Effect of Helical Geometry on the Axial Compressive Capacity

by Ratna Dewi

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Abstract:- Helical pile is an invention in pile foundation with a main objective of increasing pile capacity. According to Prasad, et.al (1996), definition of helical pile is a pile foundation that equipped with one or more helix that has a round shape, attached to the shaft with a certain distance between helixes. The aim of this study is to understand the effect of helixes number to the bearing capacity. In this study, empirical model is validated with the static loading test on three different type of helical pile: 1) single shaft, 2) helical pile with the same diameter of helixes and, 3) helical pile with different diameter of helixes on clay soil. The diameter of helixes are 15 cm, 20 cm, and 25 cm with distance between helixes 50 cm. The result shows the bearing capacity increase of single shaft to helical pile 252% - 369%. Moreover, the comparison of bearing capacity between helical pile with the same diameter of helixes and helical pile with different diameter of helixes is explained in this study.

Keywords:- *Helical Pile, Axial Compressive Capacity, Helical Diameter, Clay Soil, Static Loading Test.*

I. INTRODUCTION

Foundation is constructed to support the upper building. One of the essential functions of foundation is to distribute the load to the soil layer, to prevent the building failure or collapse. The current development of the technology, resulting in a heavy self-weight building in a various location, lead to the thoroughly decision of an effective foundation from the technical and economy aspect. The surrounding situation and geotechnical problem such as soft soil and a heavy foundation promote the research to discover a suitable technology to overcome those problems, such as fundex pile, franki pile, screw pile and helical pile. According to Narasimha, Prasad & Shetty (1991) [1], helical pile which is known as screw anchor is a foundation that consists of one or more helixes that has a round shape attached to the shaft made of steel, with a certain distance between helixes.

According to the K. P. Nainan & J. S. Syed (2009) [2], helical pile has been discovered for a long time ago. Recently, it is revived since its capability to provide larger pile capacity of axial compressive, tension and lateral. The decision to utilize single helix or multiple helixes depends on several factors, such as soil type, load, and method to install the pile. Helixes number not only increasing the capacity of pile but also increasing the shear stress along the shaft (J. P. Hambleton, 2014) [3].

The research of the effect of the helix number on the capacity of helical pile by A. Sprince and L. Pakrastinsh (2010) [4], utilized 1 helix to the 6 helixes with a decreasing size of helix from top to the end pile. Pile capacity increase in line with the increase of helix number. Besides that, the geometry of helical pile such as diameter of helix and distance between helix had been studied by other researchers. S. S. Fatnanta and Muhardi (2015) [5] conducted a full-scaled research of helical pile on the peat soil. A prefabricated helical pile has a shaft diameter of 6 cm. The number of helixes is 1 to 3 with the diameter of helix of 35 cm and the thickness of 5 mm. The research considers the distance between helixes. The result shows the capacity of helical pile is higher than the pile without helix. It is increasing for 2.90 – 5.65 times compare to the pile without helix.

Khazaie Javad and A. Eslami (2016) [6] conducted experimental test using Frustum Confining Veseel (FCV) to understand the behaviour of helical pile on the sand with a smooth gradation. Helical pile has one or more helixes with the thickness of 4 mm. Fourteen different helical piles in this study were installed to the depth of 750 mm with diameter of helix 64 -89 mm. The result shows that the effect of helical pile depend on the helix configuration and the soil. In the study, the capacity of the axial compressive with two helixes shows similar result with the close -end type shaft pile. Besides that, the capacity of the axial compressive increase to 30% in line with the helix number.

The effect of helixes number to the uplift capacity of helical pile has been studied in Mulyandha, Dhevi (2020) [7]. The result shows the helixes number increasing the uplift capacity of helical pile. However, there is no study indicating the effect of helical pile geometry to the axial compressive capacity.

Previous research shows a linier increase of installed helix number in a certain distance between helixes on a different soil type. The research shows the effect of a various diameter of helix without considering the distance between helixes and helix diameter configuration to the pile capacity. Hence, it is important to study further effect of different helix diameter by considering different distance between helixes to the pile capacity.

II. METHOD

A full-scaled static loading test of axial compressive is conducted to obtain the capacity of helical pile. Soil investigation is conducted as a preliminary test as an input in helical pile design.

A. Preparation Phase

Prior to the soil investigation and static loading test, preparation of determination of test location, preparation of helical pile and the tools of static loading test are conducted in the early stage.

➢ *Determination of location*

Location is determined at the first stage to indicate suitable site, the soft clay layer. Preparation activity such as land clearing and open the access to transport the soil investigation apparatus, visual observation of the soil and measuring the surface of the soil.

➢ *Helical pile preparation*

Helical pile in this study has a characteristic to resist axial compressive load (Fig. 1)

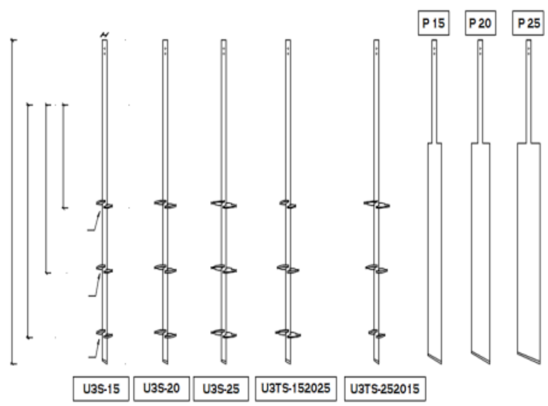

Fig. 1. Visual of the helical pile

Pile made of steel hollow pipe with diameter 5 cm, total length is 2.5 m, consists of 3 helixes with diameter 15-25 cm. The top pile arises from 0,5 m from the soil surface. Helix is installed by following cylindrical failure shear theory with ratio of S/D ≤ 3. According to its ratio, helix is installed with distance between helix 50 cm with 3 maximum helixes in each pile. Besides that, static loading test of shaft is conducted to determine capacity of single shaft only. Helical pile test combination as follow in Table 1.

Position & Diameter of Helix			Space Between Helical, S (cm)	Shaft Diameter (cm)	Pile Notation
Top (cm)	*Middle (cm)*	*Bottom (cm)*			
15	15	15	50	5.08	U3S - 15
20	20	20	50	5.08	U3S - 20
25	25	25	50	5.08	U3S - 25
15	20	25	50	5.08	U3TS - 152025
25	20	15	50	5.08	U3TS - 252015
Single Shaft				15	P 15
				20	P 20
				25	P 25

Table 1:- Helical Pile Notation

➢ *Apparatus preparation*

Prior to the static loading test, preparation of apparatus is mandatory. The apparatus is as follow:

- Main Beam with H-Beam profile 300 x 300 x 10 x 10, 4 m length
- Hydraulic Jack 10 ton
- Plate 10 ton
- Electric Pump
- Load Cell 5 ton and 50 ton
- Linier Variable Differential Transformer (LVDT)
- Casing and anchor
- Steel plate for hydraulic jack

B. Testing Phase

Testing phase is as follow:

➢ *Boring*

Boring in this study is referring to the ASTM D 1452-80. Undisturbed sample (UDS) is obtained by using a tube. UDS sampling should be at the minimum effect of sampling activity.

➢ *Cone Penetration Test (CPT)*

Cone penetration test (CPT) of 2.5 ton is referring to the ASTM D 3441-75T. Mechanical shear cone has an angle 600 and projection area 10 cm^2. Penetration rate is 2 cm/second. Cone resistance (qc) and local friction (fs) is recorded for each interval of 20 cm. Test should be terminated at depth of 20 m or if reaching cone resistance of 150 kg/cm^2.

➢ *Laboratory Test*

Physical and mechanical behaviour of the soil sample should be tested in the laboratory. The test is conducted to assess the characteristic of soil in this study. Soil properties can be observed in Table 2. The complete procedure of laboratory test is referring to the ASTM as seen in table below.

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Test Type	ASTM
Water content	D2216 - 95
Volume weight	D4532 - R03
Specific gravity	D854 - 02
Atterberg limits	D4318 - 08
Sieve analysis	D422 - 63 R07
Hydrometer	D1140 - 00
Triaxial CU	D4767 - 11

Table 2:- Laboratory Test Standard

- *Static loading test*

Static loading of axial compressive is conducted to obtain the capacity of the helical pile. It is referring to the ASTM D1143-07. The settlement at the pile head is measuring by using dial gauge and keep the level of pile head. Load sequence is referring to the (ASTM D1143-07) [8], article "8.1.2 Procedure A: Quick Test".

In the QML, the load increases frequently by 5% from the design load to the maximum failure load. The load is hold for 5 minutes. The interval of recording is following period of 0, 2.5, and 5 minutes.

The data is analyzed to estimate the ultimate load. The result is showed in the output of load – settlement graph. The interpretation to determine the ultimate load is method of Davisson, Mazurkiewich, Chin, and De Beer.

III. RESULT AND DISCUSSION

In this part, each phase of study will be explained in detail. Every phase is referring to the research method which has been discussed in previous chapter. In general, helical pile test is conducted in two phases. The first phase is the soil investigation and the second phase is the static loading test.

A. *Result of soil investigation*

Soil type identification in this study is using the site characteristic test and laboratory test. The sample is collected from two CPT data, S-01 and S-02 and boring at depth of 8000 m, BH-1.

Data S-01, shows hard layer at the depth of 10.40 m with qc > 150 kg/cm^2. Data S-02 shows consistency to the S-01, which has qc > 150 kg/cm^2 at the depth 10.40 m. In this study the helical pile is installed at the depth of 2.50 m with average qc 24 kg/cm^2. According to the qc value, the soil consistency at the depth of 2.50 m is medium. Soil stratification for every layer in the site as shown in Table 3.

S – 01			S - 02		
Depth (m)	*qc (kg/cm^2)*	*Consistency*	*Depth (m)*	*qc (kg/cm^2)*	*Consistency*
0.00 – 2.00	18	Medium	0.00 – 2.00	15	Medium
2.00 – 4.20	20	Medium	2.00 – 4.20	28	Medium
4.20 – 6.40	42	Hard	4.20 – 6.40	50	Hard
6.40 – 8.60	72	Very hard	6.40 – 8.60	62	Very hard
8.6 – 10.40	114	Dense	8.6 – 10.40	138	Dense

Table 3:- Soil Stratification from CPT

From table above, it can be concluded soil stratification of each location is identical. Each location shows the hard soil layer at the same depth.

Meanwhile, boring (BH–1) indicate the soil type is clay soil. Soil profile from the boring is shown in Table 4.

Depth	N-SPT	Consistency
0 - 2 m	8	Medium
2 - 4 m	5	Medium
4 - 6 m	3	Soft
6 - 8 m	5	Medium

Table 4:- N – SPT

According to the table abov, at depth 2 m where helical pile is installed, has N-SPT of 8. It is indicating soil layer in the study location as clay soil with medium consistency. Summary of laboratory test of two UDS is shown in Table 5.

Properties	Unit	Sample	
		UDS – 1	UDS - 2
		2.00 - 2.50	4.00 - 4.50
Specific		2.631	2.617
Unit weight	ton/m3	1.60	1.09
Water content	%	51.59	51.28
Atterberg limits			
LL	%	81	91
PL	%	40	34
IP	%	41	38
Clay < 0,002	%	60.4	74.7
c	kg/cm2	0.38	0.33
θ	°	18.8	4.0
Consolidation			
eo		1.43	1.19
po	kg/cm2	0.37	0.11
pc	kg/cm2	1.19	0.26
Cc		0.37	0.32
Cr		0.02	0.06
Cv		2.00	7.00

Table 5:- Summary of Laboratory Test

B. Static Loading Test

The hypothesis of helix can increase the capacity is proven in this study. Helix with various configuration is installed to study the characteristic of axial compressive capacity of helical pile. The procedure of loading test is referring to the ASTM D 1143 – 07. The result of settlement to the load graphs is presented in this study.

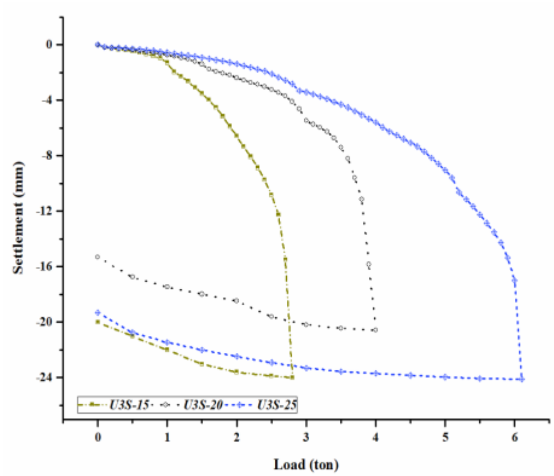

Fig. 2. Load – settlement curve of uniform helixes

Fig. 2 shows behaviour of helical pile with uniform helixes. Three helical pile U3S–15, U3S–20, and U3S–25 is loaded until failure. The result of static loading test shows in table below.

According to the load – settlement curve using analysis method explained previously, the estimation of ultimate capacity of uniform shows in Table 6 and Fig. 3

Method	U3S-15 (ton)	U3S-20 (ton)	U3S-25 (ton)
Davisson	2.12	3.65	5.51
Mazurkiewich	2.86	3.55	5.81
Chin	2.65	3.73	5.81
De Beer	2.62	3.75	5.92

Table 6:- Estimation of Ultimate Capacity of Helical Pile with Uniform Helixes

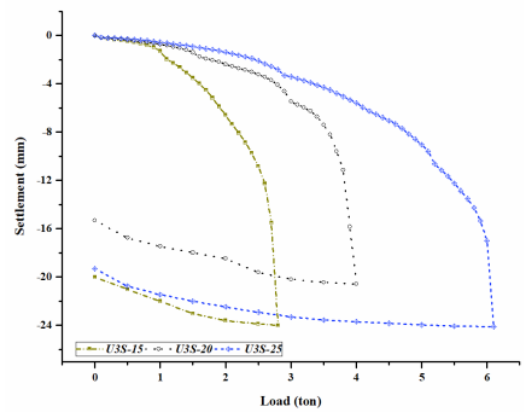

Fig. 3. Comparisons of capacity of helical pile with uniform helixes

In this study, pile modification of different helixes diameter is conducted to understand the optimum design of helical pile. Pile Notation is shown in Table 1. The result of static loading test of each pile is shown in Fig. 4.

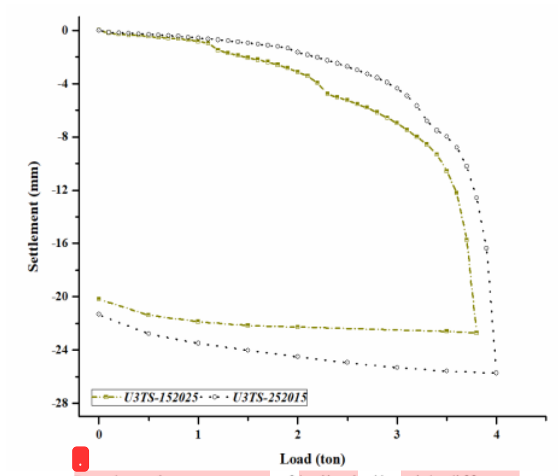

Fig. 4. Load-settlement curve of helical pile with different diameter of helixes

Fig. above shows maximum load of every helical pile, 3,8 ton on helical pile U3TS-152025, helical pile U3TS-252015 shows failure load at 4.0 ton. Analysis summary of ultimate capacity of helical pile with different diameter of helixes is shown in Table 7.

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Method	U3TS-152025 (ton)	U3TS-152025 (ton)
Davisson	3.32	3.5
Mazurkiewich	3.76	3.84
Chin	3.6	3.75
De Beer	3.58	3.85

Table 7:- Estimation of Helical Pile Capacity with Different Diameter of Helixes

According to the table 7, configuration of helical pile with helix diameter big – small shows higher axial compressive capacity compares to the helical pile with the helix diameter small to big, which is 150-200 kg.

As a comparison, behaviour of single shaft shows on Fig. 5. It indicates the increase of pile capacity. Pile capacity of every method increase in line with the size of helix diameter by 33.33%.

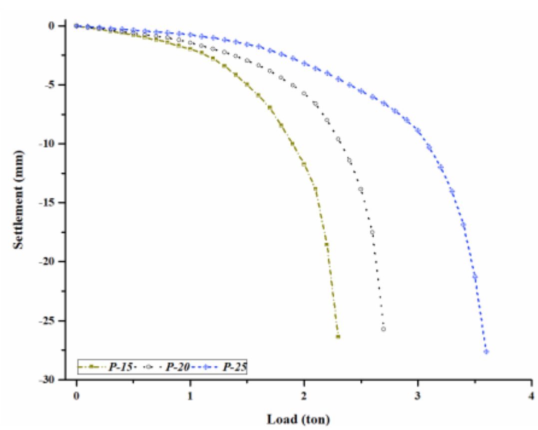

Fig. 5. Load-settlement curve of single shaft

Comparison of ultimate capacity on single shaft of each interpretation method is shown in Fig. 6.

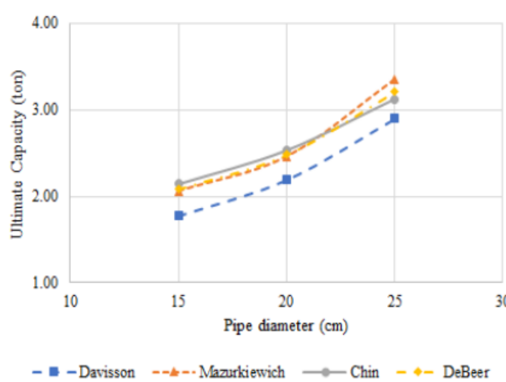

Fig. 6. Comparisons of capacity of single shaft

Davisson method shows increase to 28.08% of pile capacity by increasing the size of diameter. Meanwhile, Mazurkiewich method, shows increase to 27.8% of pile capacity by increasing the size of diameter. Chin and De Beer method shows increase to 20.77% and 24.33%, respectively, of pile capacity by increasing the size of diameter.

C. Analysis of effect of helixes number to the pile axial compressive capacity

Analysis of the axial compressive capacity by increasing the number of helixes is presented in this part. In helical pile, mechanism of pile capacity is the sum of pile friction ($Q_{friction}$) and helical pile capacity (Q_{helix}). Fig. 7 shows the effect of helix to the pile capacity. Ultimate capacity shown is the estimation of De Beer method. De Beer method is selected since it provides smaller ratio compare to other methods.

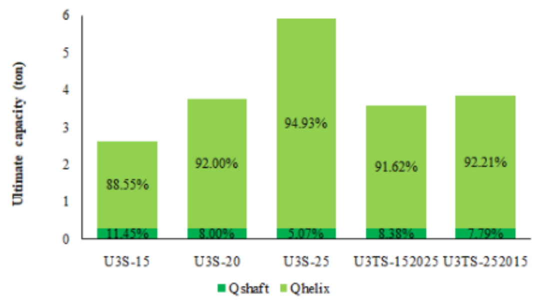

Fig. 7. Load distribution of helical pile

Summary of helical pile load distribution is presented in Table 8.

Pile Notation	Load distribution (%)	
	shaft	***helix***
U3S - 15	11.45	88.55
U3S - 20	8.00	92.00
U3S - 15	5.07	94.93
U3TS - 152025	8.38	91.62
U3TS - 252015	7.79	92.21

Table 8:- Load Distribution of Helical Pile

Overall, in the analysis of the helix number in various helical pile, it can be concluded that the increase of helix number increases the axial compressive capacity of pile, significantly. Helix contribute to ± 91.86% of overall axial compressive capacity.

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D. Analysis of helical pile and single shaft

In this study, ultimate capacity of helical pile is compared with the single shaft. The study analysis is conducted to observe the effect of pile modification to the axial compressive capacity. The analysis is conducted by comparing the axial compressive capacity of helical pile with the uniform helixes and the single shaft.

The proportional of the ratio of total helix distance of the bottom to top helix to the shaft length multiply by the axial compressive capacity of shaft. In this study total distance of the bottom to top helix is 100 cm, while embedded shaft length is 200 cm (50%). Summary of axial compressive capacity and the proportional from the ultimate axial compressive capacity of single shaft based on De Beer method is presented in Table 9.

Diameter (cm)	U3S (cm)	TP (cm)	Increase (%)
	(i)	*(ii)*	*(i/ii)*
15	2.62	1.58	252
20	3.75	2.51	302
25	5.92	4.32	369

Table 9:- Estimation of Ultimate Capacity ff Helical Pile with the Uniform Helixes and Single Shaft Proportional (De Beer)

Table 9 indicates helix 15cm increase pile capacity to 2,96 times compare to the single shaft. Helix diameter 20cm increase pile capacity to 3,42 times and Helix diameter 25cm increase pile capacity to 4,08 times as shown in Fig. 8.

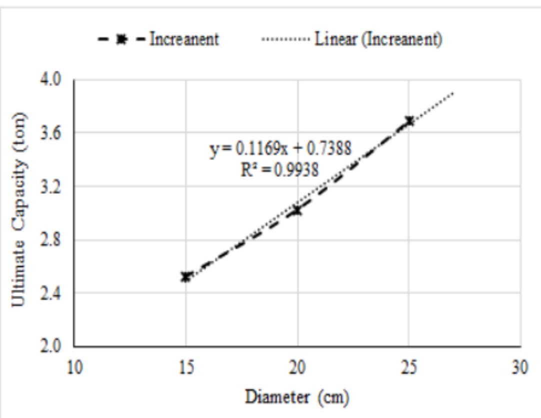

Fig. 8. Axial compressive capacity increase on single shaft compare to helical pile

E. Analysis of helical pile with uniform and non-uniform helixes

Comparison of ultimate capacity of helical pile with different diameter size of helixes and helical pile with the same diameter of helixes is presented in this study. It is made to understand helical pile configuration that contribute to the axial compressive capacity.

Data of helical pile U3TS-152025, U3TS-252015 and U3S-20 is compared since they have similar average helixes area.

Summary of ultimate capacity of every helical pile is presented in Table 6 and Table 7. Based on the data the comparison is conducted in Fig. 9.

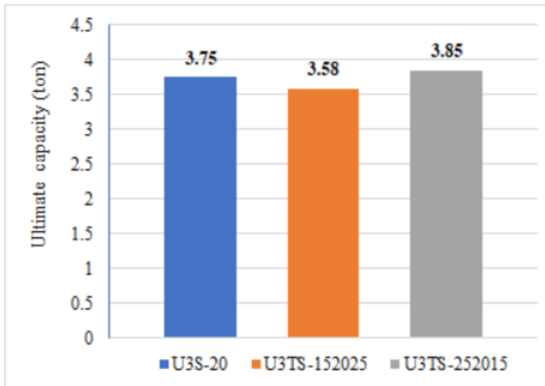

Fig. 9. Diagram of capacity of helical pile with uniform and non-uniform helix

IV. CONCLUSIONS

According to the analysis, the conclusions are as follow:

- Effect of helix diameter which is observed from the static loading test shows significant effect to the ultimate axial compressive capacity. In the helical pile with the uniform helixes, axial compressive capacity increase 252% - 369%, higher than single shaft compare to the de beer method. It shows helical provides larger capacity compare to the single shaft.
- Helix size diameter increase the ultimate axial compressive capacity 43.13% - 60%. The result shows axial compressive capacity increase in line with the helix size.
- Configuration of helix on helical pile with the different size of helix diameter is an economically alternative. Helical pile with helix diameter decreasing from top to the bottom shows larger axial compressive capacity compare to the opposite arrangement of helix and the uniform helixes.

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