

BEARING CAPACITY OF FULL-FRICTION MICROPILES BASED ON SIMPLE FIELD LOAD TEST RESULTS IN BANJARMASIN VERY SOFT SOIL

*Yusti Yudiawati¹

¹ Department of Civil and Earth Engineering, State Polytechnic of Banjarmasin, Indonesia

*Corresponding Author, Received: 15 Jan. 2024, Revised: 27 Feb. 2024, Accepted: 28 Feb. 2024

ABSTRACT: Piles for foundations are used when hard soil layers are located far below the ground surface. Full-friction piles are defined as piles that depend solely on the friction between the pile and soil where the embedded depth is less than 10 meters. For decades, Galam wood piles have been used as foundations for light to medium-weight constructions. Due to Galam wood restrictions in length and diameter, concrete micropiles are used as an alternative. Therefore, it is important to know the actual bearing capacity of concrete micropiles in the field. A simple axial field load test was carried out on 3 (three) test pile samples of 15 cm x 15 cm concrete micro piles with pile length variations of 4 m, 5 m, and 9 m. This paper shows the ultimate and unit shaft bearing capacity for full-friction piles fully embedded in very soft soil. The 4 m long concrete micro piles produced an ultimate bearing capacity of 1,700 kg = 1.7 tons, the 5 m length 2,400 kg = 2.4 tons, and the 9 m length 3,550 kg = 3.55 tons indicating the ultimate bearing capacity increased linearly with the pile lengths. The pile shaft unit bearing capacity obtained was between 657.407 – 800 kg/m² of pile shaft area, where the obtained values show nearly constant results with similar conditions.

Keywords: Load test, Micropile, Pile shaft, Soft soil, Ultimate bearing capacity

1. INTRODUCTION

Soft soils are usually found in low-lying areas, river banks, estuaries, swamps, and beaches. Influenced by soil mineral deposits and time intervals, these soft soil deposits vary greatly and are complex. Soft clay soil conditions with high plasticity index, very small internal shear angles, and high void ratios are problems always faced in civil works [1]. Banjarmasin is located on the banks of the Barito River. The Barito River is the largest and longest river in South Kalimantan, with an average width between 650 – 800 m and an average depth of 8 m. The longest part of the river, starting from the upstream, is located in Central Kalimantan, and the remaining part, which reaches 1,000 m, is located in South Kalimantan [2]. Sediment flows into surrounding rivers and ends up in the Barito River due to erosion occurring in upstream areas. History shows that the tidal fluctuations from the sea and surrounding rivers, combined with water erosion, formed tidal swamp deposits [3].

The deposits resulting from the Barito River sedimentation process that became tidal swamp land are the surface soil layer in Banjarmasin in the form of very soft to soft clay and silt layers. The soft soil in Banjarmasin reaches a depth of 10 m and is still in the form of very soft soil with q_c values less than 6 kg/cm² [4]. The Banjarmasin cohesive soil in the form of very soft to soft clay and silt has a thickness of up to 25 – 30 m from the ground surface [5].

Soft soils have a poor bearing capacity, thus

shallow foundations cannot be used unless they are fortified with pile foundations to increase their bearing capacity [6]. There were several cases of tilted and collapsed buildings in Banjarmasin; The Indonesian Architectural Association in South Kalimantan reported there were at least 21 buildings in Banjarmasin that tilted and collapsed from 2018 to 2021 [7].

This problem can be resolved by using end-bearing piles as foundations. However, end-bearing piles in hard soil layers located deep from the ground surface cost more than the upper structure itself, thus full-friction piles are preferred for light to medium-load buildings [8]. Pile foundations used in Banjarmasin soil at depths less than 10 m are classified as full-friction piles, meaning that the sole factor determining the pile-bearing capacity is the friction between the pile and the soil [5]. Because of the homogenous characteristics of Banjarmasin's soft soil, the bearing capacity of full-friction piles is nearly constant [9].

Galam wood piles are typically used for full-friction pile foundations in Banjarmasin and the neighboring areas. Currently, it is very difficult to find sufficient length and large-diameter Galam wood for foundations. Concrete micro piles are starting to be used more frequently in the community, particularly for medium-sized buildings like shophouses and warehouses. According to [10], light buildings such as single and double-story houses on soft soil require alternatives to concrete micro piles, considering the scarcity of Galam wood.

In cases where the pile is entirely dependent on frictional resistance to support weight, deepening the piles is more preferred than adding more piles to the group as this will result in reduced bearing capacity efficiency [8]. The field static load test is the best method to determine the pile's actual bearing capacity. The loading test is conducted by applying loads gradually to the pile samples until they settle continuously at the same load [8, 9, 12-14].

Numerous studies have been done to obtain the ultimate bearing capacity of piles by conducting load tests; small-scale laboratory load tests on full-friction model piles in sand [14], pile field load tests on multi-layered soils with medium to very dense consistency [15], ultimate bearing capacity of end-bearing bored piles embedded in a layer of firmer soil [16], etc. However, study on full-friction piles fully embedded in very soft soil is still limited. Previous studies of full-friction piles were done to compare ultimate bearing capacity from field load tests and numerical calculations of single piles [9], and only focused on the ultimate bearing capacity and the efficiency of single and pile groups with lengths > 10 m [5].

In this study, direct field axial loading tests are conducted on 3 (three) concrete pile foundation samples of 15 cm × 15 cm with different pile lengths of 4 m, 5 m, and 9 m. This research focuses on the pile's actual bearing capacity based on the test data interpretation. The test results can be used as a reference to estimate the actual ultimate load in the field for full-friction piles in very soft soil.

2. RESEARCH SIGNIFICANCE

Many of the previous studies in obtaining the pile-bearing capacity from load test data are limited to only laboratory testing by using model friction piles, end-bearing piles in multi-layered soil with heterogeneous soil consistency (from soft to stiff/hard), or friction piles but the tip is embedded in a firmer soil, while this study focuses on obtaining actual pile bearing capacity from field load test data in homogeneous very soft soil consistency based on Banjarmasin soil condition. The significance of this study is to minimize the efforts and costs in estimating pile actual bearing capacity for full-friction piles without conducting expensive field load tests by using the pile unit shaft bearing capacity value obtained in this study. Full-friction micropiles and their ability to withstand the loads in very soft soil are necessary to choose the appropriate amount and length.

3. PILE BEARING CAPACITY DETERMINATION USING CPT AND N-SPT TESTS

Saturated clay soils contain clay minerals and high water content, which causes low shear strength,

high shrinkage swelling potential, and low bearing capacity. Clay soil is a type of cohesive soil with fine particles and a fairly good attractive force between the soil particles. Cohesive clay or silt with a high water content is usually called soft soil. The bearing capacity value of soft soil is only 7 – 29 kN/m², with small shear and compression forces [15, 16].

Before beginning structural work, soil investigation is crucial in civil works to ascertain the soil's bearing capacity, its physical and mechanical characteristics, and its classification, which will help determine the best type of foundation to use to withstand the load above. Depending on the type and size of the building that will be constructed, several soil tests are conducted.

Meyerhof [19], Chin [20], Janbu [21], and Danish Formula [22], among others, have devised methods for calculating pile-bearing capacity under soft soil conditions. Soil mechanical tests such as Standard Penetration Test (SPT), California Bearing Ratio (CBR), and Cone Penetration Test (CPT) can be used to determine the soil-bearing capacity [23]. CPT is the most common method to use as it provides cone resistance and friction resistance results that can be read by the manometer readings per 20 cm of testing depth even when the soil conditions are very soft, making it ideal for very soft soils. CPT provides results of cone resistance and friction resistance along the embedded pile's length to determine the ultimate bearing capacity (Q_{ult}) of full friction piles [8, 10, 11]. Meanwhile, the SPT data in very soft soil conditions usually has an N-value (N-SPT) of zero so it cannot be used to determine the bearing capacity of full-friction piles [26]. N-value is the summation of blows needed to penetrate through a 150 mm interval of soil depth and is a rough estimate of the soil density, it is also used in many empirical geotechnical engineering formulas [27].

If the hard soil is exceptionally deep, as indicated by a D_f/B ratio greater than 10, pile foundations are used [28]. Pile foundations are structures made of wood, concrete, steel, or other materials that are used to transfer the weight of the super-structure onto a strong layer of soil as piles can distribute load vertically [29]. This form of foundation is utilized when the soil beneath the building lacks the bearing capacity to support the weight of the building load [30]. Pile foundations can be tested for their actual bearing capacity by being subjected to loading above them. The best and most accurate method that can be used is by using a loading test or static loading test. The loading test data can be interpreted to obtain the actual bearing capacity of the pile foundation [31]. Pile loading tests are needed to prove the accuracy of calculating the design capacity of piles from various calculation methods based on soil test data in the field.

Interpretation of pile loading test results can be used to determine the bearing capacity. There are many ways to interpret the ultimate load from the

results of pile loading tests. The Graphical Method with the Elastic Plastic Method (Tangent Method) is one of the easiest ways [13]. This method shows the estimated ultimate bearing capacity by dragging each tangent line from the initial and the end of the load-settlement curve. The point of intersection between the tangent line on the elastic part and the plastic part determines the limit or ultimate load.

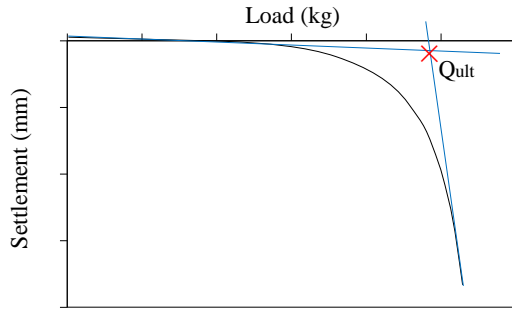


Fig.1 The plastic-elastic method (tangent method)

4. RESEARCH METHODOLOGY

4.1 Banjarmasin Soil Conditions and Parameters

The results of soil investigation using bore-drilling/SPT and CPT are shown in Fig.2. It is known that soft soil layers consisted of very soft clay and soft to medium silt with an *N*-SPT value of 0 – 1 and Cone values of 1 – 6 kg/cm² are found up to a depth of around 20 m, the next layer is silt with stiff to hard consistency up to a depth of 25 m. Sandy soil layers with medium density were found at depths around 25 m to the end of the test at a depth of 30 m.

The physical and mechanical features of soil or soil properties can be identified and studied from laboratory test results on soil samples taken during drilling at the soil investigation site. The test results obtained can be used to determine the properties of the soil and calculate the bearing capacity and settlement of the soil and foundation [32].

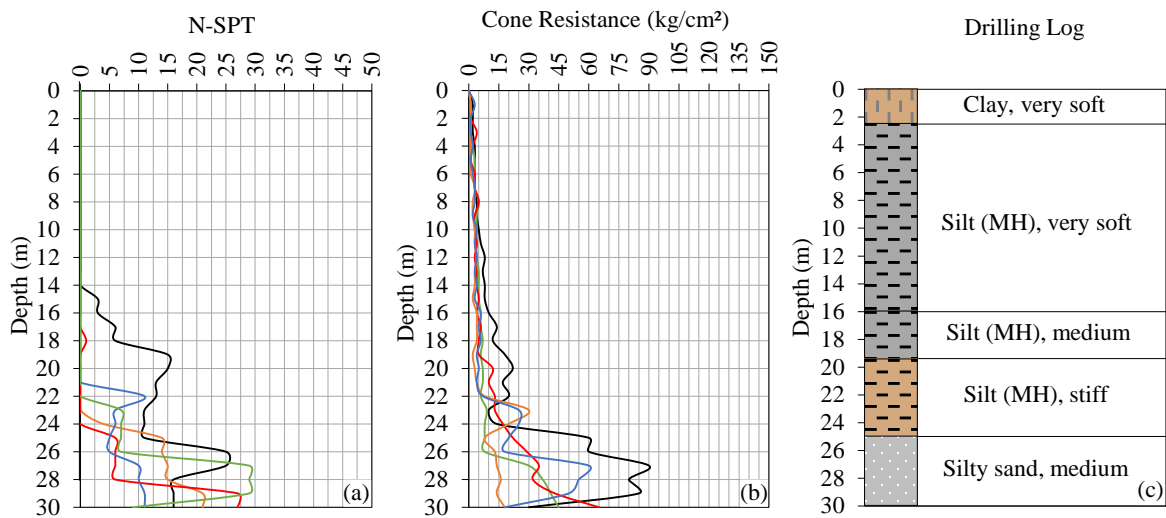


Fig.2 (a) N-SPT values based on the results of bore-drilling/SPT, (b) Cone resistance values based on the results of CPT, (c) Soil classifications based on bore-drilling/SPT and CPT

Table 1 Soil properties data

Depth (m)	Moisture Content, w (%)	Specific Gravity, G _s	Volume Weight, γ (kg/cm ³)	Soil Proportion by Gradation Curves (%)			Liquid Limit, LL (%)	Plasticity Index, PI	Cohesion, c (kg/cm ²)	Internal Friction Angle, φ (°)	Void Ratio, e
				Sand	Silt	Clay					
1	145.26	2.21	1.33	4.91	38.89	56.20	50.50	3.26	0.14	9.40	2.53
3	89.46	2.53	1.53	2.50	86.50	11.00	47.80	10.18	0.13	18.4	2.21
5	85.32	2.52	1.50	11.08	76.72	12.20	43.20	6.44	0.09	12.4	2.24
7	89.36	2.49	1.49	0.90	90.30	8.80	48.70	7.18	0.05	4.9	2.11
9	89.30	2.50	1.46	0.18	86.82	13.00	53.50	11.52	0.14	10.2	2.17
12	98.50	2.45	1.48	0.41	72.80	26.80	69.30	28.25	0.59	8.80	2.81
15	93.39	2.46	1.46	0.28	80.72	19.00	58.15	11.66	0.11	23.0	2.28
21	86.63	2.49	1.50	26.50	55.10	18.40	55.00	6.30	0.17	12.7	2.32

Laboratory test results from samples taken in Banjarmasin at depths of 1.0 – 21.0 m (Table 1) show moisture content ranges from 85% – 145%, unit weights of 1.33 – 1.5 gr.cm³, and specific gravity ranging from 2.21 – 2.53. Soil cohesion values based on Unconfined Compression Test (UCS) tests range from 0.05 – 0.59 kg/cm². The resulting physical properties of the soil all indicate the soil is soft. The soil type based on the Unified Soil Classification System (USCS) is silty soil with medium to high plasticity. Void ratios range from 2.11 – 2.81, with void ratios > 2 indicating that Banjarmasin soil has high compressibility.

4.2 Field Axial Loading Tests

Field axial load test research was carried out in the State Polytechnic of Banjarmasin campus area. Simple loading tests were carried out on 3 (three) test pile samples of 15 cm x 15 cm concrete micro piles with pile length variations of 4 m, 5 m, and 9 m as shown in Fig.3.

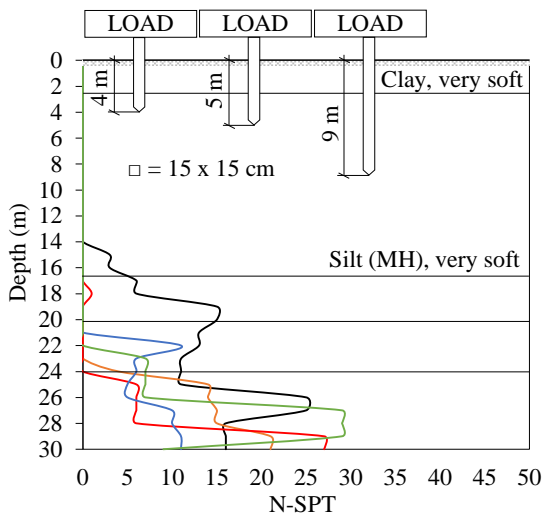


Fig.3 Description of concrete micropile test piles for field load test

The research location is on a swamp land with a groundwater level around 50 cm from the ground surface. The ground surface condition which was below the groundwater level caused the driving and loading methods to be adjusted to the field conditions. Test piles could only be driven using a tripod drop hammer with a 500 kg hammer. The piles were driven to the planned embedded depth, and 100 cm of the pile was left above the ground to place the load frame. After the piles were driven, they were left for 15 days to allow the friction between the soil and the pile shaft to take effect.

Preparations for field load testing began by making a loading frame as shown in Fig.4. The load frame is made from welded steel. A steel cap on the

pile head is also prepared to be welded with the loading frame. Steel bars were installed on the loading frame to place the measuring ruler during settlement observation. Then for the loads used during testing, precast concrete piles were used with the dimensions of 20 cm x 20 cm, 3 m in length, and weighed 300 kg each pile.



Fig.4 Loading frame from welded steel

A waterpass and a ruler staff is used in the measurements to accommodate the needed accuracy in taking the height difference data from observations of settlements during field load tests, illustration is shown in Fig.5. The waterpass was placed at a point where the initial elevation has been set so that the subsequent height difference can be determined at each settlement observation.

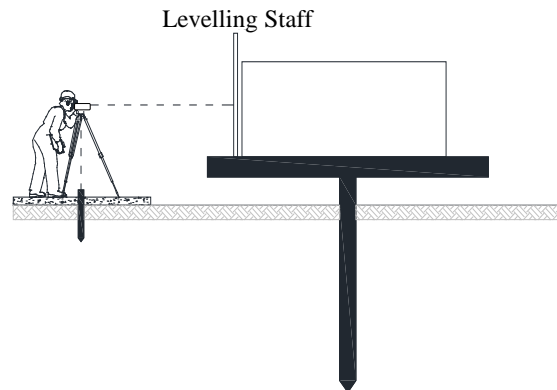


Fig.5 Measurement of settlement during load test using waterpass

The load test process was carried out by applying several load stages and observing the settlement that occurred at each stage. Observations were made at each stage for 2 × 60 minutes where settlements were measured every 15 minutes. Further loading was carried out with the same process and loading would be stopped if, at a certain load stage, settlement continued to occur even exceeding the pile diameter size. Field load tests can be stopped if the movement/settlement that occurs is more than 10% of the pile diameter [6]. Implementation of load tests on the 3 (three) test pile samples is shown in Fig.6.

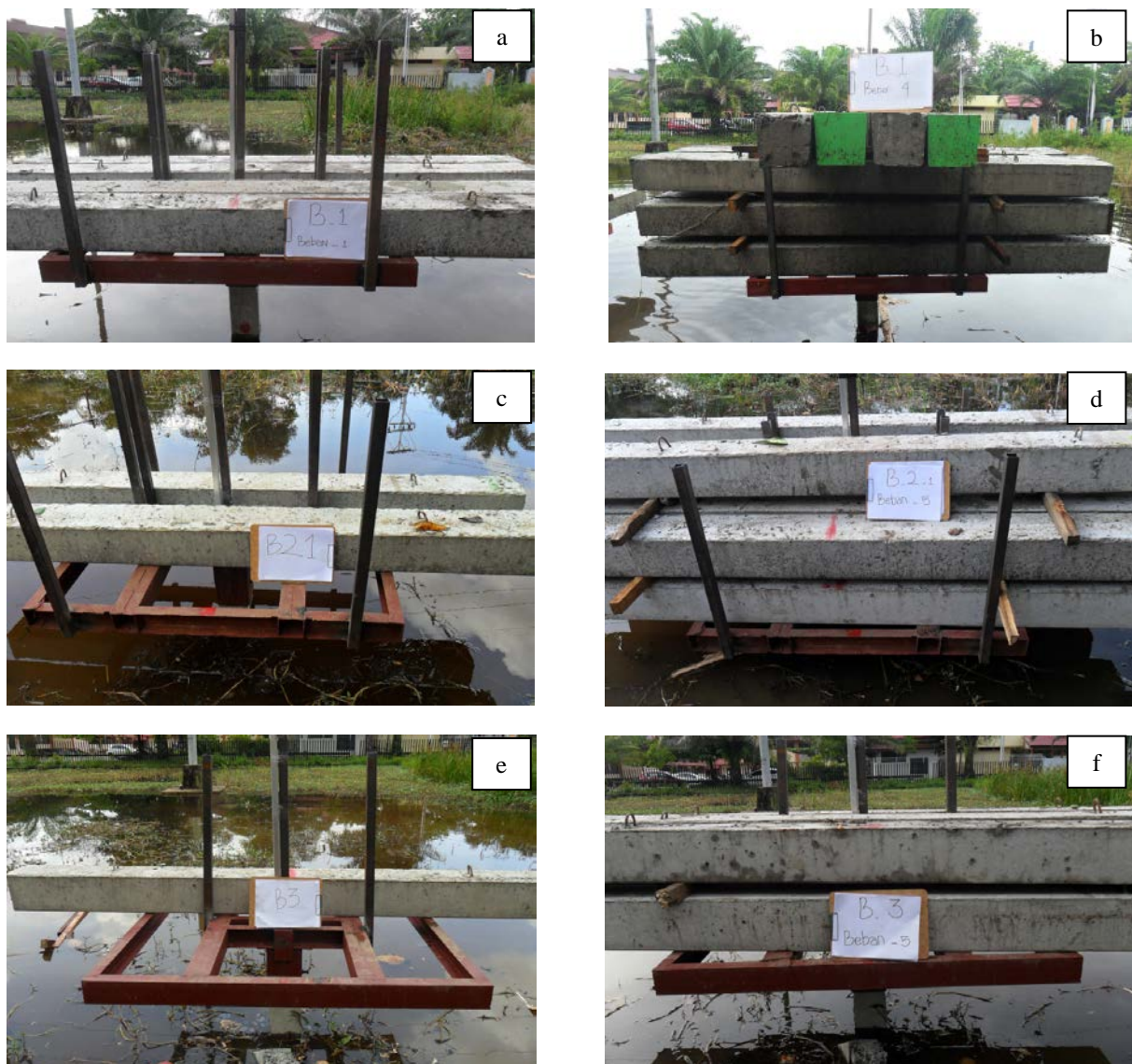


Fig.6 Field loading test process: (a) B1 first stage loading, (b) B1 final stage loading, (c) B2.1 first stage loading, (d) B2.1 final stage loading, (e) B3 first stage loading, (f) B3 final stage loading

5. RESULTS AND DISCUSSIONS

The results of observing settlements at each loading stage in this simple load test are described in the form of a curve of the relationship between the load and settlement, as shown in Fig.7 – Fig.9. Determination of ultimate bearing capacity (Q_{ult}) in this simple load test is done graphically using the Tangent Method.

The intersection of the load-settlement curve's initial and final tangent lines is identified as the ultimate bearing capacity (Q_{ult}) [33]. The settlement reaction during the initial stages of loading is relatively minimal as the pile is still in the elastic stage. The end-bearing resistance still support the load given to the test piles at this stage. When the load

given is nearing the estimated ultimate bearing capacity (Q_{ult}), a huge settlement occurs rapidly in a short time. This rapid settlement is causing the test piles to experience failure. At this stage, the end-bearing resistance has little to no involvement in supporting the load and the piles relies fully on the skin friction resistance of the pile shaft.

Each single pile test results depending on the pile lengths showed that B1, B2.1, and B.3 produces an ultimate bearing capacity (Q_{ult}) of 3,550 kg or 3.55 tons, 2,400 kg or 2.4 tons, and 1,700 kg or 1.7 tons, respectively. This means the pile ultimate bearing capacity (Q_{ult}) increases with the increase of the pile lengths. Found results are similar to [5] and [9], where ultimate bearing capacity is linear with pile lengths. A minimum safety factor of 3.0 is recommended to

use in estimating ultimate bearing capacity for full-friction piles [5].

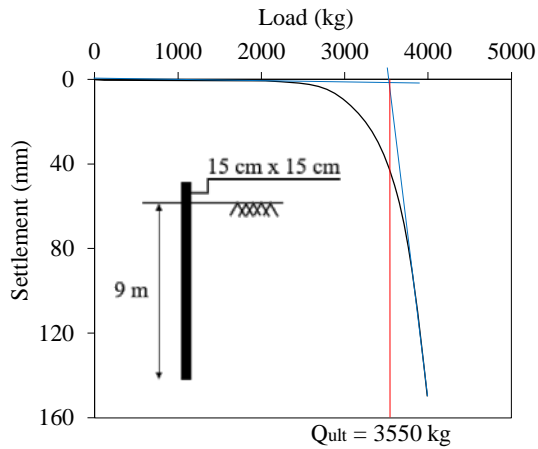


Fig.7 Axial load test curve on 15 cm × 15 cm micro pile with 9 m length (B1)

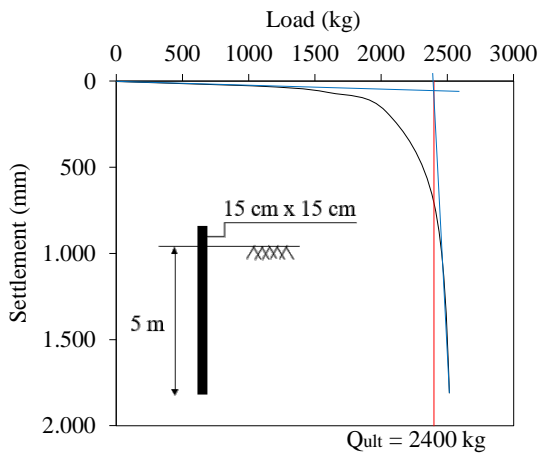


Fig.8 Axial load test curve on 15 cm × 15 cm micro pile with 5 m length (B2.1)

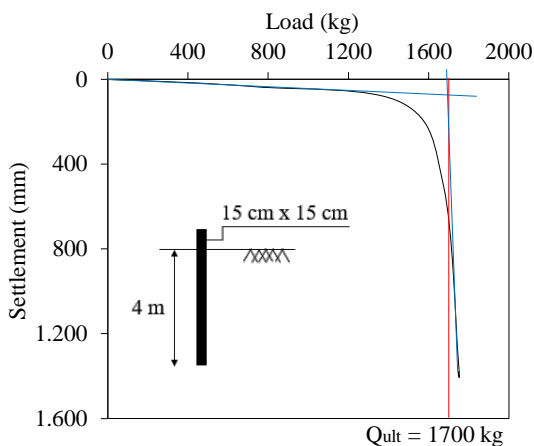


Fig.9 Axial load test curve on 15 cm × 15 cm micro pile with 4 m length (B3)

Based on the loading test done to the test piles, it can be assumed that the pile ultimate bearing capacity (Q_{ult}) in soft to very soft soil relies solely on the friction between the pile shaft surface and the surrounding soil while the pile tip bearing capacity is ignored, which means the ultimate bearing capacity is the shaft bearing capacity itself ($Q_{ult} = Q_s$). The pile unit shaft bearing capacity (q_s) is obtained by dividing the ultimate bearing capacity (Q_{ult}) by the pile shaft area (A_s) showed in Eq. (1).

$$q_s = \frac{Q_{ult}}{A_s} \tag{1}$$

Table 2 Results of axial load test on test piles

Pile Number	Pile Dimension (cm)	Pile Length (m)	A_s (m ²)	Q_{ult} (kg)	q_s (kg/m ²)
B1	15 x 15	9	5.4	3,550	657.407
B2.1	15 x 15	5	3.0	2,400	800.000
B3	15 x 15	4	2.4	1,700	708.333

The results obtained shows that B1, B2.1, and B.3 produces a unit shaft bearing capacity (q_s) of 657 kg/m², 800 kg/m², and 708 kg/m², respectively. A previous study of full-friction piles in very soft soil with a length of 5,5 m estimated ultimate bearing capacity from CPT data shows that Begemann Formula [34] produces pile ultimate bearing capacity of 3,320 kg and 7,350 kg [10] or pile shaft unit bearing capacity of 754.545 kg/m² and 715.909 kg/m², which falls into the range of results obtained in this study. This is also in agreement of [9], where the bearing capacity is nearly constant in homogenous Banjarmasin very soft soil.

Although all samples in this paper show comparable results, further research is needed to ensure the consistency of the unit shaft bearing capacity of full-friction piles in very soft soil as the research done in this paper is limited to only 3 (three) different pile lengths samples with the same dimensions.

6. CONCLUSIONS

The research was carried out by utilizing axial field load tests on 3 (three) samples of 15 cm x 15 cm concrete micro pile samples, with lengths of 4 m, 5 m, and 9 m. The tangent method is used to interpret the test results; the ultimate bearing capacities (Q_{ult}) of the test piles are 1,700 kg for the 4 m pile, 2,400 kg for the 5 m pile, and 3,550 kg for the 9 m pile. According to the results obtained, the pile's ultimate bearing capacity (Q_{ult}) increases with the pile lengths.

Based on the assumption that the pile bearing capacity fully depends on the pile friction, the pile shaft bearing capacity (Q_s) has the same value as the pile ultimate bearing capacity (Q_{ult}). Meanwhile, the pile unit shaft capacity (q_s) shows a nearly constant results of 708.333 kg/m² for the 4 m pile, 800 kg/m² for the 5 m pile, and 657.407 kg/m² for the 9 m pile.

While this paper shows the relationship between pile lengths and pile ultimate bearing capacity (Q_{ult}), and obtained pile unit shaft bearing capacity (q_s) for full-friction piles in very soft soil, it is still limited to only one type of pile dimensions for each observed length. Recommendations for future studies; researchers are encouraged to add more variations of different pile cross-sections and lengths to attest if the pile capacity per square meter of pile shaft area obtained is nearly the same with piles of different cross sections.

7. ABBREVIATIONS AND NOMENCLATURE

SPT	= Standard Penetration Test
CBR	= California Bearing Ratio
CPT	= Cone Penetration Test
UCS	= Unconfined Compression Test
USCS	= Unified Soil Classification System
Q_{ult}	= Ultimate bearing capacity (kg)
Q_s	= Shaft Bearing Capacity (kg)
A_s	= Pile Shaft Area (m ²)
q_s	= Unit Shaft Bearing Capacity (kg/m ²)
w	= Moisture Content (%)
G _s	= Specific Gravity
γ	= Volume Weight (kg/cm ³)
LL	= Liquid Limit (%)
PI	= Plasticity Index
c	= Cohesion (kg/cm ²)
ϕ	= Internal Friction Angle (°)
e	= Void Ratio

8. REFERENCES

- [1] Wisnantara, I. G. N. N. and Budiarnaya, P., Methods for Increasing the Bearing Capacity of Soft Soil, *Scientific Journal TELSINAS*, Vol. 3, No. 2, 2020, pp. 37–40.
- [2] Susilowati, E., The Role of River Networks as Trade Routes in South Kalimantan in the Second Half of the XIX Century, *Historical Journal Citra Lekha*, Vol. 15, No. 1, 2011, pp. 1–8.
- [3] Mawardi, M., Sudira, P., Sunarminto, B. H., Gunawan, T., and Purwanto, B. H., Effects of the Tides on the Mud Clay Deposition in the Wetland Rice Field of Tidal Swamps of Barito River of South Kalimantan Mawardi, *agriTECH*, Vol. 38, No. 3, 2018, pp. 273–281, doi: 10.22146/agritech.33863.
- [4] Yudiawati, Y. and Lestari, A. M. F., Geotechnical Properties of Very Soft Clay from Banjarmasin, in 21st Annual National Conference on Geotechnical Engineering, 2017, pp. 181–185.
- [5] Yudiawati, Y., Mochtar, I. B., and Mochtar, N. E., Group Capacity and Efficiency of Full Friction Piles on Very Soft Soil, *International Journal of GEOMATE*, Vol. 16, No. 57, 2019, pp. 201–208, doi: 10.21660/2019.57.68950.
- [6] Satria, Z., Fatnanta, F., and Nugroho, S. A., The Effect of Time on Bearing Capacity of Pile Foundations in Soft Soil with Varying Roughness, *Civil Engineering Journal (JRS-Unand)*, Vol. 16, No. 1, 2020, pp. 12–24, doi: 10.25077/jrs.16.1.12-24.2020.
- [7] [mediakita.co.id](https://mediakita.co.id/marakhunian-ambruk-di-banjarmasin-dua-dosen-ulm-beberkan-solusinya), Several Buildings Collapsed in Banjarmasin, Two ULM Lecturers Explain the Solutions, 2021. <https://mediakita.co.id/marakhunian-ambruk-di-banjarmasin-dua-dosen-ulm-beberkan-solusinya>
- [8] Amariansah, W., Apriyanto, and Doni Febriansah, M., Optimization of Bearing Capacity of Pile Groups in Soft Soil, *Neo Teknika*, Vol. 7, No. 2, 2021, pp. 31–36, doi: 10.37760/neoteknika.v7i2.1837.
- [9] Yudiawati, Y., Mochtar, I. B., and Mochtar, N. E., Bearing Capacity of Single Full Friction Pile Based on the Results of CPT Calculation and Field Loading Test, in 20th Annual National Conference on Geotechnical Engineering, 2016, pp. 283–288.
- [10] Yudiawati, Y. and Marzuki, A., Bearing Capacity Evaluation of Axial Surface on Full Friction Pile in Banjarmasin Soft Clay, in 21st Annual National Conference on Geotechnical Engineering, 2017, pp. 323–330.
- [11] Sapriyadi, W., Priadi, E., and Faisal, A., Study of Pile Bearing Capacity in Soft Soil Using Ensoft, JeLAST: *Journal of Marine, PWK, Civil, and Mining Engineering*, Vol. 5, No. 1, 2018, pp. 1–14, doi: 10.26418/jelast.v5i1.24483.
- [12] Abdulla, N. A., The Behavior of Concrete-Filled Plastic Tube Specimens under Axial Load, *Jordan Journal of Civil Engineering*, Vol. 14, No. 1, 2020, pp. 69–81.
- [13] Idris, Y., Dewi, R., Yulindasari, and Munawar, S. A. Al, The Effect of Folded Plate Angles on Bearing Capacity of Foundations in Clay, in National Conference AVoER XII, 2020, pp. 488–493.
- [14] Chan, C.-M. and Mansor, N. A., Improved Soil-Pile Interaction Of Floating Pile In Sand With Shaft Treatment, *International Journal of GEOMATE*, Vol. 13, No. 39, 2017, pp. 73–79, doi: 10.21660/2017.39.31979.
- [15] Zein, A. K. M. and Ayoub, E. M., Evaluation Of Measured And Interpreted Failure Loads Of Bored Piles In Alluvial Soil Deposits, *International Journal of GEOMATE*, Vol. 10,

- No. 1, 2016, pp. 1636–1643, doi: 10.21660/2016.19.201111.
- [16] Rusnardi, R. P., Relationship Between Obtained Ultimate Bearing Capacity Results Based On N-Spt Results And Static Load Tests, *International Journal of GEOMATE*, Vol. 19, No. 74, 2020, pp. 153–160, doi: 10.21660/2020.74.60639.
- [17] Sumiyanto, S. and Yanto, Y., Flexible Pavement Reinforcement on Soft Clay Soil Using Used Tire Rubber Matting, *Engineering Dynamics*, Vol. 19, No. 1, 2023, pp. 1–7, doi: 10.20884/1.dr.2023.19.1.407.
- [18] Naibaho, A. G. and Waruwu, A., Study on Capacity of Pile Group in Soft Soil Using a Small-Scale Laboratory, *Civil Engineering Communication Media*, Vol. 27, No. 2, 2021, pp. 179–186, doi: 10.14710/mkts.v27i2.33737.
- [19] Meyerhof, G. G., Some Recent Research on the Bearing Capacity of Foundations, *Canadian Geotechnical Journal*, Vol. 1, No. 1, 1963, pp. 16–26, doi: 10.1139/t63-003.
- [20] Chin, F. K., Estimation of the Ultimate Load of Piles from Tests Not Carried to Failure, in *Proceedings of Second Southeast Asian Conference on Soil Engineering*, Singapore City, 1970, pp. 81–92.
- [21] Janbu, N., Static bearing capacity of friction piles, in *Proceedings of the 6th European Conference on Soil Mechanics and Foundation Engineering*, 1976, Vol. 1, No. 2, pp. 479–488.
- [22] Sorensen, T. and Hansen, B., Pile Driving Formulae—An Investigation based on Dimensional Considerations and a Statistical Analysis, in *4th International Conference on Soil Mechanics and Foundation Engineering (London)*, 1957, pp. 61–65.
- [23] Ahmad, L. G. and Surahman, M., Bearing Capacity of Piles Analysis Using In Situ Test Data, Laboratory Parameters for the Kantledge Loading Test, *Konstruksia Journal*, Vol. 7, No. 2, 2016, pp. 65–74, doi: 10.24853/jk.7.2.%25p.
- [24] Ridhayani, I., Study of Soil Bearing Capacity Analysis Based on CPT Data at Padhang-Padhang Campus, University of West Sulawesi, *Bandar: Journal of Civil Engineering*, Vol. 3, No. 2, 2021, pp. 37–42.
- [25] Okviyani, N., Ridhayani, I., Suryani, H., Sainuddin, Adriani, and Amirullah, Soil Investigation Based on CPT Data and Geoelectric Data in UNSULBAR Hall Building, *GEOMining Journal*, Vol. 4, No. 1, 2023, pp. 8–13, doi: 10.33387/geomining.v4i1.6200.
- [26] Bela, K. R. and Sianto, P., Soil Investigation Using Cone Penetration Test Method, *Eternitas: Civil Engineering Journal*, Vol. 2, No. 1, 2022, pp. 50–58, doi: 10.30822/eternitas.v2i1.1755.
- [27] Alel, M. N. A., Upom, M. R. A., Abdullah, R. A., and Abidin, M. H. Z., Estimating SPT-N Value Based on Soil Resistivity using Hybrid ANN-PSO Algorithm, *Journal of Physics: Conference Series*, Vol. 995, 2018, pp. 012035, doi: 10.1088/1742-6596/995/1/012035.
- [28] Ningrum, P., Husnah, and Saputro, D. A., Bearing Capacity Analysis of Pile Foundation in Reservoir Construction, *Journal International Multidisciplinary*, Vol. 1, No. 2, 2023, pp. 33–42, doi: 10.58794/jim.v1i2.502.
- [29] Kaladi, F., Wang, F., and Kherazi, F. Z., Structural Stability: A Comprehensive Review of Pile Foundations in Construction, *Journal of Asian Development Studies*, Vol. 12, No. 4, 2023, pp. 412–425.
- [30] Atmoko, R. D., Andriyanto, Sonjaya, E., Ramadhan, J., and Setiawan, A., Re-Analysis Of Building Foundations, *PalArch's Journal Of Archaeology Of Egypt/Egyptology*, Vol. 17, No. 10, 2020, pp. 3369–3386.
- [31] Silitonga, A. P. and Iskandar, R., Comparison of Pile Foundation Bearing Capacity by Analytical and Loading Test Method Against the Finite Element Method Using Mohr-Coulomb and Soft Soil Models in Bore-Hole I (Case Study of Rusunawa Development in West Jatinegara, East Jakarta), *Civil Engineering Journal USU*, Vol. 6, No. 1, 2017, pp. 15–29.
- [32] Lakshmi, R., Study On Soil Investigation Practises Among Local Residential Construction Works, *Epra International Journal of Multidisciplinary Research (IJMR)*, Vol. 7, No. 12, 2021, pp. 45–49, doi: 10.36713/epra2013.
- [33] Baek, S.-H. and Bong, T., Influence of Load Test Scale on Prediction of Ultimate Bearing Capacity of Aggregate Pier Reinforced Clay, *Advances in Civil Engineering*, Vol. 2022, 2022, pp. 1–13, doi: 10.1155/2022/2742360.
- [34] Begemann, H. K. S. P., The Maximum Pulling Force on a Single Tension Pile Calculated on the Basis of Results of the Adhesion Jacket Cone, in *6th International Conference on Soil Mechanics and Foundation Engineering*, 1965, pp. 229–233.