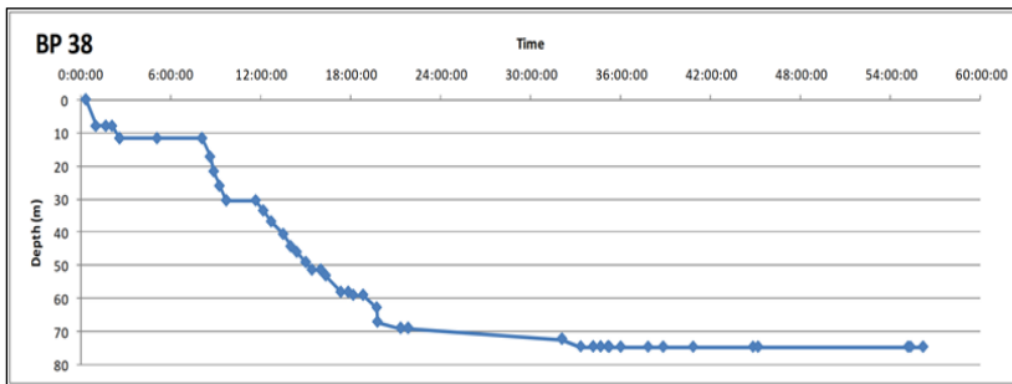
4. Results and Discussions

4.1 Instrumentation Result.

To validate the information, pile tests were conducted on-site. Both methods were performed to verify the differences between the two methods. According to the test conducted on-site, the bidirectional test has a more efficient time than the kentledge system. As shown in the following figure, the kentledge system shown as BP 24 needs more time to do the work, that is almost 70-hour work. Meanwhile, bidirectional shown as BP 38 can give less time to work about 57 hours.



(a)

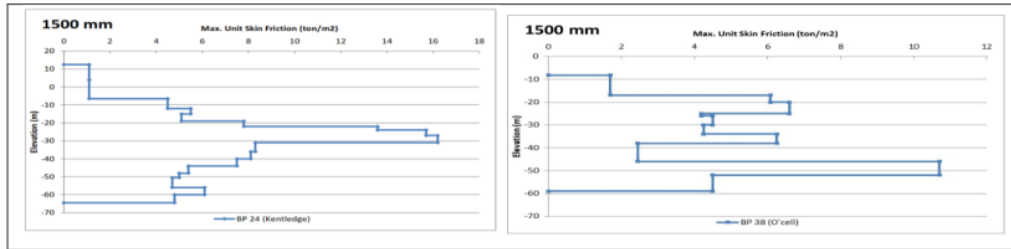


(b)

Source : Instrumentation Final Report of BP 24 and BP 38. (2013).

Figure 5. Time Efficiency of Kentledge System and Bidirectional Test, (a) Duration of Kentledge System; (b) Duration of Bidirectional Test.

According to the field's execution, significant differences shown that it is true head-down pile loading test gives a bigger result in mobilized skin friction along with the pile than the bidirectional test shown in the following figure.



Source : Instrumentation Final Report of BP 24 and BP 38. (2013).

Figure 6. Interpretation Results of Kentledge System and Bidirectional Test.

Figure 6 shows that the bidirectional test shown as BP 38 gives smaller maximum skin friction than the kentledge system by 6 t/m2 difference. Based on the t-z curve calculation, it will be shown that the bidirectional test has smaller maximum skin friction than the kentledge system.

1. Head-Down Static Loading Test (Kentledge).

Soil stratification is classified based on boring in two locations of pile loading test. On the head-down loading test (BP 24), there is bore log BH-04 can be used to assess the pile test result. Based on the borehole, soil condition in area BP 24 is dominated by clayey soil with several sand lenses. On the surface, there is a soft clay layer. Medium clay layer is identified in 1 m to 18 m depth, followed by stiff to very stiff sandy silt layer in 34 m depth. A medium dense sand layer is identified in the depth of 35 m. The consistency is increasing throughout the boring.

Table 1. Soil Stratification And Pile Segment.

Segment	Elevation (m)		Pile Length (m)	Soil Type
A	12.5	- 4	8.5	10 Medium Clay
B	4	- 6.5	10.5	Stiff to V. Stiff Clay 10
C	-6.5	- 12	5.5	Sandy Silt, Stiff to V. Stiff
D	-12	- 15	3	Sandy Silt, Stiff to V. Stiff
E	-15	- 19	4	Very Dense Sand 10
F	-19	- 22	3	Sandy Silt, Stiff to V. Stiff
G	-22	- 24	2	Sandy Silt, Stiff to V. Stiff
H	-24	- 27	3	Very Dense Sand
I	-27	- 31	4	Hard Clay
J	-31	- 36	5	Very Dense Sand
K	-36	- 40	4	Sandy Silt, Hard
L	-40	- 44	4	Sandy Silt, Hard
M	-44	- 48	4	Hard Clay
N	-48	- 50.5	2.5	Hard Clay
O	-50.5	- 56	5.5	Hard Clay
P	-56	- 60	4	Hard Clay
Q	-60	- 64.5	4.5	Hard Clay
R	-64.5			Hard Clay

Source : Instrumentation Final Report of BP 24. (2013).

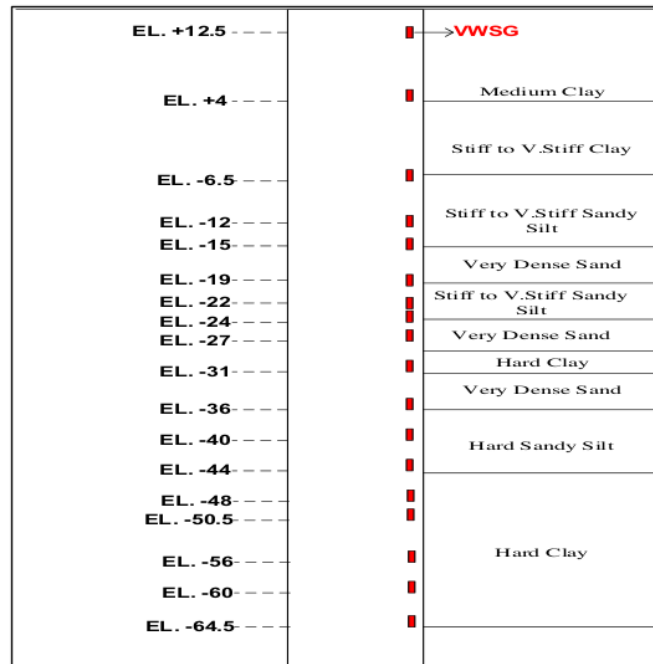
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Table 1 shows the soil stratification, and pile segment on each depth of instrumentation of vibrating wire strain gauge is installed. There are 18 strain gauges installed at several depths. Each tell-tale extensometer is installed at a depth of its COL (EL.-8.2m and -65.0m).



Source : Instrumentation Final Report of BP 24. (2013).

Figure 7. Illustration of VWSG installation on Bored Pile.

Figure 7. shows the illustration of every strain gauge is installed. The tell-tale extensometer consists of a steel rod with 9.5 mm diameter, hooked in the anchor inside the pile and placed inside of PVC pipe with 25 mm diameter. Four dial gauges with an accuracy of ± 0.01 mm used to measure the settlement from the steel rod, aligned with the reference beam.

A head-down static loading test is conducted based on ASTM D1143-07 [6]. The procedure is using the reaction system, where the load on top of the pile is affected by friction capacity from four reaction piles connected to the beam frame. Axial load established by the hydraulic jack Osterberg cell is 1000 tons with a designated load of 1150 tons, and loading is conducted in four cycles. Maximum load on each cycle contains 575 ton (50%), 1150 ton (100%), 1725 ton (150%), 2013 ton (175%) and 2300 ton (200%). This research presents the fourth cycle to be analyzed.

According to the loading test, the pile settlement for each designed load is shown in this following **Table 2**.

Table 2. Pile Settlement And Stage Loading At Fourth Cycle.

Load (ton)	Settlement (mm)
0	4.72
575	7.57
1150	11.13
1725	15.48
2013	19.81
2300	28.52

Source : Instrumentation Final Report of BP 24. (2013).

Table 3 shows the average strain measured by vibrating wire strain gauge (VWSG) on each stage of loading in fourth cycle at each depth along the pile.

Table 3. VWSG Result.

SEGMENT	VWSG Depth (m)	Δ at APPLIED LOAD									
		0	575	1150	1725	2012.5	2300	1725	1150	575	0
A	12.5	0	160.5	283.75	417.25	494	630.5	518.25	366	227	38.75
B	4	0	148.75	272.75	407	483	618	342.75	242.5	148.75	14
C	-6.5	0	135.5	261	394.5	470.5	603.5	391.75	261.25	156.5	13.25
D	-12	0	111.25	233	366.5	441.75	571.25	371.25	249.5	159	25
E	-15	0	97.75	216	348	423	549.75	275.5	215.25	133.25	17.75
F	-19	0	80.75	194	325	399.25	523.25	332.75	275.75	181	45.5
G	-22	0	62	170.75	298.75	372.25	493	379.5	335.5	246.25	63.25
H	-24	0	49	154.25	272	341.5	457.75	299.5	265.25	194.5	64.5
I	-27	0	24	110	225.25	288.25	397	266.25	230.25	173.5	59.75
J	-31	0	8.75	74	165.25	222.75	313	235.5	228.5	205.5	48.5
K	-36	0	1	32.5	124	177.25	259.5	282.75	278	263	49.5
L	-40	0	0.5	17.5	101	149.5	217.5	235	232	223.5	70.75
M	-44	0	0.25	14.5	82	121	178.75	149.25	127	126	82.5
N	-48	0	0.25	11.5	61	97.5	164	147	145.75	142.25	122.25
O	-50.5	0	0.25	9.75	51	83.75	134.5	116.5	115.5	112.5	99
P	-56	0	0.5	8	29	56.5	101.5	71.5	71.25	70	62.25
Q	-60	0	0.25	6.75	20.25	43.5	86.25	38.75	38.75	37.75	33.75
R	-64.5	0	0.5	3.5	16.25	31	70.75	18.75	18.75	18.5	16.5

Source : Instrumentation Final Report of BP 24. (2013).

2. Bidirectional Test.

On a bidirectional test (BP 38), BH-03 is used as the reference bore log for soil classification conducted side by side with BP 38. According to the borehole, there is a fill material 2.5 m thick. There is medium clay until 18 m depth. The soft soil layer is 5 m thick then followed by hard clay until the end of boring. The dense sand layer is identified at a few certain depths.

Table 4. Soil Stratification And Pile Segment.

Segment	Elevation (m)		Pile Length (m)	Soil Type
A	-8.3	-16.9	8.5	Sandy Silt, Stiff to V.Stiff
B	-16.9	-19.9	10.5	Sandy Silt, Stiff to V.Stiff
C	-19.9	-24.9	5.5	Dense Sand
D	-24.9	-25.9	3	Sandy Silt, Stiff to V.Stiff
E	-25.9	-29.9	4	Sandy Silt, Stiff to V.Stiff
F	-29.9	-33.9	3	Stiff to V.Stiff Clay
G	-33.9	-45.2	2	Hard Clay
H	-45.2	-52.2	3	Hard Clay
I	-52.2	-59.2	4	Hard Clay
J	-59.2	-	5	Hard Clay

Source : Instrumentation Final Report of BP 38. (2013).

Table 4 shows the soil stratification and pile segment at each depth the instrumentation is installed along with the pile. There are 10 strain gauges installed at few depths. Both tell-tale extensometers are installed at a depth of its COL (EL. -8.3 m to 59.2 m).

Pile with 1.5 m diameter drilled into the depth of -60.30 m, under a layer of slurry bentonite. The bidirectional test's loading procedure has two hydraulic jacks of Osterberg cells with a diameter of 610 mm, at a depth of 22 m above the pile toe. The load on o-cell is calibrated into 1.36 tons.

Based on the literature, the bidirectional test establishes two-directional loadings. Hence pile movement measured in this pile test is generated in two directions, upward and downward movement [14]. The load is corrected with the designed load given on the top pile.

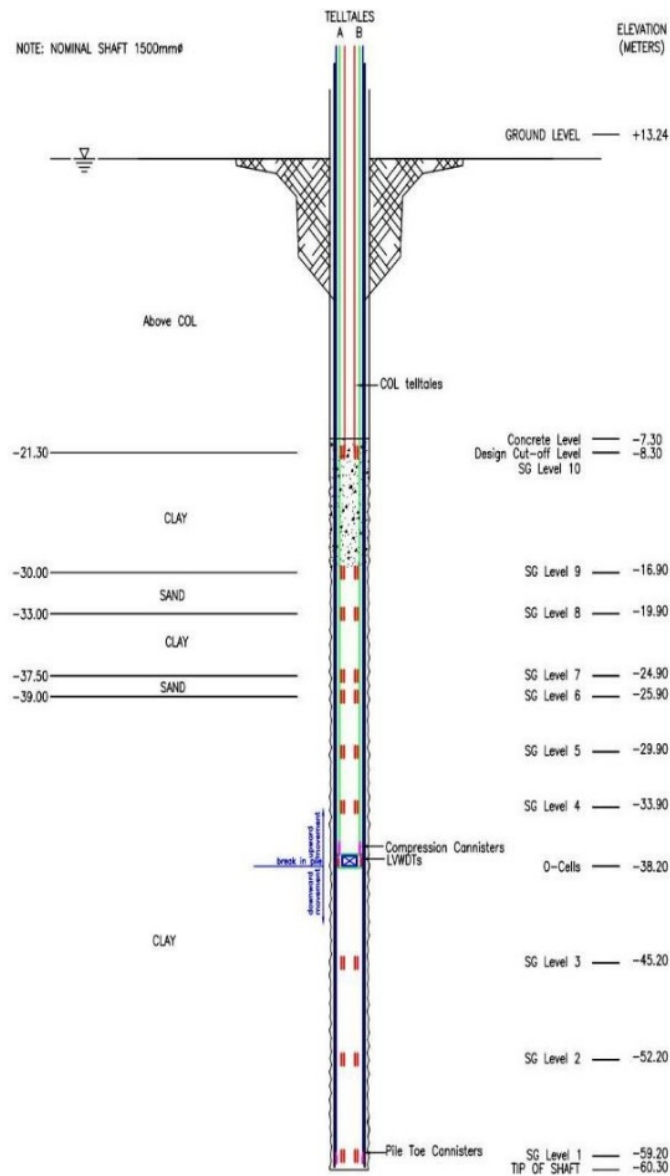
Table 5. Pile Movement During Load Test.

Load (ton)	Max. Settlement		Top Pile Load (ton)	Corrected load (ton)
	Cell Top	Cell Bot		
0	0	0	113	0
264	0.06	-1.79	113	151
486	0.84	-4.23	113	373
699	4.9	-25.89	113	586
792	9.34	-45.02	113	679
896	19.56	-115.9	113	783

Source : Instrumentation Final Report of BP 38. (2013).

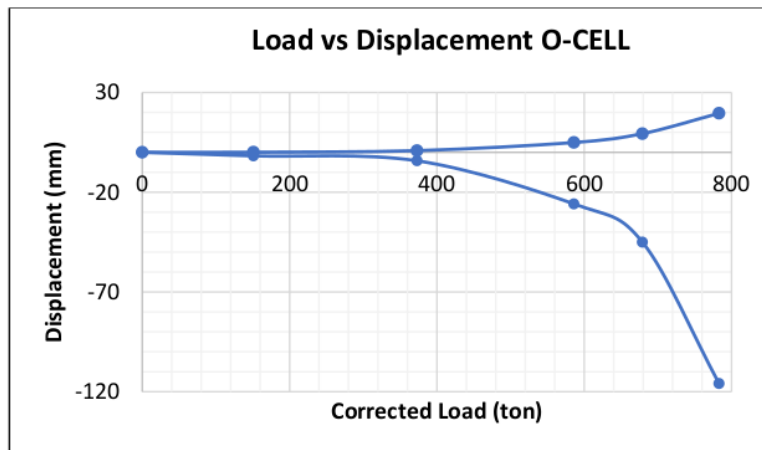
The bidirectional test shows two-way settlement during the load test. As shown in **Table 5**, on each step of loading, maximum settlement occurs during the load test on cell top and bottom.

On this test, top pile load (buoyancy weight) placed axially is 113 tons. On a bidirectional test, the load has to be corrected with the buoyancy weight itself, and it is called a corrected load. This corrected load is the data that will be used for analysis afterward. The following figure shows the soil condition of the location where the bidirectional test was undertaken.

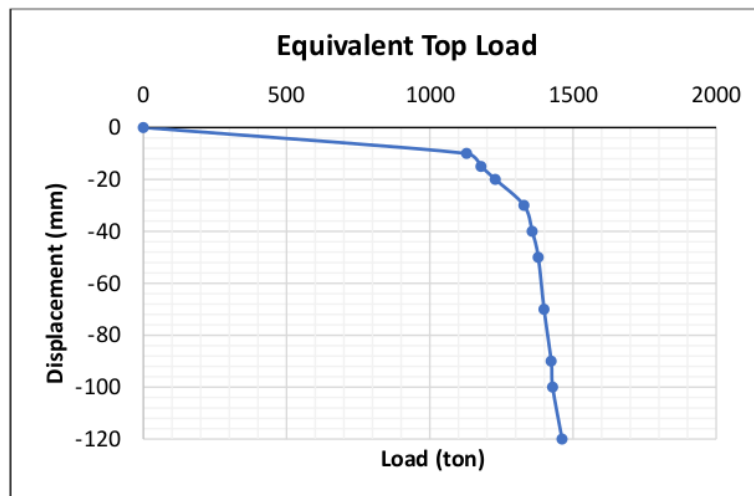


Source : Instrumentation report of BP 38. (2013).

Figure 8. Illustration of VWSG installation.



(a)



(b)

Source : Instrumentation Final Report of BP 38. (2013).

Figure 9. (a) Load vs displacement; (b) Equivalent top load

According to the bidirectional test's load vs. settlement curve, the equivalent top load curve can be determined to measure the settlement from the top of the pile. Based on Kim and Chung (2012), piles for axial load are designed to function similarly to a head-down test, and the design load is determined after combining shaft and toe resistance. Thus, a method to construct an equivalent head-down load-movement curve is needed [15].

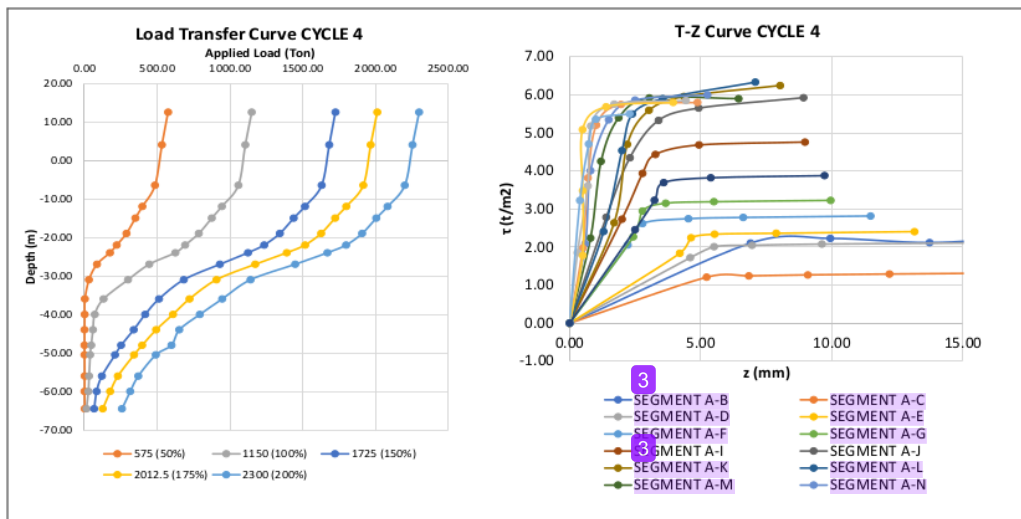
4.2 The T-Z Curve.

To determine the mobilized skin friction along the pile, it is necessary to do load transfer analysis along with the depth of the pile [16]. Load transfer analysis is developed into a curve that shows the relationship of skin friction and the pile movement at each segment, whereas instrumentation of strain gauge is installed [17].

1. Head-Down Static Loading Test (Kentledge).

A strain gauge instrumented on the pile during the pile loading test can produce a load distribution curve through the strain measured in the gauge installed [7]. Hence, the load distribution curve at the fourth cycle in each load stage is shown in Figure 10.

Figure 10 shows the load distribution in each stage loading. The curve shows that during loading at 200% load, the load has been distributed throughout the depths of pile until the pile toe. This can be seen on the depth of -64.5 m that the load distribution is 258 tons. The load distribution curve is then developed into the t-z curve that shows the mobilized skin friction along the pile during the loading test [18] [19].



Source : Bored Pile Interface and Expansive Soil on Pile with Bidirectional Test. (2020).

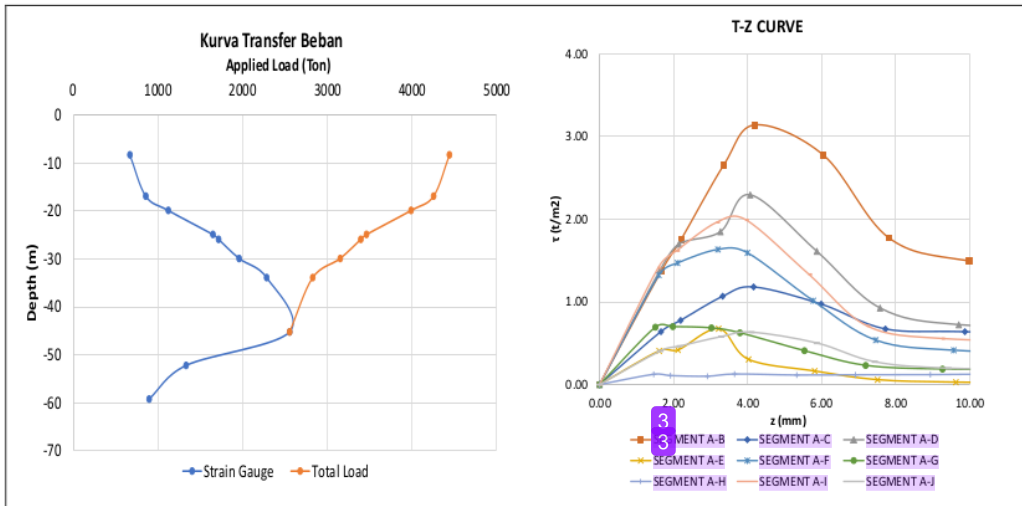
Figure 10. Load Transfer Curve And T-Z Curve of Kentledge System.

Based on the t-z curve in Figure 10, the maximum mobilized skin friction described as τ is around 6 t/m² at pile movement around 4 mm as this depth consists of stiff clay. The tz curve also shows how soil behavior acts on certain types of soil. As the soil classification is mostly dominated by clayey soil, the soil behaviour shows strain softening where the soil has reached its peak stress and releases stress afterward.

2. Bidirectional Test

4

On a bidirectional test, the same concept as the kentledge system, the t-z curve can be developed to determine the load distribution along with the pile. However, the bidirectional test will show a different type of load distribution. As there are two loading directions (upward and downward), the distribution will be upward and downward as well. The load distribution is then flipped over to produce the equivalent head-down load distribution [20]. This line is known as a total load.



Source : Thesis on Behaviour of Bored Pile Interface and Expansive Soil on Pile with Bidirectional Test. (2020)

Figure 11. Load Distribution of T-Z Curve And Bidirectional Test.

The bidirectional test's load distribution curve shows at the depth where strain gauge above o-cell is installed (-45.2 m) there is a different direction show. The t-z curve shows that the maximum mobilized skin friction is around 3 t/m² at pile movement around 4 mm.

5. Conclusion and Suggestion

5.1 Conclusion.

Based on the interpretation result from both methods of pile test, it shows the significant differences between the two. Bidirectional is assured of having more efficiency in time management to perform the work than the kentledge system. From the test in the site, mobilized skin friction that occurs along the pile shows a smaller result in the bidirectional test than the kentledge system. 3

This research would have concluded that there is about 20-50% difference on the load distribution of pile under axial load developed by t-z curve from the test result based on the bidirectional test and kentledge system. The t-z curve may represent the developed calculation that will describe how different pile behavior under axial load during pile test either using kentledge system of the bidirectional test.

The maximum skin friction mobilized along with the pile under load test of Kentledge, is bigger than the bidirectional test. This may occur as the bidirectional test establishes tension force during upward loading. The pile movement at maximum stress mobilized on the pile under axial load is around 2 – 6 mm on medium stiff clay. The t-z curve also shows the soil behaviour affected by the pile load test tends to be strain-softening soil. Most clayey soil exhibits strain to soften behavior, affecting the stability of an embankment of bearing capacity of a foundation. Therefore, in the design, there is much consideration in this. There will also be different approaches to the axial load test on sand layer as the soil behavior shows a different curve.

5.1 Suggestion.

It is recommended to use better technology instrumentation such as fiber optic, to get a more accurate and smooth result of load distribution curve and t-z curve. It is possible to have more strain gauges at more close depths to better accuracy. It will give a better approach if to do numerical analysis using the finite element method.

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