Bearing capacity of helical pile foundation in peat soil from different, diameter and spacing of helical plates

F Fatnanta\(^1\), S Satibi\(^1\) and Muhardi\(^1\)

\(^1\) Civil Engineering Dept, Faculty Engineering, Riau University, Campus Binawidya
Jl. HR Subrantas, Pekanbaru 28294 Indonesia
e-mail: fatnanto1964@gmail.com

Abstract. In an area dominated by thick peat soil layers, driven piles foundation is often used. These piles are generally skin friction piles where the pile tips do not reach hard stratum. Since the bearing capacity of the piles rely on the resistance of their smooth skin, the bearing capacity of the piles are generally low. One way to increase the bearing capacity of the piles is by installing helical plates around the pile tips. Many research has been performed on helical pile foundation. However, literature on the use of helical pile foundation on peat soil is still hardly found. This research focus on the study of axial bearing capacity of helical pile foundation in peat soil, especially in Riau Province. These full-scale tests on helical pile foundation were performed in a rectangular box partially embedded into the ground. The box is filled with peat soil, which was taken from Rimbo Panjang area in the district of Kampar, Riau Province. Several helical piles with different number, diameter and spacing of the helical plates have been tested and analysed. The tests result show that helical pile with three helical plates of uniform diameter has better bearing capacity compared to other helical piles with varying diameter and different number of helical plates. The bearing capacity of helical pile foundation is affected by the spacing between helical plates. It is found that the effective helical plates spacing for helical pile foundation with diameter of 15cm to 35cm is between 20cm to 30cm. This behaviour may be considered to apply to other type of helical pile foundations in peat soil.

Keywords : bearing capacity helical piles, helical pile foundation, peat soil, various number and spacing of helical plates.

1. INTRODUCTION
Peat soil is a type of soil with high organic content [1]. Peat soil mainly comprises of water-saturated pores, which turns it to be highly compressible. Due to the high water content, peat soil can be categorized as very soft soil with very low bearing capacity.

To overcome these problems, light construction on peat soil is generally built using cerocok pile or conventional pile foundation. To save costs, the piles are generally installed far above the hard soil layer. Consequently, the axial load carrying capacities of the piles are determined solely by their skin frictions, which are generally low. To increase the pile bearing capacity, the area of the pile tips is increased by installing helical plates at around the tip of the pile foundation.

Many research has been performed on helical pile foundation. However, literature on the use of helical pile foundation on peat soil is still hardly found. Hence, there are still some gaps on the information about the application of helical pile foundation on the peat soil. Method and parameters considerations related to helical pile foundation design on inorganic soil cannot be adopted directly in...
the design of helical pile foundation on peat soils. Therefore, this study was conducted to investigate the behaviour of helical pile foundation in peat soil.

2. METHODOLOGY

2.1 Materials and Equipment

The full scale helical pile loading tests were conducted in a site near the Soil Mechanics Laboratory of Civil Engineering Department, University of Riau. The tests were performed in a rectangular pit filled with peat soil taken from Rimbo Panjang area in the district of Kampar. Before each helical pile loading test was performed, vane shear test on the peat soil close to the test pile was done to obtain the shear strength parameter [2]. The equipment used for the tests is listed in Table 1 and the schematic configuration of the tests is depicted in Figure 1.

| Equipment used for helical pile loading tests |
|-----------------------------------------------|
| Mechanical jack                              |
| Capacity: 5 tons                             |
| Proving ring                                 |
| Capacity: 28 kN and 50 kN                    |
| Dial gauge                                   |
| Maximum displacement: 50 mm                  |
| A rectangular box filled with peat soil       |
| Dimension: 3 x 6 m, height 2.8 m             |

![Figure 1. Schematic configuration of helical pile loading test](image)

2.2 Helical Pile Test Nomenclature

The Helical piles were screwed down to the depth of 2 m in the peat soil. The piles diameter was 6 cm. The installed helical plates were 15, 25, and 35 cm in diameter. The 15cm diameter helical plate is referred as small plate (S), the 25cm diameter helical plate is referred as medium plate (M) and the 35cm diameter helical plate as large helical plate (L), as shown in Figure 2. The number of helical plates and their spacings were varied. The numbers of installed helical plates were 1, 2, or 3 plates. The spacings between plates were 20 cm, 30 cm or 50 cm.
If a helical pile is referred as LMS 30, then the helical pile is installed with three plates and a spacing of 30 cm. The upper plate L (large) is 35 cm diameter, the middle plate M (medium) is 25 cm diameter, and the lower plate S (small) is 15 cm diameter (see Figure 3).

Each helical pile is named based on the number, diameter, and spacing of the helical plates. Several types of helical pile used in this study are tabulated in Table 2.
Table 2. Types of tested Helical Piles

| Helical Plate Diameter, cm | Spacing, cm | Nomenclature |
|---------------------------|-------------|--------------|
| Upper | Middle | Lower |
| - | 35 | 35 | 20 | LL 20 |
| - | 35 | 35 | 30 | LL 30 |
| - | 35 | 35 | 50 | LL 50 |
| - | 35 | 25 | 20 | LM 20 |
| - | 35 | 25 | 30 | LM 30 |
| - | 35 | 25 | 50 | LM 50 |
| 35 | 25 | 15 | 30 | LMS 20 |
| 35 | 25 | 15 | 50 | LMS 30 |
| 35 | 35 | 35 | 50 | LLL 50 |
| - | - | 35 | - | L |
| - | - | - | - | Pile without helical plate |
| - | - | - | - | Cerocok pile |

2.3 Test Procedure and Interpretation of Ultimate Bearing Capacity of Helical Pile

The helical piles were screwed down to the depth of 1.5 m in the peat soil. Before the loading was conducted, field vane shear tests were performed in the peat soil at 50, 100, and 150 cm depth. The axial loading tests for the helical pile foundation was performed using constant rate of penetration method. Mechanical jack, proving ring, and dial gauge were used for the pile test [3]. The rate of penetration was 1 mm per 30 seconds (2 mm/minute). The load was recorded at every 1 mm of settlement. The test was performed until the maximum settlement of 45 mm, which was based on the capacity of the dial gauge. Figure 4 shows typical load-settlement plot based on the data acquired from load test.

The bearing capacity of a foundation is limited by two limit states. First, the ultimate shear failure must be adequate and second, the settlement of the foundation shall not exceed tolerable values [4]. In the case of peat soil, foundation design is most likely governed by settlement, rather than shear strength. Therefore, the bearing capacity is calculated based on 25 mm of [5]. This method is simpler and has the same interpretation for load versus settlement data. For example, in a load-settlement plot shown in Figure 4, the bearing capacity of the helical pile is 8.3 kN which is selected at 25 mm of settlement.
3. RESULT AND ANALYSIS

3.1 Soil Properties
Soil samples were taken at depths of 50 – 100 and 100 – 150 cm. The peat soil properties are tabulated in Table 3.

Table 3. Peat Soil Properties

| Characteristics     | Unit     | Depth (cm)       |
|---------------------|----------|------------------|
|                     |          | 50 - 100         | 100 - 150 |
| Water content       | %        | 190.949          | 236.837   |
| Dry density         | gr/cm³   | 0.273            | 0.236     |
| Specific gravity    |          | 1.355            | 1.480     |
| Ash content         | %        | 35.544           | 54.463    |
| Fibre content       | %        | 5.281            | 6.114     |

Figure 5 shows the peat soil shear strength test results for each foundation type. In Figure 5 it can be seen that the shear strength of the peat soil is between 3.83 to 5.25 kPa. Vane shear test is often used for measuring the shear strength of an organic soil. In engineering practices, some reduction factors are introduced to produce safe design. The reduction factors were developed in response to local experience and practice [6-9].
3.2 Number of Plates
Sprince and Pakrasinsh [10] stated that the bearing capacity of a helical pile is affected by the number of helical plates. This research is conducted to investigate the impact of the number of helical plates to the bearing capacity of helical pile in peat soil. The results show that as the number of helical plates is increased, the bearing capacity is also improved. The improvement of the bearing capacity is caused by the larger surface area of the foundation as the number of helical plates increase. LLL50 helical pile has larger bearing capacity than L50 and LL50, as shown in Figure 6. This indicates that the helical pile bearing capacity is dominated by helical plate resistance. This result agrees with other research on helical pile foundation such as by Rao et. Al. [11] and L.A and Jong [12].

3.3 Plate Spacing
The bearing capacity of helical plate foundation is affected by plate spacing. The use of effective plate spacing will give maximum bearing capacity [14]. In this study, tests were conducted on LL20, LL30, LL50, LM 20, LM 30, and LM 50 helical pile foundations. Test results show that LM 30 and LL20
helical foundation provide maximum bearing capacities, as shown in Figure 7. The result also indicates that effective plate spacing is also influenced by helical plate diameter. The bottom helical plate plays significant role to increase the bearing capacity of helical foundation. LM50 foundation bearing capacity is smaller than LL50. It occurs because the bottom helical plate in LM 50 foundation is of small diameter, thus the end resistance is small.

Figure 7. Load vs settlement with various spacing of helical plate [15]

3.4 Helical Pile Compared with Cerocok Pile (Wooden pile) And Pile Without Helical Plate
The addition of helical plates is aimed to improve the pile sectional area such that the bearing capacity of the foundation will increase. However, the magnitude of the improvement in bearing capacity needs to be checked by comparing helical pile bearing capacity with conventional pile without helical plate. In addition to that, since one of the backgrounds of this study is to find alternative to cerocok pile foundation, it is important to show how much the bearing capacity of a helical pile foundation is improved relative to cerocok pile foundation.

Figure 8 shows that the installation of helical plates significantly increases the bearing capacity of foundation. The bearing capacities of LL20 and LMS 50 helical pile foundations is significantly larger than cerocok pile foundation and pile without helical plate of similar size. The load carrying capacity of cerocok pile is mainly provided by the frictional resistance between the relatively rough pile skin and the soil layer. The pile foundation without helical plate exhibits the smallest bearing capacity. This is due to its smallest diameter of 6 cm and the smoother pile skin surface compared to cerocok pile.

3.5 Prediction vs Measurement
According to Perko [12] there are two methods to approximate the bearing capacity of helical foundation. The first one is individual bearing method, and the second one is cylindrical shear method. Individual bearing method assumes that each helical plate contributes to bearing capacity, whereas cylindrical shear method assumes that the bearing capacity is provided by the friction between the soil and helical plates.

The comparison analysis of pile bearing capacities in this study is conducted using both methods, the individual bearing method and the cylindrical shear method. The peat soil shear strength reduction factor is taken as 0.65, which is slightly higher than 0.5 – 0.57 as suggested by [6] and [7]. The change in reduction factor was done to obtain the smallest error between the predicted and measured bearing capacity.
In Figure 9, it can be observed that the helical pile bearing capacities predicted using individual bearing method is close to the test results. This is indicated by the smallest error value of 18.80%. Therefore, it can be concluded that the shear strength reduction factor of 0.65 of the peat soil shear strength test results and the individual bearing method provides best fit between the measured and predicted values. If the value of shear strength reduction factor is changed, then the error value increases. However, individual bearing method still having lowest error value.

4. CONCLUSION
The conclusion of this research are as follows:
The pile foundation with three uniform helical plates produces the largest bearing capacity compared to helical pile foundations with one and two plates. The bearing capacity of a helical pile is affected by
helical plate spacing. The effective spacing for L (35 cm), M (25 cm), and S (15 cm) helical pile diameters as used in this study is between 20 to 30 cm.

The bottom helical plate plays significant role to increase the bearing capacity of a helical pile foundation. The bearing capacity of LM 50 foundation is smaller than LL 50, which shows that smaller bottom plate gives smaller end point resistance.

The peat soil shear strength reduction factor $s_u$ used in this research is 0.65, which is determined based on the the smallest error of 0.188.

Helical pile foundation exhibits significantly greater bearing capacity than 10,30 cm diameter cerocok pile. Therefore, the application of helical pile foundation in peat soil can be more profitable than cerocok pile foundation.

The individual bearing method provides better prediction on the bearing capacity of helical pile compared to cylindrical shear method.

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