Journal of Applied Engineering and Technological Science
Vol 6(2) 2025: 1397-1411

AN EMPIRICAL STUDY FOR ESTIMATING ULTIMATE BEARING CAPACITY OF CONCRETE SMALL-PILE CLUSTER IN SOFT CLAYS

Suyuti Suyuti[1*], Mukhlis Muslimin[2]
Department of Civil Engineering, Universitas Khairun, Indonesia[1]
Department of Mechanical Engineering, Universitas Khairun, Indonesia[2]
suyuti@unkhair.ac.id[1]

Received: 01 April 2024, Revised: 25 February 2025, Accepted: 18 March 2025
*Corresponding Author

ABSTRACT
Soft subgrades with shear strength, c_u of 10 kPa to 25 kPa are given low bearing capacity and high settlement. Local government has been built infrastructure of embankment such unpaved road on the soft subgrade by using timber and bamboo materials (called "Cerucuk") are very familiar for Indonesian local people. By developing load capacity of floating pile type, bamboo pile cluster was applied for Tol road in North the Java Island. However, bamboo material limited of life construction inside the soft ground, and exploitation of timber pile was violated environmental issue. Therefore, this research method is developed a new geometrical small - cluster pile by using concrete from local material or Igneus stone such as gravel and sand produced in quarry Ternate Island. Ultimate bearing capacity of single small - cluster pile installation modelled in soft subgrade tank. Then, observed by several block concretes and it is presented by empirical formulae. Finally, the ultimate load capacity of small-pile cluster in soft subgrade is obtained Q_u of 15.92 kN and 19.79 kN for observation and calculation, respectively. Rearrange of piles can be increased load capacity of small-cluster pile in soft subgrade as spacing single pile by spacing $5D_{eq}$ to $3D_{eq}$. Mostly load capacity of small-pile clusters should be calculated by using empirical method to provide bearing capacity based on geotechnical rule with laboratory and field soil investigation data and load standard for unpaved roads.
Keywords*: *Empirical Study, Load Capacity, Small-Pile Cluster, Soft Clay.

1. Introduction

Situation of lowland deposit of soft soil layers covered about 30 percents in Indonesia, it is included soft soil, soft clay and peat soil (Buana et al., 2019). These produces seriously problems soft subgrades of road embankment again saturated condition, consolidation process and big compressible layers (PUPR, 1999; PUPR 2002; Terzaghi et al., 1948). In fact, the soft subgrade given low bearing capacity and large settlement under load pressures of static and dynamic. Recently the problem of small pile materials such as bamboo and timber pile are limited life construction beneath soft ground, and also timber pile damaged environmental issue.

Local engineers and government have to make a robust foundation of road construction on weak foundation. By considering high intensity loads, a foundation structure must be satisfied design stability rule. Consequently, stability criteria of embankment on soft subgrades are often considered by soil stabilization and piling method, and its soft ground for reinforcing chemical and mechanical. By ensuing procedure construction step of embankment on soft soil for road, public work services were explained such as 1) Clearing and cutting top soil, 2) installed pile into soft ground, 3) layed geotextile, 4) spread and compacted granular material or cement-soil, and 5) Filling up soil for road embankment (PUPR, 1999; PUPR 2002; PUPR 2005). This guideline procedural is not explained the stability criterion design in detailed foundation by using piles.

In scientific report, the capacity of soft soil reinforced by timber piles as called in Indonesian "*Cerucuk*" (Roosseno, 1989). By experimental method of timber pile installed beneath a granular layer with polyfelt sheets as mattress for building foundation on the very soft soil (soil mechanics of consistency c_u of 25kN/m^2) located at Semarang, it gives settlement as recorded about 25 centimeters. By comparing ratio of load pressure p of 4,700 kg/m^2 (or 46 kN/m^2) to the settlement above, there was found bearing capacity of foundation up to two times by c_u of 50 kN/m^2. But this scientific is too difficult to understand, because there are not presented mechanism of pile installation effect by mathematical formula based on physical meaning.

The mechanism of mechanical reinforcement used geotextile and timber piles on soft ground, they were explained settlement subtraction again the settlement due to embankment with timber pile installation to deformation on piles alone. This timber pile installation was applied to construct soil embankment with floating pile system. Mathematical equations prepared explanation based on geotechnical engineering rules, which used single timber pile (PWRC, 2000).

By investigation performances capacity of bamboo material, they were reported uses bamboo for soft subgrade as foundation in mattress and pile cluster installation in worked trial embankment construction unity. The trial embankment for Tol road in North Jakarta on the soft soil reinforced by bamboo cluster, those trials were reported by settlement plates for 98 days, which were placed by crossing beneath embankment. The real settlements were recorded and compared with Finite Element (FE) – Method by consolidation effect and water process dissipation under loading pressure of embankment (Irsyam et al., 2008; PUPR, 2005; Sandyutama et al., 2015; Y Daryanto et al., 1995).

Satibi (2009) presented design criterion of behavior of soil embankment on the floating piles with cap system using FE-Method, which used concrete size pile d of 20 centimeters. The piling into soft ground installed by length variation L of 20 up to 100 centimeters, soft soil layer H down to 20 meters, and effective bulk density γ' of 7 kN/m^3.

Loading pressure of soil embankment constructed H_b of 1 meter up to 4 meters with bulk density γ_b of 18 kN/m^3. In simulations are used constitutive models to calculate deformation ground surface due to load of embankment. A concept block behavior was effective to estimate heigh of embankment on floating pile of soft soil (Ghalesari et al., 2013).

Structure performance of timber pile within the soft ground, several researchers were reported such as determination method of the oedometer direct permeability. The multi- layers analysis includes any variation of consolidation parameters with several depths.

The consolidation parameters, settlement and pore water pressure analyses were simulated by using case histories two test fills on soft clays, which are used empirical relation in graphs of the soil plasticity index and ratio of undrained shear strength to effective overburden of subsoil, it can be produced soil stresses at the tip pile (AM. Mesri, 1975).

Field and laboratory test results presented to describe disturbance of timber pile driving into soft clays, glacial and lake soil deposit (Cummings et al., 1950). Relation of between soil cohesion with vane shear test results determined into load and settlement of pile driving alone 23 meters into saturated soft clay with plasticity index PI of 22% (Seed & Reese, 1957).

They were monitored the settlement due to loading tests during 33 days, and given increment from 2.2 kN to 4.44 kN. Axial pile capacity in clay soil, which reported the effect of pile length of penetration on developing shaft friction pile in clays (Al-Gharbawi et al., 2024; Azzouz et al., 1990; Gavin et al., 2010; Seed & Reese, 1957).

Practically, the use the small-pile clusters to become effective to increase bearing capacity of floating pile type again decreasing water content due to consolidation process at the surrounding pile installation. The decreasing water content to be changed undrained shear strength s_u or undrained cohesive soil c_u. The factual, bearing capacity of pile in the soft clay can be considered mainly the influence of soil cohesion at along till tip of pile and circumference of timber single pile as well as skin friction of pile (Burland, 1973; Carter, 1981; Tomlinson, 1957; Tomlinson, 1971; Seed & Reese, 1957).

Moreover, a potential area of increasing skin friction capacity developed by approaching method for river dike on soft soil using bamboo piles. Where results were validated by trial embankment data on soft soil of using timber piles beneath mattress by spacing 5d, diameter 10cm, and length 3 meters. The mattress was applied with soil cement wet mixing by empirical equations of friction capacity.

A foundation system on very soft clay must be satisfied by stability and settlement criterion as referred the theoretical profile for embankment performance, which are using several treatments such mechanical improvement (Almeida & Marques, 2013; Elaarabi & Soorkty, 2014; Zolotuchin et al., 2018). The bearing capacity performance of small-pile within soft clays depends on excess pressure of water dissipation due to consolidation. Whatever, the soil permeability of clay layer is usually too small.

The gaps can be summarized that resiliency of bamboo inside the soft clay is very limited for long life embankment construction, and again the environment issue. In reality, a bamboo pile installation as foundation is to damaged range during long time inside soft ground. The other hand, an engineer and government have to make an innovation structure of pile for road embankment, which is using local material for pile innovation.

Therefore, this study focused load capacity performance of concrete of small pile with cluster in soft clays, which used material local as solution alternative for bamboo and timber pile. By piling small-pile cluster into soft clay, a treatment foundation of mechanically soil improvement system can be provided.

2. Literature Review

In order to improve soft subgrades for supporting unpaved road with behind rear P, this research focused on three parts of application of full reinforcement method for increasing ultimate bearing capacity such as 1) Soft subgrade alone, 2) foundation mattress with geotextile, and 3) mini-pile installation. The illustration of unpaved road is followed standard design as below (Giroud & Noiray, 1981; Milligan et al., 1989; Lyons & Fannin, 2006; Mulungye et al., 2007)

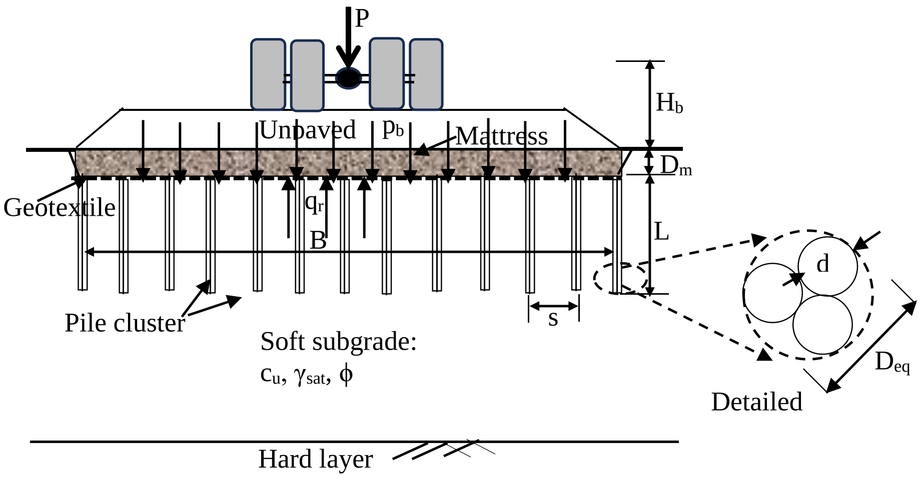


Fig.1. Schematics of Unpaved Road on Soft Subgrade Reinforced by Pile Cluster

Mechanism load pressures p_b o rested by reinforcement system is formed as

$$p_b \leq q_r \tag{1}$$

$$p_b = p_{tr} + p_m + p_{uv} \tag{2}$$

where p_{tr}, p_m, and p_{uv} are load pressures due to tires truck, mattress and unpaved layer respectively.

Figure 1 shows Firstly, deposited alluvial of soft subgrades such as soft soil, peat soft clay. The soil properties of consistency concerned by less than 12.5 kN/m^2 and 25 kN/m^2 for very soft soil and soft. There are reported investigation data results soil data, reported planning projects for new airport runway 2,500 meters and 45 meters in width in North Maluku (Jewell, 1988; Ikhwan et al., 2022; Lambe & Witmann, 1969).

Mathematic equations for predicting ultimate bearing of soft soil subgrade with piling small-pile cluster for embankment. So, the ultimate bearing capacity of soft soil with small-pile cluster of precast concrete (q_r) may predict as (Miki, 1996; Koerner et al., 1987; Suyuti et al., 2019)

$$q_r = q_c + q_{gt} + q_{pc} \tag{3}$$

This research focused clay subgrades as original foundation, the ultimate stress of clay subgrade can be delivered by several theoretical such (Vesić, 1973; Kenny & Andrawes, 1997; Terzaghi et al., 1948). In intermediate cases in which $c_u \neq 0$, $q \neq 0$, and $\gamma \neq 0$, ultimate bearing capacity for strip footing considered by soil sharing strength of the overburden is written as

$$q_c = \xi_{cd} c_u N_c + \xi_{qd} q N_q + \frac{1}{2} \xi_{\gamma d} B N_\gamma \quad (4)$$

Shearing bearing factors of the overburden of mattress depth D_m for $D_f/B \leq 1.0$ are defined as (Vesić, 1973)

$$\xi_{cd} = 1 + 0.4 \frac{D_f}{B} \quad (5)$$

$$\xi_{qd} = 1 + 2tan\phi(1 - sin\phi)^2 \frac{D_f}{B} \quad (6)$$

$$\xi_{cd} = 1 + 0.4 \frac{D_f}{B} \quad (7)$$

$$\xi_{\phi d} = 1.0 \quad (8)$$

In case general shearing failure, bearing factors of subsoil are predicted as

$$N_q = e^{\pi tan\phi} tan^2 \left(\frac{\pi}{4} + \frac{\phi}{2}\right) \quad (9a)$$

$$N_c = \left(N_q - 1\right) cot\phi \quad (9b)$$

$$N_\gamma = 2\left(N_q + 1\right) tan\phi \quad (9c)$$

From equation of (4), the ultimate stress of soft subgrade alone with cohesion $c_u \neq 0$ for a foundation strip footing is formed as

$$q_c = \xi_{cd} c_u N_c \quad (10)$$

where c_u is the soil cohesion undrained (kN/m^2), N_c is bearing capacity factor, ξ_{cd} is the compressible factor (ξ_c = 0.67 ~ 1.0)

Secondly, many soil unpaved constructed on soft subgrades used geosynthetic as geotextile, previously researches reported to increase bearing capacity of soft soil with tensile forces, to anticipate soil materials fall down into soft ground, and to ensure any access pore water due to consolidation. The reported originally several researches of geotechnical reinforcement system (Davis & Booker, 1973; Miki, 1996; Jewell, 1988; PWRC, 2000; Suyuti et al., 2020)

$$q_{gt} = \frac{2T_{gt} sin\phi_r}{B} \quad (11)$$

where T_{gt} is the tensile strength of geotextile layer, ϕ_r is the friction of the geotextile and mattress layer, B is the width of unpaved construction road.

Thirdly, to perform a good capacity of unpaved road on the soft subgrades, previous results for ultimate bearing capacity of pile cluster are presented. Several researchers presented timber single capacity in clays. In reported, ultimate load capacity Q_u during 800 hours was given load 23.35 kN. Micro-single pile dimension of 15 centimeters in square by 4, 5 and 9 meters embedded in very soft soil in Kalimantan, they found ultimate load capacity Q_u of 34.8 kN (Sandyutama et al., 2015; Seed & Reese, 1957; Yudiawati, 2024).

By using loading step with concrete blocks on the small-pile concrete installation in soft soil, the ultimate load (Q_u) can be observed by using Figure 2 (Reznik, 1990).

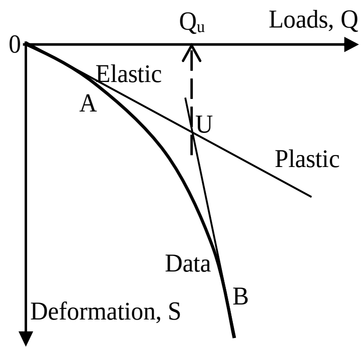


Fig. 2. Mechanism prediction data of load and deformation data set

Notes: Line of graph 0A: elastic area; Line B: plastic area; Point-U: Intersection line for ultimate load.

Figure 2 shown the ultimate bearing capacity of point load (Q_u) may be predicted from the observation data. The following steps are plotting observation data, forming graph with axis-load and ordinate-deformation, making tangent as elastic line (point 0 – to A), making tangent as plastic line B, from point intersection and it is to continue and take liner line parallel with ordinate Y or deformation (S), and reading the load intensity (Q_u).

Theoretical ultimate load capacity of pile embedded into soil clays Q_u is (Tomlinson, 1957; Tomlinson, 1971)

$$Q_u = Q_s + Q_b \quad (12)$$

$$Q_u = C.L.c_a + N_c A_b c_b \quad (13)$$

where C is the circumference of pile, L is the length of pile, c_a is the adhesion between pile and soil, N_c is the bearing capacity factor, A_b is the area of base pile, c_b is the adhesion at base of pile.

By addressing plasticity index PI to the ratio of c_u/p'_c, there are any increasing parabolic due to intensity values of PI. Ratio of (c_u/p'_c) may express in linear equation as (AM. Mesri, 1975; AW. Skempton, 1954). Then, cohesion undrained during and after piling into soft clay becomes,

$$\frac{c_u}{p'_0} = 0.11 + 0.037PI \quad (14)$$

where PI is the plasticity index of soft subgrades unit percent, c_u is the cohesion undrained, and p'_c is the overburden pressure of sub soil.

Allowable load of piling in soft clays presented by adhesion parameters c_a, diameter d and length of pile L, excess pore pressure should change an increasing adhesion between pile and clays c_a. Therefore, adhesion factor of pile and clay layer was verified field test data as (Flaate, 1972; Gavin et al., 2010; Carter, 1981; Kolk & Van Der Velde, 1996)

$$\alpha = 0.9\left(\frac{L-z}{D_{eq}}\right)^{0.2}\left(\frac{c_u}{p'_0}\right)^{-0.3} \text{for } \alpha \leq 1.0 \quad (15)$$

Where L is the length pile embedded, z is any depth of soil layer, D is the diameter of pile cluster ($D \approx 2.5d$) (Suyuti et al., 2020) , d is diameter of single pile.

The research results reported potential developed area intensity of skin friction of piles with cluster, which was piling small-pile cluster for trial embankments by using timber and bamboo (Irsyam et al., 2008; Suyuti et al., 2019; Ready & Nurtjahjaningtyas, 2020; Sandyutama et al., 2015; Suyuti et al., 2020)

Then, time factor for consolidation around pile suggested as

$$T = c_v \left(\frac{t}{D_{eq}^2} \right) \quad (16)$$

and coefficient of consolidation c_v is written as

$$c_v = 10^{-\frac{LL}{40}}$$
(17)

where LL is the liquid limit in percents, t is the consolidation time.

3. Research Methods

Outline research method, the steps of prototype small-pile cluster process of precast concrete can be explained in figure 3 flow chart as below:

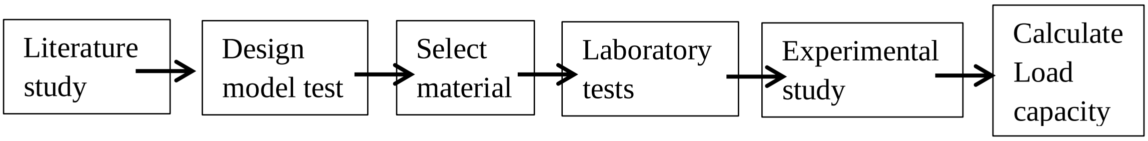
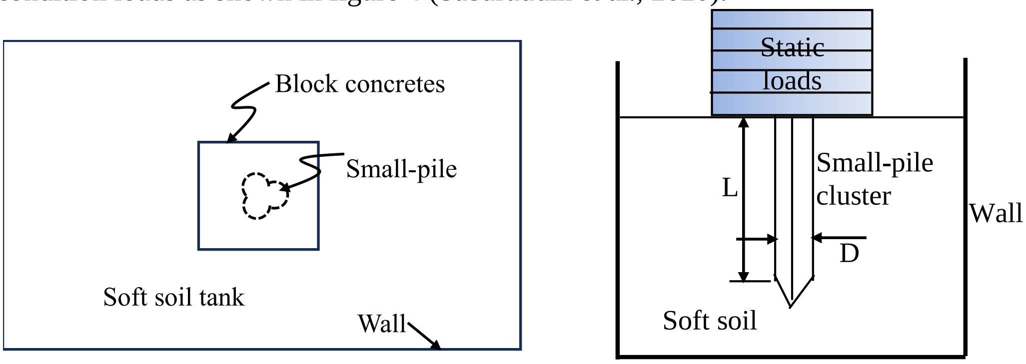


Fig.3. Flow Chart of Construction Research

Design model test

Illustration of the installation small-pile cluster in the soft soil tank. The static loads are applied five blocks for each day. Then, a surveyor takes deformation due elastic and plastic for condition loads as shown in figure 4 (Sabaruddin et al., 2020).



a. Top view   b. Cross section

Fig. 4. Illustration of Experimental Study

Mathematic equations for predicting ultimate bearing of soft soil subgrade with piling small-pile cluster for embankment, it is expressed in figure 6 below. Small-pile cluster installation should be placed by square pattern by spacing of pile (S_p) = $3D_{eq}$ ~ $7D_{eq}$, where D_{eq} = √3d ~ 2.5d (d = diameter of regularly pile).

To keep soft subgrades on saturated condition, these piles are installed on soft soil with water level QWT equal to GS. (where GS = ground surface, GWT = ground water table) (Miki, 1996; Irsyam et al., 2008; PWRC, 2000).

Selecting and laboratory tests

Prepared local material sampling to produce precast small-pile cluster by using manual gravel at Takome and sand at Kalumata as local site in Ternate as shown in figure 5 below:

a. Sampling materials

b. Check concrete consistency

c. Measure bulk density

d. Measure load compressive strength

Fig. 5. Job Mix Design Formula for Producing Concrete

Figure 5 shows laboratory test processing, from sampling material concrete to make mix design, and gives proportional of job mix design per cubic of concrete was given cement of 370 kg, water of 185 kg, sand of 509 kg, and gravel 1,135 kg. This procedure mix design for normal concrete quality was followed National Standard of Indonesia no. SNI .03.2834.2000 (BSN, 2000). The result of three cubes for compression test are shown in figure 5.

Experimental study

Precast concrete of small-pile cluster process, it is produced prototype 3d (diameter d of 10cm) as shown in figure 6 below.

Figure 6 shows that precast concrete of small-pile cluster process with quality compressive strength of 20 MPa, it was produced prototype 3d (with single diameter (d) of 10 cm).

a. Fabrication process of small-pile

b. Installation illustration

c. Remove small- pile cluster

d. Measure circumference

Fig. 6. Schematics of Installation Process For Small-Pile Cluster

Experimental Step Process

In these simulations are conducted by several lengths of pile, diameter pile, spacing of piles and etc. Also in reinforcing, it is giving 8mm for main bars and 6mm with space of 125mm for shear bar in figure 7.

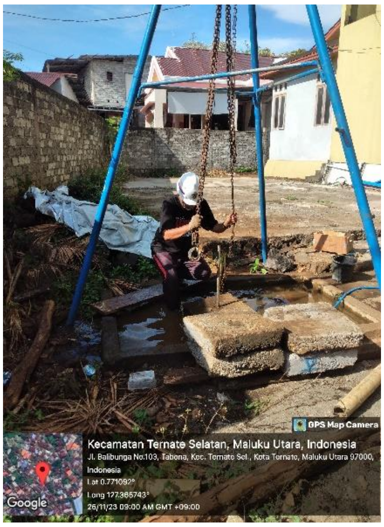
The experimental step to observe an ultimate bearing capacity of single small-pile cluster modelled in the soft soil such as a) install small-pile cluster concrete in soft soil with length (L) of 100cm, it becomes 3 times of single diameter (d) of 10 cm, b) Put layer local material to separate load, c) Put five concrete blocks step by step, a block concrete keeping 24 hours in figure 7, d) Observe deformation with 3(three) points, and e) Calculate ultimate bearing capacity of soft subgrade with reinforcement q_r as shown in figure 1 (PUPR, 1999; PUPR, 2002).

In normally preparation for unpaved road on soft soil layers. It is to make easy installation of small-pile cluster is tapered at tip on soft soil layer. The soft soil tank was setting up saturated condition with heigh of 200 cm, width of 150 cm and length of 200 cm as shown in Figure 7.

a. Install small-pile cluster

b. Observe deformation due to loads

c. Complete step of static loading with concrete



d. Removed the concrete blocks

Fig. 7. Schematics of Experimental For Small-Pile Cluster in Soft Soil Tank

4. Results and Discussions

This section, analyses are applying soil properties in model full scale of soft soil tank such as undrained cohesion (c_u), internal friction (ϕ) and bulk density (γ). Concrete precast small-pile can be observed as shown in figure 3. Then, it is made simulation for several variations of soft soil properties and small-pile dimension.

Soil Properties dan small-pile Data

Soil properties data in soft soil tank with area of 130 cm by 200 cm in heigh 130 cm. It is due to pile installation in clays, recently soil properties are listed in Table 1.

Table 1 - Soft subgrades tank for observation (Suyuti et al., 2020)

Items	Unit	Result
Undrained cohesion, c_u	kN/m^2	20.0
Bulk density, γ	kN/m^3	16.5
Internal friction, ϕ	degs	9.5
Plasticity Index, PI	%	10.0

Empirical Simulations

In these simulations are conducted by several lengths of pile, diameter pile

Dimension of concrete precast data was observed such diameter of single pile (d) of 10 cm, length L of 100 cm, diameter equivalent D_{eq} of 2.5d of 25 cm in width B of 1.0 meter.

Experimental Results

In order to observe an ultimate bearing capacity of soft clay with small-pile cluster installation, an experimental is conducted several block concretes and deformations. The data set results as listed Table 2.

Table 2 - Experimental result of loads and deformations

Block concrete load (kg)	Static pressure load (kPa)	Deformation records, Δ(mm)			
		Point-1	Point-2	Point-3	Average
101	92	2	35	35	24
148	135	3	72	40	39
201	183	13	76	55	48
255	232	50	82	75	69
310	282	85	100	78	87.7

Table 3 can be seen that loading five steps, it is plotting with five steps. The results of recording deformation are plotting in curve loading and deformation as shown in Figure 8. Then, figure 8 seen that ultimate load on soft clay with mini-pile cluster gives q_u of 203 kN/m^2.

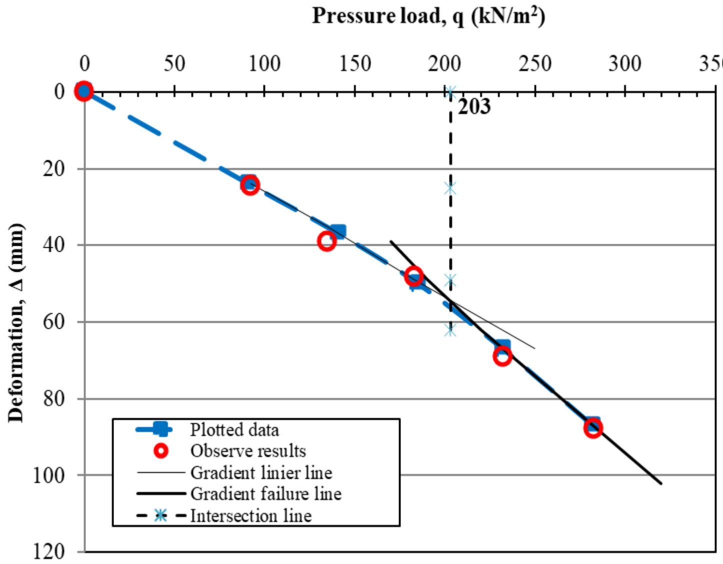
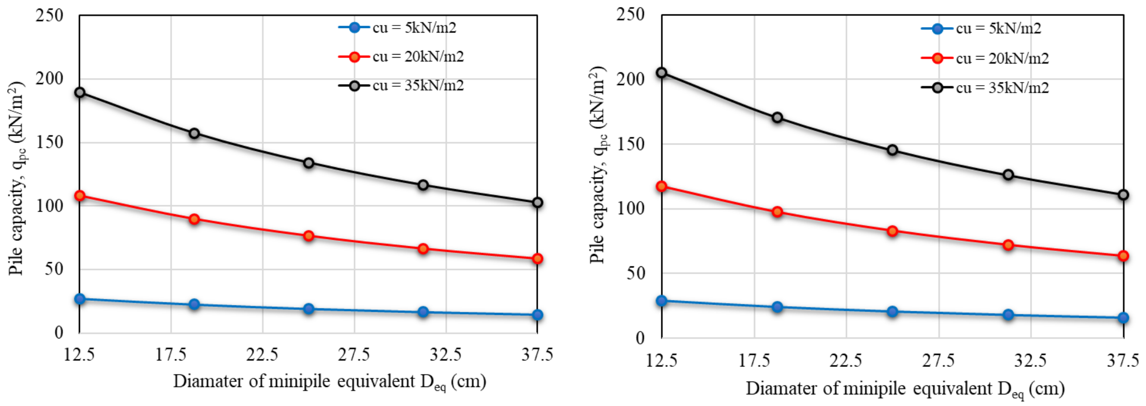


Fig. 8. Expression of The Ultimate Bearing Capacity For Small-Pile Cluster in Soft Clay

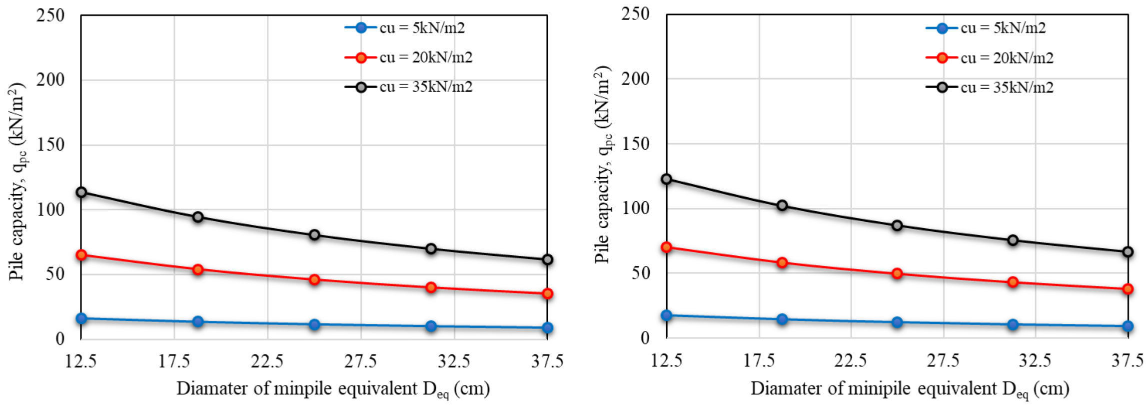
Simulation Results

In order to observe an ultimate bearing capacity of soft clay with small-pile cluster installation, simulation results for three variations of pile spacing s of 3_{Deq} and $5D_{eq}$ as well as with low plasticity index PI of 10% are shown in Figures 9 and 10 as below.



a. Length of pile (L) = 100cm b. Length of pile (L) = 150cm

Fig .9. Simulation Results of Ultimate Bearing Capacity and Diameter Equivalent for Spacing Pile s of $3D_{eq}$



a. Length of pile (L) = 100cm b. Length of pile (L) = 150cm

Fig. 10. Simulation Results of Ultimate Bearing Capacity and Diameter Equivalent for Spacing Pile s = $5D_{eq}$

Figures 9 and 10 shown the ultimate bearing capacity of mini-pile cluster in soft clays for plasticity index PI is about 5 percents.

Table 3 - Comparison Results Data and Calculation Method of Load Capacity

Data no	Location	Material	Pile dimension Dia (m)	L (m)	Ratio L/D	Ratio c_u/p'_0	Alfa	Load capacity kN Calc	kN Obs	Remark
1	Venice	Concrete	0.17	11	65	0.52	0.92	132.9	132.9	Kolk & Der Velde, 1996
2	Ternate	Concrete	0.26	1.2	5	2.49	0.51	19.79	15.92	Recently study
3	Hamilton	Concrete	0.11	11.8	104	0.48	0.62	56.92	56.92	Kolk &
4	Pentre NGI	Concrete	0.22	7.5	34	0.28	0.42	132.7	132.7	Der Velde, 1996
5	Banjarmasin	Concrete	0.19	9.0	47	0.22	0.66	37.82	23.54	Yudiawati, 2024
6	Mare Island	Timber	0.20	24.38	120	NA	NA	100	100	Tomlinson,
7	Mare Island	Timber	0.19	11.28	59	NA	NA	27	27	1957
8	Ditto	Timber	0.26	18.29	70	NA	NA	46	46	
9	Grimsby	Timber	0.36	18.29	51	NA	NA	80	80	
10	Ditto	Timber	0.14	14.94	107	NA	NA	33	33	
11	San Fransisco	Still pile	0.17	4.27	26	NA	NA	46	46	
12	Ditto	Ditto	0.20	13.11	65	NA	NA	25	25	
13	Gothenburg	Ditto	0.16	11.13	70	NA	NA	11	11	
14	Ditto	Ditto	0.16	11.28	71	NA	NA	27	27	
15	Ditto	Ditto	0.30	20.57	68	NA	NA	60	60	

Load capacities in Table 3 shown us that to find the solution of local material for small-pile cluster as solution, results of previously research in relevant in recently this research were presented.

Then, load capacities Q_us above, it can be validated by observation this study results. The implication of calculation and observation can be applied for supporting unpaved road. This research is given load capacity Q_u of 19.79 kN and 15.92 kN for calculation and observation respectively. The comparison results of calculation and observation as novelty of this study are inside the fifteen cases are presented in figure 11.

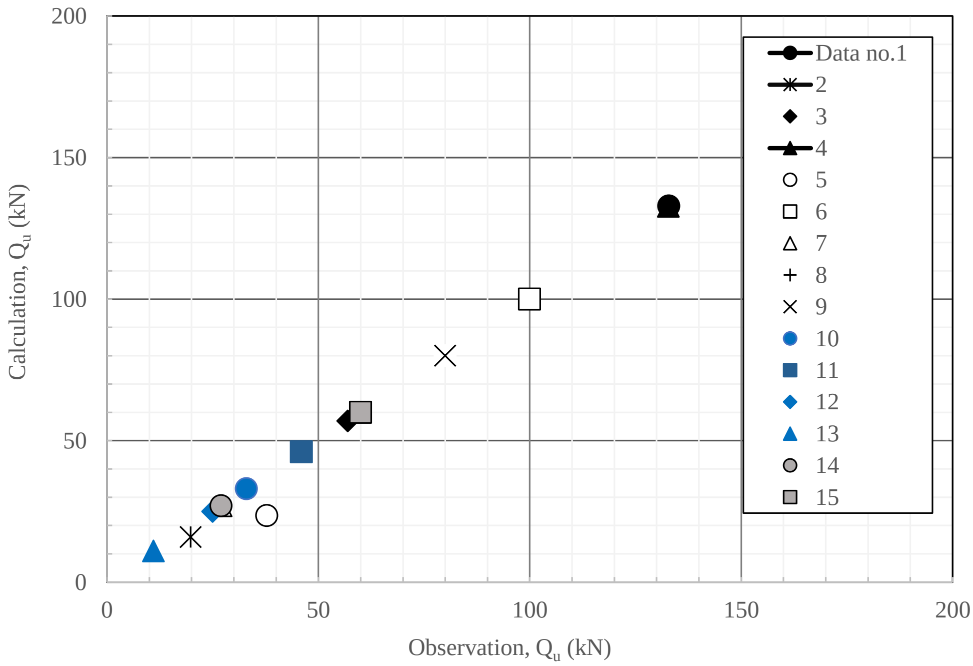
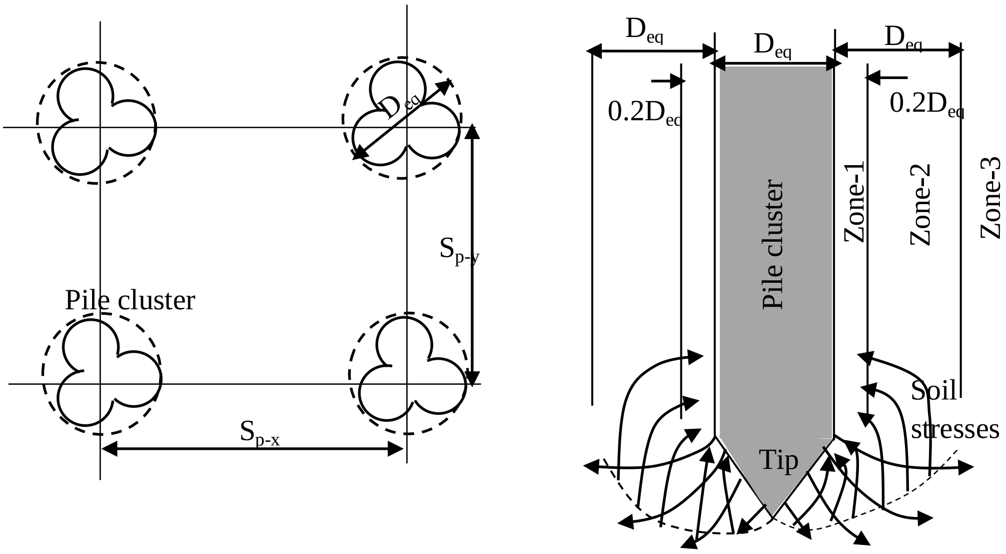


Fig. 11. Comparison Results of Calculation and Observation for Load Capacity of Single Pile

Based on comparison data of several studies above, the piling installation was affected to increase load bearing capacity of soft subgrade for unpaved road. Generally, these matters can be influenced by soil stresses at surrounding tip piles as shown in figure 12.



a) Layout pile installation b. Soil stresses at surrounding tip pile

Fig. 12. Illustration of State of the Clay Surrounding Small- Pile Clusters

The generalization of use small- pile cluster was installed easily in soft subgrade by placing square pattern with spacing S_{p-x} and S_{p-y} for axis, and ordinate. Then due to consolidation process, parameter of cohesion c_u of soil elasticity can be changed. The load capacity of shaft resistance of between piles and soil for reinforcing soft ground with single and group pile method can be increased to support unpaved roads.

5. Conclusions

In natural condition, based on simulation result seen that low soil consistency, it can be decreased the ultimate bearing capacity of pile in the soft clays. The evidence, when the spacing of piles made dense from spacing of $5D_{eq}$ to $3D_{eq}$, then the ultimate bearing capacity of mini-pile in soft clays is increased about 65 percents.

Plasticity index, soil cohesion, effective pressure as well as pile dimensions are affecting into parameter of empirical calculation for determining ultimate load capacity of cluster pile Q_u in soft ground.

In experimental, single small-pile cluster installed in soft clays, the loaded by concrete blocks as static loading and observe the elastic deformation during 24 hours, load capacity of small-pile cluster in soft clays Q_u can be increased due to consolidation effect and shaft friction of pile that is correlating to the parameter of soil properties-mechanically and dimension of pile.

Finally, phenomenon of small-pile clusters of concrete local materials should be effectively used by longer spacing of small size in the soft clays for unpaved road based on geotechnical rule. It is can be as alternatively bamboo or wooden pile to improve soft subgrade for constructing long life. It can be applied by local engineer and government for unpaved road.

Acknowledgement

Grateful acknowledgement to the ministry of education, culture, research and technology for supporting funding of prototype products in year 2023. Also, thanks to the laboratory of Civil engineering program, Engineering faculty of Universitas Khairun.

References

Al-Gharbawi, A. S., Fattah, M. Y., & Abduhussain, S. A. (2024). Behavior of soil reinforced with micropiles. *Open Engineering, 14*(1), 20220563. https://doi.org/10.1515/eng-2022-0563

Almeida, M. de S. S., & Marques, M. E. S. (2013). *Design and Performance of Embankments on Very Soft Soils*. CRC Press. https://doi.org/10.1201/b15788

AW. Skempton. (1954). Discussion of the structure of organics soil. *2nd International Conference Soil Mechanics*, 19–30.

Azzouz, A. S., Baligh, M. M., & Whittle, A. J. (1990). Shaft Resistance of Piles in Clay. *Journal of Geotechnical Engineering*, *116*(2), 205–221. https://doi.org/10.1061/(ASCE)0733-9410(1990)116:2(205)

Buana, T. W. (2019). *Atlas Zona Kerentanan Likuefaksi Indonesia*. Badan Geologi, Kementerian Energi dan Sumber Daya Mineral, Badan Geologi.

Burland, J. (1973). Shaft friction of piles in clay--a simple fundamental approach. *Publication of: Ground Engineering/UK/*, *6*(3).

BSN. (2000). Procedure for Making Mix Design Normal Concrete (In Indonesian). In *BSN* (Vol. 1, pp. 1–37).

Carter, J. P. (1981). Stress changes in clay due to installation of a displacement pile. *Institution of Eng (Aust) Queensland Div Tech Pap, 22*(4).

Cummings, A. E., Kerkhoff, G. O., & Peck, R. B. (1950). Effect of Driving Piles into Soft Clay. *Transactions of the American Society of Civil Engineers*, *115*(1), 275–285. https://doi.org/10.1061/TACEAT.0006327

Davis, E. H., & Booker, J. R. (1973). The effect of increasing strength with depth on the bearing capacity of clays. *Géotechnique*, *23*(4), 551–563. https://doi.org/10.1680/geot.1973.23.4.551

Elarabi, H., & Soorkty, A. A. (2014). Construction of micropiles using pressure techniques. *J Civil Eng Architecture, 8*(1), 74.

Flaate, K. (1972). Effects of Pile Driving in Clays. *Canadian Geotechnical Journal*, *9*(1), 81–88. https://doi.org/10.1139/t72-006

Gavin, K., Gallagher, D., Doherty, P., & McCabe, B. (2010). Field investigation of the effect of installation method on the shaft resistance of piles in clay. *Canadian Geotechnical Journal*, *47*(7), 730–741. https://doi.org/10.1139/T09-146

Ghalesari, A. T., Barari, A., Amini, P. F., & Ibsen, L. B. (2013). The settlement behavior of piled raft interaction in undrained soil. In *IACGE 2013: Challenges and Recent Advances in Geotechnical and Seismic Research and Practices* (pp. 605-612). https://doi.org/10.1061/9780784413128.071

Giroud, J. P., & Noiray, L. (1981). Geotextile-Reinforced Unpaved Road Design. *Journal of the Geotechnical Engineering Division*, *107*(9), 1233–1254. https://doi.org/10.1061/AJGEB6.0001187

Ikhwan, M., Suyuti, S., & Samad, S. (2022). *Executive Summary of New Airport of Loleo, North Maluku (In Indonesian)*.

Irsyam, M., Krisnanto, S., & Wardhani, S. P. R. (2008). Instrumented full scale test and numerical analysis to investigate performance of bamboo pile-mattress system as soil reinforcement for coastal embankment on soft clay. In *Geotechnical Engineering for Disaster Mitigation and Rehabilitation: Proceedings of the 2nd International Conference GEDMAR08, Nanjing, China 30 May–2 June, 2008* (pp. 165-170). Springer Berlin Heidelberg.

Jewell, R. A. (1988). The mechanics of reinforced embankments on soft soils. *Geotextiles and Geomembranes*, *7*(4), 237–273. https://doi.org/10.1016/0266-1144(88)90001-5

Kenny, M. J., & Andrawes, K. Z. (1997). The bearing capacity of footings on a sand layer overlying soft clay. *Géotechnique*, *47*(2), 339–345. https://doi.org/10.1680/geot.1997.47.2.339

Koerner, R. M., Hwu, B. L., & Wayne, M. H. (1987). Soft soil stabilization designs using geosynthetics. *Geotextiles and Geomembranes, 6*(1-3), 33-51. https://doi.org/10.1016/0266-1144(87)90056-2

Kolk, H. J., & Der Velde, E. (1996, May). A reliable method to determine friction capacity of piles driven into clays. In *Offshore Technology Conference* (pp. OTC-7993). OTC.

Lambe, T. W., & Whitman, R. V. (1969). Soil mechanics, 553 pp.

Lyons, C. K., & Fannin, J. (2006). A comparison of two design methods for unpaved roads reinforced with geogrids. *Canadian Geotechnical Journal*, *43*(12), 1389–1394. https://doi.org/10.1139/t06-075

Mesri, G. (1975). Discussion of "New design procedure for stability of soft clays". *Journal of the Geotechnical Engineering Division*, *101*(4), 409-412.

Miki, H. (1996). Application of geosynthetics to embankment on soft ground and reclamation using soft soil. In *Proceedings of the International Symposium on Earth Reinforcement. Fukuoka, Kyushu, Japan* (pp. 919-942).

Milligan, G. W. E., Jewell, R. A., Houlsby, G. T., & Burd, H. J. (1989). A New Approach To The Design Of Unpaved Roads--Part 1. *Ground Engineering*, *22*(3).

Mulungye, R. M., Owende, P. M. O., & Mellon, K. (2007). Finite element modelling of flexible pavements on soft soil subgrades. *Materials & Design*, *28*(3), 739–756. https://doi.org/10.1016/j.matdes.2005.12.006

Nurdin, S., Sawada, K., & Moriguchi, S. (2019). Design criterion of reinforcement on thick soft clay foundations of traditional construction method in Indonesia. In *MATEC Web of Conferences* (Vol. 258, p. 03010). EDP Sciences. https://doi.org/10.1051/matecconf/20192

PUPR. (1999). *Tata Cara Pelaksanaan Pondasi Cerucuk Kayu di Atas Tanah Lembek dan Tanah Gambut (Indonesian)*.

PUPR. (2002). *Panduan Geoteknik-4 Desain dan Konstruksi: Timbunan Jalan pada Tanah Lunak (Indonesian)*.

PUPR. (2005). *Stabilisasi Dangkal Tanah Lunak untuk Konstruksi Timbunan Jalan- Dengan Semen dan Cerucuk (Indonesian)*.

PWRC. (2000). *Manual on Design and Execution of Reinforcement Soil Method with Use of Geotextiles (In Japanese)* (pp. 367–388).

Ready, B., & Nurtjahjaningtyas, I. (2020). Analysis of slope stability in soft soil using hardening soil modeling and strengthening of bamboo mattress. *GEOMATE Journal, 19*(73), 226-234. https://doi.org/10.21660/2020.73.58422

Reznik, Y. M. (1990). Evaluation of allowable pressure under foundations. *Geotechnical Testing Journal*, *13*(1), 53-57.

Roosseno. (1989). *Foundation of Building Stored Third to Fourth on Wet Soil of Very Soft Soil (in Indonesian)* (pp. 641–657).

Sabaruddin, Suyuti, & Hakim, R. (2020). Predicted Overall Stability of Embankment on Very Soft Soil Reinforced by Bamboo Piles Based on Full-scale Test Data. *International Journal of GEOMATE*, *18*(65), 102–109. https://doi.org/10.21660/2020.65.59237

Sandyutama, Y., Samang, L., Imran, A. M., & Harianto, T. (2015). *Study of Soft Soil Reinforcement Using Hybrid Pile-PVD*. *10*(8), 3798–3805. https://core.ac.uk/download/pdf/77624548.pdf

Satibi, S. (2009). Numerical analysis and design criteria of embankments on floating piles. *Institut für Geotechnik der Universität Stuttgart IGS*.

Seed, H. B., & Reese, L. C. (1957). The Action of Soft Clay along Friction Piles. *Transactions of the American Society of Civil Engineers*, *122*(1), 731–754. https://doi.org/10.1061/TACEAT.0007501

Suyuti, S., Sawada, K., Yashima, A., & Moriguchi S. (2020). *Stability research of river embankment on soft ground using traditional reinforcement system in Indonesia* [Gifu University]. https://doi.org/10.13140/RG.2.2.17380.71045

Suyuti, Sultan, M. A., & Misbah, Z. K. (2020). Bearing Capacity of Soil Bags on Soft Ground Reinforced by Bamboo Pile. *International Journal of GEOMATE*, *16*(53), 32–39. https://doi.org/10.21660/2019.53.09817

Tomlinson, M. J. (1957, August). The adhesion of piles driven in clay soils. In *Proceedings of the 4th international conference on soil mechanics and foundation engineering* (Vol. 2, pp. 66-71).

Tomlinson, M. J. (1971). Some effects of pile driving on skin friction. In *Behaviour of piles* (pp. 107-114). Thomas Telford Publishing.

Terzaghi, K., Peck, R. B., & Mesri, G. (1996). *Soil mechanics in engineering practice*. John wiley & sons.

Vesić, A. S. (1973). Analysis of ultimate loads of shallow foundations. *Journal of the soil mechanics and foundations division*, *99*(1), 45-73.

Y Daryanto, Suharno G, Budi Setiadi, & Hendryono Widodo. (1995). *Perbaikan Daya Dukung Tanah dengan Cerucuk Bambu di Pantai Utara Kota Semarang (in Indonesian)*.

Yudiawati, Y. (2024). Bearing Capacity of Full-Friction Micropiles Based on Simple Field Load Results in Banjarmasin Very Soft Soil. *International Journal of GEOMATE*, *26*(117). https://doi.org/10.21660/2024.117.4373

Zolotuchin, S. N., Novikova, K. K., & Kim, M. S. (2018). New Method For The Construction Of Pile Foundations In Low-Rise Constructions Using Micro-Piles In The Knocked-Out Wells. *IOP Conference Series: Materials Science and Engineering*, *463*, 022067. https://doi.org/10.1088/1757-899X/463/2/022067