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COMPARATIVE ANALYSIS PILE BEARING CAPACITY OF PILE FOUNDATIONS BASED ON SPT TEST RESULTS AND DYNAMIC TESTING DATA (Case Study: Construction of Halang Island Pier)

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Abstract
The foundation is the lower structural part of a building that must be able to support the load of the structure above it. In foundation planning, the bearing capacity of the foundation can be calculated using soil investigation data and field load test data. This study aims to analyze and compare the bearing capacity of pile foundations using the empirical Meyerhof (1976) method based on N-SPT (Standard Penetration Test) data and the Hiley (1930) dynamic method based on driving record data from the Halang Island pier construction project in Rohil, Riau. The data used includes SPT test results from 3 drilling points (BH-01, BH-02, and BH-03) as well as driving record data from 40 pile driving points. The research subject consists of precast concrete piles with a diameter of 300 mm and an analysis depth of 42 m. The allowable bearing capacity (Qall) is calculated using a safety factor of 3. The analysis results show that the Meyerhof method yields a Qall value of 28.06 tons, while the Hiley method yields Qall values ranging from 15.30 to 29.93 tons. A comparison of the two methods reveals a ratio of 0.95 to 1.83 times, with a percentage difference ranging from -5.12% to 83.41%. The higher values in the Meyerhof method are influenced by the empirical correlation of N-SPT values representing soil conditions from investigations, whereas the Hiley method yields more conservative values because it accounts for the pile's actual response during driving through energy transfer, penetration, and rebound. The research results indicate that the Meyerhof method is suitable for initial estimation of pile capacity, whereas the Hiley method is more representative in evaluating actual bearing capacity in the field.

Keywords: *Standard Penetration Test* (SPT), kalendring test, Hiley, Meyerhof.

INTRODUCTION
Research Background

Infrastructure development in Indonesia continues to grow as part of efforts to support economic development, regional connectivity, and equitable development, particularly in the transportation sector, ports, industrial zones, and coastal areas, which require safe, economical, and efficient foundation systems in soft soil conditions (Nisa et al., 2000). Coastal areas generally have soft, water-saturated, and layered soil characteristics, leading to issues such as low soil bearing capacity and a high potential for settlement; consequently, pile foundations are widely used to transfer structural loads to stronger and more stable soil layers (Das & Sobhan, 2014)(Poulos, 2023). Foundation work is one of the primary tasks in pier construction, particularly where hard soil is encountered at depths exceeding 10 meters (Santoso & Hartono, 2020). Previous studies have been conducted by (Tanjung, 2025), who developed an empirical relationship between N-SPT values and pile foundation bearing capacity, stating that N-SPT values can serve as an indicator of soil strength when properly corrected; thus, this method remains widely used as a practical approach in foundation design. (Sagita & Fahriani, 2020) used the Hiley formula to analyze pile bearing capacity based on the soil's dynamic response to driving energy and demonstrated that energy loss due to the elastic properties of the pile and soil must be considered, particularly in saturated coastal soils sensitive to dynamic loading. (Suparjo et al., 2024) concluded that pile bearing capacity estimates based on SPT data yield results close to those of PDA and CAPWAP dynamic tests, while (Gumilar P et al., 2022) study showed that using cone penetration and N-SPT data results in pile quantities and depths that are adequate while still meeting structural safety requirements. Additionally, (Aprianti et al., 2023) conducted an analysis of pile bearing capacity based on dynamic testing data using the WIKA and Hiley methods, demonstrating that dynamic approaches can be used to estimate pile capacity based on driving energy in the field. Based on previous research, it can be concluded that the integration of SPT data and driving data is a rational, practical, and relevant approach for estimating pile bearing capacity; however, research specifically addressing the comparison of these two parameters in Indonesia remains limited. Therefore, further study is needed to support the development of more applicable empirical methods, which will be examined in this paper.

Given these conditions, this study will compare bearing capacity values using a quantitative comparative approach and dynamic testing, and draw conclusions from the results of the comparison. Calculations are performed using N-SPT data from 3 test points via the Meyerhof method and driving record data from 40 pile driving points using the Hiley method. The use of these two methods is intended to provide a more representative estimate of pile capacity and to assess the consistency between empirical predictions and actual field behavior. Since studies specifically comparing N-SPT values and hammer blow records in coastal soil conditions remain relatively limited—as previous research has generally focused on only one approach—there has been little direct examination of the differences between the results of these two methods in coastal soil conditions. This is particularly true for Halang Island, Riau, a coastal area of the Malacca Strait with alluvial soil conditions that tend to be moist, have a high water table, and exhibit varying soil layer changes with depth (Effendi et al., 2020).These conditions can lead to significant differences between theoretical bearing capacity and actual field behavior, particularly in pile driving projects. On the other hand, the use of PDA or statistical tests in specific projects is often hindered by relatively high costs, equipment availability, and field implementation constraints (Setio, 2000) (Santoso & Hartono, 2020).

LITERATURE REVIEW

Characteristics of Coastal Soils

In coastal soils, the soil is generally very soft clay, silt, saturated sand, and bedrock at certain depths, while pile driving behavior is influenced by several factors such as soil properties, shear strength, compressibility, groundwater level, stress, and erosion/scouring, and disturbances during pile driving also play an important role (Yin et al., 2023). (Fu et al., 2023) conducted a study on the coastal soils of Zhuhai, showing that coastal soil characteristics significantly influence foundation behavior; sudden changes in sea level can increase soil pore air pressure and cause significant foundation settlement. Thus, coastal soil characteristics significantly influence piling results and estimates of pile bearing capacity. Consequently, the soil's response to piling energy becomes more complex. These conditions can result in substantial energy dissipation, increased rebound, and variations in pile penetration at specific depths. As a result, estimates of bearing capacity based on empirical and dynamic methods may show significant differences.

Bearing Capacity of Pile Foundations

Foundation bearing capacity is the foundation's ability to withstand the maximum allowable pressure or load based on the soil conditions where the foundation is placed (Santoso & Hartono, 2020). The bearing capacity mechanism of pile foundations essentially consists of end bearing and skin friction. End bearing occurs when the pile tip reaches a hard soil layer, so that the structural load is transmitted predominantly through the pile tip, while skin friction is the resistance resulting from the interaction between the pile surface and the soil along the depth of the embedded pile. The general formula used to calculate the axial bearing capacity of deep foundations is (Das & Sobhan, 2014)(Fellenius, 2004):

$$\boldsymbol{Q_u = Q_p + Q_s}$$
$$\boldsymbol{= (f_p + A_p) + (f_s + A_s)}$$

Where Qu = ultimate bearing capacity of the foundation (tons), Qp = bearing capacity at the pile tip (tons), fp = resistance at the pile tip (tons/m²), Ap = cross-sectional area of the pile base (m²), Qs = friction resistance of the pile shaft (tons), fs = resistance along the pile shaft (tons/m²), As = pile shaft area (m²),

Calculation of pile foundation bearing capacity using an empirical approach based on SPT (Standard Penetration Test) (Indonesia & Nasional, 2008) values using the Meyerhof method (1976), (J et al., 2016).

- Meyerhof Method (1976)

$$\boldsymbol{Q_u = (f_p + A_p) + (f_s + A_s)}$$
$$\boldsymbol{= [0,4 \text{ x } N_p \text{ x } (L/d) \text{ x } A_p] + [0,5N \text{ x } A_s]}$$

Where Np = the corrected N-SPT value at the base elevation of the pile (2d below and 10d above the pile tip), L = pile length (m), d = pile diameter (m), fs = 0.2 N for sandy soil and 0.5 N for clay soil, and N = the average N-SPT value. Or using the equation:

$$Q_u = 40.\ Nr.\ Ap + \frac{Ak\ .Li\ .Nk}{5}$$

With the simplified formula:

Q_p = 40. Nr. Ap
Q_s = (As. Nk)/5

A_s = Ak . Li

hus, we obtain:

$$Q_u = Q_p + Q_s$$

Where Qu = Ultimate bearing capacity of the pile (tons), Nr = SPT "N" value at the pile tip, Ap = Cross-sectional area of the pile/sheet pile (cm²), As = Surface area of the embedded pile (m²), Nk = Average N value along the embedded pile, Ak = Pile circumference (cm), Li = Length of the pile embedded in the ground

The Meyerhof method has advantages because it is simple, practical, and has been sufficiently proven in many projects; however, it often yields higher capacity values than other methods and tends to overestimate under certain conditions (Agustyawan & Arif, 2020). The Meyerhof method should be used in conjunction with other methods (CPT or field tests), especially in projects with varying soil conditions.

Bearing Capacity Based on Piling Data *(Driving Record)*

Driving records are used to empirically determine bearing capacity based on the results of pile driving calculations during the installation process. Driving record data is collected when the pile reaches a hard soil layer or the final 1 meter of the pile where penetration becomes very minimal and rebound values are observed to be high. Bearing capacity calculations based on driving record data have been widely used in the installation of both concrete and steel piles; the process is relatively straightforward and employs simple equipment.

Calculation of pile foundation bearing capacity using empirical methods based on driving records (driving record) employs the Hiley method (1930), (Wismantaraharjo et al., 2020).

- Hiley method (1930)

- $$Q_u = \frac{2\ .\ ef\ .\ W\ .\ h}{S+C} \cdot \frac{W+(n^2\ .\ Wp)}{W+Wp}$$

Where W = Hammer weight (tons), H = Hammer drop height (cm), Wp = Pile weight (tons), S = Final set or pile penetration per blow (cm), C = Average rebound for the last 10 blows (cm), ef = Hammer efficiency, n = Restitution coefficient

The safety factor calculation is:

$$Q_{all} = Q_u / SF$$

Where Qu = Ultimate bearing capacity (tons), Qall = Allowable bearing capacity (tons), SF = Safety factor

In this equation, the value of n (the coefficient of restitution) is determined based on the type of pile material (precast concrete) and the type of bearing used. The factor in the formula is the impact efficiency coefficient, which describes the transfer of energy from the ram to the pile head. The values for the hammer efficiency and the coefficient of restitution are determined based on Table 1 and Table 2.(Wardani, 2017)

Table 1. Hammer Efficiency Value (e_f)

Types of hammers	Efficiency *(ef)*
Drop hammer	0.75 – 1.00
Single acting hammer	0.75 – 0.85
Double acting hammer	0.85
Diesel hammer	0.85 – 1.00

Table 2. 2Coefficient Values

Material	N
Wooden piles	0.25
Wooden sleepers on steel piles	0.35
Wooden sleepers on steel piles	0.4
Steel pile without wooden bearing / concrete pile with bearing	0.5
Cast iron hammer on concrete pile without cap	0.4

Although the Hiley method better represents actual pile driving conditions using an energy-based approach, it still has limitations compared to PDA (Pile Driving Analyzer) testing and static load testing. This is because PDA testing is capable of recording stress distribution and wave propagation during the pile driving process in greater detail. Meanwhile, static load tests can directly illustrate the actual behavior of the foundation under loading. However, the use of PDA or static load tests is often constrained by cost, execution time, and equipment limitations in the field, so calendering tests are still widely used as a practical alternative in construction projects and are commonly employed.

METHOD

Research stages

The research method began with the identification of the problem and was followed by a literature review related to this study. Subsequently, primary and secondary data were collected, including borehole logs, N-SPT values, and driving records. This data was then analyzed using the Meyerhof method based on N-SPT values and the Hiley method based on driving records to determine the ultimate bearing capacity and allowable bearing capacity of the piles. The calculation results from both methods were then compared to evaluate differences in bearing capacity estimates and determine the most representative value as the basis for foundation evaluation at this study site. The final stage of the research includes the interpretation of results, conclusions, and recommendations based on the analysis obtained. This study employs a quantitative method with a comparative approach to compare pile bearing capacities in the construction of the Halang Island pier, Rohil Regency, Riau, Indonesia. Based on N-SPT data and driving record data, the data used include bore logs, N-SPT values from 3 points (BH-01, BH-02, BH-03), driving record data from 40 pile driving points, and pile driving hammer data, which were then converted into allowable bearing capacity using a safety factor of 3. This study is limited to comparing the Meyerhof and Hiley methods without using PDA or static load tests.

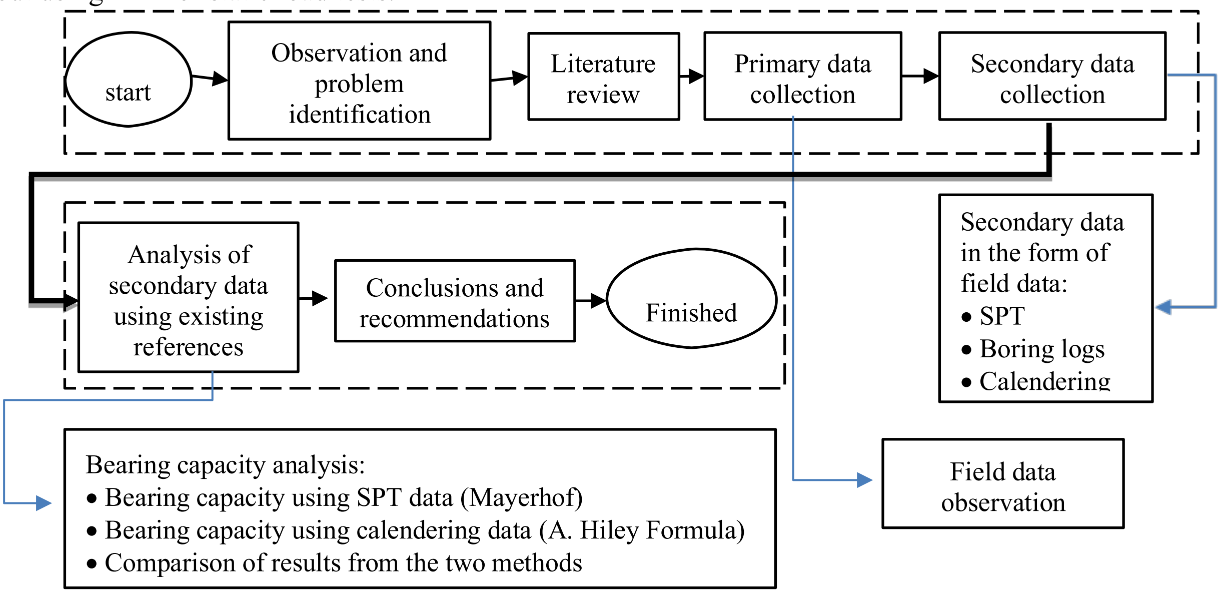

Figure 1. Research Flowchart

The case study in this research focuses on the construction project of the Tin Hai King Temple pier on Halang Island, located in Halang Muka, Rohil, Riau. The project utilizes prestressed concrete pile foundations with a diameter of 300 mm, driven to a planned depth of 50 meters.

RESULTS AND DISCUSSION

Soil Characteristics Based on Standard Penetration Test Results

Based on data from soil investigations at the project site using core drilling and the Standard Penetration Test (SPT), it was found that the soil layers are dominated by clay from a depth of 0 to 47.5 meters, and at depths greater than 47.5 meters, the soil layers undergo a lithological change to fine sandy silt to fine sand to medium-grained sand with a density ranging from dense to very dense. This is shown in Table 3 (Thoriq Maulana et al., 2015).

Table 3. Summary of Interpretation Results of Soil Characteristics at Point BH - 01

Depth (m)	Layer Thickness (m)	Description
0		
2.00		
4.00		
6.00		
8.00	**16.00**	Silt Clay, Dark Grey, Medium Plastic, Medium to High Moisture Content, Soft Stiffness.
10.00		
12.00		
14.00		
16.00		
18.00		
20.00		
22.00	**10.00**	Silt Clay, Dark Grey, Medium Plastic, Medium to High Moisture Content, Medium Stiffness.
24.00		
26.00		
28.00	**4.45**	Silt Clay, Dark Grey, Medium Plastic, Medium to High Moisture Content, Stiff Stiffness.
30.45		
32.45		
34.45		
36.45	**09.55**	Silt Clay, Dark Grey, Medium Plastic, Medium to High Moisture Content, Medium Stiffness.
38.45		
40.00		
42.00	**04.00**	Silt Clay, Dark Grey, Medium Plastic, Medium to High Moisture Content, Stiff Stiffness.
44.00		
46.00	**02.00**	Silt Clay, Dark Grey, Medium Plastic, Medium Moisture Content, Very Stiff Stiffness.
47.50	**01.50**	Silty Fine Sand, Dark Grey, Non-Plastic, Medium Moisture Content, Solid Density.
49.50		
51.50		
53.50	**10.50**	Fine to Medium Size Sand, Light Grey, Not Plastic, Medium Water Content, Solid Density.
55.50		
58.00		
60.45	**02.45**	Fine to Medium Sand, Light Grey, Not Plastic, Medium Water Content, Very Dense Density.
62.45		
64.45	**05.55**	Fine to Medium Size Sand, Light Grey, Not Plastic, Medium Water Content, Solid Density.
66.00		
68.00	**04.45**	Fine to Medium Size Sand, Light Grey, Non-Plastic, Medium Moisture Content, Very Dense Density.
70.45		

Bearing Capacity Based on the Results of the SPT (Standard Penetration Test) Using the Meyerhof Method

SPT (*Standard Penetration Test*) punch value N

The results of the Standard Penetration Test (SPT) at three test locations are shown in Table 4 (Thoriq Maulana et al., 2015).

Table 4. 1-SPT Values

RECORD POINT STANDARD PENETRATION TEST ASTM D.1586-67 (1974)														
SPT No.	Depth (m)	BH - 01			∑ N	BH - 02			∑ N	BH - 03			∑ N
		N 1	N 2	N 3	blows	N 1	N 2	N 3	blows	N 1	N 2	N 3	blows
0	**0**	0	0	0	**0**	0	0	0	**0**	0	0	0	**0**
1	2.00	1	1	1	**2**	1	1	1	**2**	1	1	1	**2**
2	4.00	1	1	1	**2**	1	1	1	**2**	1	1	1	**2**
3	6.00	1	1	2	**3**	1	1	1	**2**	1	3	7	**10**
4	8.00	1	1	1	**2**	1	1	2	**3**	1	2	4	**6**
5	10.00	1	2	2	**4**	1	1	1	**2**	1	2	2	**4**
6	12.00	1	1	2	**3**	1	1	1	**2**	1	1	1	**2**
7	14.00	1	2	2	**4**	1	2	2	**4**	1	1	2	**3**
8	16.00	1	3	4	**7**	1	1	2	**3**	1	1	1	**2**
9	18.00	1	2	2	**4**	1	1	3	**4**	1	1	1	**2**
10	20.00	1	2	4	**6**	2	3	5	**8**	1	1	1	**2**
11	22.00	1	3	3	**6**	2	3	3	**6**	1	2	2	**4**
12	24.00	1	3	5	**8**	3	4	6	**10**	1	3	3	**6**
13	26.00	1	4	6	**10**	2	3	5	**8**	2	3	5	**8**
14	28.00	2	5	5	**10**	2	6	7	**13**	1	2	4	**6**
15	30.45	2	4	7	**11**	1	1	1	**2**	2	5	7	**12**
16	32.45	1	2	4	**6**	2	6	6	**12**	2	4	6	**10**
17	34.45	2	3	5	**8**	3	10	12	**22**	2	4	4	**8**
18	36.45	2	2	2	**4**	2	6	8	**14**	3	6	8	**14**
19	38.45	2	2	4	**6**	1	3	5	**8**	4	11	11	**22**
20	40.00	4	4	6	**10**	6	10	12	**22**	4	12	24	**36**
21	42.00	3	5	8	**13**	4	8	14	**22**	6	18	24	**42**
22	44.00	4	8	12	**20**	6	16	20	**36**	60	40	20	**60**
23	46.00	10	18	18	**36**	18	22	26	**48**	40	44	16	**60**
24	47.50	14	14	18	**32**	30	28	32	**60**	14	50	10	**60**
25	49.50	6	13	17	**30**	46	50	10	**60**				
26	51.50	8	19	27	**46**	40	46	14	**60**				
27	53.50	10	22	28	**50**								
28	55.50	8	16	24	**40**								
29	58.00	10	25	27	**52**								
30	60.45	12	30	30	**60**								
31	62.45	6	20	22	**42**								
32	64.45	9	14	17	**31**								
33	66.00	22	26	32	**58**								
34	68.00	36	40	20	**60**								
35	70.45	30	46	14	**60**								

At the study site, N-SPT values increased from a range of 0–10 in the shallow soil layer to 30–60 at a depth of approximately 48–70 m, indicating a significant increase in soil density and strength. Furthermore, the differences in N-SPT values at the three points indicate lateral variations in soil conditions at the study site. This is common in coastal alluvial soils formed by uneven sedimentation processes.

Bearing capacity of pile foundations using the Meyerhof method

The ultimate bearing capacity of a pile (Qu) is the maximum load that the pile can withstand before failure occurs. The value of Qu is obtained by summing the tip bearing capacity Qp and the shaft bearing capacity Qs, which represent the load transfer mechanisms through the pile tip and along the pile surface, respectively. The calculated Qu for Ø 30 at 42 m is 84.19 tons.

$$Q_u = Q_p + Q_s$$

$$\mathbf{Q_u = 36{,}74 + 47{,}45 = 84{,}19}$$

Based on the calculation results, it is found that the Qu value increases as the pile diameter increases. This is due to the increased contribution of the tip bearing capacity (Qp) and the shaft bearing capacity (Qs), both of which are influenced by the pile dimensions and the soil conditions around the pile. These values can be seen in Table 5

Table 5. Ultimate Bearing Capacity of Piles: An Empirical Approach Using the Meyerhof Method

Depth	Ø 20	Ø 30	Ø 40	Ø 50	Ø 20	Ø 30	Ø 40	Ø 50	Ø 20	Ø 30	Ø 40	Ø 50
	Ton											
	Qu (BH-01)				Qu (BH-02)				Qu (BH-03)			
2.00	2.76	6.03	10.55	16.33	2.76	6.03	10.55	16.33	2.76	6.03	10.55	16.45
12.00	7.45	14.00	22.44	32.76	5.51	10.14	16.03	23.18	8.50	14.63	22.02	30.67
22.00	17.85	32.42	50.77	72.88	16.65	30.62	48.37	69.88	14.38	25.33	38.80	54.78
32.00	28.95	49.08	72.97	100.64	35.27	64.21	100.68	144.70	32.27	57.83	89.66	127.78
42.00	47.96	84.19	128.58	181.13	69.56	125.07	194.39	277.53	102.53	193.36	310.57	454.15
48.00	93.57	170.49	267.52	384.64	152.84	285.78	456.40	664.70	169.57	310.87	489.85	706.51
50.00	98.49	175.99	272.33	387.51	167.68	308.03	486.07	701.79				
52.00	129.96	238.28	375.48	541.57	182.53	330.32	515.78	738.93				
62.00	185.47	317.77	476.45	661.50								
70.00	260.08	446.64	670.88	932.80								

Based on the calculated data, the graphs showing the relationship between depth and the Qu value are shown in Figures 1, 2, and 3 below:

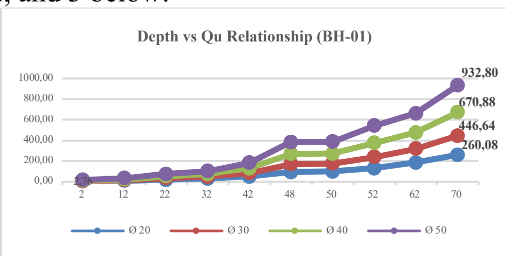

Figure 1. graph of the relationship between depth and Qu at point BH-01

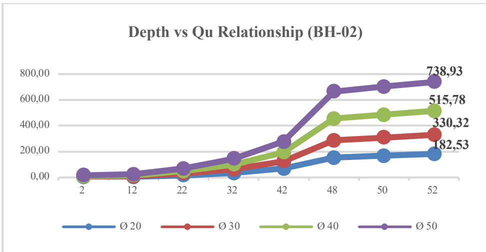

Figure 2. graph of the relationship between depth and Qu at point BH-02

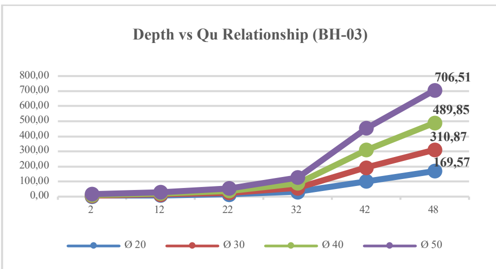

Figure 3. graph of the relationship between depth and Qu at point BH-03

Thus, it can be concluded that the ultimate bearing capacity (Q_u) is greatly influenced by the combination of soil characteristics and pile dimensions, so as to obtain a safe and efficient foundation capacity.

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Bearing Capacity Based on the Dynamic Driving Record Test (Hiley Method)

This method relates the hammer blow energy to pile penetration (set per blow) to estimate the pile's ultimate bearing capacity. The calculation is performed by integrating the hammer blow energy, the total system deformation, and the interaction characteristics between the hammer and the pile during the driving process. The effective energy applied is calculated by multiplying the hammer efficiency, hammer weight, and drop height, which is then compared to the total deformation consisting of permanent penetration and elastic compression. Thus, the ultimate bearing capacity value depends not only on the amount of energy applied but is also significantly influenced by the deformation response of the soil and the driving system as a whole. The steps for calculating the Qu value using the equation are as follows (Liu et al., 2023):

$$Q_u = \frac{2\,.\,ef\,.\,W\,.\,h}{S+C} \cdot \frac{W+(n^{\wedge}2\,.\,Wp)}{W+Wp}$$

The main parameters used include hammer weight, hammer drop height, energy efficiency, pile weight, and the final penetration depth of the pile during driving. Based on field data, the following parameters were obtained: Hammer weight (W) = 3.5 tons, Drop height (H) = 240 cm, Pile weight (Wp) = 11.25 tons, Coefficient of restitution (n) = 0.5 (since a drop hammer was used, as shown in Table 1. Value of the coefficient of restitution (n), Hammer efficiency (ef) = 0.75 (since a drop hammer is used, as shown in Table 2. Hammer efficiency value (ef)). These values serve as the primary inputs in calculating the pile bearing capacity using the Hiley method. Then, the allowable bearing capacity (Qall) is calculated by dividing the ultimate bearing capacity (Qu) by the safety factor of 3. The results can be seen in Table 6.

Table 6. Bearing Capacity Values Based on Driving Record Test Data

No	No Titik	Penetrasi Tiang (S/10) (mm) (S)	Rebound (k/10) (m)	Energi Efektif Hammer	Faktor Distribusi Energi	Deformasi (S + C)	Qu (Ton)	Qall (Ton)
1	T1	9.4340	1.4	6.5625	0.4280	10.8340	51.8467	17.282
2	T2	8.8496	1.4	6.5625	0.4280	10.2496	54.8029	18.268
3	T3	8.8496	1.2	6.5625	0.4280	10.0496	55.8936	18.631
4	T4	7.8125	1.3	6.5625	0.4280	9.1125	61.6412	20.547
5	T5	8.2645	1.3	6.5625	0.4280	9.5645	58.7284	19.576
6	T6	8.0645	1.3	6.5625	0.4280	9.3645	59.9823	19.994
7	T7	8.0000	1.3	6.5625	0.4280	9.3000	60.3984	20.133
8	T8	8.9286	1.2	6.5625	0.4280	10.1286	55.4575	18.486
9	T9	6.9930	1.1	6.5625	0.4280	8.0930	69.4063	23.135
10	T10	10.6383	1.2	6.5625	0.4280	11.8383	47.4482	15.816
11	T11	8.6957	1.2	6.5625	0.4280	9.8957	56.7629	18.921
12	T12	9.8039	1.2	6.5625	0.4280	11.0039	51.0459	17.015
13	T13	9.2593	1.1	6.5625	0.4280	10.3593	54.2226	18.074
14	T14	6.4103	1.1	6.5625	0.4280	7.5103	74.7918	24.931
15	T15	10.6383	1.6	6.5625	0.4280	12.2383	45.8974	15.299
16	T16	8.5470	1.6	6.5625	0.4280	10.1470	55.3568	18.452
17	T17	10.2041	1.6	6.5625	0.4280	11.8041	47.5857	15.862
18	T18	9.6154	1.05	6.5625	0.4280	10.6654	52.6662	17.555
19	T19	6.8493	1.3	6.5625	0.4280	8.1493	68.9267	22.976
20	T20	6.5789	1.4	6.5625	0.4280	7.9789	70.3984	23.466
21	T21	8.3333	1.5	6.5625	0.4280	9.8333	57.1226	19.041
22	T22	8.1301	1.4	6.5625	0.4280	9.5301	58.9403	19.647
23	T23	8.5470	1.05	6.5625	0.4280	9.5970	58.5292	19.51

24	T24	8.2645	1.3	6.5625	0.4280	9.5645	58.7284	19.576
25	T25	7.4627	1.4	6.5625	0.4280	8.8627	63.3787	21.126
26	T26	8.6957	1.5	6.5625	0.4280	10.1957	55.0927	18.364
27	T27	8.6957	1.4	6.5625	0.4280	10.0957	55.6384	18.546
28	T28	9.2593	1.05	6.5625	0.4280	10.3093	54.4855	18.162
29	T29	6.7568	1.3	6.5625	0.4280	8.0568	69.7186	23.24
30	T30	7.1942	1.4	6.5625	0.4280	8.5942	65.3583	21.786
31	T31	8.6957	1.5	6.5625	0.4280	10.1957	55.0927	18.364
32	T32	8.0000	1.4	6.5625	0.4280	9.4000	59.7559	19.919
33	T33	8.6957	1.05	6.5625	0.4280	9.7457	57.6365	19.212
34	T34	7.0922	1.3	6.5625	0.4280	8.3922	66.9319	22.311
35	T35	4.8309	1.5	6.5625	0.4280	6.3309	88.7242	29.575
36	T36	4.8544	1.4	6.5625	0.4280	6.2544	89.8101	29.937
37	T37	9.8039	1.05	6.5625	0.4280	10.8539	51.7514	17.25
38	T38	7.3529	1.3	6.5625	0.4280	8.6529	64.915	21.638
39	T39	4.7847	1.5	6.5625	0.4280	6.2847	89.3768	29.792
40	T40	4.9751	1.4	6.5625	0.4280	6.3751	88.1089	29.37

A total of 40 pile locations were tested. The piles used as test samples were precast concrete piles with a diameter of 300 mm and a length of 10 meters.(Pondasi & Hilir, n.d.).

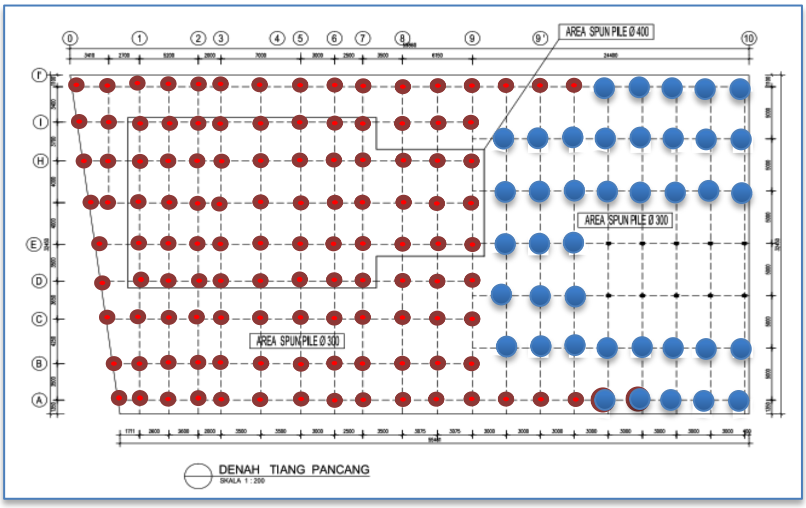

Figure 4. Test Pile Location

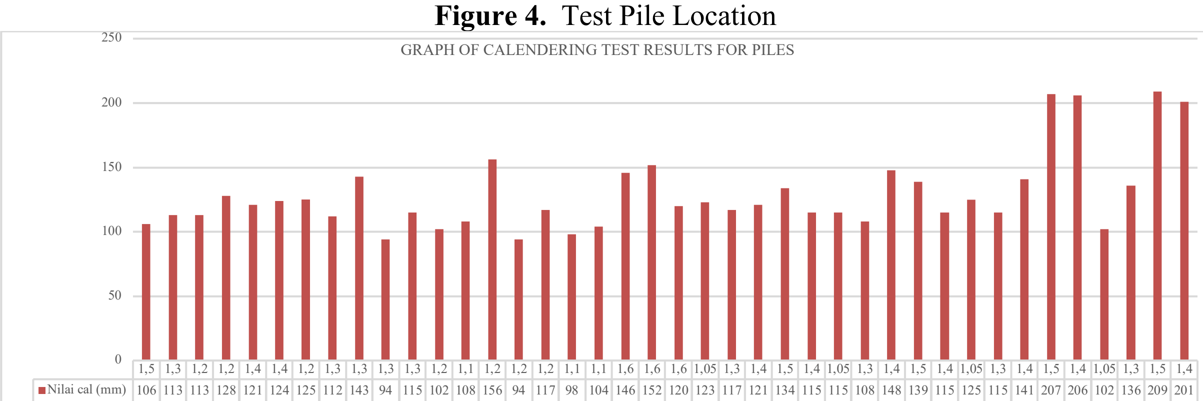

Figure 5. Graph of Pile Calendering Test Results

Evaluation of Data Interpretation

The evaluation of data interpretation can be seen in Table 7. below:

Table 7. Carrying Capacity Value Using the Qall Empirical Approach Based on the Meyerhof Method (1976)

Depth	Static Qall (ton)		
	BH-01	**BH-02**	**BH-03**
2.00	2.01	2.01	2.01
12.00	4.67	3.38	4.88
22.00	10.81	10.21	8.44
32.00	16.36	21.40	19.28
42.00	28.06	41.69	64.45
48.00	56.83	95.26	103.62
50.00	58.66	102.68	

Based on the calculation results, the Meyerhof method uses N-SPT values in a dynamic approach based on the Hiley formula, which is derived from driving records. The results of the bearing capacity comparison are shown in Table 8.

Table 8. Comparison of Bearing Capacity of Piles Using an Empirical Approach

Component	Analysis Method	Data Source	Depth (m)	Diameter	Qu (ton)	Qall (ton)
SPT		BH-01	42	Ø 30	84,19	28,01
SPT	Meyerhof	BH-02	42	Ø 30	125,07	41,69
SPT		BH-03	42	Ø 30	193,36	64,45
SPT (Desain)		min BH	42	Ø 30	84,19	28,01
Driving Record	A.Hiley	Data Titik Pemancangan	42	Ø 30	Min 45,897 Max 89,81	Min 15,299 Max 29,937
Driving Record (Desain)		Titik min (T15)	42	Ø 30	45,90	15,299

Based on the calculation results, the Meyerhof method yielded a design bearing capacity (Qall) of 28.06 tons at a depth of 42 m and a pile diameter of 30 cm, whereas the Hiley method yielded Qall values ranging from 15.30 to 29.93 tons at different driving points. A comparison of the two methods shows a ratio of 0.96–1.83 times, with a difference ranging from -5.12% to 83.41%, as shown in Table 9.

Table 9. Ratio Values

No Dot	Qall Hiley (Ton)	Qall Meyerhof (Ton)	Ratio	difference (%)
T1	17.28	28.06	1.62	62.36
T5	19.58	28.06	1.43	43.34
T10	15.82	28.06	1.77	77.41
T15	15.30	28.06	1.83	83.41
T20	23.47	28.06	1.20	19.58
T25	21.13	28.06	1.33	32.82
T30	21.79	28.06	1.29	28.80
T35	29.57	28.06	0.95	-5.12
T40	29.37	28.06	0.96	-4.46

These differences are due to the different analytical methods used. The Meyerhof method is based on empirical correlations of N-SPT values, so the bearing capacity is strongly influenced by the soil conditions determined by the investigation. At a depth of 42 m, the N-SPT values at BH-01, BH-02, and BH-03 were 32, 48, and 60, respectively, indicating dense to very dense soil conditions. High N-SPT values result in a significant increase in bearing capacity. However, in soil conditions approaching refusal, the Meyerhof method has the potential to produce higher estimates because it does not account for the actual soil response during the driving process. Conversely, the Hiley method is based on the driving energy transferred from the hammer to the pile and the soil. The obtained capacity is influenced by hammer efficiency, energy loss, final penetration (final set), and rebound during the driving process. Therefore, the Hiley method is more sensitive to field conditions and generally yields more conservative values compared to N-SPT-based empirical methods. Differences in bearing capacity values at relatively the same depths indicate that soil conditions at the study site are not homogeneous and vary from one point to another.

Based on the analysis results, the minimum allowable bearing capacity value from the Hiley method of 15.30 tons was selected as the basis for evaluation because it provides a more conservative approach to variations in soil conditions and on-site driving operations. The minimum value was selected to account for uncertainties in geotechnical conditions and to reduce the risk of overestimating foundation capacity. However, this study only compared bearing capacity values based on the Meyerhof and Hiley methods without considering the design loads of the structure; therefore, the results obtained cannot yet be used to assess foundation safety comprehensively. Thus, the two methods can be used complementarily, where the Meyerhof method is used for an initial estimate based on soil parameters, while the Hiley method is used to determine bearing capacity based on actual responses during the piling process. In this study, the minimum value from the Hiley method was selected as the basis for evaluation because it provides a more conservative approach to soil conditions and variations in piling execution in the field.

CONCLUSION

Based on the results of calculations and data analysis and evaluations that have been carried out, the following conclusions were obtained:

1. Based on an analysis using the Meyerhof (1976) method based on N-SPT values, the allowable bearing capacity (Qall) was found to be 28.06 tons at a depth of 42 m for a 30 cm diameter pile. The bearing capacity value increases as the N-SPT value increases, indicating that the soil becomes denser.
2. Based on an analysis using the Hiley method based on driving records, the results were lower, with allowable bearing capacity (Qall) values ranging from 15.30 tons to 29.93 tons. These variations indicate differences in soil response to driving energy at each actual field driving point and demonstrate lateral variations in soil characteristics at a depth of 42 m.
3. A comparison of the two analysis methods shows that the Meyerhof method yields higher bearing capacity than the Hiley method, with a ratio of 0.96–1.62 times. This difference is due to the Meyerhof method being based on empirical correlations of N-SPT values, whereas the Hiley method accounts for actual driving conditions through energy transfer, penetration, and rebound. The minimum allowable bearing capacity value of 15.30 tons from the Hiley method was selected as the basis for evaluation because it provides a more conservative approach to variations in soil conditions and pile driving execution. However, since the planned structural load data were not analyzed in this study, the results obtained cannot yet be used to determine the overall safety level of the foundation.

Suggestion

Based on the results of the research and analysis that has been carried out, the following are some suggestions:

1. The research results are limited to a comparison of pile bearing capacity using a wider variety of calculation methods, such as static load tests, to obtain more accurate results as validation of the empirical and dynamic methods. Further study is needed on the influence of pile efficiency on bearing capacity, particularly in coastal soil conditions.
2. Further study is needed regarding the correlation between bearing capacity results from dynamic tests and calendering results, to ensure structural safety against soil variations in the field and reduce the risk of overestimation.

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