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Comparison of Field Ultimate Capacity (Static and Dynamic Load Test) with the Analytic Design of Bored Pile in Granular Soil, Batam, Indonesia

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Abstract. A bored pile provides a large capacity obtained to toe and friction pile to support some loads such as axial, lateral, and tensile due to hydrostatic pressure or overturning moment. Static and dynamic load tests are often carried out to validate pile design before pile production in a project. This study aims to compare the ultimate capacity of the pile based on the result of static load test, dynamic load test, and pile design in granular soil of Batam, Indonesia, in which Chin-Kondner, Mazurkiewicz, Davisson, and Hansen 80% methods are utilized to obtain ultimate capacity (Q_u) of static load test and dynamic test analysis apply Case Pile Wave Analysis Program (CAPWAP) method to gain ultimate capacity. The result analysis of the static load test of ultimate capacity using Chin-Kondner, Mazurkiewicz, Davisson, and Hansen 80% methods obtained results of 1379, 1300, 1375, and 1182 tons, respectively, with a Q_u average of 1309 tons. A bearing capacity (RMX) of 1204 tons was obtained through a dynamic load test. Using the CAPWAP method based on the dynamic test, the ultimate bearing capacity (R_u) of 1248 tons was obtained. Analysis of pile design shows that the ultimate capacity of the bored pile in the granular soil of Batam, Indonesia, was 1157 tons. The Q_u examination between field loading testing (1278.5 tons) and design pile foundation (1158 tons) was 9.4%.

Keywords: damping factor, static load test, PDA test, drilled pile.

INTRODUCTION

A pile foundation to support a building requires a large capacity, or a hard soil layer lies very deep. A bored pile is a deep pile foundation, which is the most common type in the granular soil of Batam, Indonesia which is installed to a deep soil layer by drilling it, then inserting the assembled rebar and pouring the concrete [1]. A bored pile provides a large capacity obtained to toe and friction pile to support some loads such as axial, lateral, and tensile due to hydrostatic pressure or overturning moment. Static and dynamic load tests are often carried out to validate pile design before pile production in a project [2, 3].

In static load tests, methods for interpreting ultimate bearing capacities are Chin-Kondner (1985), Mazurkiewicz (1972), Davisson (1972), and Hansen (1963) [3, 4, 5, 6]. In the Pile Dynamic Analyzer (PDA) test on pile foundations, the CAPWAP and Case method are general analysis methods developed at Case Western Reserve University [7]. In the case method analysis, the bearing capacity of the pile based on the one-dimensional wave equation is very dependent on the damping factor (J_c) when calculating.

Several studies have analyzed the results of static load tests using Chin-Kondner, Brinch Hansen, Decourt, and DeBeer, Mazurkiewicz and Buttler-Hoy methods to obtain final ultimate capacity (Q_u) of static load test [8, 9, 10, 11].

The bearing capacity values from the interpretation of the Chin-Kondner, Mazurkiewicz and Davisson methods compare values close to each other to the smallest order of Davisson, Mazurkiewicz, and Chin-Kondner. The method results used are ASTM D-1143, American and British Standard Code of Practice BS 800 in determining Q_u value. Studying a bearing capacity analysis based on the PDA (Case & CAPWAP) and static load (Davisson) tests suggested that ultimate capacities have values that are close to each other in order of smallest to largest, namely Case, CAPWAP, and Davisson methods 1620, 1660 and 1670 kN respectively [12]. Subsequently, this study aims to compare the ultimate capacity of the pile based on the result of static load test, dynamic load test, and pile design in granular soil of Batam, Indonesia, in which Chin-Kondner, Mazurkiewicz, Davisson, and Hansen 80% methods is utilized to obtain ultimate capacity (Q_u) of static load test and dynamic test analysis apply Case Pile Wave Analysis Program (CAPWAP) method to gain ultimate capacity.

RESEARCH METHODOLOGY

Bored Pile Properties

The object of research is the bored pile foundation located in Teluk Tering, Batam, Indonesia. Figure 1 shows that piles used on static load tests, dynamic load tests, and soil data are close to each other. Both testing piles have similar data properties such as 100 cm diameters, 15 m length effective of the pile, and 33.2 MPa concrete. The pile for the static load test is applied 1000-ton loads, divided into four cycles, and 11-ton hammers with a 1.5 m drop-off distance from the pile head are carried out on the selected dynamic test (PDA).

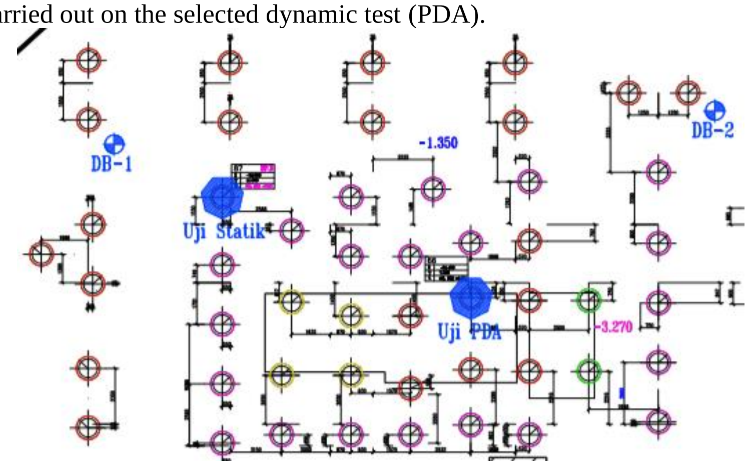


FIGURE 1. Static load test, dynamic load test, and soil data layout

Soil Condition

Soil condition on DB-1 has drilled soil data for 24 meters from the surface layer, where at an elevation of 0-18 meters is dominated by the granular soil layer and at a depth of 18-24 is the rock layer. The elevation of the pile foundation is at a depth of 18 meters, located on a layer of cemented sand soil with a very stiff consistency. Along the bored pile is embedded in granular soil. Completed soil data is presented in Table 1.

TABLE 1. Soil condition of DB-1

Depth	Soil	Consistency	N-SPT	RQD	TCR
1 - 2	Sandy silt		3		
2 - 3	Silt	Soft to medium	4		
3 - 5	Silt	Soft to medium	2		
5 - 6	Sandy silt	Soft to medium	4		
6 - 8	Clayey silt	Medium to very stiff	18		
8 - 9	Sandy silt	Very stiff to hard	20		
9 - 11	Sandy silt	Very stiff to hard	25		
11 - 12	Silty sand	Dense to very dense	43		
12 - 15	Silty sand	Dense to very dense	60		
15 - 16	Cemented Sand	Very dense	60		
16 - 18	Cemented Sand	Very dense	60		
18 - 20	Granite			14%	90%
20 - 21	Granite			21%	90%
21 - 22	Granite			31%	95%
22 - 23	Granite			23%	96%
23 - 24	Granite			72%	100%

Analysis of Pile Design

The ultimate bearing capacity of a static pile foundation is calculated using soil mechanics theories [1]. Ultimate bearing capacity (Q_u) is the amount of the pile capacity (Q_b) and frictional pile capacity (Q_s) minus its weight of pile (W_p), which is expressed in the equation:

$$Q_u = Q_b + Q_s - W_p \tag{1}$$

$$Q_u = A_b f_b + A_s f_s - W_p \tag{2}$$

$$Q_u = A_b 0{,}60\sigma_r N_{60} + A_s \beta p_o' - W_p \tag{3}$$

$$Q_u = A_b 0{,}60\sigma_r N_{60} + A_s K tg\delta p_o' - W_p \tag{4}$$

$$W_p = \frac{1}{4}\pi d^2 L \gamma_{concrete} \tag{5}$$

with,

Q_u : ultimate bearing capacity (ton)
Q_b : toe bearing capacity (ton)
Q_s : friction capacity (ton)
W_p : weight of pile (ton)

RESULT AND DISCUSSION

Static Load Test

Based on the static load test, examination of pile head settlement caused loading-unloading cycles thus forming a non-linear graph in line with load. The non-linear graph of the static load test is caused by the alternating increase and decrease in load over a specific time. At the same time, the pile settlement value (δ) also increases and decreases. The settlement (δ) in cycle 1 was 1.61 mm, in cycle two there was a decrease in the pile head of 4.03 mm; in cycle 3, when the applied load was 750 tons there was a decrease of 6.81 mm, and the ultimate settlement (δ_u) measured in cycle 4 was 11.12 mm. It is shown in Figure 2 below.

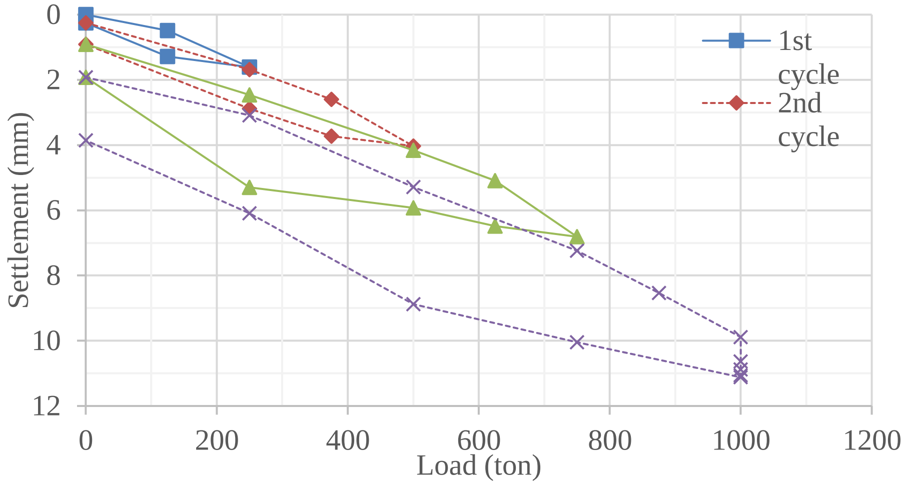
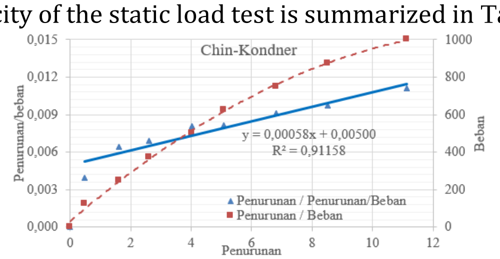
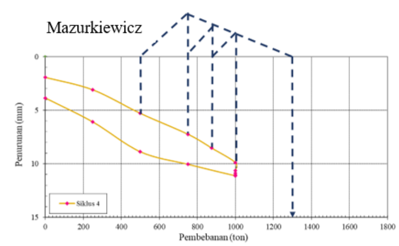


FIGURE 2 Settlement pile against cyclic loads

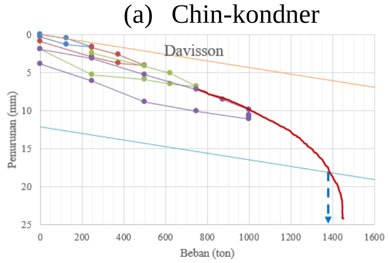
To obtain ultimate capacity based on static load test, Chin-Kondner, Mazurkiewicz, Davisson, and Hansen 80% methods are utilized. Each interpretation method suggested graphs that could be analyzed due to Q_u. These graphs are completely presented in Figure 3. Chin-Kondner method results y = 0,00058x + 0,00500 and R^2 = 0,91158 and Hansen 80% method obtain y = -0,000113x + 0,004397 and R^2 = 0,797250. Subsequently, the ultimate capacity of the static load test is summarized in Table 2.



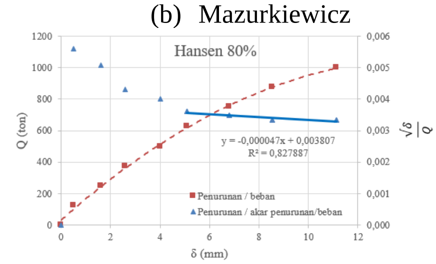
(a) Chin-kondner



(b) Mazurkiewicz



(c) Davisson



(D) Hansen 80%

FIGURE 3. Determination of Q_u based on all methods.

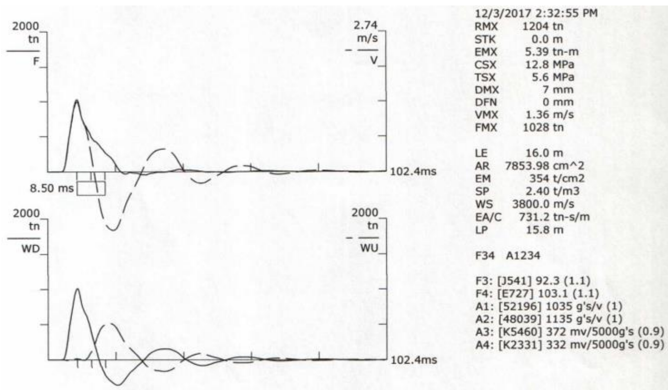
TABLE 2. Ultimate Capacity (Q_u) of static load test

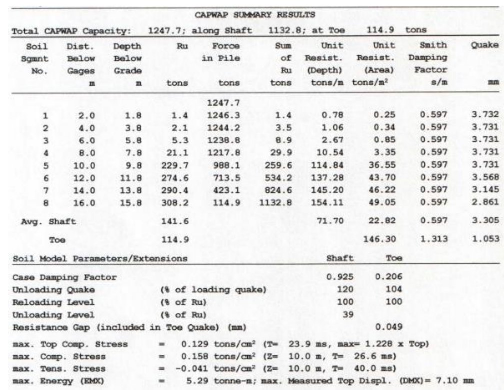
Method	**Ultimate Capacity (Q_u)**
Chin-Kondner	1379 ton
Mazurkiewicz	1300 ton
Davisson	1375 ton
Hansen 80%	1182 ton
Average	1309 ton

According to the result analysis of static load test of ultimate pile capacity using Chin-Kondner, Mazurkiewicz, Davisson, and Hansen 80% methods obtained results of 1379, 1300, 1375, and 1182 tons respectively, with Q_u average of 1309 tons. It implies that the safety factor of the pile is about 2.6 against the axial design load of 500 tons.

Dynamic Load Test

Energy and Stress-Induced on the Pile such as maximum energy transferred to the pile (EMX), recorded final displacement (DFN), compression stress maximum (CSX), and tension stress maximum (TSX) presented in Fig. 4. It is summarized in Table 3 and Table 4.





CAPWAP SUMMARY RESULTS

Total CAPWAP Capacity: 1247.7; along Shaft 1132.8; at Toe 114.9 tons

Soil Sgmnt No.	Dist. Below Gages (m)	Depth Below Grade (m)	Ru (tons)	Force in Pile (tons)	Sum of Ru (tons)	Unit Resist. (Depth) (tons/m)	Unit Resist. (Area) (tons/m²)	Smith Damping Factor (s/m)	Quake (mm)
				1247.7					
1	2.0	1.8	1.4	1246.3	1.4	0.78	0.25	0.597	3.732
2	4.0	3.8	2.1	1244.2	3.5	1.06	0.34	0.597	3.731
3	6.0	5.8	5.3	1238.8	8.9	2.67	0.85	0.597	3.731
4	8.0	7.8	21.1	1217.8	29.9	10.54	3.35	0.597	3.731
5	10.0	9.8	229.7	988.1	259.6	114.84	36.55	0.597	3.731
6	12.0	11.8	274.6	713.5	534.2	137.28	43.70	0.597	3.568
7	14.0	13.8	290.4	423.1	824.6	145.20	46.22	0.597	3.145
8	16.0	15.8	308.2	114.9	1132.8	154.11	49.05	0.597	2.861
Avg. Shaft			141.6			71.70	22.82	0.597	3.305
Toe			114.9				146.30	1.313	1.053

Soil Model Parameters/Extensions		Shaft	Toe
Case Damping Factor		0.925	0.206
Unloading Quake	(% of loading quake)	120	104
Reloading Level	(% of Ru)	100	100
Unloading Level	(% of Ru)	39	
Resistance Gap (included in Toe Quake) (mm)			0.049

max. Top Comp. Stress = 0.129 tons/cm² (T= 23.9 ms, max= 1.228 x Top)
max. Comp. Stress = 0.158 tons/cm² (Z= 10.0 m, T= 26.6 ms)
max. Tens. Stress = -0.041 tons/cm² (Z= 10.0 m, T= 40.0 ms)
max. Energy (EMX) = 5.29 tonne-m; max. Measured Top Displ. (DMX)= 7.10 mm

FIGURE 4. Force-velocity wave on the pile and CAPWAP analysis

TABLE 3. Energy and stress induced on the pile

Hammer				DFN (mm)	Stress	
Weight (ton)	Drop height (m)	EMX (t-m)	Hammer efficiency (%)		CSX (MPa)	TSX (MPa)
11	1.5	5.39	33	0	12.8	5.6

TABLE 4. Bearing capacity and displacement

PDA	CAPWAP				
Bearing capacity, RMX (ton)	Bearing capacity			Displacement	
	Toe (ton)	Friction (ton)	Total (ton)	Total (mm)	Residual (mm)
1204	115	1133	1248	9.8	0.1

The result of PDA and CAPWAP's pile capacity (Dia. 100 cm) was about 1248 tons. It implies the pile has a safety factor of about 2.5 against the axial design load of 500 tons.

Analysis of Pile Design

The analysis of ultimate pile capacity is the amount of the toe pile capacity (Q_b) and the frictional pile capacity (Q_s). It is summarized in Table 5.

TABLE 5. Analysis of pile design

Friction						Toe					
Depth (m)		N	f_s (kPa)	A_s (m^2)	Q_s (ton)	Depth (m)		N	F_b (kPa)	A_s (m^2)	Q_s (ton)
0	0.45	4	15.4	14.14	21.78	9	15	60	3600	0.79	282.86
4.5	9	22	84.7	14.14	119.79						
9	15	60	388.8	18.86	733.17						
					874.74						

Analysis of pile design gave an ultimate pile capacity of about 1157.59 tons, in which the frictional pile capacity is 874.74 tons, and the toe pile capacity is 282.86 tons. According to the analysis of pile design, it has a safety factor against axial design load of about 2.3.

Comparison of Result

The average result test of the Static loading test and PDA test was 1278.5 tons in Table 5. The field loading testing (1278.5 tons) and the design pile foundation (1158 tons) had similar results, with a difference of about 9.4% in Table 6.

TABLE 6. Analysis of pile design

Field testing	Bearing capacity (ton)
Static	1309
Dynamic	1248
Average	1278.5

TABLE 7. Comparison between field pile testing analysis of pile design

Comparison	Bearing capacity (ton)
Field testing	1278.5
Analysis of pile design	1158
Error (%)	9.4%

CONCLUSION

- The result of the static load test of ultimate pile capacity using Chin-Kondner, Mazurkiewicz, Davisson, and Hansen 80% methods obtained results of 1379, 1300, 1375, and 1182 tons, respectively with a Qu average of 1309 tons.
- The result of PDA and CAPWAP have a pile capacity of 1248 tons.
- The analysis of pile design gave an ultimate pile capacity of about 1157.59 tons, in which the frictional pile capacity is 874.74 tons and the toe pile capacity is 282.86 tons.
- The average result test of the static loading test and PDA test was 1278.5 tons.
- The field loading testing (1278.5 tons) was compared with the design pile foundation (1158 tons) was 9.4%.

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