The Influence of Diameter and Spacing between Helix on the Bearing Capacity of Helical Pile

by Ratna Dewi

The Influence of Diameter and Spacing between Helix on the Bearing Capacity of Helical Pile

Ghina Amalia[1], Maulid M. Iqbal[2], Ratna Dewi[3]*
[1]Post Graduate Student of Civil Engineering Departement, Faculty of Engineering Sriwijaya University, Indonesia
[2]Lecturer in The Civil Engineering Departement, Faculty of Engineering Sriwijaya University, Indonesia
[3]Lecturer in The Civil Engineering Departement,, Faculty of Engineering Sriwijaya University, Indonesia

Abstract:- Helical pile is an alternative foundation with several advantages. It is easy and fast piling process, does not cause vibrations that could disrupt the soil in its environment and its bearing capacity is greater than the ordinary pile foundation. The bearing capacity of helical pile is contributed by the end bearing (Q_b), shaft friction bearing (Q_S), and cylindrical bearing (Q_{Cyc}) that is influenced by several factors such as diameter, configuration, and spacing between helis. This research was conducted experimentally in a laboratory using 2.1 m x 1 m x 0.95 m test box and sand as the medium. The diameter of pile was 1.5 cm, the length was 63 cm and the diameters of helical plates were 6 cm, 8 cm, and 10 cm. The spacing between helix of each pile were 20 cm, 15 cm, and 10 cm. The loading test was conducted using Quick Maintained Load (QML) Test while each of the test objects were analyzed using the Cylindrical Shear Failure Method because the value of S/D was ≤ 3. The result of this test were analyzed using Chin, Davisson and de Beer methods to obtain the ultimate bearing capacity. The results showed the percentage of difference between the test objects in terms of the influence of diameter on the space and this means for 10 cm, D06 to D08 48 %, D08 to D10 104 %; for 15 cm, D06 to D08 was 55% while D08 to D10 was 104%; and for 20 cm, D06 to D08 was 71% while D08 to D10 was 90%. Furthermore, Q_b was found to be influenced by the diameter of the helix where it increases as the diameter helix increase. While Q_S and Q_{Cyc} were influenced by the space between the helix, where they increase as the space between helix increases. The empirical calculations also showed Q_b, Q_S, and Q_{Cyc} contributed to the average ultimate bearing capacity by 59.4%, 2.1%, and 38.5%, respectively. It was concluded that the diameter provided the most significant effect to the bearing capacity of helical pile

Keywords:- *Helical pile, Foundation Bearing Capacity, Diameter of Helix, Spacing between Helix, Helix Configuration.*

I. INTRODUCTION

Helical pile is a modification to the ordinary pile foundation and was first made by Alexander Mitchel in 1833 [1]. The difference is the placement of helical steel plates along with the piles at a certain space to facilitate the installation process [2]. The bearing capacity of an ordinary pile is contributed by both the end and friction bearing capacities. Meanwhile, apart from these two, a helical pile also obtains additional bearing capacity from the plate along with its pile [3] and this makes it advantageous by having the ability to withstand tensile, compressive, and lateral loads as well as rolling moments [4]

Currently, the use of helical piles is increasing, specifically on unstable grounds due to several other advantages. These include fast and easy installation process independent of climatic and weather conditions, absence of vibration that could damage soil conditions, and non-requirement of maintenance time after installation [1]. Hamdy H.A. Abedel R, et al (201 also reported there is no need to remove the original soil when the helical pile is being installed because it causes no harm to the soil conditions [3].

Several previous research have been conducted to identify the factors influencing the bearing capacity of helical piles. Hamdy H. A. Abdel Rahim, et al (2013) reported the compressive and tensile bearing capacities of a helical pile in the sand and the factors to increase their values [3]. The results showed the bearing capacity was strongly influenced and directly proportional to the ratio of foundation depth and the diameter of the helical plate.

Sena Bayu (2018) calculated the bearing capacity of a foundation due to the increasing number of the helix on clay and sand media and the values were found to have increased by 9.38% and 5.58% respectively in the two media [5]. Moreover, the additional increase in helix diameter by 50% was improved the bearing capacity in clay by 19.66% and sand by 10.83%.

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Meanwhile, Likitha, H. et al (2017) analyzed the influence of the helix on the bearing capacity of the helical pile foundation [6]. The experiment was conducted in the laboratory on cohesive soils and the results showed the diameter of the helical plate had a very significant influence. This, therefore, means the value of the bearing capacity of the pile was directly proportional to the increasing diameter of the plate.

II. MATERIALS AND METHODOLOGY

A. *Materials*

The materials used in this research include:

➢ *Testing Instrument*

The test was conducted on a laboratory scale using a test box with 210 cm length, 100 cm width, and 95 cm height which was placed under a load frame to withstand the force exerted by a 2 tons hydraulic jack. Moreover, two LVDT were placed on the left and right sides of plate as the head of pile to measure the decrease while a 5 tons load cell was used to evaluate the load provided to the test objects. The LVDT and Load cell were subsequently connected to the Data logger with the TDS-302 series to observe the reading values. The testing instrument installation is illustrated in the following.

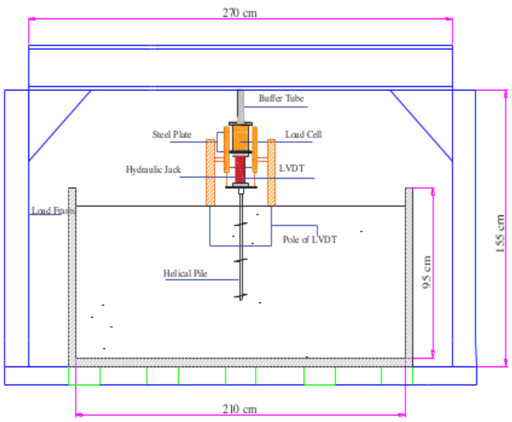

Fig 1:- Illustration of Testing Instrument

➢ *Sand*

The sand used as a testing medium was first dried and sampled and the properties obtained are presented in Table 1.

Soil Properties	Value
Specific Gravity, Gs	2.639
Grains Gradation	$C_u = 3$ and $C_c = 1.5$
Volume Weight, γ (KN/m^3)	13.92
Water Content, w (%)	0
Friction Angle, φ	30°

Table 1:- Soil Properties

➢ *Helical Pile*

The helical piles were made of steel with a diameter of 1.5 cm and a length of 63 cm. Three steel helical plates with diameters of 10 cm, 8 cm, and 6 cm and a thickness of 1 mm were placed on a pile. However, 15 pieces of helical piles with varying diameters and space were used as shown in Table 2

Space Between Helical, S (cm)	Diameter of the Helical, D (cm)			Pile Notation
	Top	*Middle*	*Bottom*	
10	6	6	6	D06-10
	8	8	8	D08-10
	10	10	10	D10-10
15	6	6	6	D06-15
	8	8	8	D08-15
	10	10	10	D10-15
20	6	6	6	D06-20
	8	8	8	D08-20
	10	10	10	D10-20

Table 2:- Variation of The Helical Pile

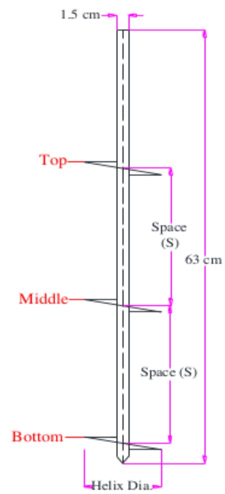

Fig 2:- Illustration of The Helical Pile

B. *Methodology*

Before the loading test was conducted, the dried sand was placed in a test box under the load frame and inserted in layers with a thickness of approximately 30 cm for each followed by a little compaction using a plate compactor. After the sand reached an elevation of 90 cm, the helical pile was slowly inserted by turning to the specified depth of 53 cm. Subsequently, the retaining plate was mounted above the helical pile as the footing of the testing instrument and the hydraulic jacks, load cells, and support tubes were arranged on the plates until they reached the elevation of the load frame while the LVDT was mounted on the left and right sides of the plate. All instruments were arranged symmetrically making the resultant load parallel to the axis of the helical pile [7] as shown in Figure 1.

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The loading test conducted was Quick Maintained Load Test (QML) using the ASTM D-1143 procedure [8]. This method is relatively faster compared to others required by ASTM and it involves a gradual increase of load at every 5% of the planned load calculated using the cylindrical bearing method of Mitsch and Clemence [3] until the load collapse is reached. The load increase was withheld at the fastest 4 minutes but not more than 15 minutes and the values were recorded at 5 minutes interval starting from 0. Moreover, the loading test was conducted until the pile collapsed in accordance with the provision of ASTM D 1143 [8] that testing should be stopped if the load reaches 1.5 to 2x of the planned load.

III. RESULT AND DISCUSSION

The load-settlement curve from the loading test generally produces a shape showing three phases of change in the behavior of the test object.

The first is the linear-elastic starting phase where the increases in load lead to a constant decrease thereby creating a linear curve. The second part is the transition from the elastic to the plastic phase where there is an imbalance between the load and the decrease thereby creating a parabolic curve. Meanwhile, the third or linear-plastic phase shows a significant decrease irrespective of the load and the stiffness of the test object was observed to be reduced or totally lost in this phase.

Table 3 shows the recapitulation of the load and the maximum reduction achieved by each test object during the loading test process.

Fig. 3 shows a load-settlement curve on the influence of the diameter of the helical plate represented by D06-20, D08-20, and D10-20 test objects.

Helical piles	Achieved Maximum Load (KN)	Maximum Settlement (mm)
D06-10	4.60	228.00
D06-15	5.00	235.50
D06-20	4.90	235.50
D08-10	9.00	249.00
D08-15	10.10	226.00
D08-20	9.70	235.00
D10-10	14.80	233.00
D10-15	14.10	239.00
D10-20	17.70	242.00

Table 3:- Summary Of Loading Test

The size diameter of the helix had a great and direct proportional effect on the stiffness of the test object. This was discovered from the ability of the D10-20 test object with the largest helix diameter to maintain its stiffness against the load given compared to the others.

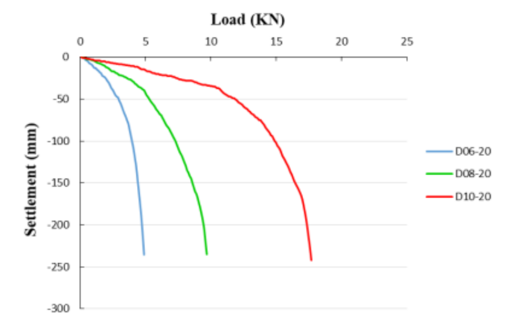

Fig 3:- Influence of Diameter on the Bearing Capacity of the Helical pile

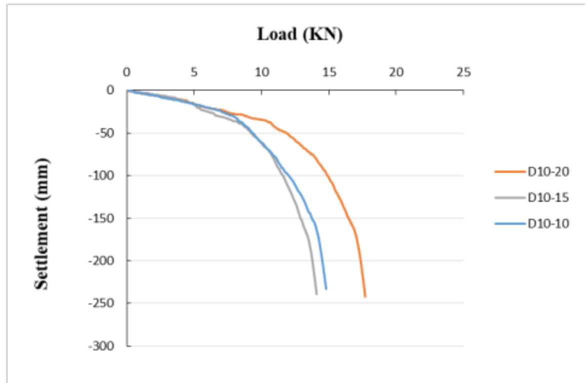

Fig 4:- Influence of Space on the Bearing Capacity of Helical pile

Fig. 4 is a Load-Settlement curve with the variation in the space between the helix represented by D10-20, D10-15, and D10-10 test objects. The figure shows the additional space between the helical plates does not have a significant effect on the stiffness of the test object.

A graphical method involving dee Beer, Chin, and Davisson were used to obtain the ultimate bearing capacity of each test object in addition to the use of an empirical method.

A. Bearing Capacity of Pile With Empirical Methods

The helical pile were designed to fulfill the cylindrical failure method with an S/D ratio less than 3 and the use of sand as the soil media. Therefore, the empirical method formula used to determine the bearing capacity of the helical pile involved the cylindrical failure method for the non-cohesion soil by Mitsch and Clemence [3]. The following is an example involving the calculation of the empirical bearing capacity for the D06-20 pile.

$Q_b \;= N_q\, \gamma \;\; H_n\, (\pi\, (D^2 - d^2) / 4)$
$= (22.5)\ (13.92\ KN/m^3)\ (0.5\ m)(\pi\ ((0.06\ m)^2 - (0.015\ m)^2)/4)$
$= 0.415$ KN

$Q_s \;= \pi\, d\, h_{eff}\ 0.5\ \ \gamma'\ K_S\, tan\theta$

$= \pi\ (0.015\ m)\ (0.04\ m)\ (13.92\ KN/m^3)\ (2.5)\ (0.32)$
$= 0.01$ KN

$Q_{cyc} = \pi\, D\ 0.5\ \ \gamma'\ K_S\, tan\theta\ \ (H_n^2 - H_l^2)$
$= \pi\ (0.06\ m)\ (13.92\ KN/m^3)\ (2.5)(0.32)(\ (0.5\ m)^2 - (0.1\ m)^2)$
$= 0.45$ KN

$Q_{ult} \;= Q_b + Q_s + Q_{cyc}$

$= 0.145\ KN + 0.01\ KN + 0.45\ KN$
$= 0.88$ KN

The recapitulation of the bearing capacity of each test object using the empirical formula is presented in Table 8.

B. *Bearing Capacity of Pile With Graphic Method*

These figures below show some of the graphic methods used to obtain bearing capacity values based on loading test data obtained from the field. The interpretation of the test result data to obtain bearing capacity using the Chin method is shown in Fig.5.

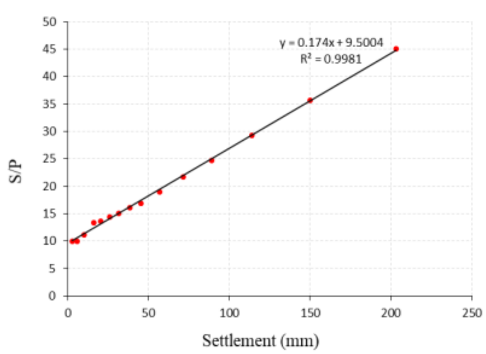

Fig 5:- Ultimate Bearing Capacity Using Chin Method for the D06-20 Pile

In the Chin method, the ultimate bearing capacity value was obtained by using the following formula

$$Q_u = \frac{1}{C1}$$

Where C1 is the slope coefficient of the linear regression line from the data of the loading test which according to the graph was 0.1737, therefore, the value of the bearing capacity was 4.80 KN.

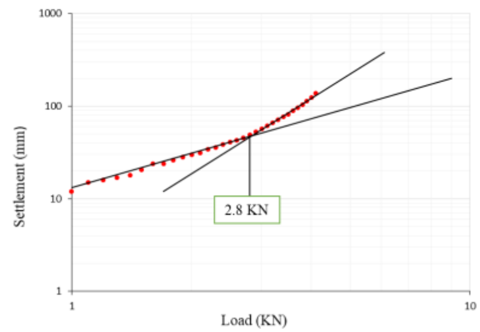

Fig 6:- Ultimate Bearing Capacity Using the De-Beer Method for the D06-20 Pile

Fig. 6 shows the data interpretation method using the de Beer method with the loading test results plotted on a double-logarithmic graph to produce a form that seems to intersect each other and the cutoff point was the ultimate bearing capacity value [10]. Therefore, according to the figure, the value for the D06-20 test object was 3.7 KN.

The Davisson method presented in Fig.7 shows the ultimate bearing capacity is the intersection between the second linear line against the loading graph [11] and the value for the D06-20 test object was found to 2.5 KN.

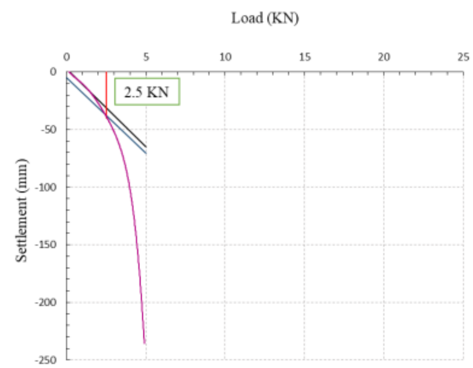

Fig 7:- Ultimate Bearing Capacity Using the Davisson Method for the D06-20 Test Object

Pile	Ultimate Bearing Capacity, Qu (KN)		
	Davisson	***De Beer***	***Chin***
D06-10	1.80	2.80	4.79
D08-10	3.20	2.60	7.80
D10-10	7.50	7.00	13.23
D06-15	2.30	3.00	4.98
D08-15	4.00	3.10	9.52
D10-15	9.00	8.80	14.52
D06-20	2.50	3.70	4.80
D08-20	5.00	4.80	9.53
D10-20	10.50	10.10	18.73

Table 4:- Recapitulation of Bearing Capacity with Graphic Methods

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C. The Bearing Capacity of Pile Due to Variations In Spacing Between Helix

Fig. 8 shows the graph to compare the bearing capacity using different methods with the diameter of helix fixed at 10 cm while the space was varied at 20 cm, 15 cm, and 10 cm. It was discovered that the space between the helix influences the magnitude of bearing capacity generated by the helical pile.

Table 5 shows the results of the overall bearing capacity of test objects obtained using the empirical, de Beer, Davisson and Chin methods by varying the space between helical plates. It also indicates the percentage of additional bearing capacity. However, the average percentages for the four methods in terms of the influence of space on diameter at 6 cm, S10 to S15 was 12% while S15 to S20 was 8%; for 8 cm, S10 to S15 was 18% while S15 to S24 was 22%; and for 10 cm, S10 to S15 was 16% while S16 to S20 was 16%.

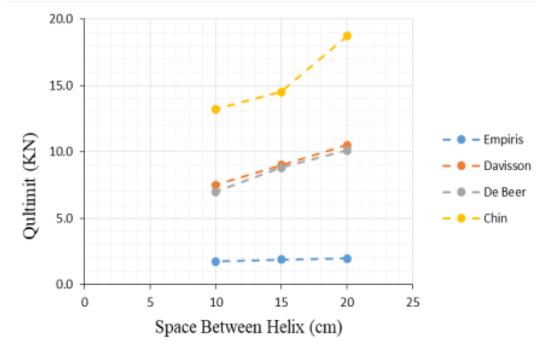

Fig 8:- Comparison of the Bearing Capacity Between The Methods Due to The Influence of Spacing

A greater value of space between the helix was found to have increased the bearing capacity of the pile but the effect is not really significant as observed from the relatively small percentage of addition between the test objects.

D (cm)	S (cm)	Pile	Ultimate Bearing Capacity, Qu (KN)							
			Empirical		*Davisson*		*De Beer*		*Chin*	
			Q	*%*	*Q*	*%*	*Q*	*%*	*Q*	*%*
6	10	D06-10	0.77		1.8		2.8		4.79	
	15	D06-15	0.85	9	2.3	28	3	7	4.98	4
	20	D06-20	0.87	4	2.5	9	3.7	23	4.80	-4
8	10	D08-10	1.22		3.2		2.6		7.80	
	15	D08-15	1.32	8	4	25	3.1	15	9.52	22
	20	D08-20	1.37	4	5	25	4.8	60	9.53	0
10	10	D10-10	1.75		7.5		7		13.2	
	15	D10-15	1.89	8	9	20	8.8	26	14.5	16
	20	D10-20	1.96	4	10.5	17	10.1	15	18.7	17

Table 5:- Recapitulation of Ultimate Bearing Capacity of Helical pile Due to Variation in Spacing between Helix
Note: D (the diameter of the helical plate), S (the spacing between the helical plates)

D. The Bearing Capacity of The Pile Due to Variation in Diameter of Helix

Fig. 9 and Table 6 compare the bearing capacity between the four methods with the helical plate diameter fixed at 10 cm while the space was varied at 20 cm, 15 cm, and 10 cm. The pattern obtained shows the increase in the diameter influenced the bearing capacity produced.

S (cm)	D (cm)	Test Object Notation	Ultimate bearing capacity, Qu (KN)							
			Empirical		*Davisson*		*De Beer*		*Chin*	
			Q	*%*	*Q*	*%*	*Q*	*%*	*Q*	*%*
10	6	D06-10	0.77		1.8		2.8		4.79	
	8	D08-10	1.22	58	3.2	78	2.6	-7	7.80	63
	10	D10-10	1.75	44	7.5	134	7.0	169	13.23	70
15	6	D06-15	0.85		2.3		3.0		4.98	
	8	D08-15	1.32	56	4.0	74	3.1	0	9.52	91
	10	D10-15	1.89	43	9.0	125	8.8	193	14.52	52
20	6	D06-20	0.88		2.5		3.7		4.80	
	8	D08-20	1.37	56	5.0	100	4.8	30	9.53	99
	10	D10-20	1.96	43	10.5	110	10.1	110	18.73	96

Table 6:- Recapitulation of the Ultimate Bearing Capacity of Helical Pile Due to The Diameter of Helix
Note: D (Helical Plate Diameter), S (Spacing between Helical Plate)

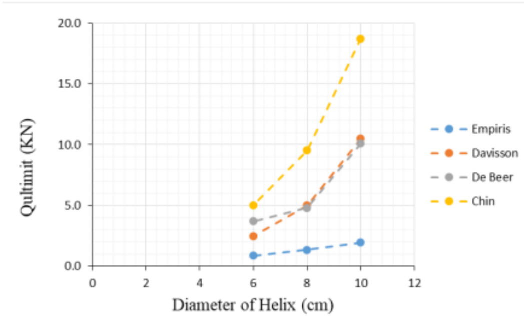

Fig 9:- Comparison of Bearing Capacity Value between Methods Due to The Influence of Diameter

Table 7 also shows the percentage of the additional bearing capacity of each test object through the use of the four methods and the influence of the diameter on space was found to include for 10 cm, D06 to D08 was 48% while D08 to D10 was 104%; for 15cm, D06 to D08 was 55% while D08 to D10 was 104%; and for 20cm, the D06 to D08 was 71% while D08 to D10 was 90%.

These data, therefore, showed a higher value of diameter of the helical plate increased the bearing capacity of the helical pile and this effect was found to be significant based on the percentage of addition

E. The Influence of Diameter and Space on the Ultimate Bearing Capacity of the Helical Pile

The helical pile used in this study was designed to fulfill the cylindrical failure method by ensuring S/D ≤ 3 on each test object. Therefore, the ultimate bearing capacity was calculated using the contribution from the end bearing capacity (Qb), the friction bearing capacity (QS), and the cylindrical bearing capacity of the helical plate (QC). Moreover, Table 6 shows a recapitulation of the contribution of the bearing capacity of the pile.

Table 7 shows Q_b was influenced by the helical plate diameter such that a higher value of the diameter produced a greater tip bearing capacity. However, the same effect was observed with the relationship between space and Q_S and Q_{Cyc}.

Pile	Q_b (KN)	Q_S (KN)	Q_{cyc} (KN)	Q_b (KN)
D06-10	0.42	0.06	0.30	0.77
D06-15	0.42	0.03	0.40	0.85
D06-20	0.42	0.01	0.45	0.88
D08-10	0.76	0.05	0.40	1.22
D08-15	0.76	0.03	0.53	1.32
D08-20	0.76	0.00	0.61	1.37
D10-10	1.20	0.05	0.50	1.75
D10-15	1.20	0.02	0.66	1.89
D10-20	1.20	0.00	0.76	1.96

Table 7:- Recapitulation of Ultimate Bearing Capacity Contributions

The table also shows Q_b, Q_S, and Q_{Cyc} averagely contributed to the ultimate bearing capacity by 51.4%, 2.1%, and 38.5%, respectively. Therefore, it is possible to conclude that the diameter has the most significant effect compared to space on the ultimate bearing capacity produced.

IV. CONCLUSION

Based on the research, it was concluded that:

- A higher value for the diameter and a farther space between the helical plates was found to produce more bearing capacity. However, the average additional percentage showed the diameter variation had the most significant effect.
- Concerning the contributions of Q_b, Q_S, and Q_{Cyc} from empirical calculations, the end bearing capacity (Q_b) was found to be influenced by the diameter of the helix where the Q_b increases as the diameter helx increase. While the values of saft friction bearing capacity (Q_S) and cylindrical bearing capacity (Q_{Cyc}) were influenced by the space between the helix, where Q_S and Q_{Cyc} incease as the space between helix increases. Moreover, the empirical calculations showed the Q_b, Q_S, and Q_{Cyc} contributed to the ultimate bearing capacity on the average by 59.4%, 2.1%, and 38.5% respectively. Furthermore, the percentage values indicated the addition of the helical plate diameter had the most significant influence on the increase in the bearing capacity.

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- The ratio between the average values of bearing capacity of the Davisson to empirical, de Beer to empirical, and Chin to empirical methods were 3.8, 3.8 and 7.3 respectively.

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