Pile Spacing Optimization of Short Piled Raft Foundation System for Obtaining Minimum Settlement on Peat

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Abstract. Short Piled Raft is a modified piled raft foundation system, which represents combination between raft foundation and pile foundation, but the length of pile is relatively shorter. The basic concept of the Short Piled Raft foundation system considers the passive soil pressure creating a stiff condition of slab-pile system. This means that the thin concrete slab floats on the supporting soil, while the piles serve as stiffeners concrete slab and also to reduce settlement of the foundation. Slab to pile ratio of such system has been mentioned by several researchers, however the optimum pile spacing of stability performance for obtaining minimum settlement on peat haven't been clearly discussed. In this study, finite element method to simulate the stability performance related to settlement of Short Piled Raft foundation system was used. Short Piled Raft foundation system with concrete slab of 7.0 m x 7.0 m square was assumed to be built on peat with the thickness of 3.5 m. The material properties of pile and raft were constant. The outer diameter of galvanized steel pipe as pile was 0.30 m; raft thickness was considered to be constant of 0.15 m and the length of pile was 3.00 m, while the pile spacing varied from 0.50 to 3.00 m. Point load varied from 0 to 100 kN with increment of 20 kN was also considered as a static load, acted on the centre of the concrete slab. Optimization was done by comparing each numerical result of simulations, thus conclusion can easily be drawn. The optimum pile spacing was 1.00 m which produced minimum settlement of 30.11 mm under the load of 100 kN.

Keywords: Soft soil, ground modification, pile raft.

1. Introduction

Currently, due to limited land available, many construction projects have penetrated into the problematic soil area, with some of the problems faced [1]. Completion of construction by using a conventional foundation system such as pile foundation system is still considered to be quite expensive [2]. 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 [3] and even proves to be more effective on such conditions, increasingly recognized as a foundation more economical and effective on problematic soil [4]. Moreover, especially at the peat

area, the construction method on peat is different for the different depth of peat [5]. For peat with depth less than 3 m, the removal and replacement method are usually used. For the depth 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 that can be directly applied on peat with the depth less than 3 m, neither using removal and replacement method nor soil stabilization.

In this study, a Short Piled Raft foundation system was introduced, built on peat which is known as problematic soil. Short Piled Raft foundation system is a modified piled raft foundation system, which is a combination between pile foundation and raft foundation, with the pile length relatively shorter, and considered as a reinforced concrete slab resting on a number of piles. The general plan and cross section of Short Piled Raft foundation system are shown in Fig.1. The basic concept of Short Piled Raft foundation system considers passive soil pressure creating a stiff condition of slab-pile system. This means 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. Slab to pile ratio of such system has been mentioned by several researchers [6], however the optimum pile spacing of stability performance for obtaining minimum settlement on peat haven't been clearly discussed.

In this parametric study, concrete slab of 7.0 m x 7.0 m square as a raft was assumed and the material properties of pile and raft were constant whereas peat was used. The raft thickness was considered to be constant of 0.15 m and the outer diameter of pile was 0.30 m; the length of pile was 3.00 m. To find out the optimum pile spacing of Short Piled Raft Foundation System, piles spacing varied from 0.50 m, 0.75 m, 1.00 m, 1.50 m, 2.00 m and 3.00 m were observed. 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. The settlements that caused by the varying point load have been investigated.

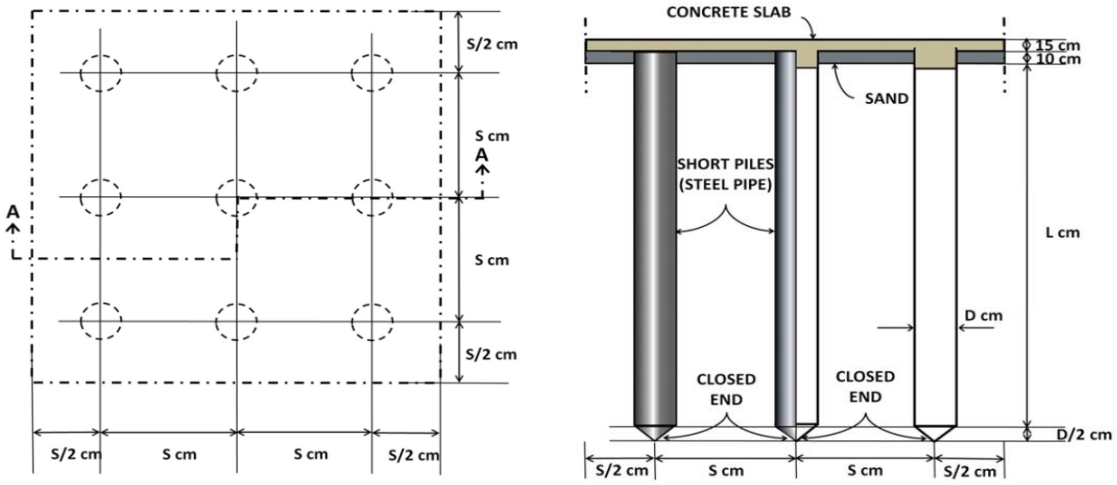


Figure 1. Short Piled Raft Foundation System; **(a)** general plan; **(b)** cross section A-A.

2. Scope and Limitation

The scope of this study is to determine the optimum pile spacing of Short Piled Raft foundation system by trial and error, using finite element method program for simulation, then comparing the results and finally to select the pile spacing that produced the minimum settlement.

The limitation of this study is 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 and considered static load. While the thickness of concrete slab, length and diameter of pile assumed to be constant.

3. Finite Element Method

In this study, 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. The program uses a convenient graphical user interface that enables users to quickly generate a geometry model and finite element mesh. 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 incorporates "Embedded pile" model, in which the pile is assumed as a slender beam element [7].

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 structure to simulate their stress – strain behavior, while the Mohr - Coulomb model is used for soft soil. [8]

4. Numerical Result

In this study, a Short Piled Raft 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 and 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. Parameters used for simulating the short piled raft foundation system as shown in Table 1.
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.

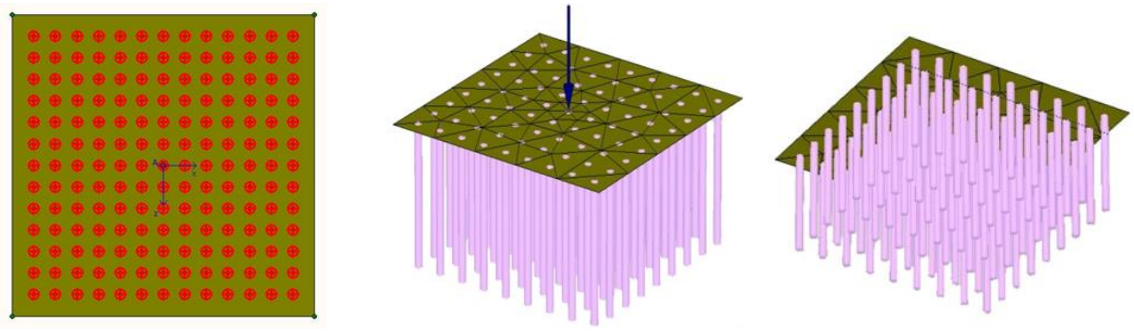
Table 1. Soil, pile and raft parameters used for Short Piled Raft foundation simulation.

Soil (Peat) Properties	
C	4.0 [kN/m^2]
ϕ	16 [^{0}]
E_{ref}	200 [kN/m^2]
γ_{unsat}	10 [kN/m^3]
γ_{sat}	11 [kN/m^3]
v	0.12
Thickness of layer	3.50 [m]
Soil (Soft Clay) Properties	
C	5.0 [kN/m^2]
ϕ	25 [^{0}]
E_{50}	2000 [kN/m^2]
γ_{unsat}	16 [kN/m^3]
γ_{sat}	17 [kN/m^3]
v	0.3
Thickness of layer	6.50 [m]

Short Piled Raft Foundation	
Thickness of raft	0.15 [m]
Point Load (varies)	0 to 100 [kN]
Outer pile diameter	0.30 [m]
Thickness of pipe	0.005 [m]
Pile length	3.0 [m]
Pile spacing (varies)	0.5 to 3.0 [m]

Illustration of Short Piled Raft foundation system in numerical model is shown in Figure-2, while generated 3-D mesh of Short Piled Raft foundation system is shown in Figure-3.

Based on the determined parameters, the results of simulation are shown in Table 2 and in order to obtain a more informative, the results are displayed graphically as shown in Figure-4. By comparing the numerical results of each simulation, it can be seen that the optimum pile spacing was identified to be 1.00 m. If the pile spacing increased (more than 1.0 m), in general the settlement will become greater, likewise, if the pile spacing decreased (less than 1.0 m), the settlement will also increase.



(a) **(b)** **(c)**

Figure 2. Model of Short Piled Raft foundation system with 7.0 m x 7.0 m concrete slab, **(a)** plan with pile spacing of 0.50 m; **(b)** & **(c)** upper & bottom view with pile spacing of 0.75 m.

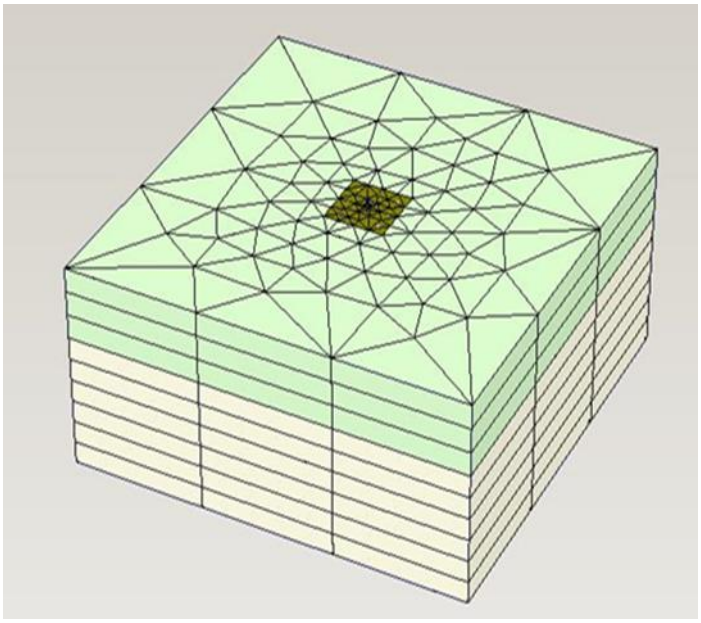


Figure 3. Generated 3-D mesh of Short Piled Raft Foundation System model.

Table 2. Results of Simulation for each Pile Spacing.

Pile Spacing [m]	**Settlement [mm]**					
	0 [kN]	20 [kN]	40 [kN]	60 [kN]	80 [kN]	100 [kN]
0.50	30.52	32.20	33.88	35.56	37.23	38.91
0.75	22.41	24.28	26.16	28.03	29.91	31.78
1.00	19.94	21.97	24.01	26.04	28.08	30.11
1.50	19.58	21.97	24.36	26.76	29.22	31.80
2.00	21.28	23.97	26.80	29.73	32.65	35.57
3.00	25.94	29.69	33.43	37.19	40.95	44.74

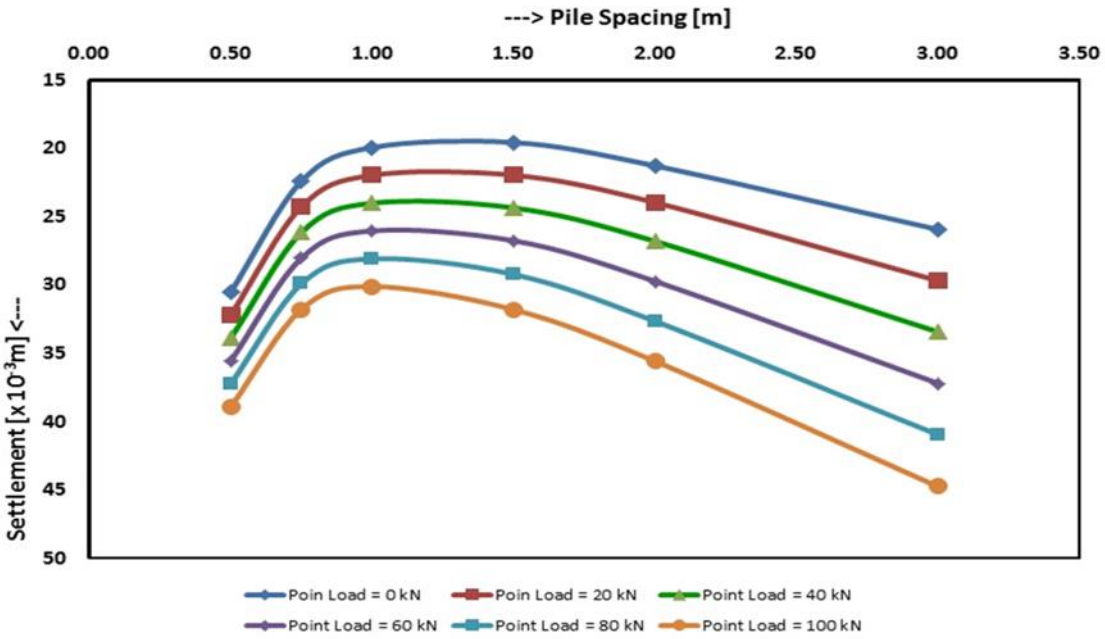


Figure 4. Numerical Results of Simulations for Different Pile Spacing.

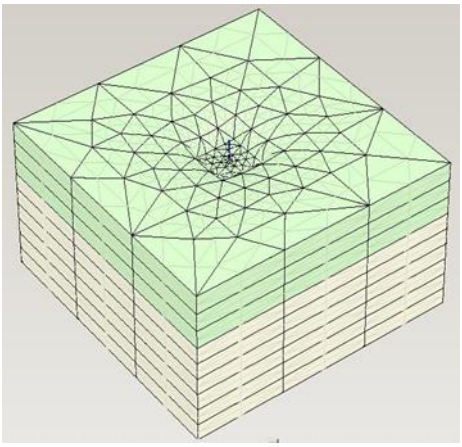


Figure 5. Deformation of 3-D mesh stage

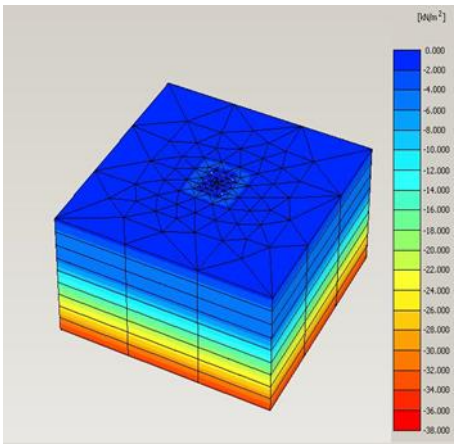


Figure 6. Normal stress of 3-D after final after final stage.

5. Discussion

Based on the numerical results shown in Fig. 4, the optimum pile spacing was identified to be 1.00 m. It can easily be seen when the pile spacing increased (more than 1.00 m), in general the settlement will become greater, likewise, when the pile spacing decreased (less than 1.00 m), the settlement will also increase.

This phenomena can be explained that if the pile spacing increased (more than 1.00 m), the effectiveness of total earth passive pressure decreased, followed by decreasing function of piles as stiffeners of concrete slab and will produce greater settlement. While if the pile spacing decreased

(less than 1.00 m), although the total earth passive pressure increased but the total weight of foundation relatively heavier and lead to contribute a greater settlement.

6. Conclusion

Based on the result and discussion, it can be concluded that the optimum pile spacing of Short Piled Raft foundation system on peat with a certain conditioned as explained in this study is 1.00 m, which produced minimum settlement of 30.11 mm under the static load of 100 kN.
It is seemed that Short Piled Raft foundation system on peat is functioning effectively to reduce settlement produced.

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