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Analysis of Borepile Foundation Bearing Capacity in Building Construction Projects with Pile Driving Analyzer Test

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Abstract

In the construction process, buildings require careful planning because structural elements must withstand axial loads, such as gravitational forces, and lateral loads, such as wind and earthquake forces, which are transferred to the foundation. One key aspect of foundation design is determining its bearing capacity. This capacity can be calculated theoretically using soil investigation data, while the Pile Driving Analyzer (PDA) verifies these results. This study aims to calculate and analyze foundation bearing capacity and compare it with PDA results. The Schmertmann & Nottingham and Meyerhoff methods were used. Using the Schmertmann & Nottingham method, the carrying capacities based on sondir test results were: S1—804.15 tons, S2—761.99 tons, S3—823.45 tons, and S4—841.68 tons. Using the Meyerhoff method, the values were: S1—572.39 tons, S2—568.93 tons, S3—568.84 tons, and S4—562.4 tons. The highest ultimate bearing capacity (Qu) was from the Schmertmann & Nottingham method at S4, while the lowest was from the Meyerhoff method at S4. The Meyerhoff method at S4 and the BP-109 PDA showed the closest results, differing by 115.5 tons, whereas the Schmertmann & Nottingham method yielded significantly greater values than the PDA.

Keywords: Foundation Bearing Capacity, Schmertmann & Nottingham, Meyerhoff, Sondir Test, PDA

INTRODUCTION

In the construction process, buildings require careful planning because structural elements must resist both axial loads, such as gravitational forces, and lateral loads, such as wind and earthquake forces. These loads are transferred to the lower structure, namely the foundation, making it a crucial element in building stability. One key parameter reviewed in foundation design is the carrying capacity. This capacity can be theoretically calculated through manual methods based on soil investigation data obtained in the field (Geoengineer.org, n.d.; Sari et al., 2023).

To verify bearing capacity calculations, load tests can be performed on piles using dynamic testing methods such as the Pile Driving Analyzer (PDA) test. The PDA test analyzes one-dimensional wave propagation generated when a pile is impacted by a hammer dropped from a certain height (Bachtiar, 2020). The PDA outputs the ultimate bearing capacity of the foundation. The collected data is processed with CAPWAP software, which provides detailed information including the total and maximum pile settlements, end-bearing capacity, and shaft friction capacity.

Previous studies provide context for this work. Prativi et al. (2022) compared empirical methods (Decourt, Reese & O’Neill, Japanese methods) with PDA test results on bridge foundations, finding the Decourt method had the smallest error margin and Reese & O’Neill showed good consistency in cohesive soils. Similarly, Roniar et al. (2023) evaluated empirical formulas (Kulhawy, Reese & Wright, Meyerhof) against PDA and static load tests, concluding that the Kulhawy correlation best predicted pile bearing capacity in local West Java soils.

This study focuses on calculating and analyzing the bearing capacity of borepile foundations in buildings located in Padalarang, West Bandung Regency, using the Schmertmann & Nottingham and Meyerhoff methods. Results are compared with PDA test outcomes (Pratama & Sari, 2022; Setyadi et al., 2023).

The primary objectives are to determine the carrying capacity of borepile foundations at the site and compare manual calculation methods with PDA test results. This work aims to enhance theoretical understanding of borepile design and testing, particularly for high-rise buildings, while clarifying the relevance of PDA testing. Practically, it seeks to ensure foundation safety and provide guidance on appropriate analysis methods, serving both academic and construction industry needs.

METHOD

This research is quantitative which, according to Balaka (2022), is a research method that uses data in the form of numbers that focuses on measuring objective results and statistical analysis.

The data used were:

a. PDA Test Results: In the form of data obtained from PT. Duta Mandiri Group as the company tasked with conducting PDA tests in the field.
b. CPT/Sondir Test Results: Then there is the data on the results of the CPT/Sondir test obtained from PT. Bandung Metro Utama as the company in charge of conducting testing in the form of soil investigations aimed at finding out the condition of the deep soil. The CPT/Sondir test was carried out in Padalarang, West Bandung Regency. From the field work, the condition of the soil in the investigation site consists of clay, Ianauan clay, clay, Iunak to teguh and hard soil in the form of sand/stone clay, sand is found below a depth of 13.50 to 16.50 meters depending on the contour of the soil (Wardani & Riza, 2016).

The research is located on Jalan Parahyangan Raya.3A-3B, Kertajaya, Padalarang District, West Bandung Regency, West Java with coordinates 6°51'14.8"S 107°29'27.1"E.

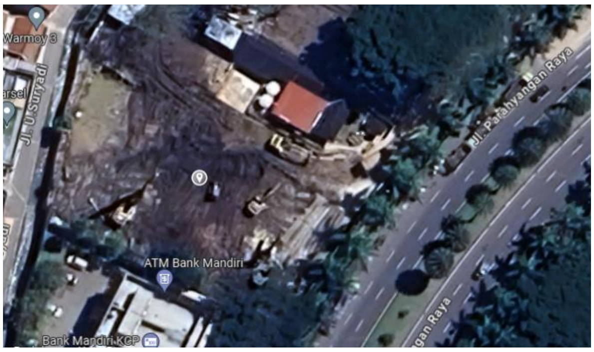

Figure 1. Research Location
Source : Google Maps Satellite Image

RESULT AND DISCUSSION

Schmertmann & Nottingham Method

Technical data bored pile

Panjang bored pile (L)	: 7 m
Diameter bored pile (D)	: 80 cm
Concrete quality	: K-350

Ttitk Sondir S1

Calculating the end bearing (Qb)

qc1 (qc average at 4D below the end of the pile)

4D (4 x Diameter)= 4 x 0,8 = 3,24

The result of 3.2 was calculated/analyzed from 7 m + 3.2 = 10.2 m, so that the qc value used was at an elevation of 7 to 10.2 meters.

$$QC1 = \frac{35+40+45+35+30+35+30+35+20+25 +30+35+40+25+30+35+40}{17} = 33.235 \text{ Kg/cm2}$$

qc2 (qc averaged at 8D on top of the pole)

8D (8 x Diameter) = 8 x 0,8 = 6,4

The result of 6.4 was calculated/analyzed from m, so that the qc value used was at an elevation of 0.6 to 7 meters.7 m − 6,4 = 0,4

$$QC2 = \frac{1+1+1+3+7+5+8+10+25+ 10+5+15+20+15+10+15 +25+25+15+5+15+10+10+20+30+25 +20+30+20+25+30+25+35}{33}$$

= 15.636 Kg/cm2

The result of 6.4 was calculated/analyzed from 7 m- 6.4 = 0.4 m, so that the qc value used was at an elevation of 0.6 to 7 meters.

$$QC2 = \frac{1+1+1+3+7+5+8+10+25+ 10+5+15+20+15+10+15 +25+25+15+5+15+10+10+20+30+25 +20+30+20+25+30+25+35}{33}$$

= 15.636 Kg/cm2

1. Calculating average cone resistance (qca)

   $qca = x\ (q\,\frac{1}{2}{}_{c1} + QC2)$

   $= x\ (33{,}235 + 15{,}636)\frac{1}{2}$

   $= x\ (48{,}872)\frac{1}{2}$

   = 24.436 Kg/cm2
2. Calculating unit end bearing (fb)

   Determine the ω factor by paying attention to the influence of OCR.

   After obtaining the value of the factor ω and the value of qca from the previous calculation, calculate fb with the equation:

   Fb = ω x qca

   = 1 x 24.436

   = 24.436 Kg/cm2

3. Calculating the end bearing (Qb)
   Calculate the area of the bottom end of the pole with the equation:
   Ab (area of the bottom end of the pile)
   = 1/4 x w x D2
   = 1/4 x 3.14 x 802
   = 5024 cm2

   Calculate Qb with the equation:
   Qb = From x fb
   = 5024 x 24.436
   = 122765.6043 kg
   = 122.77 tons

Calculating shaft resistance (Qs)

1. Calculating the area of the pile surface area (As)
   AS (pole blanket prisoners)
   = π x D x L
   = 3.14 x 80 x 700
   = 175840 cm2

2. Calculating unit shaft resistance (fs)
   Specifying Kf
   Kf = 0.9
   Calculate the average conical side sharft resistance (qf) along the pile

$$Qf = \frac{0+0+0+0+0+0+2+3+5+5+5+5+5+5+5+5+5+5+5+5+5+10+5+5+5+5+5+5+5+5+5+5+5+5+5+10+5+5+5}{36}$$

   = 4.306 Kg/cm2
   After obtaining the values Kf and qf, calculate the value of fs with the equation
   Fs = Kf x qf
   = 0.9 x 4.3056
   = 3.875 Kg/cm2

Shaft Resistance (Qs)
Friction resistance is calculated by the equation:
Qs = As x fs
= 175840 x 3.875
= 681380 kg
= 681.38 Ton
Ultimate bearing capacity (Qu)
Qu = Qb + Qs
= 122,77 + 681,38
= 804.15 Ton

Meyerhoff Method

Sondir Point S1

Calculating the end bearing (Qb)

1. Unit end bearing (fb)

   For bored pile, 70% or 50% of it is taken (Hardiyatmo, 2011)

   ω1 (coefficient of scale effect modification)

   If D < 0.5 m ω1 = 1, because the diameter of the bore pile is 0.8 > 0.5, then the equation is used:

   $\Omega 1 \quad = \left\{\frac{(d+0,5)}{2.d}\right\}^n$

   $= \left\{\frac{(0,8+0,5)}{2.0,8}\right\}^2$

   = 0,6602

ω2 (coefficient of modification for pole penetration in solid sand)

if L > 10d, ω2 = 1, because L = 7 m < 8 m (10 x 0.8 m), then the equation is used:

$\Omega 2 = \frac{L}{10.d}$

$= \frac{7}{10\times 0,8}$

$= \frac{7}{8}$

= 0,875

Q1 (average QC at 4D on the pole)

$q1 \quad = \left(\frac{25+25+15+5+15+10+10+20+30+25+20+30+20+25+30+25+35}{17}\right)$

= 21,47

Q2 (average QC at 1d under the pillar)

$q2 = \left(\frac{35+40+45+35+30}{5}\right)$

= 37

qca (Average QC1 and QC2)

Calculated by equation:

$qca \quad = \frac{q_1 + q_2}{2}$

$= \frac{21,47+37}{2}$

= 29,24

fb is calculated by the equation:

fb = ω1 x ω2 x qca

= 0.6602 x 0.875 x 29.24

= 16.89 kg/cm2

For the bored pile to take 50% of it, then:

fb $= 16,89 \times 50\%$

= 8.45 kg/cm2

Tight end (QB)

Qb = From x fb

= 1/4×π×D^2×f_b

= 1/4×3.14×80^2×8.45
= 5024×8,45
= 42428 kg
= 42.43 Ton

Calculating friction resistance (Qs)

1. Unit skin friction (fs)
   For piles, unit friction resistance is used equation:
   With Kf = 1
   Fs = Kf x qf
   = 1 x 4.3056
   = 4.3056 Kg/cm2
   For bored pile, Meyerhoff suggested using a 50% reduction factor (Hardiyatmo, 2011), then the value fs = 70%×4.3056=3.01 Kg/cm2
2. Friction resistance (Qs)
   Qs = As x fs
   = π×D×L×f_s
   = 3.14×80×700×3.01
   = 529961 kg
   = 529.96 Ton
   Calculate the ultimate bearing capacity(Qu) strength
   Qu = Qb + Qs
   = 42.43 + 529.96
   = 572.39 Ton

Evaluation of Bearing Capacity Using PDA Test Results

In PDA testing the axial load capacity of the mast is estimated by analyzing the best record, i.e. the record of the waves generated by the collision with the highest energy. PDA is analyzed using 2 methods, namely CASE Analysis and CAPWAP Analysis

Table 2. PDA Test Results of the CASE Method

Pile No.	RMX (ton)	FMX (ton)	CSX (MPa)	TSX (MPa)	DMX (mm)	DFN (mm)
BP-70	321	674	13.4	8.3	22.7	13.0
BP-108	412	478	9.5	1.1	2.9	0.3
BP-109	445	567	11.3	0.6	2.2	0.3
BP-111	348	200	4.0	1.3	5.2	1.4

Source: (PT. Duta Mandiri Group, 2024)

Table 3. PDA Test Results of CAPWAP Method

Pile No.	RMX (ton)	FMX (ton)	CSX (MPa)	TSX (MPa)	DMX (mm)	DFN (mm)
BP-70	321	674	13.4	8.3	22.7	13.0
BP-108	412	478	9.5	1.1	2.9	0.3
BP-109	445	567	11.3	0.6	2.2	0.3
BP-111	348	200	4.0	1.3	5.2	1.4

Source: (PT. Duta Mandiri Group, 2024)

The results of the PDA test of the CASE and CAPWAP methods are slightly different because the CAPWAP analysis uses a more realistic model based on soil conditions and detailed pile information, so it is recommended to use the results analyzed using CAPWAP.

Table 4. Recapitulation of Ultimate Bearing Capacity Calculation Results

Method	**Ultimate Carrying Capacity (Qu)**			
	Probe S1	**Probe S2**	**Sondir S3**	**Sondir S4**
Schmertmann & Nottingham	804.15 Ton	761.99 Ton	823.45 Ton	841.68 Ton
Meyerhoff	572.39 Ton	568.93 Ton	568.84 Ton	562.4 Ton

The results of the bearing capacity calculation obtained using the Schmertmann & Nottingham and Meyerhoff methods are then compared with the carrying capacity obtained from the PDA test of the CAPWAP analysis method, as shown in the following table:

Table 5. Comparison of Carrying Capacity Calculation Results with PDA

Comparative Bearing Capacity *of Bored Pile*								
Method	S1(Qu)(Ton)	S2(Qu)(Ton)	S4(Qu) (Ton)	S3 (Qu)(Ton)	PDA CAPWAP *Analysis*			
					BP-70(Roll)(Ton)	BP-108(Roll)(Ton)	BP-109(Roll)(Ton)	BP-111(Roll)(Ton)
Schmertmann & Nottingham	804.15 Ton	761,99Ton	841.68 Ton	823.45Ton	325.4 Ton	413.6 Ton	446.9 Ton	349.3 Ton
Meyerhoff	572.39 Tons	568.93Ton	562.4 Tons	568.84 Tons				

Based on the table, the largest ultimate bearing capacity (Qu) value was obtained from the Schmertmann & Nottingham method at the S4 sondir point, and the smallest was obtained from the Meyerhoff method at the S4 sondir point. The calculation results that show the least difference and are closest to the PDA are using the Meyerhoff method of the S4 sondir point with BP-109 with a difference of 115.5 tons.

The Schmertmann & Nottingham method shows much greater results than the PDA calculation because this method does not consider soil disturbance due to drilling for bored piles, based on the qc value which is often high in hard soils so as to give a large Qu estimate, tends to assume perfect contact between the pole and the ground, even though in the field there can be gaps or damage during casting, does not consider the factor of loss of carrying capacity due to the effect of casting or water disturbance.

CONCLUSION

The bearing capacity results from the sondir tests at points S1 to S4 show that the Schmertmann & Nottingham method yields higher values, ranging from 761.99 to 841.68 tons, with the largest ultimate bearing capacity (Qu) at point S4 (841.68 tons). In contrast, the Meyerhoff method produces lower and more consistent values between 562.4 and 572.39 tons, with the smallest Qu also at S4 (562.4 tons). When compared to the Pile Driving Analyzer (PDA) results, the Meyerhoff method at point S4 showed the closest agreement, differing by 115.5 tons from the PDA measurement (BP-109), while the Schmertmann & Nottingham method overestimated the capacity due to lack of reduction factors for tip and shaft resistances. Future research is suggested to refine the Schmertmann & Nottingham method by incorporating appropriate reduction factors and to explore hybrid or calibration approaches that integrate PDA data with theoretical calculations for more accurate prediction of borepile foundation bearing capacities in varied soil conditions.

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