Influence of Pile Spacing to Immediate Settlement of Short Piled Raft Foundation System on Peat Soil under Static Load

Sajiharjo Marto Suro
Institut Teknologi PLN

Dyah Pratiwi Kusumastuty
Institut Teknologi PLN

Kasbi Basri
Universiti Tun Hussein Onn Malaysia

Adnan Zainorabidin
Universiti Tun Hussein Onn Malaysia

ABSTRAK: Sistem pondasi rakit bertiang pendek adalah modifikasi dari pondasi rakit bertiang, yang panjang tiangnya relatif pendek. Jarak tiang merupakan parameter variabel yang penting, terkait dengan penurunan segera. Oleh karena itu pengaruh jarak tiang perlu dipelajari. Metode elemen hingga digunakan untuk mensimulasikan kinerja stabilitasnya. Sistem pondasi Rakit Bertiang Pendek dengan pelat beton 7,0 m x 7,0 m persegi dan tebal 0,15 m diasumsikan dibangun di atas lapisan tanah gambut 3,5 m. Diameter luar tiang adalah 0,32 m dan panjang tiang 3,00 m, sedangkan jarak tiang bervariasi dari 0,50 sampai 3,00 m. Beban titik bervariasi dari 0 sampai 100 kN diasumsikan sebagai beban statis, yang bekerja pada bagian tengah pelat beton. Dengan membandingkan setiap hasil simulasi numerik, dapat disimpulkan bahwa jarak tiang 1,00 m merupakan jarak yang optimal, menghasilkan penurunan segera sebesar 31,80 mm.

Kata Kunci: sistem pondasi rakit bertiang pendek, jarak tiang, penurunan segera

ABSTRACT: Short piled raft foundation system is a modified piled raft, which the pile length is relatively shorter. Pile spacing is an important variable parameter, related to immediate settlement. Therefore, the influence of pile spacing need to be studied. Finite element method was used to simulate the stability performance. Short Piled Raft foundation system with concrete slab of 7.0 m x 7.0 m square and thickness of 0.15 m was assumed to be built on 3.5 m peat layer. The outer diameter of pile was 0.32 m and pile length was 3.00 m, while the pile spacing varied from 0.50 to 3.00 m. Point load varied from 0 to 100 kN was considered as a static load, acted on the centre of the concrete slab. By comparing each numerical result of simulations, it could be concluded that 1.00 m pile spacing was an optimal one, produced immediate settlement of 31.80 mm.

Keywords: short piled raft foundation system, pile spacing, immediate settlement

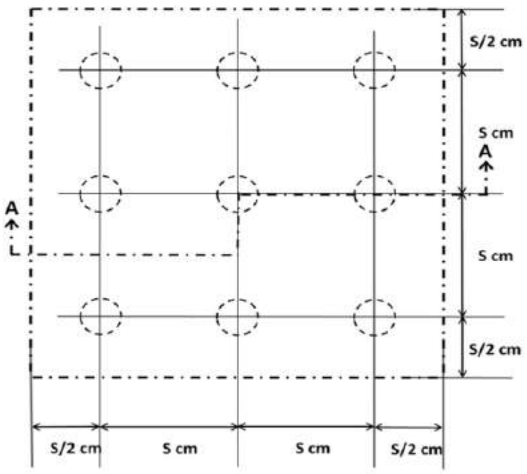
1 INTRODUCTION

The last few decades, due to limited land available, many construction projects have penetrated into the problematic soil area, with some of the problems faced, Patil et al. (2013). Completion of construction by using a conventional foundation system such as pile foundation system is still considered to be quite expensive, Effendi (2013). To overcome these problems, several foundation systems have been developed, among others, is a piled raft foundation, which the concept of this system has received considerable attention in recent years, Prakoso and Kulway (2001) and even proves to be more effective on such conditions, increasingly recognized as a foundation more economical and effective on problematic soil, Srilakshmi and Moudgalya (2013).

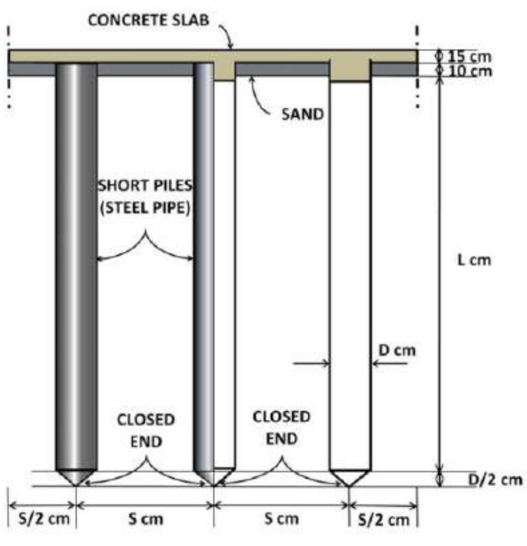
Moreover, especially at peat area, the construction method on peat is different for the different depth of peat, Bakar (2014). For peat with the depth less than 3 m, removal and replacement method are usually used. For the depth of 3 m to 10 m, engineers normally used sand drain, lightweight fills and stone column. While for the depth more than 10 m, the suitable method is deep stabilization techniques such as pile and dynamic compaction. This condition motivates to develop a foundation system that can be directly implemented on peat with the depth of 3 m to 10 m, neither by using removal and replacement method nor soil stabilization.

2 SCOPE, LIMITATION AND OBJECTIVE

In this study, a Short Piled Raft (hereinafter abbreviated as SPR only) foundation system was introduced, built on peat which is known as problematic soil. SPR foundation system is a modified piled raft foundation system, which is a combination between pile foundation and raft foundation, which the pile length relatively shorter, with a ratio between the length and diameter of pile not more than 20, Das and Sivakugan (2019), and considered as a reinforced concrete slab resting on a number of piles. Typical of SPR foundation system can be seen in Fig. 1.



(a)



(b)

Fig. 1. SPR Foundation System; (a) General Plan; (b) Cross Section A-A.

The basic concept of SPR foundation system considers that the thin concrete slab floats on the supporting soil while the piles serve as stiffeners slab concrete and also to improve stability performance by reducing settlement of the foundation, Tandjiria (1999).

The scope of this study was to simulate behaviour of SPR foundation system, on peat soil with different pile spacing under static load, especially related to immediate settlement.

The limitation of this study was only conducted numerically, with a certain condition e.g., on peat with the layer thickness of 3.5 m, constant ground water level, consolidated drained, the thickness of concrete slab, length and diameter of pile assumed to be constant.

While the objective of this study was to investigate the influence of pile spacing to immediate settlement of SPR foundation system on peat soil under static load, by using finite element method program for simulation.

3 FINITE ELEMENT METHOD

A three-dimensional finite element method program, namely Plaxis 3D Foundation was used. Plaxis 3D Foundation is a special purpose three-dimensional finite element program used to perform deformation and stability analysis for various types of geotechnical applications. With Plaxis 3D Foundation, complex geometry of soil and structures can be defined in two different modes. These modes are specifically defined for soil or structural modeling.

The finite element method provides a valuable analytical tool for the analysis and design of foundations. Since the piled raft is typical example of soil - structure interaction, a special type of element at pile – soil interface, simulating the displacement discontinuity between the pile and the soil mass is needed. Hence, PLAXIS 3D Foundation, in which the pile is assumed as a slender beam element, Dao (2011).

The pile-soil interaction is governed by relative movements between the pile nodes and the soil nodes. The connection between these nodes is established by means of special – purposed non – linear spring representing the pile - soil contact at the base. Based on the materials, linear elastic material model is used for concrete and steel pile structure to simulate their stress – strain behavior, while the Soft Soil Creep model is used for peat, Brinkgreve (2007) and for soft clay under the peat layer, the

Mohr - Coulomb model is selected, Qaissy *et al*. (2013).

4 METHODOLOGY

An SPR foundation system with the size of 7.0 m x 7.0 m was considered as a model simulation. Concrete slab was set as 0.15 m thickness. Pile outer diameter D was 0.32 m with the wall thickness of 0.003 m of galvanized steel pipe to be selected, by considering availability on the market.

Point load varied from 0 kN to 100 kN with increment of 20 kN were considered as a static load, acted on the centre of the concrete slab.

While the site of selected problematic soil area, as a model in this study was Parit Nipah Darat, Batu Pahat, Johor, Malaysia. Peat layer at Parit Nipah Darat has depth from 0.0 m to 3.0 m, while at depth 3.0 m – 3.5 m, peats have mixed clay and at depth of ≥ 3.5 m is completely soft clay, as illustrated in Fig. 2.

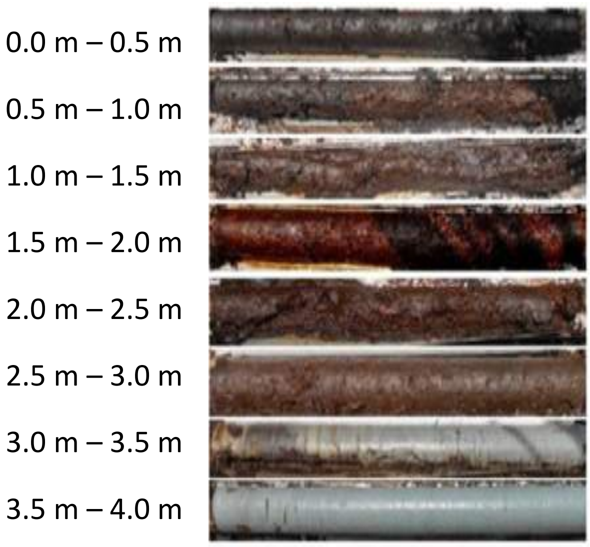


Fig. 2. Soil Profile of Parit Nipah Darat Using Peat Sampler, Said et al. (2014).

The simulations were conducted by applying pile spacing of 0.50 m, 0.75 m, 1.00 m, 1.50 m, 2.00 m and 3.00 m in each simulation series respectively. In order to obtain the best configuration of piles, some simulation series by applying varies load at the centre of raft should be conducted with the scenario as shown in Table 1.

Table 1. Variation of Pile Spacing for Simulation.

No.	Pile Spacing (m)	Number of Piles	Loading (kN)
1.	0.50	169	20, 40, 60, 80, 100
2.	0.75	81	20, 40, 60, 80, 100
3.	1.00	49	20, 40, 60, 80, 100
4.	1.50	25	20, 40, 60, 80, 100
5.	2.00	16	20, 40, 60, 80, 100
6.	3.00	9	20, 40, 60, 80, 100

Parameters used for simulating the SPR foundation system in this study as shown in Table 2.

5 RESULTS AND DISCUSSIONS

Illustration of SPR foundation system in numerical model is shown in Fig. 3.

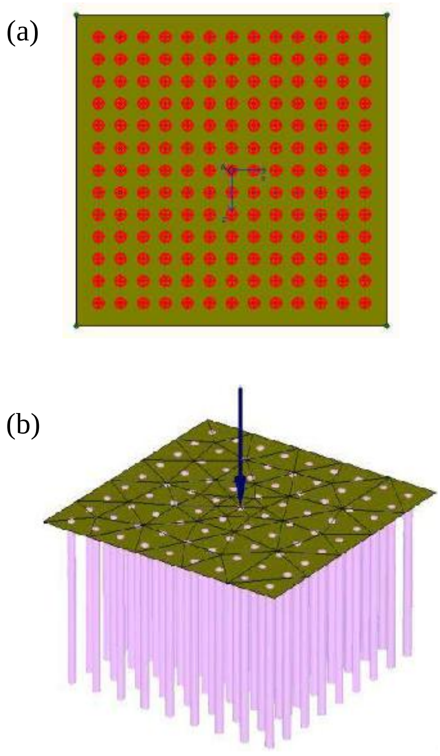


Fig. 3. Model of SPR Foundation System with 7.0 m x 7.0 m Concrete Slab, (a) Plan with Pile Spacing of 0.50 m; (b) Upper View with Pile Spacing of 0.75 m.

Table 2. Soil, Pile and Raft Parameters used for SPR Foundation System Simulation.

Soil properties (Peat)	Obtained from	Value
C	Laboratory test	4.0 (kN/m^2)
φ	Laboratory test	16 (^{0})
E_{ref}	Plaxis 3-D's suggestion	200 (kN/m^2)
γ_{unsat}	Plaxis 3-D's suggestion	10 (kN/m^3)
γ_{sat}	Plaxis 3-D's suggestion	11 (kN/m^3)
V	Plaxis 3-D's suggestion	0.12
Thickness of layer	Previous research	3.50 (m)
Soil Properties (Soft clay)	**Obtained from**	**Value**
C	Previous research	5.0 (kN/m^2)
φ	Previous research	25 (^{0})
E_{50}	Plaxis 3-D's suggestion	2000 (kN/m^2)
γ_{unsat}	Plaxis 3-D's suggestion	16 (kN/m^3)
γ_{sat}	Plaxis 3-D's suggestion	17(kN/m^3)
V	Plaxis 3-D's suggestion	0.3
Thickness of layer	Determined for numerical model simulation purposes	$\geq$ 16.50 (m)

While before calculating immediate settlement, generated 3-D mesh of SPR foundation system, automatically formed is shown in Fig. 4.

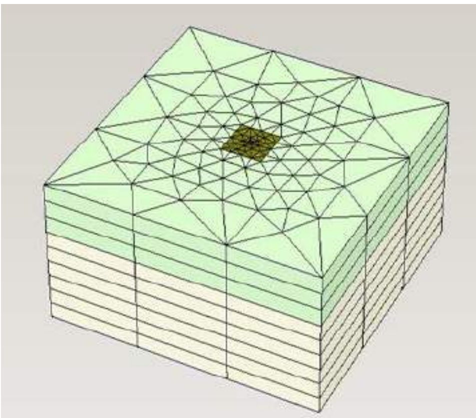


Fig. 4. Generated 3-D Mesh of SPR Foundation System Model.

Simulation by calculating of immediate settlement consist of several steps. Starting from initial condition, followed by activating piles, and then activating concrete slab, and finally activating point load from 0 kN up to 100 kN with increment of 20 kN. These steps were conducted for each pile spacing from 0.50 m, 0.75 m, 1.00 m, 1.50 m, 2.00 m and 3.00 m.

The results of these simulations are tabulated in Table 3a. and Table 3b. as follows.

Table 3.a. Relationship between Pile Spacing and Settlement Under the Load of 0 – 40 kN.

Spacing (m)	Load (kN)		
	0	20	40
	Settlement (mm)		
0.50	30.52	32.20	33.88
0.75	22.41	24.28	26.16
1.00	19.94	21.97	24.01
1.50	19.58	21.97	24.36
2.00	21.28	23.97	26.80
3.00	25.94	29.69	33.43

Table 3.b. Relationship between Pile Spacing and Settlement Under the Load of 60 – 100 kN.

Spacing (m)	Load (kN)		
	60	80	100
	Settlement (mm)		
0.50	35.56	37.23	38.91
0.75	28.03	29.91	31.78
1.00	26.04	28.08	30.11
1.50	26.76	29.22	31.80
2.00	29.73	32.65	35.57
3.00	37.19	40.95	44.74

These results of simulations can also be presented graphically as shown in Fig. 5. It can be seen, that in general if the spacing of pile increases (more than 1.0 m), the settlement will increase and so if the spacing of pile decreases (less than 1.0 m), the settlement will also increase. Das (2011) stated that ideally, the piles in a group should be spaced so the load-bearing capacity of the group is not less than the sum of the bearing capacity of the individual piles. In practice, the minimum centre-to-centre pile spacing is 2.5 D and, in ordinary situations, is actually about 3 to 3.5 D.

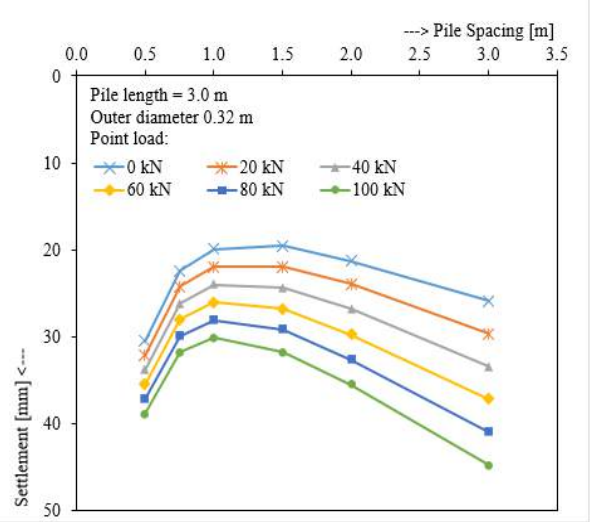


Fig. 5. Relationship between Pile Spacing and Settlement Under the Load of 0 – 100 kN.

While based on previous research, pile spacing is 2.08 D, Tandjiria (1999), 4D, Prakoso (2001), 5D – 13.3 D, Hardiyatmo (2011), 1.5D – 2D, Sönmez (2013) and 5 D, Waruwu (2017).

It means that when the piles are placed close to each other, a reasonable assumption is that the stresses transmitted by the piles to the soil will overlap, reducing the load-bearing capacity of the piles. Moreover, if pile spacing decreases (in this case less than 1.0 m), the total weight of foundation relatively heavier and leads to contribute larger settlement.

While for the piles are placed more than 1.00 m, the number of piles in a group will decrease, causes the load-bearing capacity of the group also decreases and leads to contribute larger settlement. It can be seen that in the case of SPR foundation system with 7.0 m x 7.0 m of concrete slab and vertical static load of 0, 20, 40, 60, 80 and 100 kN on it, at the center of concrete slab, then pile spacing of 1.0 m produces the minimum settlement. Therefore, the pile spacing influences on immediate settlement of SPR foundation system significantly. In this study, the optimum pile spacing was 1.00 m. In this case, 3 to 3.5 D is equal to 0.96 m to 1.12 m, it means that the optimum pile spacing 1.0 m is in that range.

6 CONCLUSION

Based on the results and discussions, it can be drawn some conclusions as follows. When the piles are placed too close to each other, it will cause reducing the load-bearing capacity of the piles. Moreover, if pile spacing decreases, the total weight of foundation relatively heavier and leads to contribute larger settlement. While for the piles are placed too far, the number of piles in a group will decrease, causes the load-bearing capacity of the group also decreases and leads to contribute larger settlement. In this study, pile spacing of 1.0 m was an optimum pile spacing and produced the minimum settlement. Therefore, it is obviously that the pile spacing influences to immediate settlement of SPR foundation system significantly.

ACKNOWLEDGEMENTS

The authors wish to express their gratitude to Research Centre for Soft Soil – Universiti Tun Hussein Onn Malaysia (RECESS – UTHM) for their supports and provision of excellent facilities during this study.

REFERENCES

Bakar, I. 2014. Challenges in Peat Soil Research - Malaysian Experiences. *South East Asia Conference on Soft Soils Engineering and Ground Improvement*. Bandung.

Brinkgreve, R.B.J. 2007. *Plaxis 3D Foundation, Version 2*. Delft University of Technology and Plaxis bv, The Netherlands.

Dao, T.P.T. 2011. *Validation of PLAXIS Embedded Piles for Lateral Loading*. Master of Science Thesis, Delft University of Technology, The Netherlands.

Das, B.M. 2011. *Principles of Foundation Engineering*. *Seventh Edition*. Boston: Cengage Learning.

Das, B.M., & Sivakugan N. 2019. *Principles of Foundation Engineering*. 9th Edition. Boston: Cengage Learning.

Effendi, S. 2013. Cakar Ayam Soft Foundation System Revisited. *Soft Soil Engineering International Conference*. Kuching, Sarawak.

Hardiyatmo, H. C. 2011. *Analisis dan Perancangan Fondasi II*. Edisi Kedua, Gadjah Mada University Press, Yogyakarta.

Patil, J. D., Vasanvala, S. A. & Solanki, C. H. 2013. *A* Study on Piled Raft Foundation: State of Art. *International Journal of Engineering Research & Technology* (IJERT).

Prakoso, W.A. & Kulway, F.H. 2001. Contribution To Piled Raft Foundation Design. *Journal of Geotechnical and Geoenvironmental Engineering*.

Qaissy, M.A., Karim, H.H. & Hameedi, M.K. 2013. Behavior of Experimental Model of Piled Raft Foundations on Clayey Soils. *1st International Conference for Geotechnical Engineering and Transportation ICGTE*.

Said, M. J. M., Zainorabidin, A. & Madun, A. 2014. Seismic Refraction on Peat Soils at Parit Nipah. *South*

East Asia Conference on Soft Soils Engineering and Ground Improvemnet. Bandung.

Sőnmez, N. 2013. *A Study on Design of Piled Raft Foundation Systems.* Middle East Technical University. MSc Thesis.

Srilakshmi, G. & Moudgalya, D. 2013. Analysis of Piled Raft Foundation Using Finite Element Method. *International Journal of Engineering Research and Science & Technology* Vol. 2, No. 3.

Tandjiria, V. 1999. Numerical Modelling of Chicken-Foot Foundation. *Dimensi Teknik Sipil* Volume 1, no. 1 Maret.

Waruwu, A., Hardiyatmo, H. C. & Rifa'i, A. 2017. Behaviour of Nailed-Slab System on Peat Soil Under Loading. *The 1st Warmadewa University International Conference on Architecture and Civil Engineering*. Bali, Indonesia.