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PARAMETER ANALYSIS OF PILE BEARING CAPACITY BASED ON LOADING TEST AND NUMERICAL METHODS

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ABSTRACT

Currently, numerical methods have been widely used to analyze the case of deep foundations, both determining the bearing capacity and settlement due to loads that occur on the foundation. This method has been used to obtain friction bearing capacity and end bearing capacity to obtain the adhesion factor in soft soil.

The purpose of this final project was to generate the respective values of the friction bearing and the end resistance of the pile cap on a loading test 200% of the design load through finite element simulation of FEM (Finite Element Method) using the Plaxis 2D program. This research began by collecting data from the N-SPT and CPT soil investigations, loading test data, and pile specification data. The soil investigation data were correlated into soil parameters (E, *v'*, c, dan ϕ) which were required by Mohr-Coloumb modeling on Plaxis 2D to produce end bearing and friction bearing capacities that were in accordance with the loading test results.

The results of the loading test 200% of the design load carried out on the pile of TP No.101, As.Q-5 resulted in a friction bearing capacity of 15 meters of piles is 95.98 tons, and an end bearing capacity is 4.08 tons. And then, the TP No.58F-2E pile resulted in a friction bearing capacity of 15 meters long piles is 91.96 tons, and an end bearing capacity is 8.04 tons. The results shows that at a load of 200% of the design load carried out on the piles it can still be well supported by the friction bearing capacity of the pile cap, so that the end bearing capacity still receives a much less load than the load received by the friction bearing capacity.

Keywords: bearing capacity, pile cap, loading test, numerical methods

1. INTRODUCTION

Pile bearing capacity is the ability of the foundation to support the load on it. One type of foundation is the pile foundation. The strength of its bearing capacity is determined based on the pressure of the end bearing and friction bearing. One way to determine the bearing capacity of a pile foundation is to perform an axial static pile loading test. With this test, the maximum load (Q_{ult}) of the pile can be estimated, so that the bearing capacity of the foundation can be planned close to the actual reality. Currently, numerical methods have been widely used to analyze the case of deep foundations, knowing both the bearing capacity and settlement that occurs in the foundation. This method has been used by Mulrosha (2021) to obtain the respective values for the bearing capacity of the firction bearing and the end resistance of the drill pile tip to obtain the bearing capacity factor in soft soil. One of the numerical methods that can be used is the finite element simulation method using the Plaxis 2D program. The results of the carrying capacity of the Plaxis 2D program can be used after the results of the inter-load curve with a decrease in the Loading Test and Plaxis 2D showing results that are not much different.

2. THEORITICAL STUDY

Soil Investigation

Soil investigation is one of the stages in the planning of the substructure of the building. Soil investigations are carried out to determine the location of the groundwater table and to obtain soil information such as soil properties that are useful for foundation design, types of foundations, and methods of implementation (Putri, 2021).

Deep Foundation

According to Primax (2017) deep foundations are used for buildings where the base soil does not have sufficient bearing capacity to carry the load on the superstructure or the supporting soil which has a bearing capacity deep in the soil. Based on its types, deep foundation can be divided into:

1. Pile foundations, the types of piles that are often used are cylindrical and box-shaped concrete piles. For the implementation of pile driving into the ground, heavy pile driving equipment is needed.
2. Bored pile foundation. The material used for this type of foundation is reinforced concrete which is cast directly in place (in-situ). This foundation is suitable for buildings in urban areas because the implementation process does not cause disturbing vibrations and noise around the project site. The diameter of the bored pile varies between 300-2000 mm and the depth can reach 50 m.

Pile Load Distribution

According to Simorangkir (2014), pile foundations transfer the load to the soil through two mechanisms, namely blanket friction and end resistance. friction bearing is obtained as a result of the adhesion or shear resistance between the friction pile and the surrounding soil, while end resistance arises due to the pressure of the end of the foundation against the soil. The picture of the mechanism can be seen in Figure 1. If the pile foundation is loaded, it will produce a load-reduction curve as shown in Figure 2

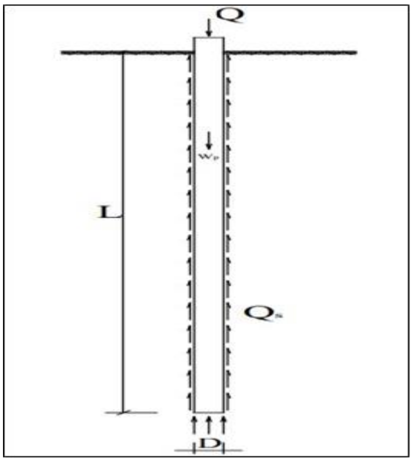


Figure 1 Soil Load Transfer Mechanism

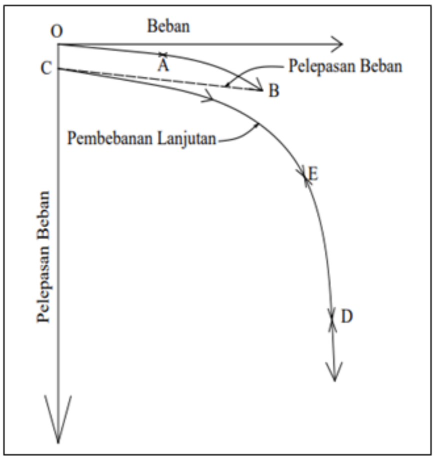


Figure 2 Load and Displacement Relation

Initially, the pile system behaves elastically in a straight line up to point A and if the load is released, the pile head will return to its beginning position. In this loading condition, the entire load is still carried out by the friction bearing capacity of pile cap. If the load is increased to point B then some of the friction bearing at the top of the pile reaches the ultimate and slip occurs between the pile and the ground at which point the pile tip moves and the end bearing begins to move. If the load is released again, the pile head will not return to its beginning position but to point C, leaving a permanent set of OC. The movement required to mobilize the ultimate bearing capacity on the firction pile is generally very small (0.3 – 1.0% of the pile diameter or in the range of 2.0 – 5.0 mm) while to mobilize the end bearing pile, larger movements are required. Therefore the ultimate friction bearing is reached first. If the load is increased continuously, the friction pile cannot be higher and subsequent loads are transferred to the pile end bearing.

Pile Bearing Capacity with Plaxis 2D Program

Plaxis 2D is a finite element program for Geotechnical applications, where the soil model is used to imitate the behavior of the soil in the field to obtain relationship curve between the load and the settlement that occurs on the pile with Plaxis 2D. The soil modeling used is the Mohr-Coulomb model with Axisymmetric analysis.

1. Mohr-Coulomb model

   The Mohr Coulomb model assumes a perfectly plastic soil behavior, by setting a limit stress value at which point the stress is no longer affected by the strain that occurs.

   Soil parameter data which is very important for this modeling consists of 4 (four) types of parameters, modulus of elasticity (e_s), poisson ratio (v'), cohesion (c), inner shear angle (ø).

2. Parameter study

   1. Modulus of Elasticity (Es) and Poisson's Ratio (')

      The value of the modulus of elasticity must be determined for each soil, this value is the basis for determining the settlement that occurs in a soil. Soil investigation data can be correlated to the modulus of elasticity as shown in Table 1. Then, the value of the poisson's ratio is rarely determined, so the values in Table 2. are usually used.

Table 1 Values of Elasticity Modulus for Soil and Rock (Coduto, 2001)

Type and Condition of Soils or Rocks	Modulus Elasticity, Es	
	(lb/ft^2)	(kPa)
Undrained Conditions		
Soft clay	30.000-200.000	1.500-5.000
Medium clay	100.000-1000.000	5.000-50.000
Stiff clay	300.000-1.500.000	15.000-75.000
Drained Conditions		
Soft clay	5.000-30.000	250-1.500
Medium clay	10.000-70.000	500-3.500
Stiff clay	25.000-400.000	1.200-20.000

Table 2 Values of Elasticity Modulus for Soil and Rock (Coduto, 2001)

Type and Condition of Soils or Rocks	Modulus Elasticity, Es	
	(lb/ft^2)	(kPa)
Loose Sand	200.000-500.000	10.000-25.000
Solid Sand	400.000-1.200.000	20.000-60.000
Very Solid Sand	1.000.000-2.000.000	50.000-100.000
Sand stone	$1{,}4x10^8$-$4{,}0x10^8$	7.000.000-20.000.000
Granite	$5{,}0x10^8$-$1{,}0x10^9$	25.000.000-50.000.000
Iron	$4{,}2x10^9$	200.000.000

Table 3 Values of Poisson's Ratio for Soil and Rock (Kulhawy, et al., 1983)

Tipe Tanah dan Batu	Poisson's Ratio, v_p
Tanah jenuh, kondisi undrained	0,50
Lempung jenuh sebagian	0,30-0,40
Pasir padat, kondisi drained	0,30-0,40
Pasir lepas, kondisi drained	0,10-0,30
Sandstone	0,25-0,30
Granite	0,23-0,27

2. Cohesion (c) and Inner Shear Angle (Ø)

Various field testing methods and the laboratory was conducted to produce parameters of shear strength, cohesion and inner shear angle.

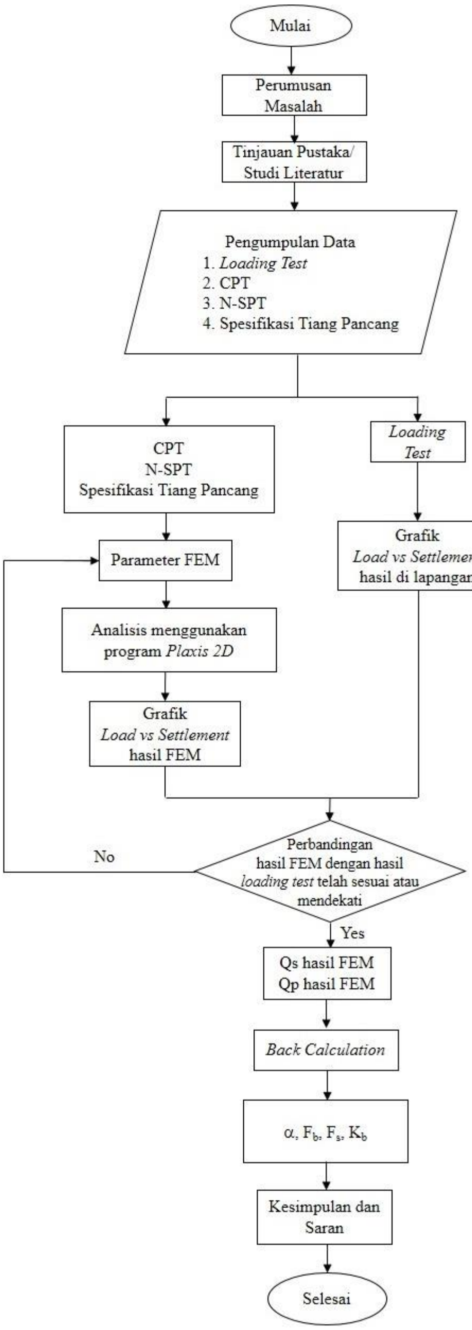
Table 4 Cohesion Values (c) (Begemann, 1965)

Konsistensi	Tekanan konus Q_c (kg/cm^2)	*Undrained Cohesion* (ton/m^2)
Sangat lunak	<2,5	<1,25
Lunak	2,5-5,0	1,25-2,50
Kaku sedang	5,0-10,0	2,50-5,0
Kaku	10,0-20,0	5,0-10,0
Sangat kaku	20,0-40,0	10,0-20,0
Keras	>40,0	>20,0

Table 5 Inner Shear Angle Values (Begemann, 1965)

Kepadatan	*Relative Density* (Dr)	Nilai N	Tekanan Konus (kg/cm^2)	Sudut geser dalam
Sangat lepas	< 0,2	< 4	< 20	< 30
Lepas	0,2 - 0,4	4 - 10	20 - 40	30 - 35
Padat sedang	0,4 - 0,6	10 - 30	40 - 120	35 - 40
Padat	0,6 - 0,8	30 - 50	120 - 200	40 - 45
Sangat padat	0,8 - 1,0	> 50	> 200	> 45

3. METHOD



4. RESULTS AND DISCUSSION

Results of Soil Parameters in The Mohr-Coulomb Model

1. Soil Parameters on pile cap TP No.101, As.Q-5

Table 6 Correlation Results of Soil Parameters for Plaxis 2D input on pile cap TP No.101,As.Q-5

Depth (m)	Description	N-SPT	Classification	Es (kPa)	v	c (tons/m²)	c (kN/m²)	Φ (°)
0,00-2,45	Organic clay	0	Very soft	1500-5000	0,5	2,5	25	>30
2,45-3,50	Clay	0	Very soft	1500-5000	0,5	2,5	25	>30
3,50-5,50	Silty clay	5	Medium	5000-50000	0,3	5	50	30
5,50-6,45	Silty clay	2	Very soft	1500-5000	0,5	2,5	25	>30
6,45-8,45	Plastic silt with sand (ML)	7	Medium	5000-50000	0,3	1,1	10,79	30
8,45-11,50	Fine sandy	12	Stiff	15000-75000	0,3	5	50	35
11,50-13,50	Non-plastic silty sand (SM)	9	Loose	10000-25000	0,1	0,001	0,01	30
13,50-15,50	Non-plastic silty sand (SM)	22	Medium	20000-60000	0,3	5	50	35
15,50-18,45	Sandy organic	47-51	Sol	15000-75000	0,3	20	200	40
18,45-20,40	Fine sand	>50	Very solid	50000-100000	0,3	20	200	45

2. Soil Parameters on pile cap TP No.58F-2E

Table 7 Correlation Results of Soil Parameters for Plaxis 2D input on pile cap TP No.58F-2E

Depth (m)	Description	N-SPT	Classification	Es (kPa)	v'	c (ton/m²)	c (kN/m²)	Φ (°)
0,00-2,45	Organic clay	0	Very soft	1500-5000	0,5	1,25	12,26	>30
2,45-4,45	Medium plasticity sand-clay (SC)	5	Loose	10000-25000	0,1	0,001	0,01	30
4,45-6,45	Medium plasticity sand-clay (SC)	3	Very loose	10000-25000	0,1	0,0001	0,00	>30
6,45-7,50	Silty clay	3	Soft	1500-5000	0,5	1,25	12,26	>30
7,50-9,50	Clay sand	4	Very loose	10000-25000	0,3	0,0001	0,00	30
9,50-10,45	Sand-organic clay	8	Medium	5000-50000	0,3	2,5	24,52	30
10,45-12,45	Non-plastic silty sand (SM)	7	Loose	10000-25000	0,1	0,001	0,01	30
12,45-14,45	Non-plastic silty sand (SM)	16	Medium	5000-50000	0,3	2,5	24,52	35
14,45-18,45	Clay and organic sands	20-29	Medium	5000-50000	0,3	2,5	24,52	35
18,45-20,30	Clay and organic sands	>50	Very solid	50000-100000	0,3	10	98,07	45

Bearing Capacity of Pile Cap on Numerical Methods

1. Comparison of Load Relationship Curves and Settlement Between Loading Test and Numerical Methods

   The results of the reduction in the field with those modeled by Plaxis 2D have not much different differences (Figures 3 and 4) so that the results of Plaxis 2D in this study can be stated to be the same as in the field (actual).

Table 8 Comparative Settlement Results of Loading Test and Plaxis 2D on TP No.101, As.Q-5

Trial Load (%)	Q (tons)	Q (kPa)	Settlement Load Test (mm)	Settlement Plaxis 2D (mm)
0	0	0	0	0
25	12,5	1362	0,107	0,69
50	25	2724	0,697	1,38
75	37,5	4086	1,84	2,07
100	50	5448	2,44	2,76
125	62,5	6810	3,56	3,46
150	75	8172	4,322	4,27
175	87,5	9534	4,725	5,13
200	100	10896	5,63	6,02

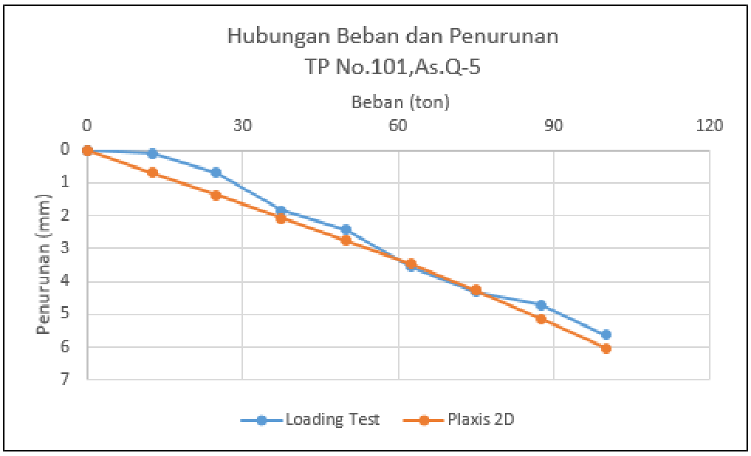


Figure 3 Graph of Load and Settlement Relationship TP No.101,As.Q-5

Table 9 Comparative Settlement Results of Loading Test and Plaxis 2D on TP No.58F-2E

Trial Load (%)	Q (tons)	Q (kPa)	Settlement Load Test (mm)	Settlement Plaxis 2D (mm)
0	0	0	0	0
25	12,5	11,03	0,82	0,7
50	25	22,06	1,3	1,35
75	37,5	33,09	2,2	2,1
100	50	44,12	2,5	2,8
125	62,5	55,16	3,15	3,58
150	75	66,19	3,8	4,4
175	87,5	77,22	4,8	5,4
200	100	88,25	7,9	7,4

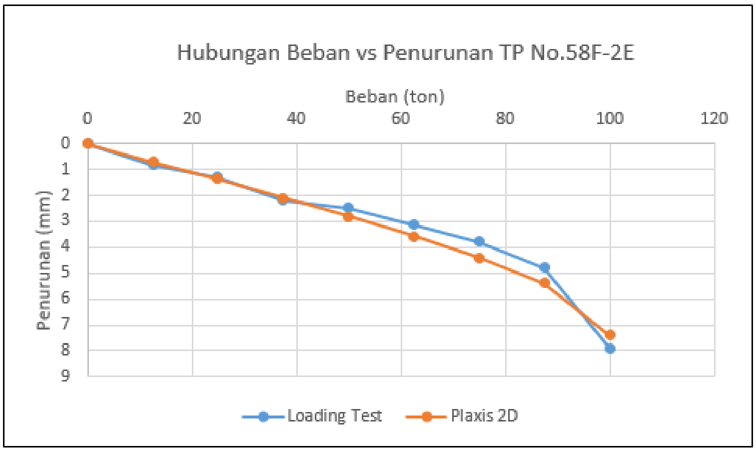


Figure 4 Graph of Load and Settlement Relationship TP No.58F-2E

2. Load Transfer Graph

   At Figure 5 can be seen in the graph of the load transfer for each pile. This load transfer is an interpretation of the carried out capacity that works along the friction to the tip of the pile.

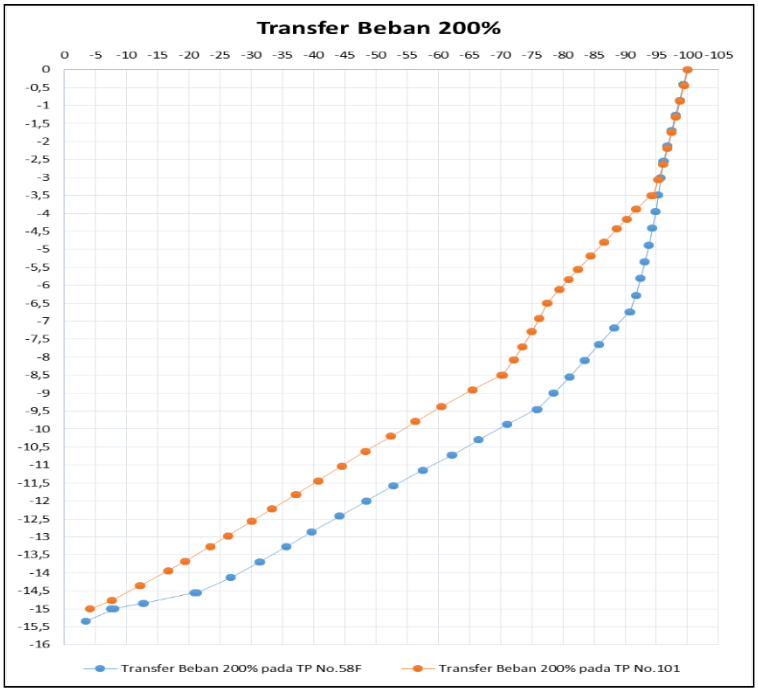


Figure 5 Graph of 200% Load Transfer TP No.101,As.Q-5 and TP No.58F-2E

The results at Figures 5 is in accordance with the results obtained by Chao et al. (2020) who conducted a pile loading test with sensors placed along the pile that in the ultimate load condition of the loading test loading test, the distribution of the load along the friction pile was greater and more dominant than the distribution of the end resistance load, where the received only a small part of the ultimate load.

5. CONCLUSIONS

From the results obtained in this study, it can be concluded:

1. The results of the analysis of the friction bearing capacity and pile tip based on the finite element numerical methods (FEM) carried out with the *Plaxis 2D* are as follows:
   a. The pile TP No.101, As.Q-5 obtain a friction bearing capacity of 15 meters long is 95.98 tons, and an end bearing capacity is 4.08 tons.
   b. The pile TP No. 58F-2E obtain a friction bearing capacity of 15 meters long is 91.96 tons, and an end bearing capacity is 8.04 tons.
   c. The load test 200% of the design load carried out on the piles can still be well supported by the carrying capacity of the friction pile, so that the end resistance still receives a much less load than the load received by the friction pile.

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