An Analysis of the Influence of the Diameter-to-Depth Ratio on the Bearing Capacity of Single and Group Bored Piles in Cohesive Soil

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ABSTRACT

The load-bearing capacity of both single and group piles is influenced by the diameter-to-depth ratio (D/L), especially in soil with high plasticity and saturation, such as clay. Selecting an appropriate D/L ratio is crucial for the foundation design, ensuring structural stability and efficiency. The objective of this study is to evaluate the impact of varying D/L ratios on the allowable bearing capacity of bored pile foundations, examine how these variations affect the pile group efficiency, and formulate technical recommendations for the optimal D/L range. A quantitative approach was performed using the Meyerhof (1956) empirical method, which was supported by borehole examination data and laboratory soil testing, with pile diameters ranging from 0.6 m to 2.0 m and depths from 10 m to 20 m, resulting in D/L ratios between 0.03 and 0.20. The findings indicate that a lower D/L ratio significantly increases the bearing capacity, particularly when the depth increases from 10 m to 12 m. There was an increase of over 50% for diameters of 1.5–2.0 m and over 70% for diameters of 0.6–1.2 m. The average efficiency ranged from 64% to 73%, and the optimal D/L ratio depended on the pile diameter.

Keywords-bored pile; D/L ratio; single pile bearing capacity; pile group; cohesive soil; efficiency

I. INTRODUCTION

The stability and safety of a building depend on the strength of its foundation, especially in large-scale construction projects, such as high buildings and bridges [1]. The diameter-to-depth ratio (D/L) is a key parameter in foundation design, indicating the balance between the cross-sectional dimensions and the pile length, which is the primary load transfer path. An improperly designed D/L ratio can reduce bearing efficiency. Therefore, a comprehensive analysis of how this ratio influences the foundation capacity is essential for geotechnical design. Authors in [2] found that increasing the L/D ratio enhances the contribution of the end-bearing resistance to overall bearing capacity. Authors in [3] found that a higher L/D ratio mitigates the negative impact of mud cakes on the bearing capacity and settlement, whereas authors in [4] concluded that the pile length, diameter, configuration, and spacing significantly influence the load capacity and settlement behavior. Authors in [5] reported that side friction resisted more than 94% of the vertical load. Meanwhile, authors in [6] showed that large-diameter piles have increased the bearing capacity and reduced settlement. Authors in [7] revealed that an optimal bearing capacity is achieved with a 0.8 m pile at a depth of 10–15 m, which is over 140% greater than that of a 0.5 m pile. Authors in [8] examined the behavior of single and group bored piles (1×1, 1×2, and 2×2) in soft clay with an L/D ratio of 13.33. The results indicate that the method of Poulos and Vesic overestimates settlement, rendering it less suitable for soft clay. In contrast, Hansen's 90% method and the interpretation of Butler and Hoy are considered more accurate. Authors in [9] used a three-dimensional elasto-plastic finite element analysis with coupled consolidation to evaluate the effects of a 6-m open-face tunnel excavation on a 2×2 pile group embedded in saturated stiff clay. The results showed that the pile group experienced an additional equivalent load of 13,400 kN, reducing its safety factor from 3.0 to 1.6. Authors in [10] explored the interactions between the soil, pile group foundations, and twin tunnel excavation. At a depth of 0.3D, the corner pile experienced a 60% greater impact than the middle pile. At this depth, the bending moment affected the entire pile length, and decreased by 48% and 60% as the tunnel depth increased to 0.7D and 1D, respectively. Finally, authors in [11] found that group piles consistently demonstrate higher bearing capacities than single piles, particularly in layered soils. However, there is a notable gap in the literature concerning the systematic investigation of the effects of the diameter-to-depth (D/L) ratio on pile groups, especially across a broad range of incremental D/L variations in cohesive soils. The present study aims to analyze the effect of D/L ratio variations on the bearing capacity of single piles and pile groups in cohesive soils, thereby complementing and extending previous research. The study is expected to theoretically and practically contribute to the field of geotechnical engineering, particularly regarding the relationship between the D/L ratio of bored piles and their bearing capacity in cohesive soils.

II. RESEARCH METHODOLOGY

A. *Approach and Types of Research*

The current study used a quantitative descriptive approach to examine the effect of the diameter-to-depth ratio (D/L) of bored pile foundations on the bearing capacity of both single piles and pile groups in cohesive soils. The analysis was conducted using a combination of theoretical and empirical methods, primarily based on the calculation approach proposed by Meyerhof (1956). All calculations were conducted manually using Microsoft Excel to generate tables and graphs, and to determine the pile-bearing capacities.

B. *Location and Data Sources of the Study*

The secondary data in this study were obtained from a geotechnical site investigation using the Standard Penetration Test (N-SPT) method at a particular location characterized by cohesive soil. The collected information included N-SPT values, soil types for each layer, and the depth to the hard soil layer required for bearing capacity calculations.

C. *Calculation Method*

An analysis of the bearing capacity of bored pile foundations was conducted using a theoretical approach, based on the Meyerhof's method:

1) End Bearing Capacity of Bored Pile Foundation

$$Q_p = 40 \times N_b \times A_p \tag{1}$$

where Q_p is the end bearing capacity of the pile (kN), N_b is the average N-SPT value at the pile base ($\frac{N_1+N_2}{2}$), N_1 is the average N-SPT value at a depth of 4D below the pile base, N_2 is the average N-SPT value at a depth of 8D above the pile base, and A_p is the surface area of the bored pile (m^2).

2) Skin Friction Capacity of Bored Pile Foundation

$$Q_S = 2 \times \text{N} - \text{SPT} \times A_S \tag{2}$$

where Q_s is the skin friction capacity (kN), A_s is the skin area (m^2), P is the perimeter of the bored pile (m), and L_i is the depth of the foundation (m).

3) Negative Skin Friction of Bored Pile Foundation

$$Q_{neg} = \sum P_{\acute{o}} \times K_d \; t_g \; \acute{\delta} \times A_\Sigma \tag{3}$$

where Q_{neg} is the negative skin friction (kN), P_o' is the average effective overburden pressure of the soil (kN/m^2), $K_d \; t_g \; \delta'$ is the coefficient of Broms (1976), as shown in Table I, and A_s is the surface area subjected to negative skin friction (m^2) [12].

TABLE I. COEFFICIENT KD TG Δ'

Soil type	$K_d \; t_g \; \delta'$
Rock fill	0.40
Sand and gravel	0.35
Normally consolidated silt or clay with low to medium plasticity (PI<50%)	0.30
Normally consolidated clay with high plasticity	0.20

4) Ultimate Bearing Capacity of Bored Pile Foundation

$$Q_u = Q_p + Q_s - Q_{neg} \tag{4}$$

where Q_u is the ultimate bearing capacity (kN).

5) Allowable Bearing Capacity of Bored Pile Foundation

$$Q_{all} = Q_u / SF \tag{5}$$

where Q_{all} is the allowable bearing capacity (kN) and SF is the safety factor (2.5) [13].

6) Bearing Capacity Efficiency of Bored Pile Foundation

$$\eta = 1 - \left(\frac{(n-1)m+(m-1)n}{90 \times m \times n}\right) \times \theta \tag{6}$$

where η is the pile group efficiency (%), m is the number of piles in the vertical direction, n is the number of piles in the horizontal direction, θ is the arc t_g d/s in a single line (°), s is the pile spacing (m), and d is the pile diameter (m).

7) Bearing Capacity of Pile Group

$$Q_g = Q_{all} \times n \times \eta \tag{7}$$

where Q_g is the bearing capacity of the pile group (kN), and n is the number of piles in the group (pcs). The overall research workflow is presented in the flowchart displayed in Figure 1.

III. RESULTS AND DISCUSSION

A. *Soil Investigation Data*

1) Soil Classification

The soil layer characteristics at the research site were obtained from the results of the N-SPT, as presented in Table II. The data offer information on the depth of each soil layer, layer type, soil classification based on physical properties and plasticity, and N-SPT values as indicators of the soil strength. The data under consideration form the foundation for the analysis and design of bored pile foundations, due to the fact that they influence the bearing capacity of the pile through both shaft friction and end resistance.

B. *Bearing Capacity Analysis of Bored Pile Foundation*

1) Single Pile Bearing Capacity (Ø2 m, L:20 m, D/L: 0.10)

- Calculation of average N-SPT value $N_b = \frac{N_1+N_2}{2}$:

N_1 (4D) = 4 × 2 = 8 ↔ 20 + 8 = 28. Average N_1 value at a depth of 20-28 m = 39

N_2 (8D) = 8 × 2 = 16 ↔ 20 + 16 = 4. Average N_2 value at a depth of 4-20 m = 17.76

N_b= 28.38.

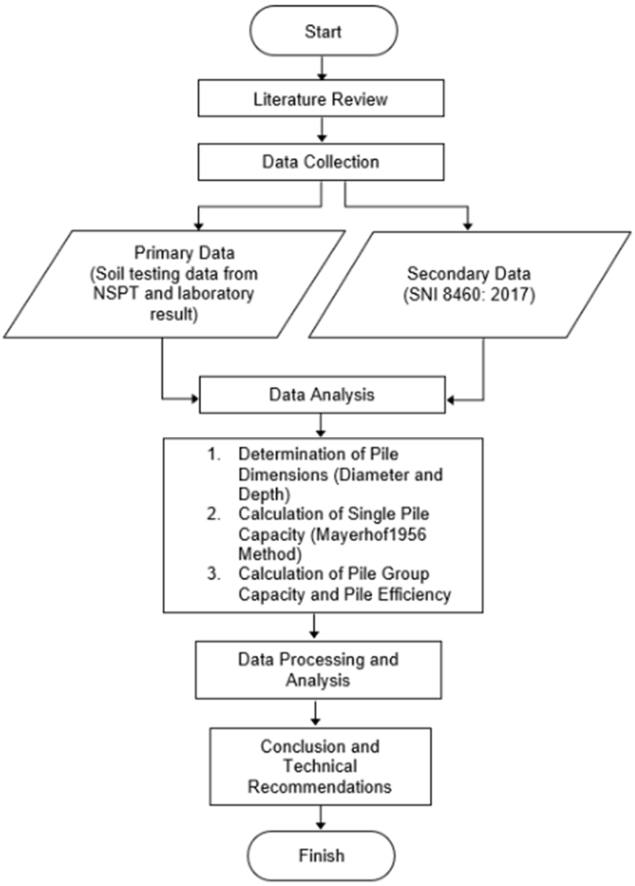

Fig. 1. Research flowchart.

TABLE II. SOIL INVESTIGATION RESULTS

Depth (m)	Soil layer	Soil classification	N-SPT (blows)
0.0 – 3.5	Clay-1	Clayey silt with high plasticity, very soft consistency	1-8
3.5 – 7.0	Sand-1	Loose sand ɣb 1.89 t/m^3; Gs 2.69; w 24.58%; c 0.01 kg/cm^2; ϕ 25.04^o	5-8
7.0 – 10.0	Clay-1	Clayey silt with high plasticity, medium stiff consistency	6-15
10.0 – 13.0	Clay-2	Clayey silt with high plasticity, stiff to very stiff consistency ɣb 1.73 t/m^3; Gs 2.67; w 42.85%; LL 86.62%; PL 33.30%; c 0.6 kg/cm^2; ϕ 6.20^o; Po 1.06 kg/cm^2; Pc 3.50 kg/cm^2; Cc 0.44; Cr 0.045; OCR 3.29 (over consolidated)	15-22
13.0 – 20.0	Silt-2	Clayey clay with high plasticity, very stiff consistency. ɣb 1.77 t/m^3; Gs 2.68; w 40.52%; LL 72.23%; PL 37.70%; c 0.47 kg/cm^2; ϕ 9.40^o; Po 1.56 kg/cm^2; Pc 4.85 kg/cm^2; Cc 0.58; Cr 0049; OCR 3.11 (over consolidated)	20-39
20.0 – 20.45	Silt-3	Clayey clay with high plasticity, hard consistency	39

- End bearing capacity (Q_P), calculated from:

  $A_p = \pi \times r^2 = 3.14$ m^2

  Q_p = 3,566.18 kN

- Skin friction capacity (Q_S) calculated from (2), as depicted in Table III:

TABLE III. SKIN FRICTION CAPACITY (QS) BORED PILE FOUNDATION (Ø2; L = 20 M)

Depth interval (m)	Depth (m)	Average N-SPT	$A_s = (L_i \times P)$ (m^2)	Q_s (kN)
0.00 – 5.00	5	5.57	31.42	350.06
5.00 – 10.00	5	8.27	31.42	519.79
10.00 – 15.00	5	20.09	31.42	1,262.35
15.00 – 20.00	5	26.82	31.42	1,685.04
Total	20			3,817.24

- Negative skin friction (Q_{neg}) calculated from (3), where the overburden pressures at depths of 0-10 m are taken from Table IV.

TABLE IV. OVERBURDEN PRESSURE VALUES

Depth (m)	Soil density (ɣ)	Po' (kN/m^2)	
2.00	16.50	2.0 x 16.5	= 33.00
3.50	16.50-9.81	33.0 + (1.5 x (16.5 – 9.81))	= 43.04
7.00	18.53-9.81	43.04 + (3.5 x (18.53 – 9.81))	= 73.56
10.00	17.5-9.81	73.56 + (3.0 x (17.50 – 9.81))	= 96.63

  Q_{neg}=882.15 kN

- Ultimate bearing capacity (Q_u), calculated from:

  Q_u = 6,501.27 kN

- Allowable bearing capacity (Q_{all}), calculated from:

  Q_{all} = 2,600.51 kN

Following this, the bearing capacity of single piles was calculated for various diameters and depths of bored pile foundations, ranging from 2.0 m to 0.6 m in diameter and 10-20 m in depth, as illustrated in Figure 2.

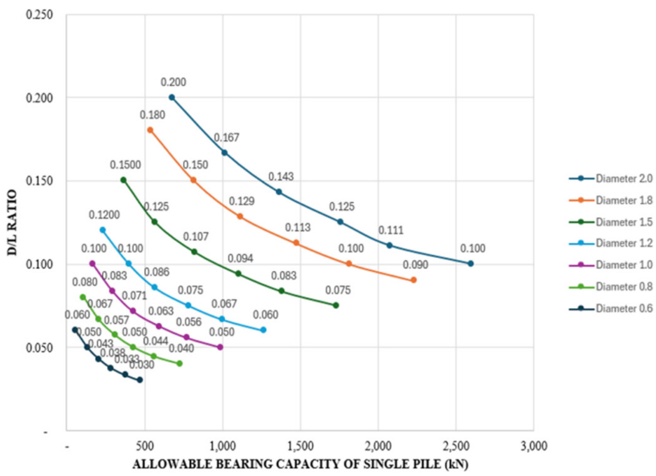

Fig. 2. Graph of D/L ratio versus single pile bearing capacity (Ø2-0.6 m).

2) Pile Group Bearing Capacity (Ø2 m, L:20 m, D/L: 0.10)

Figure 3 presents the structure of a 2 × 5 pile group (Ø2 m).

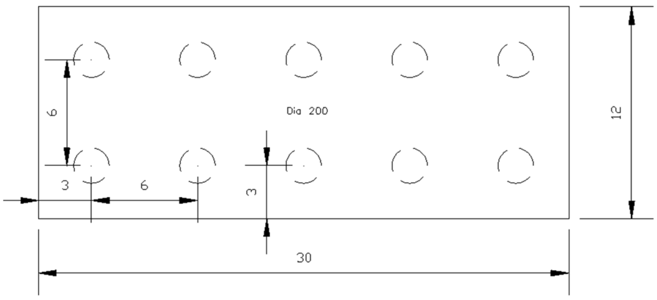

Fig. 3. Configuration of 2 × 5 pile group (Ø2 m).

- Pile group efficiency calculated from (6), with d = 2 m, s = 6 m, m = 2 (number of piles in the vertical direction), n = 5 (number of piles in the horizontal direction), and θ = 18.43°:

  η =0.73%

- Calculated bearing capacity of the pile group:

  Qg = 19,080.37 kN

The bearing capacity of the pile group was calculated for various diameters and depths of bored pile foundations, ranging from 2.0 m to 0.6 m in diameter and 10 m to 20 m in depth, as presented in Figure 4.

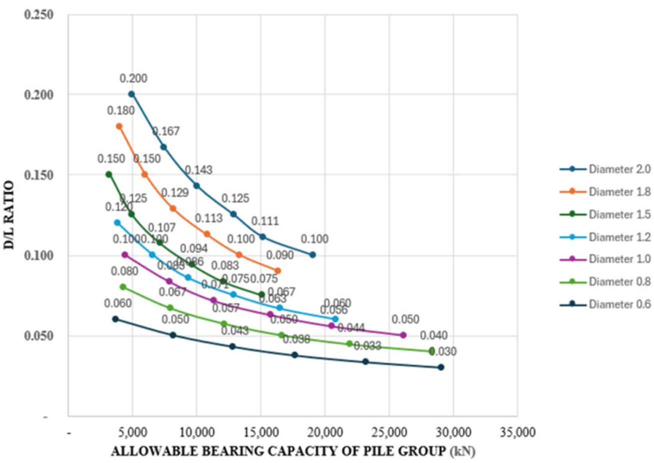

Fig. 4. Graph of D/L ratio of the pile group bearing capacity (Ø2-0.6 m).

The effectiveness of a single pile and a pile group bearing capacity for various diameter and depth combinations is presented in Figures 5 and 6, respectively. The findings of this study show that a decrease in the diameter-to-depth ratio (D/L) generally leads to an increase in the bearing capacity of single bored piles in clay soil. This increase was the result of improved contributions from the end bearing and shaft friction as the depth increased. The most significant changes occurred during the initial reduction of the D/L ratio, particularly for piles with smaller diameters. For instance, a pile with a diameter of 0.6 m exhibited an increase in bearing capacity of up to 119.82% when the D/L ratio was reduced from 0.060 to 0.050. The smaller the pile diameter was, the steeper was the increase in capacity. However, the nature of this relationship is not linear. A decline in return was observed, indicating that subsequent increases in depth did not result in a proportional increase in bearing capacity. For a 2.0 m diameter pile, a decrease in the D/L ratio from 0.200 to 0.167 led to an increase in capacity of 50.49%, while a subsequent reduction from 0.125 to 0.111 resulted in a mere 17.92% rise.

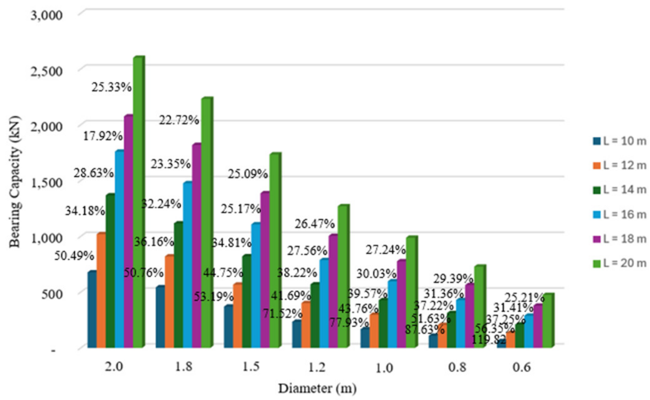

Fig. 5. Effectiveness of single pile bearing capacity with respect to diameter and depth variations.

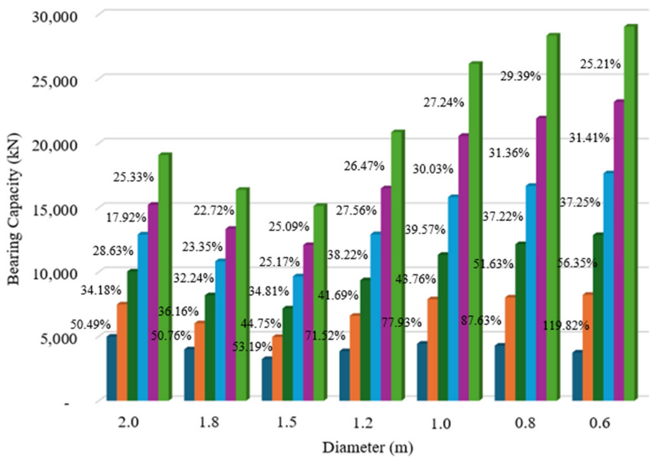

Fig. 6. Effectiveness of pile group bearing capacity with respect to diameter and depth variations.

The effectiveness of the D/L ratio also depended on the pile size. For large diameters (Ø1.8 mm–2 mm), the optimal ratio was within the range of 0.13–0.17. For medium diameters (Ø1.0 mm–1.5 mm), the optimal range was 0.10–0.13, whereas for small diameters (Ø0.6 mm–0.8 mm), effectiveness persists at ratios below 0.10. This finding suggests that the optimal D/L ratio is not a constant value, but is rather influenced by the dimensions of the pile and the characteristics of the soil. For the pile group, the efficiency did not increase with a greater depth or lower D/L ratio. The efficiency values were found to remain relatively constant for each diameter, with the influence of pile-to-pile interaction and spacing proving to be more significant. For instance, while the bearing capacity of a 0.6-m diameter pile group exhibits a notable increase, its efficiency is lower than that of larger diameters. It was found that smaller diameters yielded a higher total group capacity, as more piles could be accommodated within the same area. This resulted in a greater overall contribution from the shaft friction and end bearing. In addition, the optimal D/L ratio for a given pile group is not fixed, but depends on the diameter of the pile. For large diameters (Ø1.8 mm–2 mm), the optimal ratio ranges from 0.13 to 0.17; for medium diameters (Ø1.0 mm–1.5 mm), it ranges from 0.10 to 0.13; and for small diameters (Ø0.6 mm–0.8 mm), ratios below 0.10 remain highly effective.

IV. CONCLUSIONS

Research results show that reducing the D/L ratio enhances the bearing capacity of single bored piles in clay soils, primarily due to increased contributions from shaft friction and end bearing. However, it should be noted that this improvement is not linear and exhibits diminishing returns beyond certain ratio thresholds. An analogous tendency was observed in the pile group, wherein a reduction in the D/L ratio resulted in an increase in total capacity. The usage of smaller diameters yielded higher total bearing capacities, as more piles can be placed within the same area, thereby increasing the overall resistance. The pile group efficiency tends to remain stable across D/L variations and is more influenced by the pile spacing and stress zone interactions. The optimal D/L ratio is determined by the diameter of the pile, with values ranging from 0.13 to 0.17 for large diameters, 0.10 to 0.13 for medium diameters, and less than 0.10 for small diameters. The present study analyses the bearing capacity of single piles and pile groups with variations in the D/L ratio. The empirical method of Meyerhof was deployed, and the analysis was conducted on cohesive clay soils. Thus, the results cannot be generalized to other soil types yet. The deformation aspect was not thoroughly examined, and thus, the findings are primarily centered on the bearing capacity.

REFERENCES

[1] H. C. Hardyatmo, *Analisis dan Perancangan Fondasi I*, 4th ed. Yogyakarta, Indonesia: Gadjah Mada University Press, 2020.

[2] F. I. Shalabi, M. U. Saleem, H. J. Qureshi, M. Arifuzzaman, K. Khan, and M. M. Rahman, "3D FE analysis of bored pile- pile cap interaction in sandy soils under axial compression- parametric study," *Journal of Engineering Research*, vol. 11, no. 4, pp. 301–313, Dec. 2023, https://doi.org/10.1016/j.jer.2023.07.004.

[3] P. Xi, M. Kan, and Y. Liu, "Model Test and Numerical Simulation Study on the Effect of Mudcake and Length-Diameter Ratio on the Bearing Capacity of Bored Cast-in-Place Piles," *Advances in Civil Engineering*, vol. 2022, no. 1, 2022, Art. no. 2161744, https://doi.org/10.1155/2022/2161744.

[4] S. Mali and B. Singh, "Assessing the effect of governing parameters of bearing capacity determination of small piled rafts on clay soil," *Arabian Journal of Geosciences*, vol. 14, no. 22, Oct. 2021, Art. no. 2261, https://doi.org/10.1007/s12517-021-08609-8.

[5] A. Ibrahim, I. Malik, and O. Omar, "Assessment of load-carrying capacity of bored pile in clay soil using different methods," *International Journal of Engineering Research and Applications (IJERA)*, vol. 2, no. 4, pp. 1243–1253, 2012.

[6] A. Suhendra and T. J. Winata, "Analysis Study of Large Diameter Bored Pile Bearing Capacity," *IOP Conference Series: Earth and Environmental Science*, vol. 1324, no. 1, Dec. 2024, Art. no. 012013, https://doi.org/10.1088/1755-1315/1324/1/012013.

[7] N. A. Jamil and C. A. Siregar, "Analisis Daya Dukung Fondasi Tiang Bor (Bored Pile) Berdasarkan Data Penetrasi Standar (SPT) dan Data Sondir (CPT)," *Sistem Infrastruktur Teknik Sipil (SIMTEKS)*, vol. 3, no. 2, pp. 233–248, Sept. 2023, https://doi.org/10.32897/simteks.v3i2.1068.

[8] A. M. Al-Kinani and M. D. Ahmed, "Comparison of Single and Group Bored Piles Settlement Based on Field Test and Theoretical Methods," *Journal of Engineering*, vol. 26, no. 2, pp. 144–158, Jan. 2020, https://doi.org/10.31026/j.eng.2020.02.11.

[9] M. A. Soomro, D. K. Bangwar, M. A. Soomro, and M. A. Keerio, "3D Numerical Analysis of the Effects of an Advancing Tunnel on an Existing Loaded Pile Group," *Engineering, Technology & Applied Science Research*, vol. 8, no. 1, pp. 2520–2525, Feb. 2018, https://doi.org/10.48084/etasr.1693.

[10] M. Ayasrah, "Response of Existing Pile Groups Due to Twin Tunneling: A Numerical Study," *Engineering, Technology & Applied Science Research*, vol. 15, no. 3, pp. 23309–23316, June 2025, https://doi.org/10.48084/etasr.10689.

[11] M. I. Habib, "Comparative Study of Single and Group of Bored Pile under Axial Loading in Cohesion Less, Cohesive and Layered Soil," *Journal of Geotechnical Studies*, vol. 9, no. 2, pp. 31–37, Aug. 2024.

[12] H. C. Hardiyatmo, *Analisis dan Perancangan Fondasi II Edisi 4*, 5th ed. Yogyakarta, Indonesia: Gadjah Mada University Press, 2020.

[13] *SNI 8460:2017 Persyaratan perancangan geoteknik*. Jakarta, Indonesia: BSN, 2017.