COMPARISON BETWEEN THE RESULTS OF THE PILE BEARING CAPACITY ANALYSIS BASED ON EMPIRICAL METHOD AND FINITE ELEMENT METHOD USING THE RESULTS OF DYNAMIC ANALYSIS ON THE FIELD

Michael Antonie Prayogo[a], Herman Wahyudi [a*], Indrasurya B. Mochtar [a*]

***Abstract**: There are many methods for calculating the bearing capacity of a pile foundation. The problem is finding the most representative method for analysis dynamic load testing (PDA) results in the field. This study only covers the areas of West Surabaya and North Surabaya. The method used to analyze the bearing capacity of the pile foundation in this study is the empirical method, namely the Schmertmann, Meyerhof, and L. Decourt method and the finite element method (FEM.). This research only for calculating the bearing capacity of precast pile foundations. The initial stage of the research was to collect soil survey data in the form of N-SPT boring logs and PDA test results in the area. Then the calculation analysis is carried out using the empirical method and FEM, which will be compared with the PDA results. FEM analysis uses dynamic load with pile-driving modelling, which is similar to PDA testing. After comparison, the researchers find some ratios for each calculation method and results of PDAs in the field of study. This study indicates that the most representative method for PDA results in West Surabaya is the Meyerhof method. For the North Surabaya area, these methods have not shown expected results of PDA results in the field*

Keywords: *Pile dynamic analysis, dynamic load test, pile bearing capacity, West Surabaya, North Surabaya*

INTRODUCTION

There are many ways to calculate the bearing capacity of the pile foundation. Each method has its characteristics and suitability depending on the constraints and parameters used. However, most of the methods used to result from application or research in other countries whose soil patterns may not be the same as those in Indonesia [1]. In general, to get the actual pile bearing capacity in the field, a full-scale load test is carried out (Static Load Test, SLT) or using dynamic load testing (Dynamic Load Test, DLT). Most geotechnical experts use the empirical method and the Finite Element Method (FEM) to estimating the bearing capacity of the pile. Each of these methods will produce different results, and the results, compared with the test results with Pile Dynamic Analysis (PDA), are not always consistent.

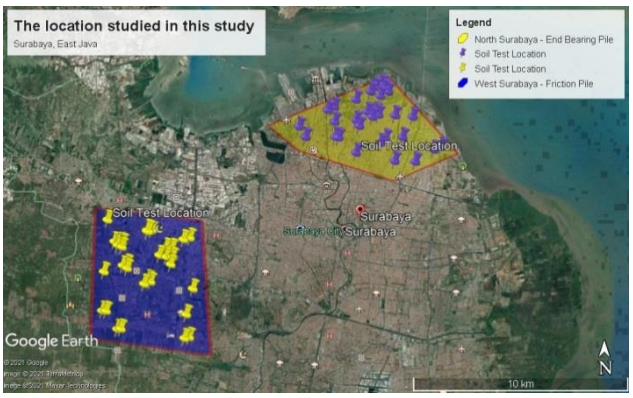

Figure 1 Location for Collecting Data

RESEARCH SIGNIFICANCE

This paper analyses which method is the most representative of the PDA test results by comparing the empirical method calculation results with the PDA test results on the field. The comparison results will produce ratios as a representative indicator of the method to the PDA results. If the balance is between the Analytical method and the PDA result is 0.75 to 1.25, conclusively, the analytical method is representative of PDA. So far, there has been no research aimed at finding out which method of the estimated bearing capacity of piles is more suitable for the city of Surabaya based on variations in soil conditions in it, which can be compared with the PDA results. For more details, the locations reviewed in this study can be seen in Figure 1.

METHODOLOGY

In the early stages of the research, Researchers collected all required data collection in the form of soil investigation data, laboratory test results to determine mechanical-physical properties, and data from PDA and SLT testing in West Surabaya and North Surabaya areas. The calculation of the bearing capacity of precast pile foundations using empirical methods consisting of L. Decourt, Schmertmann, and Meyerhof [2].It was also using FEM to calculate the bearing capacity using soil parameters from soil investigations in the field and the laboratory test results in West Surabaya and North Surabaya.

A. DATA COLLECTION OF SOIL INVESTIGATION

Soil investigation data were taken from each field study and its surroundings as many as 30 points. From all the data collected from the soil survey, a statistical analysis was carried out, and the results were shown in Table 1.

B. DATA COLLECTION OF SLT AND PDA TEST RESULTS

A comparison is made with the SLT test results to find out that these methods are reliable. The analysis of the bearing capacity calculation for a spun pile foundation with a cross-section size of 45 cm at a depth of 31 m in the West

[a]Lecturer in the Civil Engineering Department, Institut Teknologi Sepuluh Nopember, ITS Campus, Sukolilo, Surabaya 60111, Indonesia. Corresponding author email address: piscesa@ce.its.ac.id

Surabaya area. The total number of PDA test results collected for the West Surabaya and North Surabaya areas is around 40 points for each location with varying pile sizes and depths attached in Table 3 and Table 4.

Table 1 Results of Statistical Analysis in West Surabaya and North Surabaya

Depth (m)	West Surabaya		North Surabaya	
	N-SPT (bpf)	Soil Type	N-SPT (bpf)	Soil Type
1.25	1	Clay	1	Clay
3.25	1	Clay	1	Clay
5.25	3	Clay	1	Clay
7.25	4	Clay	1	Clay
9.25	1	Clay	1	Clay
11.25	4	Clay	1	Clay
13.25	6	Clay	1	Clay
15.25	8	Clay	2	Clay
17.25	8	Clay	5	Clay
19.25	10	Clay	6	Clay
21.25	9	Clay	9	Clay
23.25	12	Clay	13	Sand
25.25	10	Clay	20	Sand
27.25	12	Clay	23	Sand
29.25	14	Clay	36	Sand
31.25	13	Clay	29	Sand
33.25	12	Clay	27	Sand
35.25	14	Clay	26	Sand

ANALYSIS AND DISCUSSIONS

As explained in the previous chapter regarding the comparison of the empirical method and the finite element method with the SLT test results, an analysis of the bearing capacity calculation was carried out for a spun pile foundation with a cross-sectional size of 45 cm at a depth of 31 m in the West Surabaya area. SLT testing has been carried out on these pile conditions and produces a bearing capacity of 392 tonnes using the Davisson method by reading the Load vs Settlement curve. The researcher then analyzed calculations using the method of L. Decourt, Schmertmann, and Meyerhof. [2] and the Finite Element Method.

A. COMPARISON RESULT of Empirical Methods and FEM with SLT Test Results IN WEST SURABAYA

Comparison result of these methods with the SLT test is in Table 2. From these results, the researcher concluded the most suitable is Meyerhof. The other method is still reliable for the SLT results with an average ratio of 1.25, which can be continued to the following analysis stage.

Table 2 The results of Comparison of the Empirical Methods and FEM against SLT in West Surabaya

Analytical Method Method	Q-ult ratio against PDA
Schmertmann (1967)	1.37
Meyerhof (1976)	1.02
L. Decourt (1996)	1.57
FEM	1.05

B. COMPARISON RESULTS OF EMPIRICAL METHODS WITH PDA TEST RESULTS IN WEST SURABAYA

After analyzing using the empirical method and FEM using Dynamic load, the researcher compared the results with the PDA in Table 2. From the results of the average ratio from 41 piles in West Surabaya between Qp and Qs, it can be concluded that the most representative empirical method with the dominant clay soil conditions in West Surabaya is the Meyerhof method with a Qp ratio of 0.91 and Qs 0.71. Table 4 shows the Qp ratio for the two methods, namely L. Decourt and Schmertmann, which is 0.23 and 0.39. It is because both methods use a coefficient for a different soil. The Meyerhof method use the same coefficient for all soil types for end–bearing analysis. From this discussion, it can also be estimated that for the soil conditions in West Surabaya, Qp and Qs in the PDA results have been fully mobilized. It can be seen that the results of the PDA are more excellent than the results of the empirical calculation methods, both Qp and Qs.

Because all empirical methods are analyzed based on ultimate capacity, the PDA test results are not estimated to have reached the ultimate bearing capacity because it only produces the mobilized carrying capacity of the given hammer energy. Meanwhile, according to Santoso's [3] research, which also examines the condition of the pile foundation in areas with clay-dominant soil, it gives a ratio of 0.98 for the L. Decourt, Meyerhof, and Schmertmann methods which are in the very high category. In this study, the L. Decourt method provides a ratio of 0.51, the Schmertmann method of 0.53, and the Meyerhof method of 0.81 for the West Surabaya area, predominantly clay. This conclusion can occur due to variations in the cross-sectional size, length of the pile, and the number of pile foundations being analyzed.

C. COMPARISON RESULTS OF EMPIRICAL METHODS WITH PDA TEST RESULTS IN NORTH SURABAYA

After analyzing using the empirical method and FEM using Dynamic load, the results of the analysis are compared with the PDA test results in Table 6.

From these results, the researcher concluded that there was no sufficiently representative method for PDA results in North Surabaya. However, the method with the closest Qp ratio number to 1 is the Meyerhof method. Whereas for the method with the Qs ratio number most relative to 1 is the method is L. Decourt.

When compared with Zakahfi's research [4] which states that the L. Decourt method has a high correlation with PDA results with a ratio of 1.34, while in this study, the balance for the L. Decourt method in West Surabaya is 0.51 and in the north part of Surabaya is 1.45. The number of piles studied in Zakahfi's study is only based on one case study area. In this study, the number of piles analyzed was more varied across cross-sectional sizes and lengths of piles and different soil conditions. In this comparative analysis, it can be seen that most of the empirical methods used produce the ratio of the linear approach Qs which is

Table 3 PDA Test Results in West Surabaya

No	Pile Type	Cross-section (cm)	Depth (m)	Qp (ton)	Qs (ton)	RMX (ton)	No	Pile Type	Cross section (cm)	Depth (m)	Qp (ton)	Qs (ton)	RMX (ton)
1	Square pile	25	10	44	76	120	22	Spun pile	50	28	84	269	353
2	Square pile	25	13	46	62	108	23	Spun pile	50	28	145	239	384
3	Square pile	25	13	49	77	126	24	Spun pile	50	28	61	251	313
4	Square pile	25	15	49	77	126	25	Spun pile	50	28	65	310	376
5	Square pile	25	17	27	83	111	26	Spun pile	50	28	71	277	347
6	Square pile	25	18	23	90	113	27	Spun pile	50	28	105	165	270
7	Square pile	25	18	24	74	97	28	Spun pile	50	23	121	226	347
8	Square pile	25	18	25	70	94	29	Spun pile	50	28	105	253	358
9	Square pile	25	20	34	36	70	30	Spun pile	50	28	47	139	186
10	Square pile	25	21	18	52	70	31	Spun pile	50	28	47	320	367
11	Square pile	25	21	18	52	70	32	Spun pile	50	28	112	202	314
12	Square pile	35	25	69	177	245	33	Spun pile	50	29	81	315	396
13	Square pile	35	28	18	135	154	34	Spun pile	50	28	58	205	263
14	Square pile	35	28	22	132	154	35	Spun pile	50	29	92	287	378
15	Square pile	35	28	20	132	153	36	Spun pile	50	29	13	322	335
16	Square pile	35	29	98	261	359	37	Spun pile	50	25	93	263	355
17	Square pile	35	30	73	182	255	38	Spun pile	50	21	78	253	331
18	Spun pile	45	29	22	255	276	39	Spun pile	50	24	96	219	314
19	Square pile	50	28	109	248	357	40	Spun pile	50	22	36	265	301
20	Spun pile	50	28	67	293	360	41	Spun pile	50	28	46	169	215
21	Spun pile	50	28	94	244	338							

Note: RMX is the maximum total static resistance of hammer blow energy at PDA testing.

Table 4 PDA Test Results in North Surabaya

No	Pile Type	Cross-section (cm)	Depth (m)	Qp (ton)	Qs (ton)	RMX (ton)	No	Pile Type	Cross section (cm)	Depth (m)	Qp (ton)	Qs (ton)	RMX (ton)
1	Square pile	25	23	29	70	99	24	Spun Pile	35	27	56	153	209
2	Square pile	25	23	38	72	110	25	Square pile	35	28	38	126	163
3	Square pile	25	23	16	72	88	26	Spun Pile	35	29	50	136	185
4	Square pile	25	26	34	105	139	27	Spun pile	35	29	49	83	132
5	Square pile	25	26	83	123	206	28	Square pile	35	29	78	95	173
6	Square pile	25	26	88	118	206	29	Square pile	35	29	28	39	67
7	Square pile	25	26	98	122	220	30	Spun pile	35	33	58	134	192
8	Square pile	25	26	40	68	108	31	Spun Pile	50	25	39	204	243
9	Square pile	25	26	26	67	93	32	Spun Pile	50	25	58	243	301
10	Square pile	25	30	65	111	176	33	Spun Pile	50	25	76	127	203
11	Square pile	25	32	42	149	191	34	Spun Pile	50	26	115	170	285
12	Square pile	25	33	36	190	225	35	Spun Pile	50	28	197	259	456
13	Square pile	25	33.5	63	142	205	36	Spun Pile	50	28	187	242	429
14	Square pile	25	33.5	44	161	204	37	Square pile	50	30	98	343	441
15	Square pile	25	33.5	60	165	224	38	Square pile	50	30	89	269	358
16	Square pile	25	33.5	68	136	204	39	Square pile	50	30	110	285	395
17	Square pile	25	33.5	92	115	207	40	Square pile	50	30	73	330	403
18	Square pile	25	33.5	88	132	220	41	Square pile	50	30	93	305	398
19	Spun Pile	30	24	9	89	98	42	Spun Pile	60	30	48	137	185
20	Spun Pile	30	24	14	81	96	43	Spun Pile	60	30	41	144	184
21	Square pile	30	30	16	55	71	44	Spun Pile	60	30	33	180	212
22	Square pile	30	30	14	94	107	45	Spun Pile	60	25	78	165	243
23	Square pile	30	30	18	86	105							

Note: RMX is the maximum total static resistance of hammer blow energy at PDA testing.

Table 5 The results of Comparison of the Empirical Method against PDA in West Surabaya

Empirical Method	Average Qp ratio against PDA	Average Qs ratio against PDA
Schmertmann (1967)	0.23	0.82
Meyerhof (1976)	0.91	0.71
L. Decourt (1996)	0.39	0.66

Table 6 The results of Comparison of the Empirical Method against PDA in North Surabaya

Empirical Method	Average Qp ratio against PDA	Average Qs ratio against PDA
Schmertmann (1967)	1.67	0.45
Meyerhof (1976)	1.33	0.42
L. Decourt (1996)	2.10	0.79

smaller on average than the PDA results. It happens because when testing the PDA Qs on the pile foundation, it is first mobilized from the hammer load given, and the amount of energy and force exerted on the pile can make Qp at the end of the pile be mobilized or not. It also affects

the length of the pile foundation, where the longer the pile foundation, the greater the mobile Qs compared to the Qp.

It occurs at the end-bearing pile, where it can be seen in the tests in North Surabaya and its surroundings because the Qp of the analysis results is greater than the Qp of the PDA. For the friction pile in West Surabaya, the Qp analysis result is smaller than the PDA result. The analysis method gives too small a coefficient for clays, especially clays with stiff consistency such as those in West Surabaya. The mobilized from the energy supplied from the hammer during the PDA test. In testing PDAs with soil conditions in North Surabaya, it requires enormous hammer energy to produce enough power to mobilize Qp and Qs so that their value on PDA testing are the same as the results of empirical method calculations.

D. COMPARISON RESULT FEM USING DYNAMIC LOAD WITH PDA TEST RESULTS IN WEST SURABAYA AND NORTH SURABAYA

From the comparison of RMX between FEM and PDA, it can be seen that West Surabaya produces a better correlation number than in North Surabaya. However, RMX is only the Maximum Static Resistance that the pile foundation receives from the minimum energy applied. So the result would not produce Qp and Qs without analysis using CAPWAP. From the comparison of RMX between FEM and PDA in West Surabaya, its ratio is 1.1 and it can be concluded that the FEM analysis with dynamic loads on the dominant clay soil and friction type pile is close to the PDA results. This conclusion can be used as a back-analysis of the results of the PDAs that have been obtained. Meanwhile, in the soil conditions in North Surabaya, the FEM method is quite representative. However, further analysis is needed because the PDA results in North Surabaya are not expected to be fully mobilized.

The ratio of the FEM analysis with Dynamic Load cannot be compared with the balance from the Empirical method. It is because the ratio obtained from the two methods has two different results. RMX received from FEM cannot produce Qp and Qs without CAPWAP on the pile foundation, which is different from the results of the empirical method, which can produce Qp and Qs as a whole.

CONCLUSIONS

From the data and analysis in the previous chapter, it can be concluded that the comparison between the empirical method and the FEM on the PDA results shows that not all methods are reliable with the PDA results.

The most representative empirical method for analyzing the bearing capacity of friction pile foundations with medium to stiff clay prevailing soil conditions such as in the West part of Surabaya and its surroundings to PDA results is the Meyerhof method with the average ratio Qp and Qs is 0.91 and 0.71. The ratio of the Meyerhof method is the closest ratio to 1 compared to the L. Decourt and Schmertmann method with its Qp ratio of 0.39 and 0.23.

There is no empirical method that is most representative for analyzing the bearing capacity in the area, such as in the North part of Surabaya and its surroundings on the PDA results. This can be seen from the Qp ratio of L. Decourt, Schmertmann, and Meyerhof are 2.10, 1.66, and 1.33. It happens because, for soil conditions such as in North Surabaya, the value of Qp from PDA does not necessarily = Qp-ultimate analyzed using empirical methods. It is thought to occur because the energy from the hammer at the time of testing was not large enough to ultimately mobilize the end-bearing pile foundation in soil conditions such as North Surabaya.

The FEM method with Dynamic Load on pile foundations with PDA results gives the most representative results with a ratio of 1.1 in West Surabaya soil conditions and a ratio of 1.3 in soil conditions in North Surabaya on the comparison of RMX results.

REFERENCES

[1] Afriyanto, A., and Sipil, J. T. Macam Metode Pada Proyek Apartemen the Frontage Surabaya. 2017

[2] A. Sridharan and Y. Gurtug, "Compressibility characteristics of soils," *Geotechnical and Geological Engineering*, vol. 23, no. 5, pp. 615–634, 2005, doi: 10.1007/s10706-004-9112-2.

[3] H. T. Santoso and J. Hartono, "Analisis Perbandingan Daya Dukung Pondasi Tiang Pancang Berdasar Hasil Uji Spt Dan Pengujian Dinamis," *Jurnal Riset Rekayasa Sipil*, vol. 4, no. 1, p. 30, 2020, doi: 10.20961/jrrs.v4i1.44635.

[4] A. T. Zakahfi and R. Kusumawardani, "Perbandingan Analisa Daya Dukung Tiang Pancang Menggunakan Metode Perhitungan L. Decourt Dan Tes Pda," *Teknika*, vol. 13, no. 1, p. 1, 2018, doi: 10.26623/teknika.v13i1.724.