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ANALYSIS AND COMPARISON OF PILE BEARING CAPACITY BASED ON N-SPT, DYNAMIC METHOD, AND PILE DRIVING ANALYZER (PDA) IN MATARAMAN – SEI ULIN BRIDGE CONSTRUCTION PROJECT (MALI-MALI BRIDGE)

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ABSTRACT

Pile bearing capacity can be calculated using N-SPT and piling data. The dynamic formula which is often used for calculating the amount of pile capacity according to the general specifications of Bina Marga is the Hiley formula. The purpose of this study was to determine the bearing capacity of the pile based on the N-SPT data, the dynamic method in the form of the Hiley formula, and other formulations, along with their comparison to the results of the PDA test. The chosen research location was the Mataraman – Sei Ulin Bridge Construction Project (Mali-Mali Bridge). The calculation results for Hiley's formula show the average reduction factor was 74.71%, and SF = 1 to the PDA test results. From the analysis of calculations using N-SPT data using the Terzaghi, Peck, and Bazaraa methods, the magnitude of the frictional and end bearing capacity has the same tendency when compared to the PDA test. Namely, the end bearing resistance is greater than the frictional resistance. The corrected SF range for the end bearing resistance in the Terzaghi, Peck, and Bazaraa method is 2.33 – 3.82 and the Meyerhoff method is 2.21 – 3.51. The corrected SF range for frictional resistance in the Terzaghi, Peck, and Bazaraa method is 2,17 – 2.3 and the Meyerhoff method is 1.22 – 2.03. Of the 10 types of pile dynamic formulations, the method which is closest to the PDA test is the ENR, Sanders, and Rankine methods with reduction factors of 25.14%, 36.88%, and 42.65% and corrected SF, respectively. are 5.71, 5.7, and 4.15.

Keywords: Pile Driving Formula, N-SPT, PDA Test

1. INTRODUCTION

The foundation serves to transmit the load caused by the structure at the top to the soil layer at the bottom of the structure without causing soil shear collapse and excessive settlement of the foundation soil. Pile foundations are used when the foundation soil at normal depths is unable to support the load, while hard soil is located at a very deep depth. The dynamic formula that is often used for calculating the magnitude of the pile bearing capacity following the general specifications of Bina Marga is the Hiley formula. PDA Test, which stands for Pile Dynamic Analyzer Test, is a test to measure the carrying capacity of piles that are dynamically loaded on pile foundations. In addition, with the soil investigation in the form of N-SPT testing, the authors also want to compare the results obtained with the PDA test. Previous research regarding the Study of the Bearing Capacity of Concrete Pile Foundations on the Results of the PDA Test conducted by Luveanoor Akbar and Muliyadi stated that for the dynamic formulation of the piling results, the smallest reduction factor was obtained in the Sanders formula with a reduction of 2.8%, so the authors are interested in knowing the formulation What dynamic approach approaches the results of the PDA test on the Mataraman – Sei Ulin Bridge Construction project (Mali-Mali Bridge).

2. THEORITICAL STUDY

All construction engineered to rest on the ground must be supported by a foundation. The foundation is part of an engineering system that transmits the load received by the foundation and its weight into the soil and rock that lies below it. The resulting soil stresses, except at the soil surface, are in addition to the existing loads in the soil mass from the material's weight and geological history (Bowles, 1997). Pile bearing capacity is the ability or capacity of the pile to support the load (Hardiyatmo, 2011). The bearing capacity of the foundation is stated in the following equation.

$$\text{Qall} = \frac{Qu}{SF}$$

3. METHOD

The chosen research location was the Mataraman – Sei Ulin Bridge Construction Project (Mali-Mali Bridge). The selected research object in this research is Pile in the Bridge area. The selection of these objects is based on the availability of the data required for research.

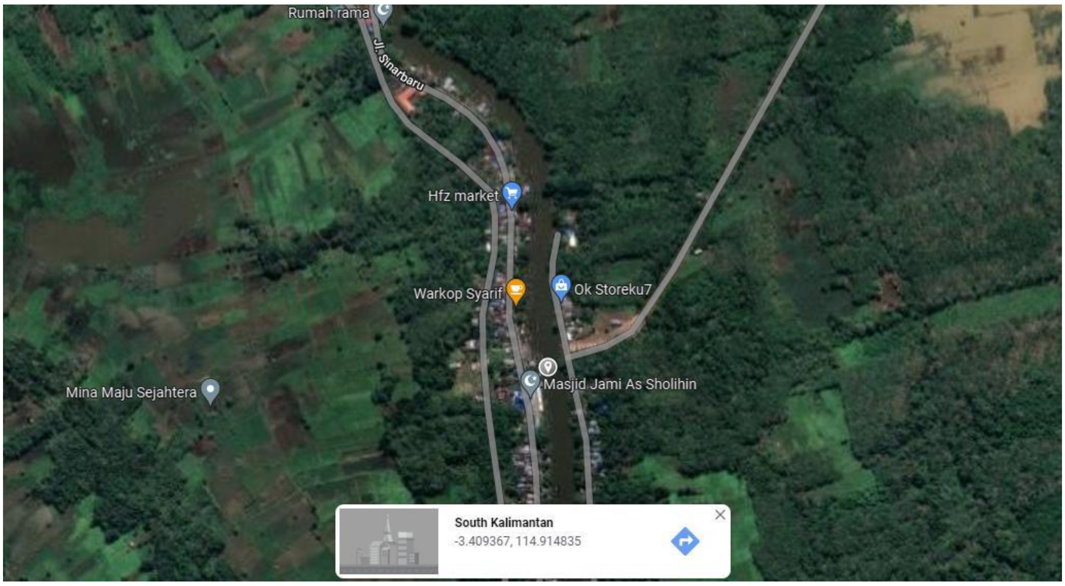

Figure 1. Research location on the Mataraman – Sei Ulin Bridge Construction Project (Mali-Mali Bridge)

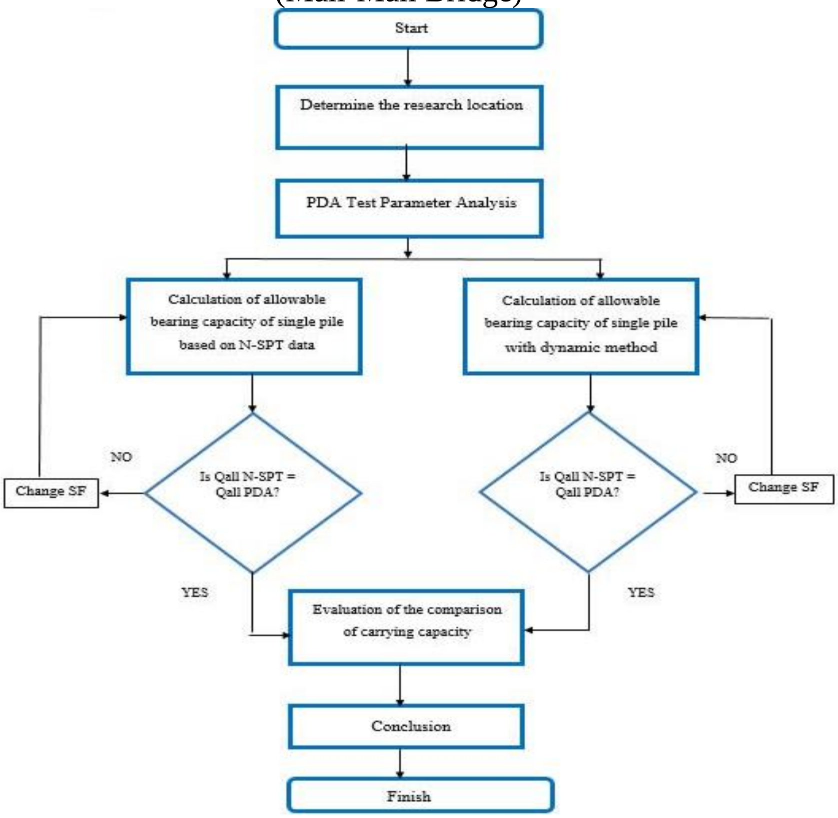

Figure 2. Research flowchart

4. RESULTS AND DISCUSSION

Calculation of Pile Bearing Capacity Using SPT Data

The data taken for the calculation example is on the BH-1 to a depth of 18 m.

a. Terzaghi, Peck, and Bazaraa Method

Pu = 40.N.Ap + $\sum_{i=1}^{n} \frac{Ni}{2\ or\ 5}.Asi$

N = 50 $\geq$ 15 then the value of N needs to be corrected.

$N_{Correction1}$ = 15 + 0.5(N-15) = 15 + 0.5(50-15) = 32.5

$N_{Correction1}$ = 0.6N = 0.6*50 = 30

The smallest N correction is used, so

$N_{correction1}$ = 30

Next, the value of N has corrected again for the overburden pressure.

Po = 7,6 ton/m2

$N_{correction2}$ = $\frac{4N1}{3,25+0,1Po}$ if Po > 7,5 ton/m2

= $\frac{4x30}{3,25+0,1x7,6}$ = 29,93

N4D = $\frac{29,93+29,53}{2}$ = 29,73

N8D = $\frac{32,61+31,09}{2}$ = 31,85

$N_{average\ tip}$ = $\frac{N4D+N8D}{2} = \frac{29,73+31,85}{2}$ = 30,80

A_{tip} = ¼. π. $0,5^2$ = 0,1962 m^2

A_{si} = Perimeter of the pile. Hi

= π . 0,5. 1 = 1,57 m^2

P_{ult} = 40.N.A_{tip} + $\sum_{i=1}^{n} \frac{Ni}{2\ atau\ 5}.Asi$

= 40.30,80. 0,1962 + $\{\left(\frac{5\ .\ 1,57}{5}\right) + \left(\frac{10.\ 1,57}{5}\right) + \cdots + \left(\frac{27,91.\ 1,57}{5}\right)\}$

= 375, 13 ton

P_{all} = 375, 13/3 = 125,043 ton

b. Meyerhoff method

A_p = ¼. π . $0,5^2$ = 0,1962 m^2

A_{si} = Perimeter of pile . Hi

= π . 0,5 . 1 = 1,57 m^2

N_{10D} = $\frac{37,07+36,14+34,29+32,61+31,09}{5}$ = 34,24

N_{4D} = $\frac{29,93+29,59+29,97}{2}$ = 29,60

N = $\frac{N_{4D}+N_{10D}}{2} = \frac{34,24+29,60}{2}$ = 31,92

$N_{average} = \frac{(0+5+10+12+\cdots+29,93)}{19} = 22,35$

X_m = 2 (large volume pile)

Qp $= Ap\,.\,40N.\frac{Lb}{B} \leq 400N.Ap$ $=0,1962\,.\,40.\,31,92\,\frac{18}{0,5} \leq$ $400.\,31,92.\,0,1962$

= 9019,88 KN ≥ 2505,52 KN So use Qp = 2505,52 KN

Qs = x_m . N. Asi = 2 . 31,92 . 1,57

= 1263,05 KN

Qtotal = Qp + Qs

= 2505,52 + 1263,05

= 3768,58 KN = 376,86 ton

Qall = 376,86/3 = 125,62 ton

Calculation of Pile Bearing Capacity Dynamic Method

An example of the calculation is taken from pile data no. 1

Hammer type: DD 3,5 tons

Hammer efficiency(e) = 0,85

Pile diameter = 500 mm

Hammer weight = 3,5 ton = 35 KN

Hammer drop height = 2,4 m

=2400 mm

Coefficient of restitution (n) = 0,5

Hammer weight (Wp) = 5220 kg

= 52,2 KN

C (Diesel Hammer) = 25,4 mm

Final set (S) = 1,1 cm = 11 mm

Rated Hammer Energy (H_E) =35 x 2,4 =84 KN.m

Pile length (L) = 18 m

Elastic modulus (E) = 33892,182

a. Modified ENR Formula

$$Q_u = \frac{e_f WH}{S+C} \times \frac{W+n^2 W_p}{W+W_p}$$

$$= \frac{0,85.35.2400}{11+25,4} \times \frac{35+0,5^2.52,2}{35+52,2}$$

= 1080,9 KN = 108,9 ton

Q_{all} = 108,9/3 = 36,029 ton

b. Modified Hiley Formula

C1 = 0,0254 m

$C2 = \frac{P_U L}{AE}$

To find out the value of C2, a trial and error was carried out on the value of Qu with a difference below 5% of the final Qu, trying Qu = 1446 KN.

Surface area of pile (A) = 2 x π x 0,25 x (0,25+ 18) = 28,6525 m2

$C2 = \frac{1446.16.\ 18}{28{,}6525.\ 33892{,}182} = 0{,}0268$

C3 = 0

So that:

$$Q_u = \frac{e_f WH}{S+(C_1+C_2+C_3)/2} \times \frac{W+n^2W_p}{W+W_p}$$

$$Q_u = \frac{0{,}85.35.2400}{0{,}011+\frac{0{,}0254+0{,}0268+0}{2}} \times \frac{35+0{,}5^2 52{,}2}{35+52{,}2}$$

= 1446,39 KN = 144,639 ton

Q_{all} = 144,639/3 = 35,35 ton

c. Michigan State Highway Commission Formula

$$Q_u = \frac{1{,}25 e_f H_E}{S+C} \times \frac{W+n^2W_p}{W+W_p}$$

$$Q_u = \frac{1{,}25.0{,}85.84}{0{,}011+0{,}0254} \times \frac{35+0{,}5^2 52{,}2}{35+52{,}2}$$

= 1393,1 KN = 139,1 ton

Q_{all} = 139,1/6 = 23,219 ton

d. Danish Formula

$$Q_u = \frac{e_f H_E}{S+\sqrt{\frac{e_f H_E L}{2A_p E_p}}}$$

$$Q_u = \frac{0{,}85.84}{0{,}011+\sqrt{\frac{0{,}85.\ 84.\ 18}{2\ .\ 0.196\ .\ 33892{,}182}}} = 65{,}33 \text{ ton}$$

Q_{all} = 65,33/3 = 21,77 ton

e. Janbu's Formula

$$Qu = \frac{e_f H_E}{K'u.S}$$

$C_d = 0{,}75 + 0{,}14\ (\frac{3{,}5}{5{,}22})$ = 0,844

$\lambda' = \frac{0{,}85.8{,}4.18}{0{,}196.\ 33892{,}192.\ 0{,}011^2}$ = 159,69

$K'_u = 0{,}844(1 + \sqrt{1 + \frac{159{,}69}{0{,}844}}$ = 12,48

$Qu = \frac{0{,}85.\ 8{,}4}{12{,}48.\ 0{,}011}$ = 51,998 ton

Q_{all} = 51,998/3 = 17,33 ton

f. Gate's Formula

$Q_u = a\sqrt{e_f H_E}\ (b - \log S)$

If Qu is in KN, use mm for S, a = 104.5, b = 2.4, and H_e in kN.m.

$Q_u = 104{,}5\sqrt{0{,}85.\ 84}\ (2{,}4 - \log 11)$

= 1199,7 KN = 119,7 ton

Q_{all} = 119,7/3 = 39,898 ton

g. Pacific Coast Uniform Building Code formula

$$Q_u = \frac{e_f H_E(\frac{W+n.W_p}{W+W_p})}{S+\frac{Q_U L}{AE}}$$

A trial is done with the value of Qu with a difference below 5% of the final Qu, Qu = 1372.74 KN

$$Q_u = \frac{e_f H_E(\frac{W+n.W_p}{W+W_p})}{0{,}011+\frac{1372{,}74.\ 18}{28{,}6525.\ 33892{,}182}}$$

= 1372.74 KN = 137,27 ton

Q_{all} = 137,27/4 = 34,32 ton

h. Sanders Formula

$Q_u = \frac{WH}{S}$

$Q_u = \frac{3{,}5.\ 240}{1{,}1}$ = 763,64 ton

Q_{all} = 763,64/8 = 95,455 ton

i. Engineering News-Record Formula

C = $\frac{0{,}1\ Wp}{W} = \frac{0{,}1.\ 5{,}22}{3{,}5} = 0{,}15$

$Q_u = \frac{WH}{S+C} = \frac{3{,}5.240}{1{,}1+0{,}15}$ =672,46 ton

Q_{all} = 672,46/6 = 112,08 ton

j. Rankine Formula

A = 0,25*3,14*0,5^2

= 0,19625 m^2

$$Q_u = \frac{2AE}{L}[\sqrt{1+\frac{WHL}{S^2AE}}-1]$$

$$= \frac{2.0{,}19625.33892{,}182}{18}$$

$$[\sqrt{1+\frac{3{,}5.2{,}4.18}{0{,}011^2 0{,}19625.33892{,}182}}-1]$$

= 523,20 ton

Q_{all} = 523,20/6 = 87,20 ton

PDA Discussion

PDA data analysis was carried out using the Case Method procedure, which included measuring velocity (velocity) and force (force) data during the test (re-strike) and calculating dynamic variables in real-time to get an idea of the bearing capacity of a single pile foundation. The further analysis carried out together with the PDA test is the CAPWAP analysis which uses the data obtained from the PDA test to provide more detailed analysis results.

Table 1. Conclusion of Bearing Capacity of PDA test from CAPWAP Analysis Results

No	Description	Total Bearing Capacity (ton)	Frictional Bearing Capacity (ton)	End Bearing Capacity (ton)
1	ABT 1 NO.3	193	90	103
2	PILAR 2 NO.10	298	139	159
3	PILAR 2 NO.12	298	135	163
4	SLAB 1 NO.2	240	96	144

Next is to compare the end bearing and frictional capacity of the SPT calculation against the results of the PDA test.

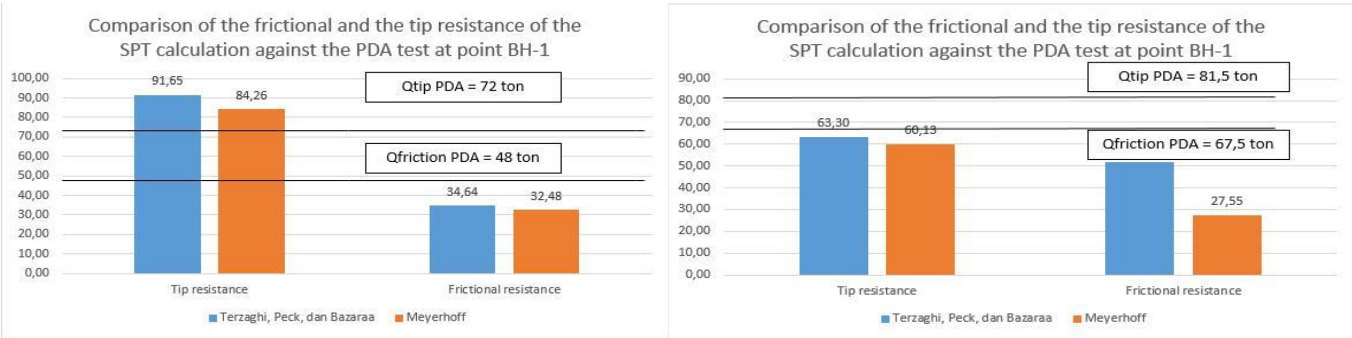

Figure 3. Comparison of the frictional and tip bearing capacity of the SPT calculation against the PDA test at Borehole 1 point and Borehole 2 point

From the two graphs above, it can be seen that the magnitude of the frictional and end bearing capacity has the same tendency as the PDA test, namely, the end bearing resistance is greater than the frictional resistance. The allowable bearing capacity for end resistance and friction is used to calculate the safety factor for each method.

Table 2. Safety factor (SF) for the calculation of the bearing capacity of the SPT to PDA

Point	Method	Ultimate tip resistance	Ultimate frictional resistance	SF of tip	SF of friction	Average
Borhole 1	Terzaghi	274,96	103,93	3,82	2,17	2,99
	Mayerhoff	252,78	97,43	3,51	2,03	2,77
Borhole 2	Terzaghi	189,90	154,97	2,33	2,30	2,31
	Mayerhoff	180,39	82,64	2,21	1,22	1,72

Comparison of the Bearing Capacity of Dynamic Methods Against PDA

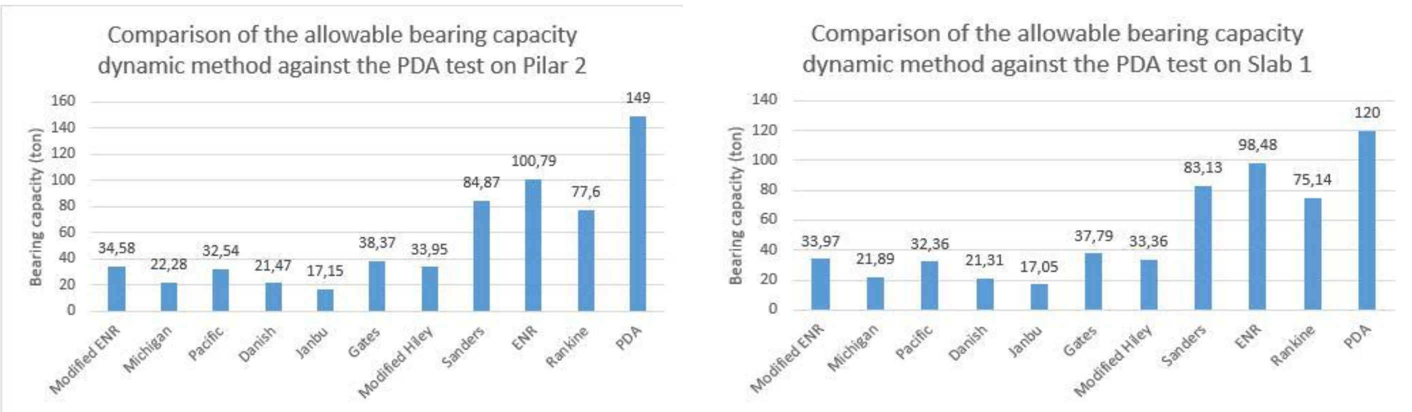

Figure 4. Comparison graph of the bearing capacity of various dynamic calculation methods on PDA results in Pilar 2 and Slab 1

Table 3. The magnitude of the safety factor (SF) for each dynamic method of PDA

No	Method	Qultimit Pilar 2	SF against PDA Pilar 2 no 10	Qultimit Slab 1	SF against PDA Slab 1 no 2	SF average
1	Modified ENR	103,73	0,70	101,9	0,85	0,88
2	Michigan	133,7	0,90	131,34	1,09	1,14
3	Pacific	131,75	0,88	129,42	1,08	1,12
4	Danish	64,4	0,43	63,93	0,53	0,55
5	Janbu	51,46	0,35	51,16	0,43	0,44
6	Gates	115,1	0,77	113,36	0,94	0,98
7	Modified Hiley	101,85	0,68	100,07	0,83	0,87
8	Sanders	604,76	4,06	590,90	4,92	5,70
9	ENR	678,92	4,56	665,00	5,54	5,71
10	Rankine	465,58	3,12	450,85	3,76	4,15

5. CONCLUSIONS

1. From the Hiley method, the average reduction factor was 74.71% from the results of the PDA test and SF to PDA 0.87 so it was rounded up to 1.
2. From the calculation analysis using N-SPT data using the Terzaghi, Peck, and Bazaraa methods, the frictional and end bearing capacities have the same tendency when compared to the PDA test, namely, the tip resistance is greater than the frictional resistance.
3. Of the 10 kinds of dynamic pile formulations, the method that is closest to the PDA test is obtained, namely the ENR, Sanders, and Rankine methods with reduction factors of 25.14%, 36.88%, and 42.65%, respectively.
4. The corrected SF range for end resistance in Terzaghi, Peck, and Bazaraa method is 2.33 – 3.82, and the Meyerhoff method is 2.21 – 3.51. While the SF range for frictional resistance in the Terzaghi, Peck, and Bazaraa methods is 2.17 – 2.3 and the Meyerhoff method is 1.22 – 2.03.
5. Corrected SF dynamic formulation for the three dynamic methods that are closest to the PDA test, namely for the ENR, Sanders, and Rankine methods are from 8, 6, 6 to 5,71, 5.7, and 4.15, respectively.

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