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An Analysis of The Static Load Test on Single Square Pile of 50 x 50 cm^2, Using Finite Element Method in Multy-Storey Building Project, Pluit, North Jakarta

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Abstract. Planning a foundation for a high building and carrying a large construction burden, must be carried out with a correct, thorough and comprehensive analysis, so that a foundation design is able to carry the burdens that works on it and can carry the loads it receives to ground beneath it safely. This study analyzed the capacity of bearing capacity and the settlement of the hydraulic stressed pile foundation of prestressed concrete square pile of 50 x 50 cm^2 in cross section of single pile or group pile. The research used empirical method, finite element method program and compared the results with the interpretation of axial static loading test on the Multy-Storey Building Project in Pluit, North Jakarta. The analysis used soil investigation and laboratory study and used 2D and 3D finite element methods by Mohr-Coulomb and Soft soils models. The result of the analysis on the ultimate bearing capacity of hydraulic stressed pile foundation with empirical method of Meyerhof gave the highest value using SPT data at DB1 borelog point of 655.23 tons, and the lowest was the result of interpretation of Loading Test by Davisson's method of 260.00 tons. The ultimate bearing capacity required by ASTM D1143-81 (1989) for the Static Axial Loading Test is 300 tons (200% of working load), while the interpretation of the Davisson's Loading Test method (260.00tons), Chin (267,86tons) and Mazurkiewicz (267.00tons), none of which have fulfilled the requirements for carrying 150 tons of working load. The lateral bearing capacity of Broms method was 16,14 tons which was the strength of the pile material against lateral loads. Whereas for the bearing capacity of the group pile (6 points in one pilecap) the lowest efficiency of 0,734 from the Converse-Labarre Equation and the highest efficiency of 0,805 from the Los Angeles Group Action Equation was obtained. For 200% of the planning load of 150 tons, that is 300 tons, the settlement of the single pile which occurred from 2D finite element method program were 18,00 mm and 15,63 mm for 3D while the results of the Loading Test was 15,00 mm. The results of the analysis of Loading Test settlement was more realible.

Keyword: Loading Test, Bearing Capacity, Settlement, Finite Element Method, Hydraulic Stressed Pile.

Abstrak. *Titik Perencanaan suatu pondasi untuk bangunan tinggi serta memikul beban konstruksi atas yang besar, haruslah dilakukan dengan analisa yang benar, teliti dan komprehensif, sehingga diperoleh desain pondasi yang mampu memikul beban-beban yang bekerja padanya dan dapat meneruskan beban-beban yang diterimanya ke tanah di bawahnya dengan aman. Penelitian ini menganalisa kapasitas daya dukung dan penurunan pada pondasi tiang tekan hidrolis jenis Prestressed Concrete Square Pile ukuran 50 x 50 cm^2 dalam bentuk tiang tunggal maupun kelompok tiang. Adapun metode yang digunakan adalah metode empiris, Program Finite Element Method dan membandingkan hasilnya dengan interpretasi uji beban statis aksial (Loading Test) pada Proyek Bangunan*

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Bertingkat di Pluit Jakarta Utara. Analisa menggunakan data penyelidikan tanah (Soil Investigation) dan laboratorium serta menggunakan metode elemen hingga 2D dan 3D dengan pemodelan tanah Mohr-Coulomb dan Soft Soil. Hasil analisa daya dukung ultimate pondasi tiang tekan hidrolis dengan menggunakan metode empiris Meyerhof memberikan nila terbesar dengan menggunakan data SPT pada titik borelog DB1 sebesar 655,23 ton, dan daya dukung terkecil adalah hasil interpretasi Loading Test dengan metode Davisson yaitu sebesar 260,00 ton. Daya dukung yang disyaratkan oleh ASTM D1143-81 (1989) untuk uji pembebanan statik aksial (Static Axial Loading Test) adalah 300 ton (200% dari working load). Sehingga hasil interpretasi Loading Test metode Davisson (260,00 ton), Chin (267,86 ton) maupun Mazurkiewicz (267 ton) belum ada yang memenuhi syarat memikul beban kerja 150 ton. Daya dukung lateral tiang metode Broms adalah sebesar 16,14 ton yang merupakan kekuatan bahan tiang terhadap beban lateral. Sedangkan untuk daya dukung kelompok tiang (6 titik dalam satu pilecap) diperoleh effisiensi terkecil 0,734 dari Converse-Labarre Equation dan effisiensi terbesar 0,805 dari Los Angeles Group Action Equation. Untuk 200% dari beban rencana 150 ton yaitu 300 ton, penurunan tiang tunggal yang terjadi dari program Finite Element Method 2D adalah 18,00 mm dan 15,63 mm untuk 3D sedangkan dari hasil Loading Test adalah sebesar 15,00 mm. Hasil analisa penurunan tiang tunggal dengan Loading Test lebih dapat dipercaya.

Kata Kunci: *Loading Test, Daya Dukung, Penurunan, Metode Elemen Hingga, Tiang Tekan Hidrolis.*

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1 Introduction

In planning the Multy-Storey Building project at Pluit, North Jakarta, an accurate foundation is highly important in determining the success in the endurance of building since a good and correct construction which is in accordance by the age of the constructed building is highly determined by its foundation. Foundation is a very crucial element in civil engineering work because it carries the entire load of the building [1]. The type which is used in the Multy-Storey Building project at Pluit, North Jakarta is square piles of 50 x 50 cm^2 produced by JHS Pile and the quality of concrete K-500.

The objective of research was to calculate the amount of bearing capacity of single sguare pile foundation, based on several conventional methods. It is obtained based on soil investigation in the field; they were static penetration and SPT (boring log) data for one location from some points of observation and the analysis of the bearing capacity of the single square pile and its settlement, based on loading test data [1]. The bearing capacity was calculated, based on interpretation of Load Test for bearing capacity. The comparison of the amount of bearing capacity of the single pile and its settlement by using 2D and 3D Finite Element Method and Mohr-Coulomb, Soft Soil modelling. To analyze the bearing power of the calculation of some methods and drawing the conclusion or suggestion from the analysis. To study the soil parameter from the SPT (boring log) data so that the input would be inserted for Mohr-Coulomb, Soft Soil modelling. To recognize the data by understanding the characteristics of soil

layer as the model and the analysis of the bearing capacity piles. To evaluate the settlement by using Slow Maintained Load Test [1].

1.1 Review of Related Literature

Piling is parts of construction made of wood, concrete, and steel to transmit surface loads to the lower level of the surface in soil mass [2]. Piling construction foundation is used as building foundation when its base does not have sufficient bearing capacity to carry the building weight and load on it [3]. Or, when and the entire load in the deepest layer of the depth soil surface reach more than eight meters [2].

1.2 Interpretation of Load Test for Bearing Capacity

1.2.1 Chin Method (1970,1971) [6]

The procedure of ultimate load of the piling foundation by using Chin Method [6] is as follows:

1. Drawing curve between settlement ratio and load (s/Q), where is settlement and Q is load as shown in Figure 1.
2. Drawing straight line which represents the drawn points. The equation of the line is $s/Q = c_1*s + c_2$. Calculating c_1 from the line equation or from the slope of the straight line which is determined.
3. $Q_{ult} = 1/c_1$ This method produces high ultimate load so that it has to be corrected or divided by the factor value of 1.2 – 1.4

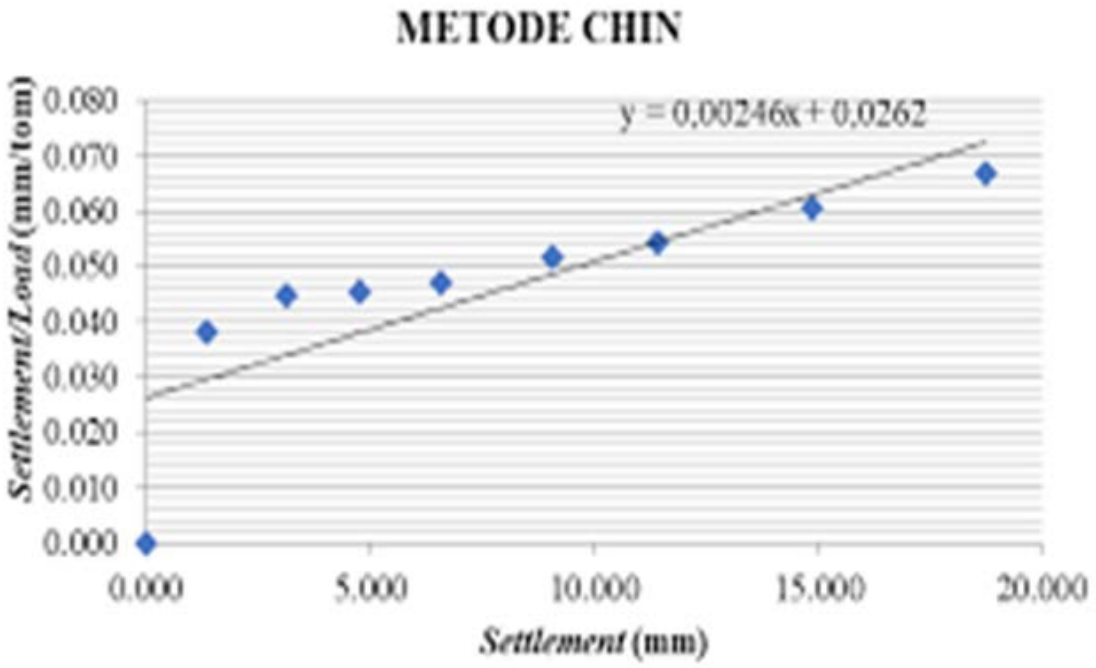

Figure 1. Graph of Ultimate Bearing Capacity, Using Chin Method [5]

1.2.2 Davisson Method (1972) [7]

In the Davisson method (1972) [7], the offset limit method is probably the best and widely known. It has been suggested by Davisson as the load which is accordance by a movement which exceeds elastic pressure (which is assumed by a column which stands by itself) at the value of 0.15 inches and a factor which is relevant to the measurement of Pile Measurement divided by 120.

1.2.3 Mazurkiewicz Method (1972) [8]

The loading procedure of the piling foundation according to Mazurkiewicz method is as follows [4] :

1. The plot of the loading test curve toward the settlement was based on the result of load test in the observed location;
2. Drawing lines from some selected settlement points until they cross the curve;
3. Vertical line is being drawn until it reaches loading pivot;
4. From the cross of the load, a line with an angle of 45^0 is being made until it crosses the next line;
5. These points are connected until straight line is formed;
6. The cross of the straight line with loading pivot is its ultimate load;
7. This method gives the assumption that loading curve movement forms the shape of parabola;
8. Therefore, the value of the collapsing loads, obtained by using Mazurkiwicz method, should approach 80% of the standardized criteria.

1.3 Element Method

In calculating the settlement of square pile foundation by using program, we need to know about the theory of modelling soil which can be selected. Errors in selecting its model will cause the mistake in the output of the calculation. In this research, the needed data were about soil parameter which was being obtained from the result of soil investigation performed in the laboratory of PT. Tarumanegara Bumiyasa Jakarta, in the construction of Multi-Storey Building project, Pluit, North Jakarta. The gathered data were being processed by using Mohr-Coulomb, Soft Soil modeling with Slow Maintained Load Test.

2 Method

The research has been conducted at the construction project of Multy-Storey Building, Pluit, North Jakarta, as shown in Figure 2.

Figure 2. Map of The Location of Multy-Storey Building Project at Pluit, North Jakarta

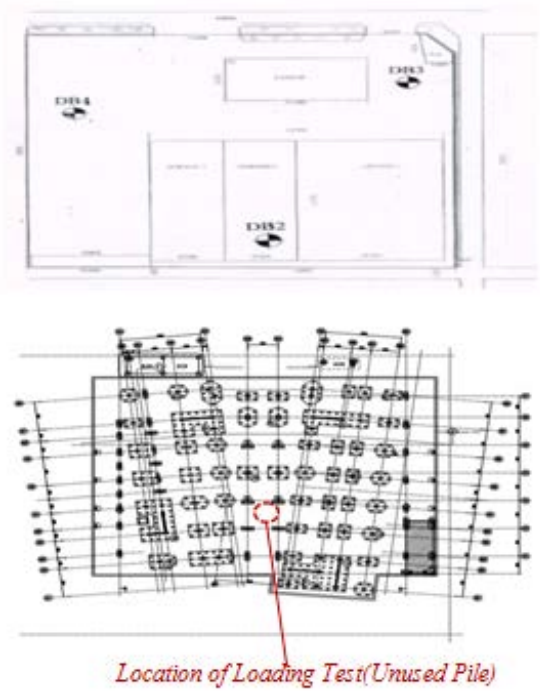

Figure 3. Map of the Location of Boring Log Points and Point of Loading Test.

SPT which was carry out in the construction of Multy-Storey Building at Pluit, North Jakarta, consisted of 3 (three) points and 1 (one) point of loading test as it shown in Figure 3. The data for square pile could being seen in Table 1:

Table 1. Data of Square Pile of Unused Pile

Explanation	**Value**
Location	Bore Hole DB3
Pile Size (m)	0,500
Length of Pile (m)	19,00
Area of Pile Section (m^2)	0,25
Elasticity Module (kN/M^2)	*fc* 42,3
Inertia Moment (m^4)	$5{,}208 \times 10^{-3}$
EA (kN)	$7{,}65 \times 10^{6}$
EI (kNm^2)	159,375
Poisson Ratio	0,20

3 Results and Discussions

From the result of loading static test, it was found that data of loading test reading at unused pile is at the following Table 2.

Table 2. Result of Reading Static Load Test at Unused Pile

Holding Time	Load		% of	Settlement
(minutes)	(Ton)	(kN)	Design Load	Averege (mm)
0	0.000	0.000	0.000	0.000
55	37.500	367.875	25.000	1.868
65	75.000	735.750	50.000	3.797
25	37.500	367.875	25.000	1.861
65	0.000	0.000	0.000	0.200
25	75.000	735.750	50.000	3.886
50	112.500	1,103.625	75.000	5.614
80	150.000	1,471.500	100.000	7.559
25	112.500	1,103.625	75.000	5.559
25	75.000	735.750	50.000	3.868
65	0.000	0.000	0.000	0.200
25	75.000	735.750	50.000	3.910
25	150.000	1,471.500	100.000	7.604
65	187.500	1,839.375	125.000	9.392
65	225.000	2,207.250	150.000	11.285
25	187.500	1,839.375	125.000	9.357
25	150.000	1,471.500	100.000	1.656
25	75.000	735.750	50.000	3.886
65	0.000	0.000	0.000	1.200
25	75.000	735.750	50.000	3.932
25	150.000	1,471.500	100.000	7.651
30	225.000	2,207.250	150.000	11.356
65	262.500	2,575.125	175.000	13.171
725	300.000	2,943.000	200.000	15.000
55	225.000	2,207.250	150.000	11.336
15	150.000	1,471.500	100.000	7.619
65	75.000	735.750	50.000	3.885
0	0.000	0.000	0.000	2.600

3.1 Calculating The Bearing Capacity of Piling, Based on Load Test

3.1.1 Calculating The Bearing Capacity of Piling from The Loading Data, Using Chin Method [6]

The procedure of determining ultimate load from the piling foundation by using Chin method is as follows :

1. Calculating S/P value from the settlement data (S) and load (P);
2. Describing S value in x pivot and S/P value in pivot to get the points as shown in Figure 4;
3. Connecting the points which have been made with step 2 to get a linier line;

4. Drawing the linier equation with regression analysis;
5. Determining P_{ult} of (1/b).

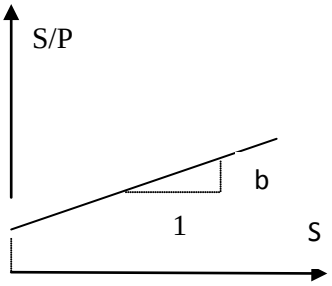

Figure 4. Equation of Linier Line in S/P Versus S

In the calculation of piling through load test data by using Chin method, it is necessary to calculate the ratio of settlement toward the load, as it is shown in Table 3 below :

Table 3. Correlation and Comparison between Settlement and Load

No	Load	Cycle	Settlement	Settlement/Load
	(Ton)	%	(mm)	
1	0.000	0	0.00	0.000
2	75.000	50	2.00	0.027
3	150.000	100	5.60	0.037
4	200.000	133.33	8.00	0.040
5	230.000	153.33	9.60	0.042
6	300.000	200	15.00	0.050

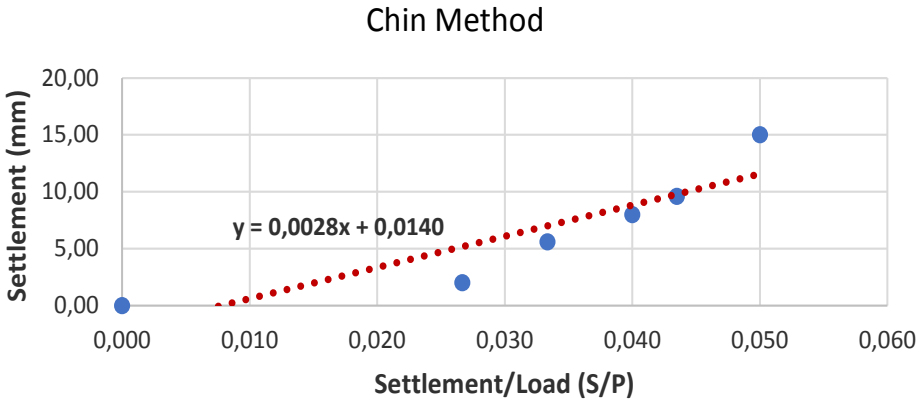

Figure 5. Soil Bearing Capacity, Based on Chin Method

From the equation of linier regression in the graph, the correlation of comparison of settlement and the load with the settlement is that P_{ult} = 267,86 tons or 2627,707 kN as in Figure 4.

3.1.2 Calculating The Bearing Capacity of Piling from The Loading Data, using Davisson Method [7]

The procedure of determining ultimate load from the piling foundation by using Davisson method was follows :

1. Based on equation, it was plotted in the diagram of load-settlement as OO' to get the best scale of line slope of OO' abaout 20% (see the Graph below).
2. The deformation of X, calculated by the following formula :
   X = 0,15 + D/12 (inch). (1)
   With D = size of piles (inches).
3. Plotting CC' line, make it parallel with OO' line which crosses in the settlement pivot in the meaning of X inch.
4. Crossing line is the amount of the tip pile settlement to get the bearing capacity. Loading Limit (Q_{ukt}) was defined as load in which CC' line crosses the curve of settlement load.
   Calculation :
   X = 0,15 + D/12 (inch). (2)
   = 0,15 + (50/2,54)/120 (3)
   = 0,314 inch = 7,9767 mm. (4)

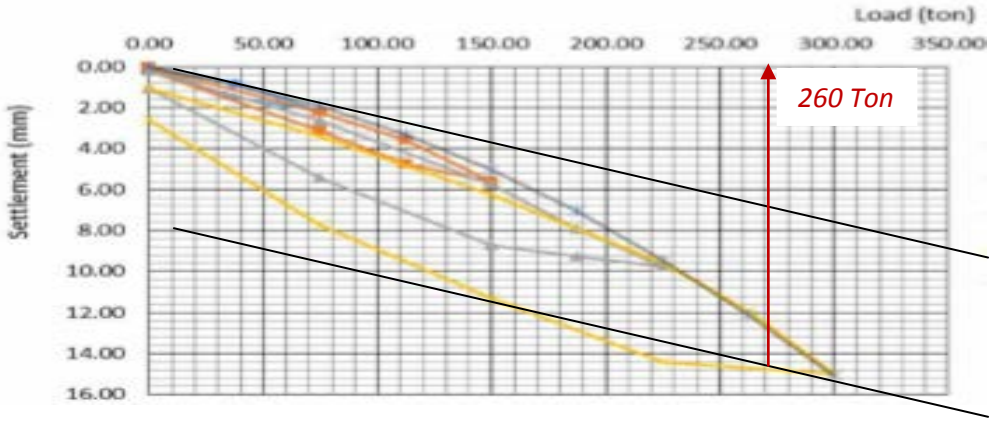

Figure 6. Soil Bearing Capacity, Based on Davisson Method

By drawing this line in the load-settlement curve, it was found that the maximum load (Q_{ult}), using Davisson method, was 260,00 tons as shown in Figure 6.

3.1.3. Calculating The Bearing Capacity of Piling from the Loading Data, using Mazurkiewicz Method [8]

The procedure of determining ultimate load from the piling foundation by using Mazurkiewicz method is as follows :

a. Plotting the load curve test given to settlement;
b. Drawing the line from several points of the chosen settlement so that they cross the curve, and drawing a vertical line so that it crosses loading pivot.
c. From the secant of each load, make a line with the angle of 45^0 toward the next secant, and so on.

Connect these points so that they procedure a straight line. The intersection line of this straight line with the load is its final load.

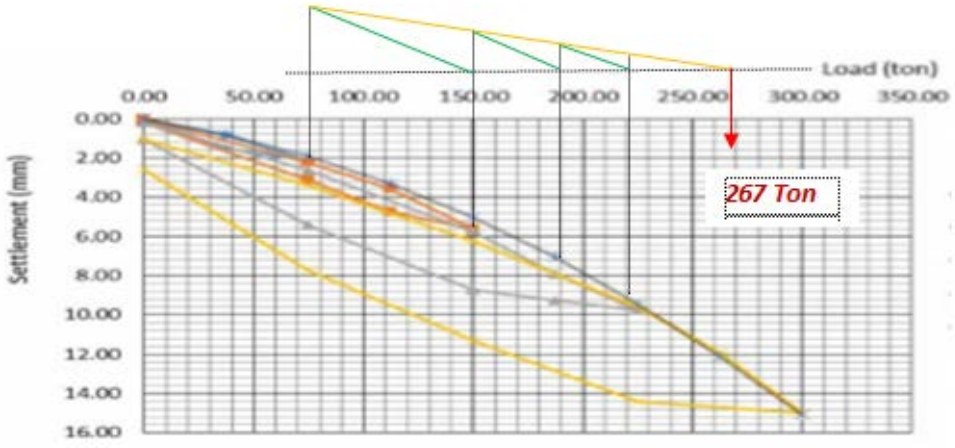

Figure 7. Soil Bearing Capacity, Based on Mazurkiewicz Method

By drawing this line in the load-settlement curve, it was found that the maximum load (Q_u). using Mazurkiewicz method is 267,00 tons as shown Figure 7.

3.2 Finite Element Modelling

Calculating the settlement of square pile foundation with finite element program in which soil layer is devided into six soil layers, as it can be seen in Table 4 below.

Table 4. Input of Soil Parameter for Finite Element Modeling in Bore Hole DB3

Number of Layer	Type of Soil	Depth	N-SPT$_{av}$	Subsurface	γ_{wet}	γ_{dry}	$K_x=K_y$	c	ϕ	Ψ	E_s	υ	Soil Model
		(m)		Condition	(kN/m^3)	(kN/m^3)	(m/hari)	(kN/m^2)	(degree)	(degree)	(kN/m^2)		
1	Fill Material	0,00 - 1,50	0.00	Soft	18.90	14.50	$5x10^{-5}$	0	28.00	0.00	3,000.00	0.15	Mohr-Coulomb
2	Clay 1, brownish grey, blackish grey	1,50 - 14,00	3.12	Soft to Medium	14.52	10.37	$1x10^{-8}$	32.38	29.25	0.00	-	0.31	Soft Soil
3	Silt, brown	14,00 - 16,00	18.11	Medium	16.59	14.49	$5x10^{-5}$	141.4	37.53	7.53	6,600.00	0.28	Mohr-Coulomb
4	Sand, black	16,00 - 32,00	39.30	Very Dense to Dense	18.74	16.16	$2x10^{-3}$	261.1	42.55	12.55	33,000.00	0.28	Mohr-Coulomb
5	Clayey Silt, black	32,00 - 34,00	36.67	Stiff	17.80	15.48	$5x10^{-4}$	234.7	41.50	11.55	18,850.00	0.27	Mohr-Coulomb
6	Clay 2, grey, reddish grey, yellowish grey	34,00 - 60,00	33.03	Stiff	17.52	14.48	$1x10^{-9}$	221.5	40.82	10.82	11,786.00	0.30	Mohr-Coulomb

This modelling according to the field soil parameter as it seen in Table 2, Table 4 and outline it can be seen in Figure 8.

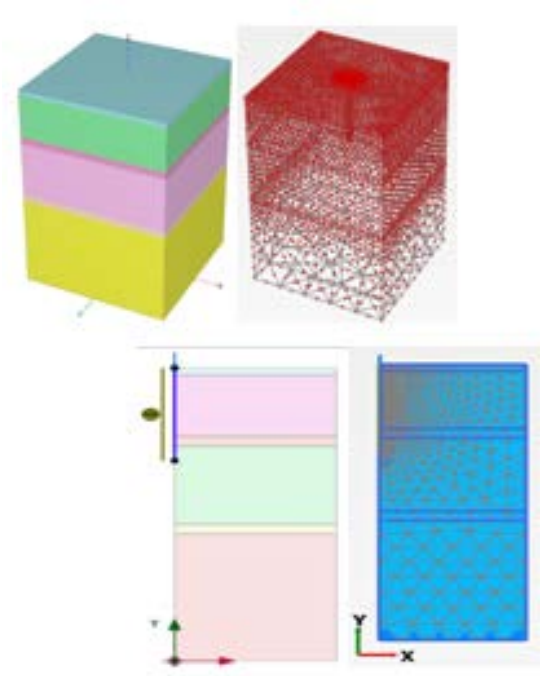

Figure 8. Soil Layer and Square Pile Modelling

The magnitude of settlement as the result of loading with element modelling was seen in Table 5.

Table 5. The Correlation of Loads and Settlements with Finite Element Modelling

No	Remark	Load	Settlement			Time
			Loading Test	FEM 3D	FEM 2D	
		(Ton)	(mm)	(mm)	(mm)	(Minute)
1	0%	0	0.000	0.000	0.000	0
2	25%	37.5	0.800	2.215	4.100	55
3	50%	75	2.000	4.447	8.017	65
4	25%	37.5	1.600	2.662	5.587	25
5	0%	0	0.200	1.016	2.715	65
6	50%	75	2.200	4.374	7.073	25
7	75%	112.5	3.600	6.282	9.433	50
8	100%	150	5.600	8.192	11.000	80
9	75%	112.5	4.600	6.225	8.827	25
10	50%	75	3.000	4.252	5.943	25
11	0%	0	0.200	0.948	2.837	65
12	50%	75	2.600	4.159	6.573	25
13	100%	150	5.800	7.944	10.000	25
14	125%	187.5	7.800	9.930	13.000	65
15	1505	225	9.600	11.880	14.000	65
16	125%	187.5	9.400	9.920	12.000	25
17	100%	150	8.800	7.939	9.357	25
18	50%	75	5.400	4.026	6.011	25

19	0	0	0.800	1.120	3.955	65
20	50%	75	3.400	3.928	7.038	25
21	100%	150	6.200	6.770	9.846	25
22	125%	225	9.800	11.660	13.000	30
23	175%	262.5	12.000	13.640	16.000	65
24	200%	300	15.000	15.630	18.000	725
25	150%	225	14.700	11.720	13.000	55
26	100%	150	11.300	8.200	10.000	15
27	50%	75	7.800	3.888	6.965	65
28	0	0	2.600	1.342	5.446	0

3.2.1 Curve of The Correlation of Loads with Loading Settlement 50% (Cycle I)

The curve below shows the correlation of loads and settlement which occurs when the load was 50% of the working load, as it was shown in Figure 9.

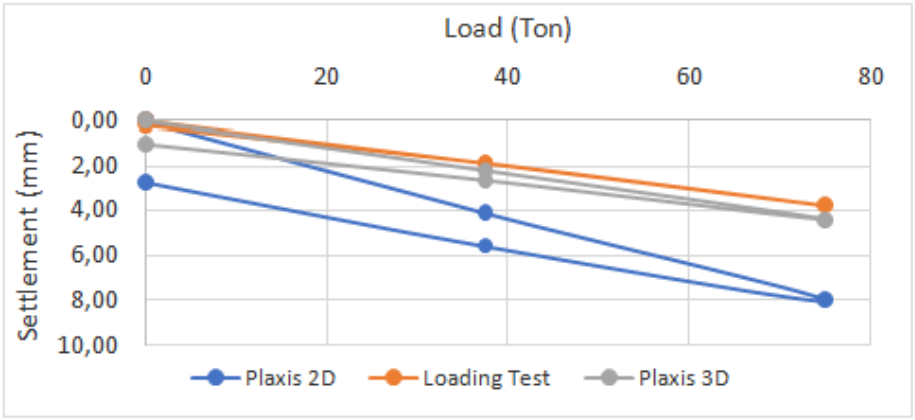

Figure 9. Curve of Correlation of Loads with Settlement 50%

3.2.2 Curve of The Correlation of Loads with Loading Settlement 100% (Cycle II)

The curve below shows the correlation of loads and settlement which occurs when the load was 100% of the working load, as it was shown in Figure 10.

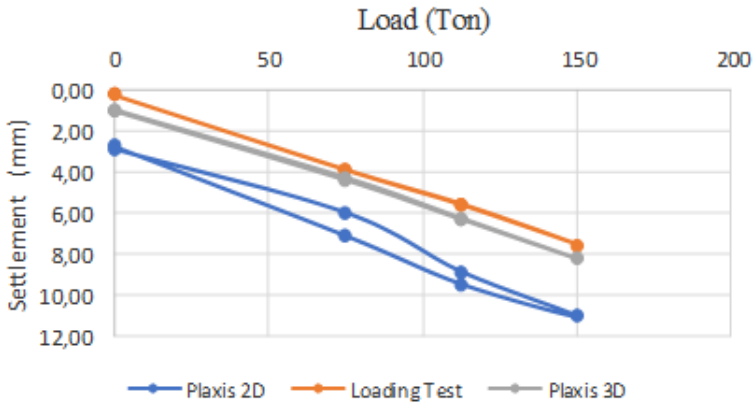

Figure 10. Curve of The Correlation of Loads with Settlement 100%

3.2.3 Curve of the Correlation of Loads with Loading Settlement 150% (Cycle III)

The curve below shows the correlation of loads and settlement which occurs when the load was 150% of the working load, as it was shown in Figure 11.

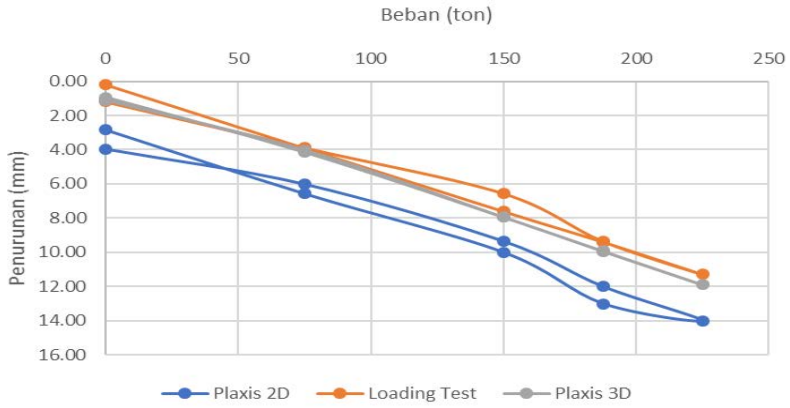

Figure 11. Curve of The Correlation of Loads with Settlement 150%

3.2.4. Curve of The Correlation of Loads with Loading Settlement 200% (Cycle IV)

The curve below shows the correlation of loads and settlement which occurs when the load was 200% of the working load, as it was shown in Figure 12.

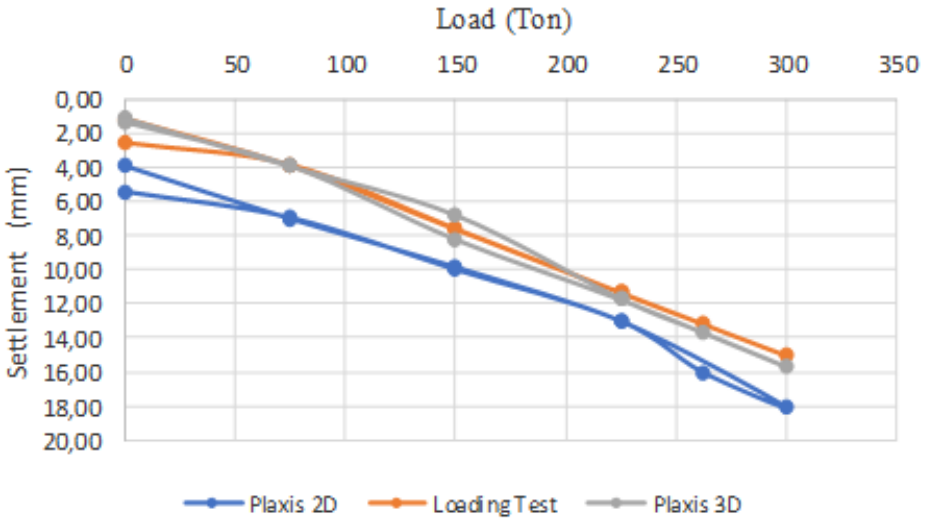

Figure 12. Curve of The Correlation of Loads with Settlement 200%

3.2.5 Comparison between The Result of Load Test in The Field and Finite Element

The total result or the correlation of loads with the settlement as the result of Finite Element Modelling will yield the graph as shown in Figure 13.

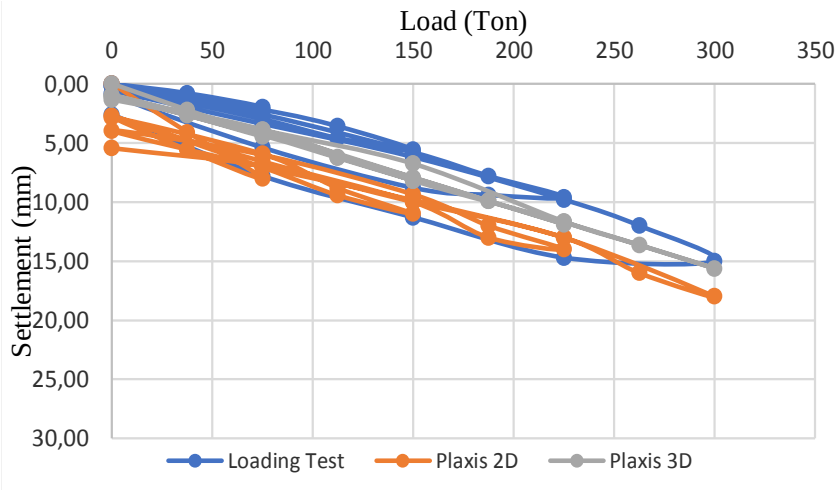

Figure 13. Graph of The Correlation of Loads with Settlement The Result of Load Test in The Field and Finite Element

The result of the comparison of N-SPT bearing capacity with finite element**.**

Table 6. The Comparison between N-SPT Bearing Capacity with The Finite Element

Depth (m)	Q_{ult} N-SPT (Ton)	Q_{ult} FEM (Ton)
8.00	24.86	30.95
12.00	53.45	66.55
16.00	126.45	157.43
19.00	582.45	730.95

4 Conclusions

1. The result of the calculation of the ultimate bearing capacity analysis on square pile foundation with 19,00 m length and the result of statistic load interpretation/loading test by using Chin method showed that it was the closest to the value of planning final load. The other methods which were also close to it were Mazurkiewicz method and Davisson method. The sequence of the result could be seen in Table 7 below :

Table 7. The Result of The Analysis on Ultimate Bearing Capacity of Square Pile Foundation

No	Explanation	Ultimate Pile Bearing Capacity (Ton)
1	N-SPT	582.45
2	FEM	730.95

3	Chin Method	267.86
4	Davisson Method	260.00
5	Mazurkiewicz Method	267.00
6	Loading Test	300.00

2. The result of the analysis of the settlement in Cycle IV at the end of 200% was the maximum value for static load test/load test of 15.00 mm. Finite elements modelling by using Slow Maintained Load Test of Plaxis 3D was 15.63 mm and Plaxis 2D was 18.00 mm. The results of the settlement of using finite element, Plaxis 3D and 2D programs were close to the result of the settlement in actual on the site. So, by using Plaxis 3D actually can estimate the real settlement on the site.

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