Journal PROKONS
Volume 19, Number 2 (31-08-2025) doi:10.33795/Prokons
ISSN : 1978-1784 (p); 2714-8815 (e)
https://jurnal.polinema.ac.id/index.php/PROKONS/

Submitted: 2025-08-08
Revised: 2025-08-29
Accepted: 2025-08-31

ANALYSIS THE IMPACT OF VARIATIONS SHAPE AND DIMENSIONS DRIVEN PILE ON THE BEARING CAPACITY IN CLAY SOIL

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ABSTRACT

The foundation is a crucial component of any structure because it distributes the building's load to the solid soil beneath. For the Pagerwojo-Sidoarjo Hospital project, a pile foundation was selected due to its advantages, such as guaranteed concrete quality and quicker implementation compared to a drilled foundation. This study aims to analyze the differences in the bearing capacity of square and spun pile foundations using the Mayerhoff and L'Court methods. The analysis focuses on saturated clay soil and examines variations in the dimensions of circular (30–50 cm) and square (30×30 cm to 50×50 cm) foundations, at depths ranging from 35 m to 55 m. Calculations from both methods indicate that square foundations consistently exhibit a higher bearing capacity than circular foundations when assessed at the same depth and dimensions. The increase in bearing capacity is directly proportional to both the dimensions and depth of the piles, which is further influenced by the enhanced soil consistency found in deeper layers. According to our calculations, the bearing capacity of a 50 cm diameter, 35 m deep circular pile, based on N-SPT data, is 536 kN, while the bearing capacity for a square pile of the same dimensions is 683 kN. Although technical recommendations favor the use of square foundations to optimize bearing capacity, it is essential to further evaluate factors such as settlement, cost, and ease of implementation in the field.

Keywords: *allowable bearing capacity, circular pile, driven pile, square pile*

Introduction

A foundation is the bottom part of a building's structure, directly in contact with the ground [1]. The foundation's purpose is to support the building's weight and transfer it directly into the solid soil [2]. There are generally two types of foundations: shallow and deep. For the construction of the Pagerwojo-Sidoarjo Hospital Building, a deep foundation is planned. The most common types of deep foundations are bored pile foundations and pile foundations. Bore pile foundations offer flexibility in implementation, but their quality can be inconsistent, making it challenging to ensure the foundation's integrity. In reality, pile foundations are precast, which guarantees a higher quality and allows for precise calculations regarding the pile's characteristics. Additionally, pile foundations enable calculations for both end bearing and friction piles [3].

Fabricated pile foundations come in various shapes, such as circular (spun pile) and square pile. Based on the specifications in the pile e-catalog and previous research, the bearing capacity of a square-shaped foundation is greater than that of a circular-shaped foundation [4]. The objective of this study is to analyze the bearing capacity of pile foundations with different cross-sectional shapes while maintaining the same dimensions. For circular cross-sections, the dimensions used are D30 cm, D35 cm, D40 cm, D45 cm, and D50 cm. For square cross-sections, the dimensions are 30 cm x 30 cm, 35 cm x 35 cm, 40 cm x 40 cm, 45 cm x 45 cm, and 50 cm x 50 cm. The research site consists of saturated clay soil.

Materials and Methods

This research includes a number of steps that are presented in the form of the following flowchart.

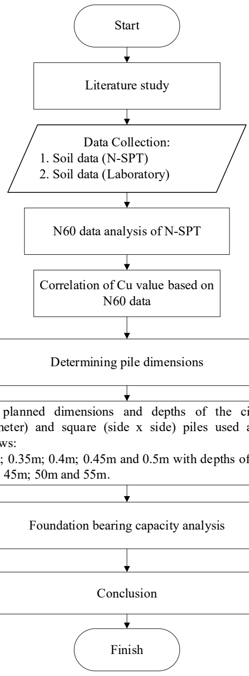

Figure 1. Research Flowchart

This research was conducted in a systematic and structured manner to yield optimal and accountable results. For this reason, the implementation process is divided into several stages as follows:

1. The literature study stage is the process of collecting materials and references that are used as the basis for conducting research. The literature used in this journal includes references regarding the calculation of the bearing capacity of pile foundations.
2. Data collection stage, in this process, the author collects all secondary data from the Sidoarjo Hospital project. The data obtained are as follows:
   a. Field soil testing data (N-SPT)
   b. Laboratory soil testing data
3. The N60 data analysis stage is based on the N-SPT data that has been obtained from the project. The following is a description:
   a. Soil data and parameter correlations
      For soil data obtained from the Sidoarjo Hospital project, the analysis reveals that several soil parameters have unknown values. To determine the values of these incomplete parameters, a correlation analysis is conducted using known data. This correlation will be guided by a book published by PUPR, namely 'Collection of Geotechnical and Foundation Parameter Correlations'.
4. The stage of determining pile dimensions and pile depth. In this study for the dimensions of the pile foundation are to be analysed as follows:
   a. The dimensions of the pile foundations consist of four dimensional variations, namely (0.3m, 0.35m, 0.4m, and 0.5m), and consist of four depth variations namely (35m, 40m, 45m, 50m and 55m) the dimensions and depth of the pile foundations used both circular and square foundation shapes are the same.
5. After determining the dimensions of the pile foundation to be analyzed, the next step is the calculation process for the bearing capacity of the foundation based on several variations in diameter and depth that have been described above. Analysis of the bearing capacity of the foundation is carried out in the following stages:
   a. Finding the end bearing capacity value of the pile (Q_p)
   b. Find the skin bearing capacity value of the pile (Q_s)
   c. Find the ultimate or maximum bearing capacity of the pile (Q_{ult})
   d. Find the allowable bearing capacity value (Q_{all})
6. The conclusion stage aims to explain the bearing capacity of pile foundations, with emphasis on the circular or square cross-sectional shape that produces the greatest bearing capacity value.
7. In this study, the calculation of the bearing capacity of the foundation uses two types of data: laboratory data and N-SPT data. Before calculating the bearing capacity values of the N-SPT and laboratory data, the N60 value and the correlation of the Cu values are calculated first. The formulas used are as follows:
   a. Calculation of N60 value

$$N_{60} = 1/6 \times E_r \times C_b \times C_s \times C_r \times N$$

Description:

E_r = Efficiency of the striker (value 0.6 used)
C_b = Borehole diameter (use value 1)
C_s = Sampler tube (value 1 used)
C_r = Length of drill rod (value used is 0.85)
N = Total score from field data

   b. Calculating the correlation value C_u

$$N_{60} = 2/3 \times \text{N-SPT} \times 10$$

Description:
N-SPT = Total score from field data

After obtaining the N60 value and correlation value from Cu, the bearing capacity was calculated using data from laboratory tests and field data (N-SPT):

c. Laboratory Data

The bearing capacity calculation using laboratory data in this study employed the Mayerhof method (1976) for the end bearing capacity (Qp) and the Tomlinson method (1997) for the skin friction bearing capacity (Qs).

1. Find the Q_p value

Q_p = $9 \times C_u \times A_p$

Description:
Q_p = End Bearing Capacity (kN)
A_p = Cross-sectional area of pole tip (m^2)
C_u = Soil cohesion at the end of the pile

2. Find the Q_s value

Q_s = $\Sigma\alpha \times C_u \times p \times \triangle L$

Description:
Q_s = Skin Friction Bearing Capacity (kN)
f = Skin friction
p = Circumference (m)
L = Pole length (m)

Tabel 1. Correlation of C_u and α Values

Cu/Pa	Faktor α
≤ 0,1	1
0,2	0,92
0,3	0,82
0,4	0,74
0,6	0,62
0,8	0,54
1,0	0,48
1,2	0,42
1,4	0,40
1,6	0,38
1,8	0,36
2,0	0,35
2,4	0,34
2,8	0,34

d. N-SPT Data

Bearing capacity was calculated using N-SPT data in this study with the Luciano D'Court method (1982).

1. Find the Q_p value

Q_p = $N_p \times K \times A_p$

Description:
K = Soil coefficient (t/m^2)
N_p = The average of N-SPT prices from 4D below the pile tip to 4D above the pile.

2. Find the Q_s Value

Q_s = $(N/3+1) \times A_s$

Description:
N = Average N-SPT value along the pile
A_s = Area of pole cover along the length of the pole (m^2)

Tabel 2. Coefficient value depending on soil type

K Value	
Soil type	K (t/m²)
Clay	12
Clay silt	20
Snd silt	25
Sand	40

e. Next, calculate the limit bearing capacity (Q_{ult}) and the allowable bearing capacity (Q_{all}). The formula is as follows:

Q_{ult} = $Q_p + Q_s$
Q_{all} = Q_{ult}/SF

Description:
Q_{ult} = Ultimate bearing capacity (kN)
Q_{all} = Allowable bearing capacity (kN)
SF = Safety Factor

Results

Based on the above steps, here is an example calculation for the bearing capacity of a 50 cm diameter, 35 m deep circular pile. The calculation steps are the same for square-shaped piles; the only difference is the value of the cross-sectional area.

1. Perform a value calculation N_{60}

N_{60} = $1/6 \times E_r \times C_b \times C_s \times C_r \times N$
N_{60} = $1/6 \times 1 \times 1 \times 0{,}85 \times 8$
N_{60} = 7

2. Calculating the correlation value C_u

C_u = $2/3 \times$ N-SPT $\times 10$
C_u = $2/3 \times 7 \times 10$
C_u = 22,56

3. After obtaining the C_u value, the carrying capacity value is calculated using the following laboratory data.

a. Perform a value calculation Q_p

Q_p = $9 \times C_u \times A_p$

Q_p = 9 x 22,56 x 0,16

Q_p = 60,83 kN

b. Calculating the Q_s, value at a depth of 35 m reveals the presence of three soil layers, yielding the following calculation

- Correlate the Cu value with the α value according to **Table 1** above.

	Cu/Pa	Faktor α
	≤ 0,1	1
Layer 2 →	0,2	0,92
Layer 3 →	0,3	0,82
Layer 1 →	0,4	0,74
	0,6	0,62

- Layer 1

Q_s = $\Sigma\alpha$ x C x p x ΔL

Q_s = 0,74 x 36,83 x 1,57 x 4

Q_s = 171,26 kN

- Layer 2

Q_s = $\Sigma\alpha$ x C x p x ΔL

Q_s = 0,92 x 15,87 x 1,57 x 10

Q_s = 229,29 kN

- Layer 3

Q_s = $\Sigma\alpha$ x C x p x ΔL

Q_s = 0,82 x 37,09 x 1,57 x 10

Q_s = 1051,05 kN

- Thus, the total value for Qs is

$Q_{s\ total}$ = ΣQ_s

$Q_{s\ total}$ = 1451,60 kN

c. Calculating the Q_{ult} value

Q_{ult} = $Q_p + Q_s$

Q_{ult} = 60,83 kN + 1451,60 kN

Q_{ult} = 1512,44 kN

d. Calculating the Q_{all} value

Q_{all} = Q_{all}/SF

Q_{all} = 1512,44 kN/3

Q_{all} = 504,15 kN

Therefore, the Q_{all} value used to calculate bearing capacity from laboratory data is 504.15 kN. First, the Q_{all} value is calculated based on laboratory data. Then, the bearing capacity value based on N-SPT data with the same diameter and depth is calculated:

e. Calculating the Q_p value

Q_p = N_p x K x A_p

Q_p = 6 x 20 x 0,20

Q_p = 23,366 ton

Q_p = 229,139 kN

f. Calculating the Q_s value

Q_s = (N/3+1) x As

Q_s = (5/3+1) x 54,98

Q_s = 140,65 ton

Q_s = 1379,329 kN

g. Calculating the Qult value

Q_{ult} = $Q_p + Q_s$

Q_{ult} = 229,139 kN + 1379,329 kN

Q_{ult} = 1608,470 kN

h. Calculating the Q_{all} value

Q_{all} = Qult/SF

Q_{all} = 1608,470/3

Q_{all} = 536,156 kN

Therefore, the Q_{all} value used to calculate bearing capacity from N-SPT data is 536.15 kN. The results of the allowable bearing capacity calculation using N-SPT data are shown in **Table 3.** In general, the larger the pile dimensions, the greater the bearing capacity. For example, at a diameter of 0,3 m and a depth of 35 m, the allowable bearing capacity is 303 kN; however, at the same depth, with a diameter of 0,5 m, the allowable bearing capacity is 536.15 kN. shows that the deeper the foundation pile, the greater the bearing capacity. For instance, at a diameter of 0.3 m and a depth of 35 m, the allowable bearing capacity is 303 kN; at a depth of 40 m, it is 352 kN.

Table 3. Test Results with N-SPT Data

	Circular Pile					Square Pile				
Depth (m)	Diameter (m)	Q_p (kN)	Q_s (kN)	Q_{ult} (kN)	Q_{all} (kN)	Sides x Sides (m)	Q_p (kN)	Q_s (kN)	Q_{ult} (kN)	Q_{all} (kN)
35	0,3	82	828	910	303	0,3	105	1054	1159	386
40	0,3	88	967	1055	352	0,3	113	1231	1343	448
45	0,3	318	1415	1733	578	0,3	533	1802	2334	778
50	0,3	471	1902	2374	791	0,3	600	2422	3022	1007

55	0,3	546	2638	3184	1061	0,3	750	3359	4109	1370
35	0,35	112	966	1078	359	0,35	143	1229	1372	457
40	0,35	120	1128	1248	416	0,35	153	1436	1589	530
45	0,35	433	1651	2084	695	0,35	725	2102	2827	942
50	0,35	642	2220	2861	954	0,35	817	2826	3643	1214
55	0,35	743	3078	3821	1274	0,35	1021	3919	4940	1647
35	0,4	147	1103	1250	417	0,4	187	1405	1592	531
40	0,4	175	1289	1464	488	0,4	200	1641	1841	614
45	0,4	566	1887	2452	817	0,4	720	2402	3122	1041
50	0,4	831	2537	3368	1123	0,4	1067	3230	4297	1432
55	0,4	971	3517	4488	1496	0,4	1236	4478	5714	1905
35	0,45	186	1241	1427	476	0,45	236	1581	1817	606
40	0,45	221	1450	1671	557	0,45	253	1846	2100	700
45	0,45	716	2123	2838	946	0,45	912	2702	3614	1205
50	0,45	1052	2854	3905	1302	0,45	1350	3633	4984	1661
55	0,45	1229	3957	5185	1728	0,45	1564	5038	6602	2201
35	0,5	229	1379	1608	536	0,5	292	1756	2048	683
40	0,5	273	1611	1884	628	0,5	313	2052	2364	788
45	0,5	884	2358	3242	1081	0,5	1125	3003	4128	1376
50	0,5	1298	3171	4469	1490	0,5	1667	4037	5704	1901
55	0,5	1517	4397	5913	1971	0,5	1931	5598	7529	2510

Table 4. Test Results with Laboratory Data

	Circular Pile					Square Pile				
Depth	Diameter	Q_p	Q_s	Q_{ult}	Q_{all}	Sides x Sides	Q_p	Q_s	Q_{ult}	Q_{all}
(m)	(m)	(kN)	(kN)	(kN)	(kN)	(m)	(kN)	(kN)	(kN)	(kN)
35	0,3	27	871	898	299	0,3	34	1109	1143	381
40	0,3	25	1002	1028	343	0,3	32	1276	1308	436
45	0,3	138	1328	1466	489	0,3	176	1691	1867	622
50	0,3	151	1621	1772	591	0,3	193	2064	2257	752
55	0,3	182	2130	2312	771	0,3	232	2711	2943	981
35	0,35	37	1016	1053	351	0,35	47	1294	1341	447
40	0,35	34	1169	1204	401	0,35	44	1489	1533	511
45	0,35	188	1550	1737	579	0,35	239	1973	2212	737
50	0,35	206	1891	2097	699	0,35	262	2408	2670	890
55	0,35	248	2484	2732	911	0,35	315	3163	3479	1160
35	0,4	48	1161	1209	403	0,4	61	1479	1540	513
40	0,4	45	1336	1381	460	0,4	57	1702	1759	586
45	0,4	245	1771	2016	672	0,4	312	2255	2567	856
50	0,4	269	2161	2430	810	0,4	343	2752	3095	1032

55	0,4	324	2839	3163	1054	0,4	412	3615	4027	1342
35	0,45	61	1306	1367	456	0,45	77	1663	1741	580
40	0,45	57	1504	1560	520	0,45	72	1914	1987	662
45	0,45	310	1992	2303	768	0,45	395	2537	2932	977
50	0,45	341	2431	2772	924	0,45	434	3096	3530	1177
55	0,45	410	3194	3604	1201	0,45	522	4067	4589	1530
35	0,5	61	1452	1512	504	0,5	77	1848	1926	642
40	0,5	57	1671	1727	576	0,5	72	2127	2199	733
45	0,5	310	2214	2524	841	0,5	395	2819	3214	1071
50	0,5	341	2702	3042	1014	0,5	434	3440	3874	1291
55	0,5	410	3549	3959	1320	0,5	522	4519	5040	1680

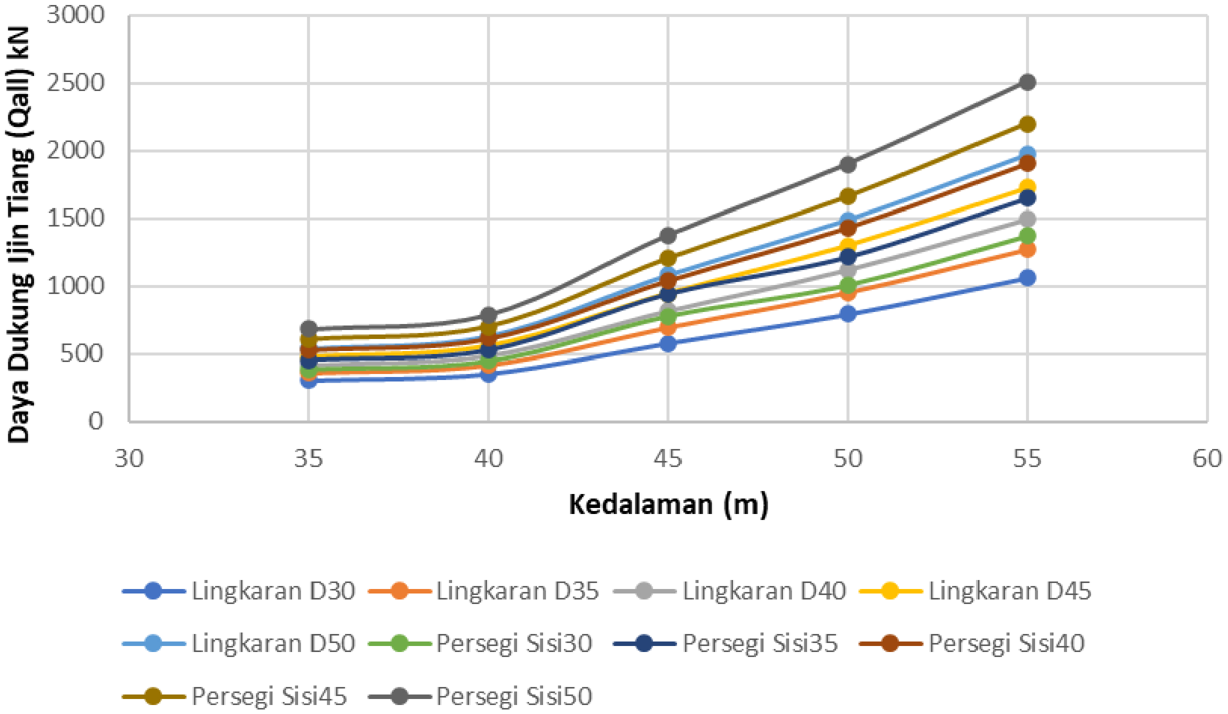

Figure 2. A Comparison of the Bearing Capacity of Circle and Square Foundations Based on N-SPT Data

The difference between **Table 3** and **Table 4** is in the cross-sectional shapes used to calculate the bearing capacity of the foundation. The piles used have square and circular cross sections. Based on allowable bearing capacity, the square cross-section provides a greater value than the circular cross-section. For example, with the same size and diameter from an N-SPT calculation with a diameter of 0.3 m and a depth of 35 m the allowable bearing capacity is 386 kN for the square cross section and 305 kN for the circular cross section. According to laboratory calculation data, the allowable bearing capacity is 381 kN for a 0.3 m diameter, 35 m deep square cross section and 299 kN for a 0.3 m diameter, 35 m deep circular cross section. **Figures 2 and Figures 3** illustrate the relationship between pile allowable bearing capacity (Q_{all}) and depth. The reviewed depth variations ranged from 35 to 55 meters. The diameter variation reviewed was from 30 cm to 50 cm. As **Figures 2 and Figures 3** show, the larger the foundation's diameter, the greater the bearing capacity value. The greater the depth, the greater the bearing capacity.

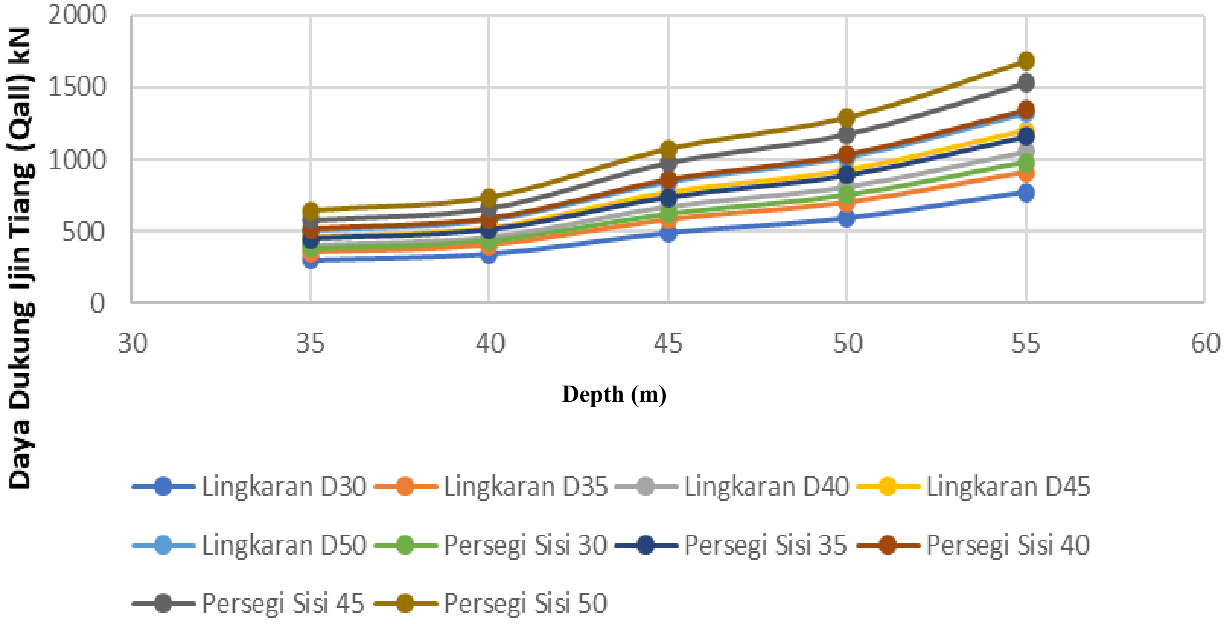

Figure 3. A Comparison of the Bearing Capacity of Circle and Square Foundations Based on Laboratory Data

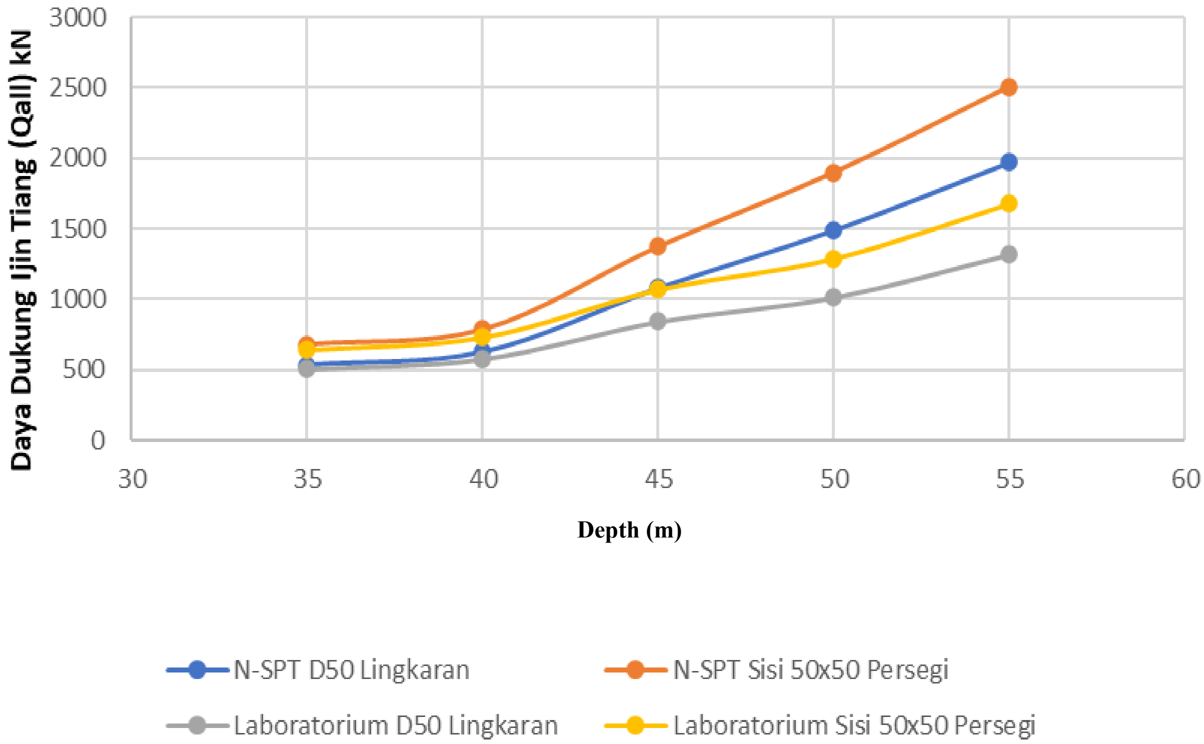

Figure 4. A comparison of the support capacity of circle and square foundations based on laboratory data for dimensions of 50 cm

This figure compares foundation bearing capacity values calculated using laboratory and N-SPT data. Figure 4 shows that the allowable bearing capacity value of piles calculated using N-SPT data is greater than that of laboratory data for the same 50 cm dimension. Foundations with square-shaped N-SPT data have the greatest bearing capacity. However, circular foundations at depths of 35 m, 40 m, and 45 m produced smaller values than laboratory data. At depths of 50 m and 55 m, though, the bearing capacity values increased significantly, exceeding those of the square laboratory data. Bearing capacity values calculated using laboratory data gave the smallest results for circular foundations.

Discussion

Research from [4] In terms of bearing capacity, square foundations have a greater bearing capacity than circular foundations when viewed at the same size and depth. Based on this, the data obtained for this study are consistent with those in the catalogue. (E-Katalog WIKA Beton, n.d.) A foundation with a square cross-section produces a higher bearing capacity. The bearing capacity increases linearly with the dimensions of the foundation and its depth. This may be because soil consistency increases with depth. The selection of foundation shape and size should consider soil conditions and structural efficiency. Square-shaped foundations are more recommended if bearing capacity is the priority. However, the settlement of both foundation types should be re-evaluated. Factors such as time, construction methods, and costs are also important considerations in the field to determine whether square-shaped foundations are indeed more effective and efficient compared to circular-shaped foundations.

The results of the ultimate bearing capacity calculation for piles with a diameter of 0.6 m and the same pile depth showed a bearing capacity of 91.01 tonnes for circular piles and 115.94 tonnes for square piles. In general, the larger the pile dimensions, the greater the bearing capacity. The deeper the foundation pile, the greater the bearing capacity. The bearing capacity values increased significantly, exceeding those of the square laboratory data. Bearing capacity values calculated using laboratory data gave the smallest results for circular foundations.

Conclusion

In terms of bearing capacity, square foundations have a greater bearing capacity than circular foundations when viewed at the same size and depth. Based on this, the data obtained for this study are consistent with those in the catalogue. [5] A foundation with a square cross-section produces a higher bearing capacity. The bearing capacity increases linearly with the dimensions of the foundation and its depth. This may be because soil consistency increases with depth. The selection of foundation shape and size should consider soil conditions and structural efficiency. Square-shaped foundations are more recommended if bearing capacity is the priority. However, the settlement of both foundation types should be re-evaluated. Factors such as time, construction methods, and costs are also important considerations in the field to determine whether square-shaped foundations are indeed more effective and efficient compared to circular-shaped foundations.

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