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Comparative Analysis of Carrying Capacity of Mini Pile Foundation and Well Case Study of Oil Palm Factory Development, Central Kalimantan Province

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Abstract

Bearing capacity is an aspect that is considered and considered before determining the type of foundation to be used in a building. The Palm Oil Mill Development Project in Central Kalimantan Province has a sand type of subgrade with a dense consistency. The Planning Consultant plans the type of Spun Pile Foundation in Zone C of Kernel Warehouse and Bakil Warehouse Buildings. The method used in the calculation uses Data Analysis of the CPT Test (Soil Test) and Hand boring. In Zone C Test Soil Test used is Soil Test 4 (S4) and Soil Test 5 (S5), for Hand boring using Hand boring 2 (HB-2). Calculation Analysis Using the Meyerhof formula to get the ultimate bearing capacity, lateral and axial bearing capacity. Based on the Calculation Analysis, the Ultimate Mini Pile Foundation Bearing Capacity is 20x20 87.20 tons in the Soil Test 4 area and 101.18 tons in the Soil Test 5 area. For the 20cm diameter well foundation, the calculation results are 68.45 tons in the Soil Test 4 area and 79.42 tons in the Soil Test 5 area. The calculation of the lateral permit load is obtained in the Soil Test 4 area for Mini Pile 20x20 2.23 tons and the Well Foundation 2.23 does not meet the requirements because it is less than the permit workload working in Zone C, which is 2.72 tons. Soil Test 5's calculation meets the requirements with higher yields than the load working in the area, namely for Mini Pile Foundations 20x20 3.12 tons and Wells Foundations 3.12 tons.

Keywords:
Carrying Capacity, Mini Pile, Soil Test, Well Foundation

1. Introduction

Based on the different soil types in each area, in construction work, there are also differences in the type of foundation used. The foundation is part of the lower structure that supports its own load and functions to transmit the load from the upper structure to the soil layer below it with a carrying capacity limit that does not exceed its capacity.

In addition to the foundations used by project planners, there are several types of foundations that can be used on sandy soils with a solid consistency to a depth of 10 meters, namely using Mini Pile Pile Foundations and Well Foundations. If the hard soil is at a depth of more than 10 meters, the type of foundation used is the Mini Pile Foundation or the Well Foundation (Putra, 2018)

In addition, other sources explain that if the hard soil is located at a depth of 10 meters below the ground surface, the type of foundation that is usually used is Mini Pile Pile Foundation or Floating Pile Foundation to improve the foundation soil.

2. Literature Review

Putra (2018) states that the way to determine the type of foundation to be used is as follows:

1. If the hard soil is on the ground surface or at a depth of 2-3 meters, the type of foundation to be used is the shallow foundation. Such as tread foundation, path foundation, raft foundation, etc.)
2. If the soil is hard at a depth of 6 meters or less, the foundation to be used is the bored pile manual or Strauss pile foundation.
3. If the hard soil is at a depth of more than 10 meters, the type of foundation to be used is a mini pile or pit foundation.
4. If the hard soil is at a depth of more than 20 meters, the foundation to be used is a bored pile or pile foundation.

5. In addition, the selection of a foundation on Sand Soil is required to carry out soil tests or tests such as the Soil Penetration Test (SPT), Static Cone Test, and Plate Load Test.

2.1. Pile Bearing Capacity from Soil Test

Soil Test Penetration Test is carried out to determine the bearing strength of the foundation based on the test results data with the formula:

Q permit = (qc x Ab)/(SF_1) + (JHP x K)/(SF_2)……………………………………...(2.1)

Ridhayani (2021) quoting from the research of Wibowo (2013), the calculation of the carrying capacity of the soil is carried out using the formula proposed by Meyerhoff as follows:

Q ult = Qc x A + TF x Kt …………...…….(2.2)
Qa = (Qc x A)/3 + (TF x Kt)/5……....(2.3)
Where numbers 3 and 5 are safety factors.

Bearing capacity to soil strength for Tensile piles:
T ult = JHL x K…………...…..……….(2.4)

Carrying capacity of the Tensile permit:
Q permit = (T ult)/3………...…..…..……(2.5)

Bearing capacity to the strength of the material:
P stake = σconcrete x Ap

2.2. Lateral Carrying Capacity

The stiffness factor for the non-constant soil modulus (T) is expressed by the equation:

$T = (\frac{EI}{nh})^{1/5}$…..……………..………(2.6)

With soil modulus
K= nh. Z…………….……….(2.7)
K= nh. z/d………………………(2.8)

After the calculation of R and T has been known, the next step is to determine whether the pile is a rigid pile (short pile) or an elastic pile (long pile) which is related to the length of the pile embedded in the ground (L).

2.3. Pile Bearing Capacity with Broms Method

2.3.1. Free End Pole

The pressure that occurs in this pile can be replaced by a concentrated force acting on the lower end. Taking the moment about the lower end, then:

$Hu = \frac{0.5 \, x \, \gamma \, x \, D \, x \, L^3 x \, Kp}{e+L}$ …………....(2.9)

The maximum moment occurs at a distance f below the ground surface, then:
Hu = 1.5 x ɣ x D x Kp x f^2…...…..(2.10)

Maximum moment location:

$f = 0.82 \, x \sqrt{\frac{Hu}{D \, x \, Kp \, x \, \gamma}}$…………(2.11)

Maximum moments location:
M max = Hu (e + 1.5f)……….. ……(2.12)

2.3.2. Pole Edge Clamp

For rigid pin-point piles (short piles), the pile failure will be translational with the ultimate load expressed as follows:

Hu = 1.5 x ɣ x D x L^2 x Kp...…....(2.13)

Maximum moment location:

$f = 0.82 \, x \sqrt{\frac{Hu}{D \, x \, Kp \, x \, \gamma}}$…….……(2.14)

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So that the maximum moment can be expressed by the equation:

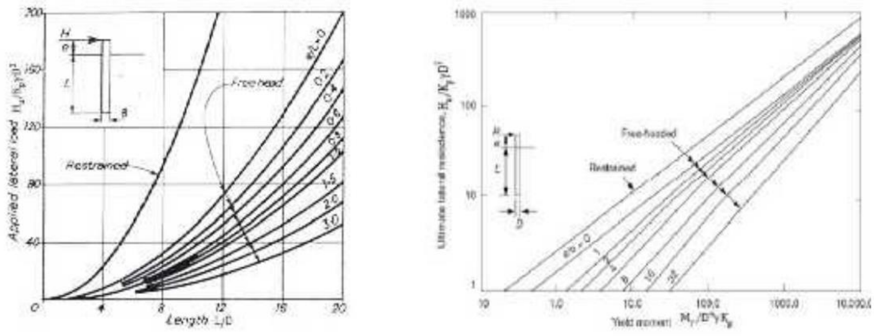
M max $= \frac{2}{3}\ x\ Hu\ x\ L$………………..…(2.15)

Melting moment:

My = (0.5 x ɣ D x L³ x Kp) – Hu x L……………………….………..…(2.16)

Equation (2.14) is substituted into equation (2.16):

Hu $= \frac{2\ My}{e+0.54\sqrt{\frac{Hu}{\gamma DKp}}}$…….………….(2.17)



(a) (b)

Figure 1. Ultimate lateral resistance of piles in granular soil. (a) Short Pole, (b) Long Pole

2.4. Axial Bearing Capacity of Group Pile Foundation

Pile foundations can be divided into single pile foundations and group pile foundations. In the pile group foundation, it is obtained from the number of piles in one pile group form. Generally the block failure model occurs when the ratio of pile distance divided by diameter (S/D) is less than 2 (two).

The ultimate capacity of the pile group by showing the pile efficiency factor expressed in the formula:

Qg = Eg x n x Qa………………..(2.18)

Pile efficiency calculation is needed to calculate group pile capacity. The following are methods for calculating pile efficiency:

Converse – Labarre Method

The pile group efficiency is obtained from the following equation:

$\eta = 1 - \varnothing \frac{(n-1)m+(m-1)n}{90mn}$…..………(2.19)

Los Angeles Method

The pile group efficiency is obtained from the pile efficiency:

$\eta = 1 - \frac{D}{\pi.s.m.n}\left[m(n-1) + N(m-1) + \sqrt{2}\ (n-1)(m-1)\right]$……………….(2.20)

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3. Methodology

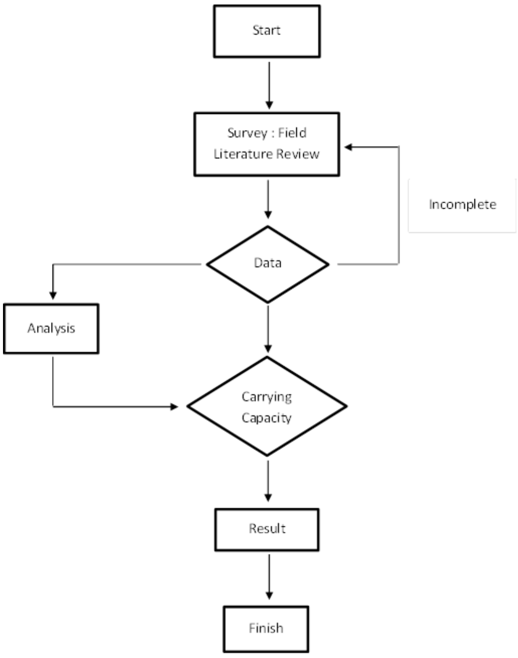

Figure 2. Methodology

4. Result and Analysis

Based on Soil Test Data with Meyerhoff Method
S4 Mini Pile Point
An example of calculating the bearing capacity at a depth of 7.60 m:
(PPK) qc = 150 kg/cm2
(JHP) = 340 kg/cm
(Ap) = 400 cm2
(K) = 80 cm

Qult = (150 x 400) + (340 x 80)
= 87.20 ton
Q permit = ((150 x 400))/3+((340 x 80))/5
= 25.44 ton
= 340 x 80
= 27.20 ton
Q permit = 27.20/3
= 9.07 ton
= 500 kg/cm2 x 400 cm2
= 200 ton

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Table 1. Sondir Data with Meyerhoff Method

ZONA C MINI PILE
Sondir Data with Meyerhoff Method
S4

Depth	qc	Ap	JPH	K	Mast Capacity		Carrying Capacity of Tensile Poles		Material strength carrying capacity
					Q ult	Q ijin	Q ult	Q ijin	
(m)	(kg/cm2)	(cm2)	(kg/cm)	(cm)	(ton)	(ton)	(ton)	(ton)	(ton)
0.00	0	400	0	80	0	0.00	0.00	0.00	200
-0.20	3	400	5.3	80	1.62	0.48	0.42	0.14	200
-0.40	3	400	10.7	80	2.06	0.57	0.86	0.29	200
-0.60	4	400	16	80	2.88	0.79	1.28	0.43	200
-0.80	4	400	22.7	80	3.42	0.90	1.82	0.61	200
-1.00	4	400	29.3	80	3.94	1.00	2.34	0.78	200
-1.20	5	400	36	80	4.88	1.24	2.88	0.96	200
-1.40	5	400	42.7	80	5.42	1.35	3.42	1.14	200
-1.60	5	400	49.3	80	5.94	1.46	3.94	1.31	200
-1.80	4	400	54.7	80	5.98	1.41	4.38	1.46	200
-2.00	4	400	60	80	6.40	1.49	4.80	1.60	200
-2.20	4	400	66.7	80	6.94	1.60	5.34	1.78	200
-2.40	6	400	73.3	80	8.26	1.97	5.86	1.95	200
-2.60	6	400	80	80	8.80	2.08	6.40	2.13	200
-2.80	6	400	86.7	80	9.34	2.19	6.94	2.31	200
-3.00	13	400	93.3	80	12.66	3.23	7.46	2.49	200
-3.20	13	400	100	80	13.20	3.33	8.00	2.67	200
-3.40	13	400	106.7	80	13.74	3.44	8.54	2.85	200
-3.60	13	400	113.3	80	14.26	3.55	9.06	3.02	200
-3.80	13	400	121.3	80	14.90	3.67	9.70	3.23	200
-4.00	17	400	129.3	80	17.14	4.34	10.34	3.45	200
-4.20	17	400	137.3	80	17.78	4.46	10.98	3.66	200
-4.40	17	400	145.3	80	18.42	4.59	11.62	3.87	200
-4.60	40	400	153.3	80	28.26	7.79	12.26	4.09	200
-4.80	40	400	168	80	29.44	8.02	13.44	4.48	200
-5.00	85	400	182.7	80	48.62	14.26	14.62	4.87	200
-5.20	85	400	196	80	49.68	14.47	15.68	5.23	200
-5.40	103	400	209.3	80	57.94	17.08	16.74	5.58	200
-5.60	103	400	222.7	80	59.02	17.30	17.82	5.94	200
-5.80	103	400	233.3	80	59.86	17.47	18.66	6.22	200
-6.00	87	400	244	80	54.32	15.50	19.52	6.51	200
-6.20	87	400	257.3	80	55.38	15.72	20.58	6.86	200
-6.40	87	400	270.7	80	56.46	15.93	21.66	7.22	200
-6.60	95	400	284	80	60.72	17.21	22.72	7.57	200
-6.80	95	400	290.7	80	61.26	17.32	23.26	7.75	200
-7.00	120	400	300	80	72.00	20.80	24.00	8.00	200
-7.20	120	400	313.3	80	73.06	21.01	25.06	8.35	200
-7.40	120	400	326.7	80	74.14	21.23	26.14	8.71	200
-7.60	150	400	340	80	87.20	25.44	27.20	9.07	200

Analysis of the Planning Consultant's Carrying Capacity with N-SPT Calculations

Q ult = 1.3cNc + qNq + 0.4ɣBNɣ

Table 2. Calculation of the Carrying Capacity of Zone C Planning Consultants

Shallow Foundation

Hand Boring	Elevation (m)	Weight B (m)	Depth H (m)	y (ton/m^3)	Q (ton/m^2)	C(ton/m^2)	Φ (°)	Nc	Nq	Ny	Qult (ton/m)	Qijin (ton/m)
HB-2	-0.50	1	0.5	1.55	0.775	0	21.41	18.18	8.14	4.22	8.92	2.97

Source: Land Investigation Report of Palm Oil Mill Development Project

Q ult = 1,3.(0) . (18,18) + 1,55(0,5).8,14 + 0,4(1,55).(0,5)(4,22)
= 0 + 6,308 + 2,616
= 8,925 ton/m2
Q permit = $\frac{8,925}{3}$
= 2,97 ton/m2
Analysis of the Planning Consultant's Carrying Capacity with N-SPT Calculations
Q ult = 1.3cNc + qNq + 0.4ɣBNɣ
SF = 3 (Pasir)
Q ult = 1,3.(0) . (18,18) + 1,55(0,5).8,14 + 0,4(1,55).(0,5)(4,22)
= 0 + 6,308 + 2,616
= 8,925 ton/m2
Q permit = 8,925/3
= 2,97 ton/m2

4.1. Calculating Lateral Carrying Capacity

Lateral (horizontal) bearing capacity serves to determine the stability of whether the soil will collapse or not. To calculate the horizontal bearing capacity, we must first calculate the pile stiffness factor for the non-cohesive soil type. The method used to calculate the carrying capacity is the Broms method.

Field data on S4 Foundation Mini Pile:
Pile lateral bearing capacity at point HB-2
Soil Type: Sand
Weight of Soil (ɣ) = 1.556 Kn/M3
Ground shear angle (Ø) = 30º
Kp = $\tan^2(45^\circ + 30/2) = 2.25$
Shear:
Stake size = 20x20
Pile Length (L) = 7.6 m
Concrete Quality (f'c) = 500 kg/cm2 = 50 Mpa
Ultimate Moment (My) = 133.8653 kNm

E = $4700\sqrt{50}$
= 33.234.019 kN/m2
I = 1/64 π 〖(0.2)〗^4
= 0.0000785

Calculations are carried out in the following stages:
Pile behavior and pile stiffness factor calculation
Coefficient of variation of soil modulus (nh) = 19400 kN/m3
T = 〖 (EI/nh)〗^(1/5)
T =√(5&(33234019x0.0000785)/19400)
= 0.669 m
$L \geq 4T$
$7.6 \geq 4\ (0.669)$
$7.6\ m \geq 2.677m$

Then the type of pile is categorized as a long pile / elastic pile with non-rigid ends.
Pile failure due to maximum bending moment of pile
Distance of lateral load from ground level (e) = 0
Passive earth pressure coefficient (Kp) = $\tan^2(45^\circ + 30/2)$
= 2.25
Hu = (2My)/(e+0.54 √(Hu/(ɣ D Kp)))
= 5.58 ton

Lateral clearance load:
H = 55.8/2.5
= 2.23 ton

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Table 3. Calculation of Axial Bearing Capacity of Pile Group

Literal Carrying Capacity (Laboratory Data) HB-2(1.8-2.2)													
											Mast stiffness		Lateral Load
Y	c	Ø	Kp	D	L	fc	My	E	I	Nh	T	e	Hu
(kN/m3)	(kN/m2)	°		(m)	(m)	Kg/cm2	kNm	kN/m2		kN/m3	(m)		(ton)
1.556	20986	30	2.25	0.35	9	50	389.04	33.234.019	0.000736244	19.400	1.05	0	13.69

Calculation of Axial Bearing Capacity of Pile Group
Known pile group data:
Distance between poles (s) = 0.6 m
Number of poles in one line (n) = 2
Number of rows of poles (m) = 3
Foundation diameter (d) =0.2 m

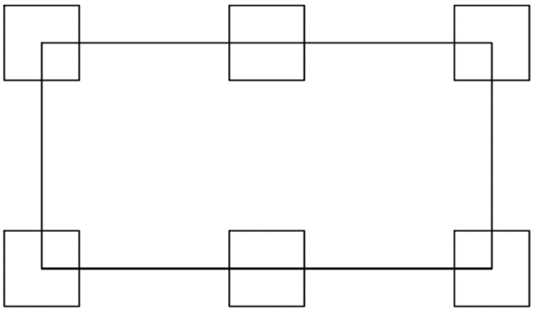

Figure 2. Mini Pile Group Arrangement Pictures

1. Converse Labarre Method

From the Efficiency of the pile group equation (Eg):

Eg = 1 – Ø ((n-1)m+(m-1)n)/90mn
Ø = Arc tan d/s
= 18.43
n = 2, m = 3
Eg = 1 – 18.43 ((2-1)3+(3-1)2)/(90 x 3 x 2)
= 0.76

2. Los Angeles Method

From the Efficiency of the pile group equation (Eg)

Eg = 1 - D/(π x s x m x n) [m(n-1) + n(m-1) + √2(n-1)(m-1)]
Eg = 1 - 0.2/(π x 0.6 x 3 x 2) [3(2-1) + 2(3-1) + √2(2-1)(3-1)]
Eg = 0.83

Table 4. Axial carrying capacity

HB-2 (1.8-2.2)						
Distance between poles	Number of poles in a row n	Number of rows of poles	Diameter		Converse-Labarre Method	Los Angeles Method
	n	m	D	Ø	Eg	Eg
(m)			(m)			
0.6	2	2	0.2	18.43	0.80	0.86

Table 5. Calculation of carrying capacity

Calculation of the carrying capacity of the group using the efficiency of the Converse-Labarre method					
Calculation Method	Depth	Efficiency	Number of Poles	Single Pole Carrying Capacity (Qult)	Group Carrying Capacity (Qg)
	(m)	(Eg)	(n)	(ton)	(ton)
Meyerhoff Method	9	0.80	4	101.18	321.81

In selecting the group efficiency of the two methods, the lowest value is chosen. Calculation of the carrying capacity of the pile group using the efficiency of the Converse-Labarre method because the value is smaller than the efficiency value of the Los Angeles Method so the calculation is as follows:

5. Conclusion

Based on the comparative results of the calculation of the Mini Pile Foundation and the Well Foundation, the results of the Mini Pile and Well Foundations in the Soil Test 4 area do not meet the requirements because the lateral permit load is smaller than the required permit load. For the calculation of the Mini Pile Foundation and the Well Foundation in the Soil Test 5 area, it has met the requirements because the lateral permit load is greater than the required permit load. For comparison between Mini Pile Foundation and Well Foundation, both of them can be used in the construction of this project, but the yield of Mini Pile bearing capacity is higher than that of Well Foundation.

Aspects related to dimensions and carrying capacity meet the requirements of this project. The dimensions of the Mini Pile Foundation were obtained with a size of 20cmx20cm and a well of 20 cm where this result is smaller than the dimensions of the Spun Pile Foundation designed by the Planning Consultant but the bearing capacity obtained meets the standard requirements of the project development.

6. Suggestion

From the calculation results, the results on Soil Test 4 Mini Pile Foundations and Well Foundations do not meet the requirements because the lateral permit load is below the work permit load in Zone C so suggestions can be given by adding the dimensions of the foundation to be Mini Pile Foundation 30cmx30cm and Well Foundation Ø30 cm.

In further research, it is expected to obtain more complete data related to the workload, at this writing the loading data provided is less detailed so it is hoped that in further research the data will be more detailed and complete. (Mulyono & Agustina, 2022)

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