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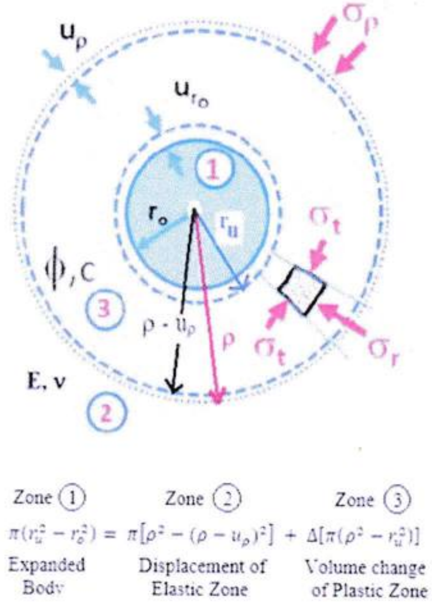

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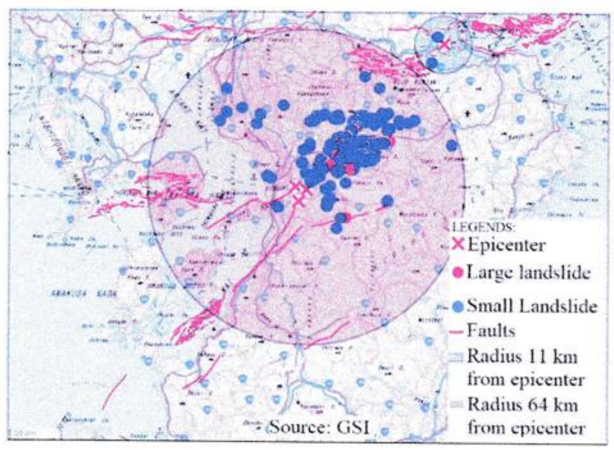

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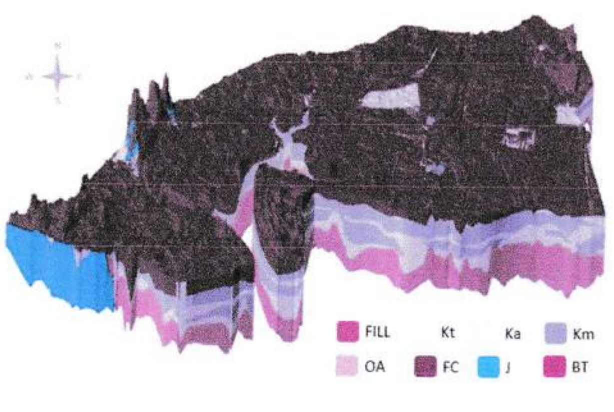

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Paper Contribution, Technical Notes, and Discussions

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2. The paper title must not exceed 70 characters including spaces.

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7. The paper must have an introduction and end with a set of conclusions.

8. Practical applications should be included, if appropriate.

9. If experimental data and/or relations fitted to measurements are presented, the uncertainty of the results must be stated. The uncertainty must include both systematic (bias) errors and imprecisions.

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12. Each author must use SI (International System) units and units acceptable in SI. Other units may be given in parentheses or in an appendix.

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14. References

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Performance of Helix Piled Raft Foundation in Tropical Fibrious Peat Soil Under Traffic Loads

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ABSTRACT: This paper presents the investigation of settlement based performance of helix piled raft foundation under traffic load through analytical and numerical methods. The analytical method is based on the concept of PDR analysis of piled raft where the stiffness of helix piled raft is computed from the stiffness of helix pile and raft with a certain helix piled – raft interaction factor. In this study, the stiffness of helix pile to peat soil is estimated by using a modified Randolph and Wroth equation, incorporating the mechanical behaviour of helix pile. On the other hand, the stiffness of raft is determined by using Richart et al equation. In the numerical model, 3-dimension FEM model of helix piled raft is undertaken in which helix pile is modeled as fixed end anchor, and raft as a plate above soft peat soil. The effect of helix pile number on the bearing capacity and settlement of helix piled raft foundation system is investigated. The results reveal that the stiffness of helix pile is too small compared to the stiffness of raft with the ratio from 1/6 to 1/4. The helix pile stifness is much influenced by the number of helice and the radius of helice in a single helix pile. Since the stiffness of helix pile is small, such critical number of helix piles is needed to have effect on the foundation system. Below this number, helix pile is insignificant to have effect in the helix piled raft foundation system, and the elasticity of the raft plays important role. In general, however, it is obvious that the increasing number of helix piles can decrease the elastic settlement of helix piled raft foundation when it is subjected with traffic load. In the stiffness ratio of helix pile to raft at 1/6, the increasing number of helix pile can reduce the settlement up to 80%, whereas that in the stiffness ratio helix pile to raft at ¼ can reduce the settlement by 65%. These finding s would beneficial for development of alternative helix piled raft foundation for road infrastructure in tropical fibrious peat soil.

KEYWORDS: Tropical fibrious peat soil, Helix piled raft, Stiffness, Elastic settlement.

1. INTRODUCTION

Peat is a type of soil, composed of high contents of fibrous organic materials. This soil is changed and fossilized in wetlands under appropriate climatic (Edil and Dhowian, 1981; Munro, 2005). Peat soil has such problematic mechanical behaviour since it has low shear strength, high compressibility and high water content. These characteristics have contributed to subgrade problem in development road infrastructures with abundant peat soil deposits in most lowland areas in Indonesia such as East Sumatera, Central and South Kalimantan, and West Sulawesi.

Typical peat soil deposit is very thick, up to 30 meters. This condition has led to such difficulty in implementing several soil improvement methods such as soil replacement and piled geotextile reinforcement soil (Arsyad et al., 2013). Moreover, the application of PVD method is also difficult since the permeability of peat is about 1000 × permeability of soft clay (Mesri and Ajlouni, 2007). Although the application of piled raft in peat soil is still challenging (Huat et al., 2014), very low undrained shear strength and creeps of peat soil neccessitates very deep piles for obtaining sufficient bearing capacity (Kazemian et al., 2011).

Alternatif method of combining raft foundation with helix piles in peat soil is needed to be investigated. This is due to previous studies just focus on bearing capacity of helix pile in fibrous peat soil (Adi et al 2016; Parlan et al. 2016). Helix piled raft may present better performance compared to just only helix piles. Thereofore, this study investigates the performance of helix piled raft foundation when it is loaded with traffic loaded, in tropical peat soil.

2. METHOD

2.1 Stiffness of Helix Pile

Screw Pile or helix pile is a pile foundation which consists of helices fixed to the shaft at specific spacing (Arup Geotechnics, 2005). Helix pile is used to compressive and lateral loadings with overturning moments (Schmidt and Nasr, 2004). Analysis used to estimate compressive and tensile bearing strength of helix pile in cohesive soils can be derived from a function of bearing strength of the end of the pile, helix plate bearing and the frictional resistance offered by the shaft-soil interface (Mooney et al., 1985; Narashima et al. 1993). The formulation of bearing capacity for compression is shown in Eq. (1).

$$Q_c = S_f(\pi D L_c)c_u + A_H c_u N_c + \pi d H_{eff} \alpha c_u \qquad (1)$$

where Q_c is ultimate pile compressive capacity, S_f is spacing ratio factor; L_c is distance between top and bottom helical plates; A_H is area of the helix, α is adhesion factor, C_u is undrained shear strength of soil, N_c is compressive bearing capacity factor for cohesive soils, H_{eff} is effective length of pile above top helix ($H_{eff} = H - D$), D = diameter of helix plate.

Stiffness of helix pile to peat soil can be estimated with pile head load-settlement by using a modified model of Randolph and Wroth (1978). However, for helix pile, the model was modified to accomodate the behaviour of helix pile. Due to axial loading, soil below the helical plate, at soil along the cylindrical shear area, and along shaft pile will deform (Figure 1). For shallow helix pile, shaft resistance is too small compared to others resistance (Mohajeneri et al, 2016). As a result, the deformation along the shaft pile does not significantly contribute to pile settlement. The stiffness of helix pile can be determined based on deformation of soil below helical plate and the deformation of soil along cylindrical shear failure as expressed in Eq. (2).

$$\frac{P_t}{G r_0^* w_t} = \left[\frac{4}{\eta(1-\nu)} + \frac{2\pi L_c \tanh(\mu L_c)}{\zeta r_0^* \mu L_c}\right]\left[1 + \frac{4 L_c \tanh(\mu L_c)}{\eta(1-\nu)\pi\lambda r_0^* \mu L_c}\right]^{-1} \qquad (2)$$

$$\mu L_c = \frac{L_c}{r_0^*}\sqrt{\frac{2}{\zeta\lambda}}$$

where

P_t = pile load
G = shear modulus of peat soil
r_o* = radius of cylindrical helix failure zone
w_t = settlement of pile

η = 1
ν = Poisson ratio of peat soil,
λ = Soil – helix pile stiffness ratio, E_p/G
ζ = relation between the radius of influence of the helix pile and the radius of the helix plate, $\ln(r_m/r_0^*)$

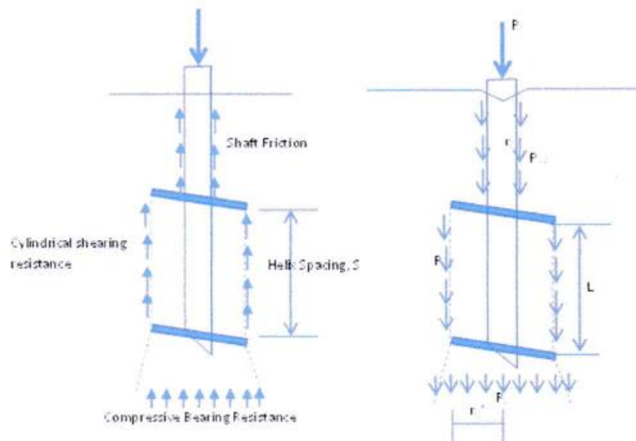

Figure 1 Bearing capacity of helix pile under a compressive load, deformation patterns of helix pile in the upper and lower soil layers

2.2 Stiffness of Helix Piled Raft and Load Sharing

Raft stiffness to peat soil was estimated by using Richart et al (1970), as described by Eq. (3).

$$K_r = \frac{G_s}{(1-v_s)}\beta_z\sqrt{(4cd)} \tag{3}$$

where: G_s is the shear modulus of the soil; v_s is the Poisson's ratio of the soil; and t is the thickness of the raft, and c and d are coefficient raft dimension.

Randolph (1994) introduced that piles are located strategically with the raft in order to reduce differential settlement. Load sharing between the raft and the piles can be estimated using simple method Randolph (1994), and Poulos and Davis (1980), shown in Eq. (4).

$$K_{pr} = \frac{1-0.6\left(\frac{K_r}{K_{hp}}\right)}{1-0.64\left(\frac{K_r}{K_{hp}}\right)}K_{hp} \tag{4}$$

where k_{pr} is stiffness of piled raft; K_{hp} is stiffness of the helix pile group; k_r is stiffness of the raft alone, and β_{hp} is raft – pile interaction factor.

The proportion of the total applied load carried by the helix pile raft is in Eq. (5).

$$\beta_{hp} = \frac{1}{1+a} \tag{5}$$

$$a = \frac{0.2}{1-0.8\left(\frac{K_r}{K_{hp}}\right)}\left(\frac{K_r}{K_{hp}}\right)$$

Tri-linear curve was generated by computing mobilization of the helix pile capacity according to Eq. (6).

$$P_1 = \frac{P_{up}}{\beta_{hp}} \tag{6}$$

$$P_{hp} = \beta_{hp}P \leq P_{up} \tag{7}$$

$$P_r = P - P_{hp} \tag{8}$$

where P_{hp} is load on helix piles, P_r is load on the raft, P_{up} is the ultimate bearing capacity of helix pile group.

3. RESULTS

Analysis of bearing capacity and settlement of helix piled raft in peat soil under axial loading was conducted by incorporating modified Randolph and Wroth (1978) method into Randolph (1994), Poulos and Davis (1980). FEM analysis with PLAXIS 3D was also undertaken to comprehend the result.

3.1 The Stiffness of Helix Pile to Peat Soil

Estimation of the stiffness of helix pile to peat soil was undertaken for homogeneous peat soil. In this case, γ = 7.94 kN/m3, c_u = 5 kPa, E_{peat} = 150 kPa, ν = 0.15 and G = 65.12 kPa. The helix pile has 3 helices with spacing distance of 0.50 m, helix radius of 0.35 m, and length of 2 m. This has resulted in the stiffness of helix pile to peat soil at 334.612 kN/m. If this stiffness was compared to the experimental study based helix pile stiffness to peat soil (300 kN/m) as investigated by Parlan et al. (2016), the result is quite closed. It should be noted that the dimension of helix pile is similar between analytical and experimental, LLL50. In the case of LL30 model, the stiffness obtained through analytical method was found at 312,43 kN/m, which has relatively closed to experimental based helix pile stiffness at 269, 23 kN/m.

The effect of number and radius of helices on the stiffness of helix pile were also examined. As shown Figure 2, the increase of number of helices in helix pile would increase its stiffness. In addition, the increase of helice radius also would increase helix pile stiffness (Figure 3). The stiffness of helix pile to peat soil depends on young modulus of peat soil. The larger young modulus of peat soil, the higher helix pile stiffness will be.

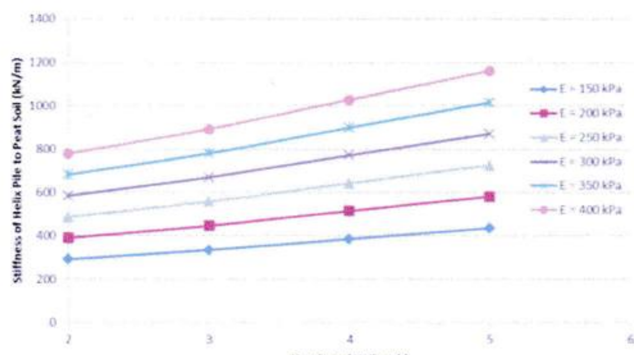

Figure 2 The effect of number of helices on the helix pile stiffness to peat soil

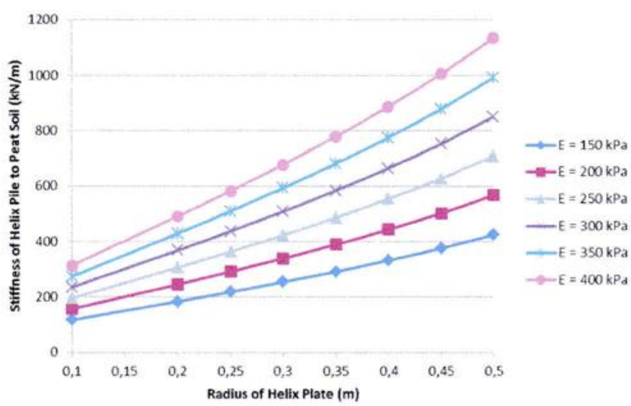

Figure 3 The effect of helice radius on the helix pile stiffness to peat soil

Raft stiffness was estimated in this study. For the raft with area of 100 m^2, in peat soil with shear modulus of 65.217 kN/m2 and ν of 0.15, is 1,687 kN/m. The raft stiffness increases as the dimension of the raft and the shear modulus of peat soil aslo increase. Fot the raft with area of 400 m^2 and the shear modulus at 173.913 kN/m2, the raft stiffness would be at 8,184 kN/m, and that with area of 900 m^2, the stiffness is 12,276 kN/m.

3.2 Settlement of Helix Piled Raft in Peat Soil Under Traffic Load: Analytical Model

We analysed the effect of the number of helix piles on elastic settlement of helix piled raft foundation system. A segment of raft with dimension of 10 m × 10 m with a 0.2 m thick was modeled and subjected with truck loads of 65 tons. The raft lies over a very soft peat soil with soil properties (E = 150 kPa, ν = 0.15 and C_u = 5 kPa). In the model, the helix pile stiffness was assumed at 300 kN/m. The result is shown in Figure 4. It is found that increasing number of helix pile would reduce the elastic settlement of the foundation system under traffic load. However, since the helix pile has a quite lower stiffness compared to the raft (1/6 to ¼), the effect of helix pile is only seen with minimum number of helix pile of about 12 piles. It means that below that quantity, there is no effect of helix pile and raft foundation is still working as a single foundation system without any support from helix pilex.

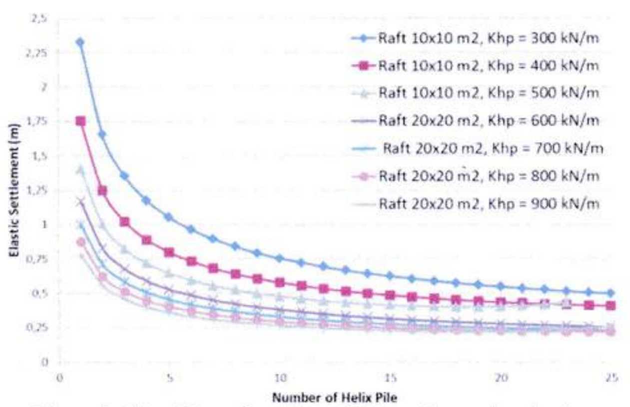

Figure 4 The effect of number of helix piles on the elastic settlement of helix piled raft foundation under traffic load with helix pile stiffness from 300 kN/m to 900 kN/m

In Figure 5, it can be seen that load sharing carried by helix piles is just 10% of the total load at the minimum number of 12 helix piles. This will increase as the number of helix piles increases. At the 25 helix piles under the raft foundation, the load sharing carried by helix pile achieves 65% (Figure 6). It should be noted that the ratio of a single helix pile stiffness to the raft stiffness is only 0.18 at a single pile, up to 0.89 at 25 helix piles.

If the raft dimension and the stiffness of helix pile increase, the elastic settlement would decrease. The more helix piles under the raft, the lower elastic settlement would be (Figure 5). It is obvious that there is critical number of helix piles where beyond this number, their effects on the elastic settlement seems to be unchanged. The critical number is much influenced by helix pile stiffness to peat soil. The larger helix pile stiffness to peat soil, the smaller critical number of helix piles required. The critical number of helix piles is about 10 piles when the helix pile stiffness at 900 kN/m, whereas that is about 21 piles when the helix pile stiffness at 400 kN/m to peat soil.

Figure 7 presents the effect of helix pile quantity on the elastic settlement of helix piled raft foundation system under traffic load, with larger helix pile stiffness and raft dimension. Similar results were found that the more helix piles, the lower elastic settlement of helix piled foundation would be. The elastic settlement becomes about 10 cm when 25 helix piles installed under raft foundation. Load sharing ratio has becomes significant at large stiffness of helix pile. It can be seen in Figure 6, helix pile stiffness of 3000 kN/m can support more than 50% of the total load, supported by only 2 helix piles installed. Load sharing increases to 90% when 11 helix piles installed under raft. However, helix pile stiffness under 1000 kN/m, the load sharing ratio seems to be much lower than that for helix pile stiffness above 1000 kN/m.

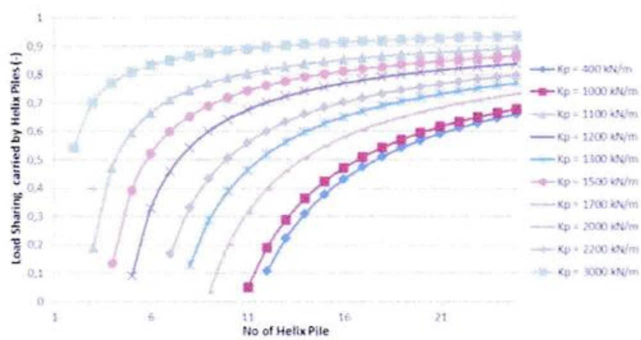

Figure 6 Load sharing ratio carried by helix piles at varies helix pile stiffness to peat soil

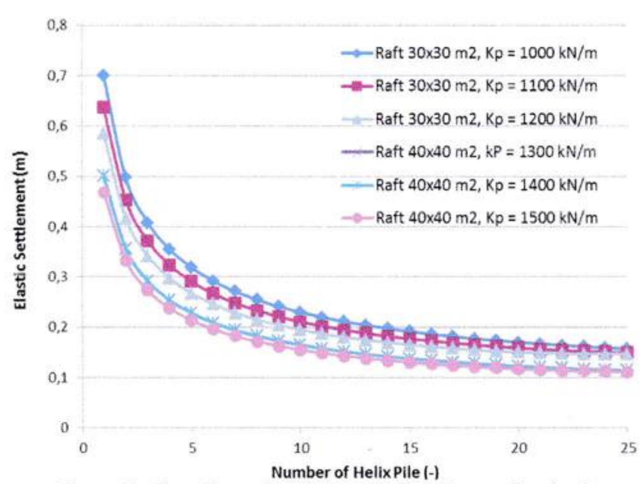

Figure 7 The effect of number of helix piles on the elastic settlement of helix piled raft foundation under traffic load, with helix pile stiffness varies from 1000 kN/m to 1500 kN/m

3.3 Elastic Settlement of Helix Piled Raft in Peat Soil: FEM Model

A three-dimension FEM modeling of helix piled raft foundation in peat soil was undertaken. The traffic load on the helix piled raft foundation was modeled as dynamic load with amplitudo 235 kN/m^2 with sample pulse at 0.20 sec duration, or 5 Hz frequency. The traffic load of 235 kN/m^2 is based on a load of full loaded 1.2H truck with 14 tons and equivalent radii of tire contact area of 250 mm (back wheels). However, since the raft is very rigid, so the load is distributed to the ground as line load of 60 kN/m. Meanwhile, the helix piles under raft foundation configurates a certain pattern distribution plans as shown Figure 8. The pattern distribution of helix piles with raft foundation varies from 5, 9, 16, and 25 piles. The helix pile itself was modeled as fixed end anchor with stiffness (EA), whereas, the raft foundation 6 m × 6 m was modeled as plate with d of 0.20 m, γ of 25 kN/m3, and E of 2.1×10^6 kN/m^2, and ν of 0.15, indicating a very rigid plate.

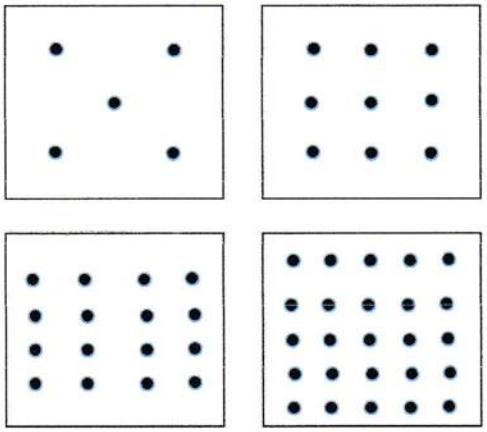

Figure 8 Helix piles with raft foundation distribution patterns plan

For tropical fibrous peat soil, the model employed soft peat soil based on hardening soil constitutive model with several mechanical parameters including a γ_{unsat} of 10 kN/m^3, γ_{sat} of 12 kPa, E_{50} of 1200 kPa, E_{oed} of 1200 kPa, and E_{ur} of 3600 kPa. The undrained cohesion is 1 kPa, with shear angle of 27°. The soil properties are typical mechanical parameters of peat soil in Bereng Bengkel Central Borneo (Susila et al. 2012).

Several stages of construction were employed in the FEM model. It consists of initial phase, helix piled raft construction, loading with traffic load. The performance of helix piled raft was investigated including elastic and consolidation settlement. The effect of helix pile number on the elastic settlement of helix pile raft foundation was examined. It can be seen that, the increase of helix pile number would decrease the elastic settlement of the foundation system (Figure 9). The larger helix pile stiffness generates the lower settlement of the helix piled raft foundation system. The stiffness of helix pile to the peat soul is critical at 1500 kN/m. Beyond that, the effect is insignificant. The critical number of helix pile is about 5 helix piles. The settlement at this number of helix piles is less than 5 cm.

In regards of consolidation settlement (Figure 10), similar results is obtained that the critical stiffness of helix pile at 1500 kN/m. However, the critical number is 9 helix piles which can generated consolidation settlement less than 5 cm. Based on those results, the helix piles spacing under raft foundation for better performance with small settlement is about 2 m to 3 m.

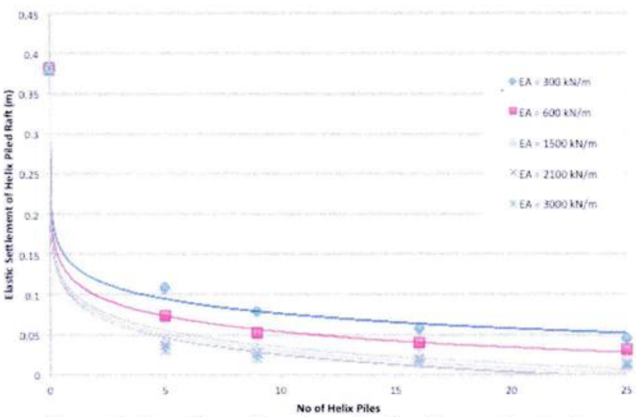

Figure 9 The effect of number of helix piles on the elastic settlement of helix piled raft foundation obtained from FEM model

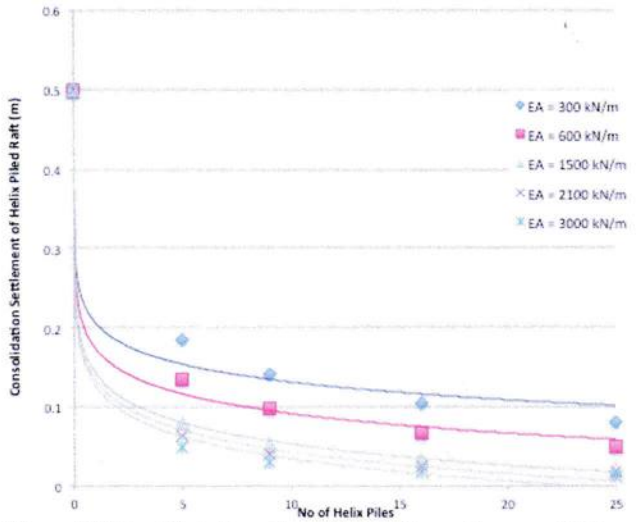

Figure 10 The effect of number of helix piles on the consolidation settlement of helix piled raft foundation obtained from FEM model

4. CONCLUSION

- The increase of number of helix piles under raft foundation in peat soil can reduce the elastic settlement of the foundation from 65% to 80%.
- Critical number of helix pile is found at about 10 piles to 21 piles, depending of the stiffness of helix pile. Beyond this number, the reduction of elastic settlement is less significant. From FEM Model, the critical number of helix pile is from 9 to 16 piles, with minimum stiffness at 1500 kN/m.
- Load sharing carried by helix pile varies from 10% (1 pile) to 65% (25 piles). This is influenced by the ratio stiffness of helix pile to raft. The larger stiffness ratio of helix pile to raft, the larger load sharing carried by helix pile will be.

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