VOL. 11, NO. 16, AUGUST 2016 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

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COMPARISON OF STABILITY PERFORMANCE BETWEEN CONCRETE PILE AND CLOSED END STEEL PIPE OF SHORT PILED RAFT FOUNDATION SYSTEM FOR REDUCING SETTLEMENT ON PEAT

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ABSTRACT

Short Piled Raft foundation system is introduced and intended to solve foundation problem on peat, neither using removal and replacement method nor soil stabilization. In order to obtain a better performance for reducing settlement, two cases concerning the use of type of pile were investigated, concrete pile and closed end steel pipe as pile respectively. Finite element method to simulate the stability performance was used. Concrete slab of 3 m x 3 m square as a raft was assumed to be built on peat and the material properties of pile and raft were constant. Point load from 10 kN to 100 kN with increment of 10 kN were also considered as a static load, acted at the centre of the concrete slab. The outer diameter of pile was 0.30 m; the length of pile was 3.00 m and the pile spacing was 1.00 m. The raft thickness was considered to be constant of 0.15 m. The result showed that the use of closed end steel pipe as pile produced better performance significantly than the use of concrete pile. At the maximum load of 100 kN, the maximum total settlement of the concrete pile used was 62.74 x 10^{-3}m which was higher than the maximum total settlement of closed end steel pipe used was 45.73 x 10^{-3}m.

Keywords: short piled raft, closed end steel pipe, finite element method, settlement.

INTRODUCTION

Currently, 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 systems such as pile foundation system is still considered to be quite expensive (Effendi, S., 2013). To overcome these problems, several foundation systems have been developed, among others, is a piled raft foundation, has received considerable attention in recent year (Prakoso and Kulhawy, 2001) which is increasingly recognized as a foundation more economical and effective on problematic soil (Srilakshmi *et al,* 2013).

Moreover, especially at the peat area, the construction method on peat is different for the different depth of peat (Bakar, 2014). 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 directly be applied on peat with the depth less than 3 m, which is expected to be more practical and inexpensive, 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, with two cases the use of pile, namely concrete pile and closed end pipe steel as pile respectively.

Short Piled Raft foundation system is a Modified Piled Raft foundation system, which is a combination between pile foundation and raft foundation, with pile length short enough, and considered as a reinforced concrete slab resting on a number of piles. The plan and cross section of Short Piled Raft foundation system are shown in Figure-1 and Figure-2.

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 slab concrete and also to reduce the settlement of the foundation.

In this parametric study, the raft thickness was considered to be constant of 0.15 m. Concrete slab of 3 m x 3 m square as a raft was assumed and the material properties of pile and raft were constant whereas peat was used. The outer diameter of pile was 0.30 m; the length of pile was 3.00 m and the pile spacing was 1.00 m. To find out the differences of stability performance between the use of concrete pile and closed end steel pipe as pile of Short Piled Raft Foundation System, point load varies from 10 kN to 100 kN with increment of 10 kN were considered as a static load, acted at the centre of the concrete slab. Total and differential settlements that caused by the vary point load have been investigated.

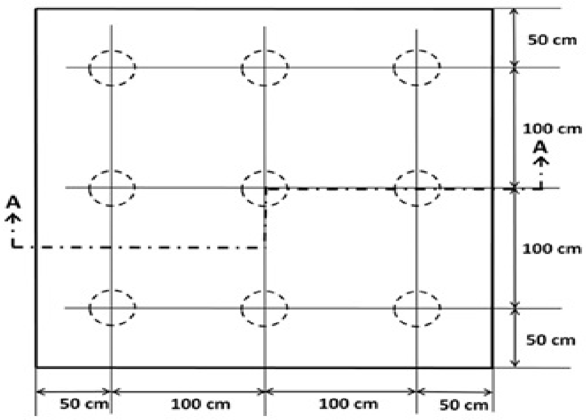

Figure-1. Plan of short piled raft foundation system.

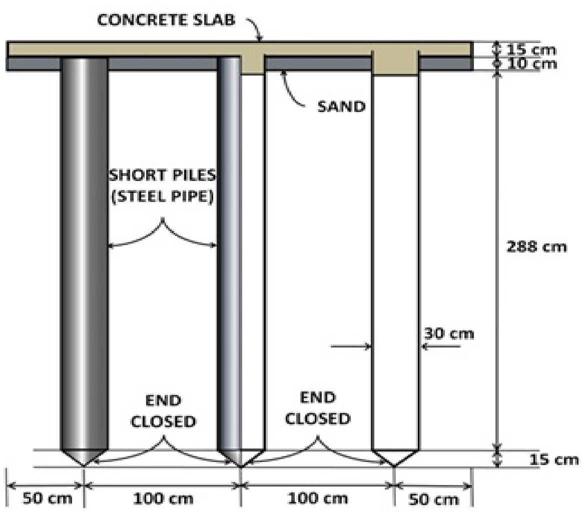

Figure-2. Cross section A – A (closed end steel pipe).

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 modelling.

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 (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 structure to simulate their stress – strain behavior, while the Mohr - Coulomb model is used for soft soil. (Qaissy *et al*. 2013)

TECHNICAL BASIS OF THE MODEL

In this study, pile and concrete slab were modelled as linear isotropic and the properties considered for analysis are Young’s modulus (E), Poisson’s ratio (μ) and density for pile and concrete slab. The connection between pile and concrete slab was assumed as rigid and concrete slab was treated as beam. The pile-concrete slab stiffness ratio was expressed as I_p/I_c (Badie and Silva, 2008).

Soil was modelled as Mohr-Coulomb criterion and properties like material cohesion strength (c) and friction angle (ϕ) are given. Regarding boundary conditions, nodes constituting bottom of the soil zone is fixed against both vertical and horizontal directions whereas the zone away from pile raft, i.e., the vertical surface of soil at the boundary is restricted against horizontal movements. The horizontal boundary was placed each side at 5 times the width of concrete slab and the vertical boundary is placed at 3 times width of concrete slab. Therefore the soil was treated as drained model because there is no restricted boundary condition and construction method enable to give enough time for releasing the water out.

A number of parameters of Short Piled Raft foundation system should be chosen beforehand in a parametric study (Tandjiria, 1999). In this case, they were the thickness of the concrete slab, the outer diameter of the pile, the pile length and the spacing between the piles.

For justification in using the model in the current study, firstly elastic settlement of a raft foundation (only) on peat was calculated using elastic formula (Das, 2011) and the same was compared with the results obtained from PLAXIS 3D. Secondly, by adding a pile at the centre of raft and assumed that the pile would reduce settlement because of the additional bearing capacity, was calculated again as done before, by using elastic settlement of pile formula (Das, 2011) and the same was compared with the results obtained from PLAXIS 3D. Here, the results obtained from PLAXIS 3D were in a good agreement with the calculated theoretical results.

NUMERICAL RESULT

In this study, at the first part, concrete slab as raft foundation was set as 0.15 m thickness and point load varies from 10 kN to 100 kN with increment of 10 kN were considered as a static load, acted at the centre of the concrete slab. Parameters used for simulating the raft foundation as shown in Table-1.

VOL. 11, NO. 16, AUGUST 2016 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

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Table-1. Soil and raft parameters used for raft foundation simulation.

Soil (Peat) Properties	
C	4.0 kN/m²
ϕ	16^0
E_{ref}	200 kN/m²
γ_{unsat}	10 kN/m³
γ_{sat}	11 kN/m³
v	0.12
Thickness of layer	3.50 m
Soil (Soft Clay) Properties	
C	5.0 kN/m²
ϕ	25^0
E_{50}	2000 kN/m²
γ_{unsat}	16 kN/m³
γ_{sat}	17 kN/m³
v	0.3
Thickness of layer	6.50 m
Raft Foundation	
Thickness of raft	0.15 m
Point Load (varies)	10 kN to 100 kN

At the second part, the parameters of the soil and raft thickness are the same as before, only with short piled embedded in the raft to give the raft more strength. Table 2 shows soil and short piled raft foundation parameters.

Illustration of Short Piled Raft foundation system in numerical model is shown in Figure-3, while generated 3-D mesh of Short Piled Raft foundation system is shown in Figure-4.

Based on those parameters, the results of simulation are shown in Table 3, Table 4 and Table 5. In order to obtain a more informative, the results are displayed graphically as shown in Figure-5 and Figure-6. While Figure-7 and Figure-8 show the shape of mesh deformation and the normal stress respectively.

Table-2. Soil, pile and raft parameters used for short piled raft foundation simulation.

Soil (Peat) Properties	
C	4.0 kN/m²
ϕ	16^0
E_{ref}	200 kN/m²
γ_{unsat}	10 kN/m³
γ_{sat}	11 kN/m³
v	0.12
Thickness of layer	3.50 m
Soil (Soft Clay) Properties	
C	5.0 kN/m²
ϕ	25^0
E_{50}	2000 kN/m²
γ_{unsat}	16 kN/m³
γ_{sat}	17 kN/m³
v	0.3
Thickness of layer	6.50 m
Short Piled Raft Foundation	
Thickness of raft	0.15 m
Point Load (varies)	10 kN to 100 kN
Outer pile diameter	0.30 m
Thickness of pipe	0.005 m
Pile length	3.0 m
Pile spacing	1.0 m

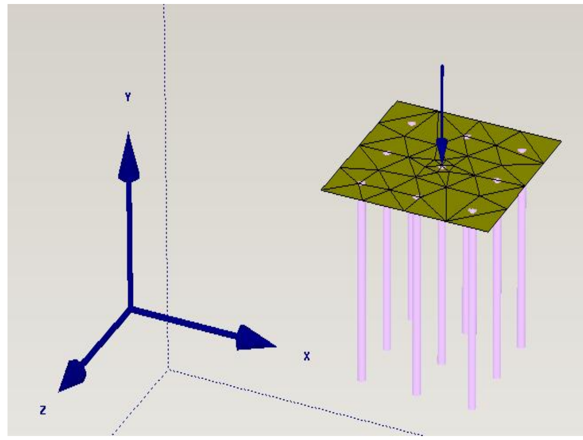

Figure-3. Model illustration of short piled raft foundation system with point load.

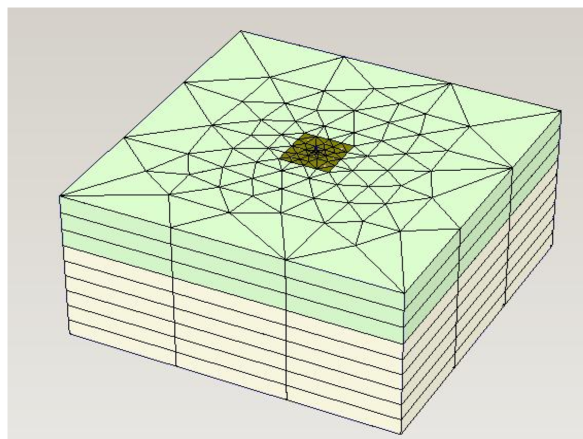

Figure-4. Generated 3-D mesh of short piled raft foundation system model.

Table-3. Settlement of raft foundation.

Raft Foundation	
Load (kN)	**Settlement ($\times 10^{-3}$m)**
0	21.74
10	29.85
20	37.98
30	46.11
40	54.25
50	62.39
60	70.53
70	78.67
80	86.81
90	94.96
100	103.52

VOL. 11, NO. 16, AUGUST 2016 ISSN 1819-6608
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Table-4. Settlement of short piled raft foundation.

Load (kN)	Short Piled Raft Foundation Settlement ($\times 10^{-3}$m) Concrete Pile	Closed End Pipe
0	24.47	10.03
10	27.95	13.40
20	31.52	16.80
30	35.18	20.20
40	39.00	23.59
50	42.85	27.03
60	46.71	30.59
70	50.60	34.21
80	54.53	38.02
90	58.52	41.87
100	62.74	45.73

Table-5. Maximum normal stress.

Load (kN)	Raft	Short Piled Raft Foundation Normal Stress ($\times 10^{-3}$kN/m²) Concrete Pile	Closed End Pipe
0	-695.91	-701.81	-896.60
10	-578.69	-655.03	-851.16
20	-461.52	-606.44	-805.72
30	-344.35	-556.95	-760.28
40	-227.18	-506.42	-714.84
50	-110.01	-455.72	-668.66
60	7.16	-404.99	-620.23
70	124.33	-354.37	-570.70
80	241.50	-303.81	-520.03
90	358.62	-253.12	-468.96
100	465.47	-201.62	-417.83

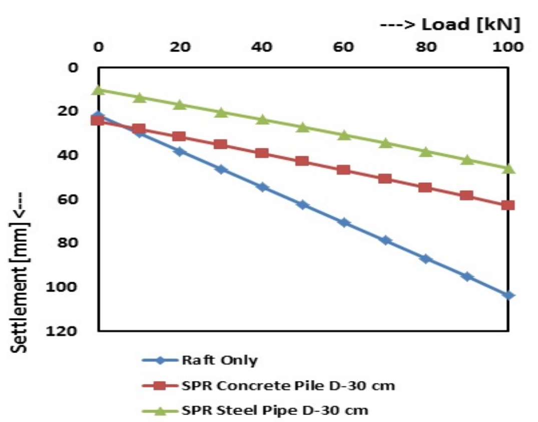

Figure-5. Maximum settlements of raft and short piled raft foundation system.

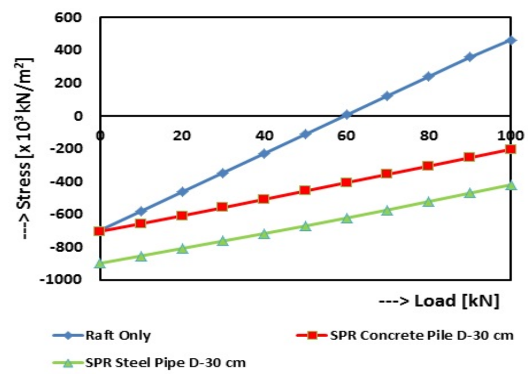

Figure-6. Maximum normal stress of raft and short piled raft foundation system.

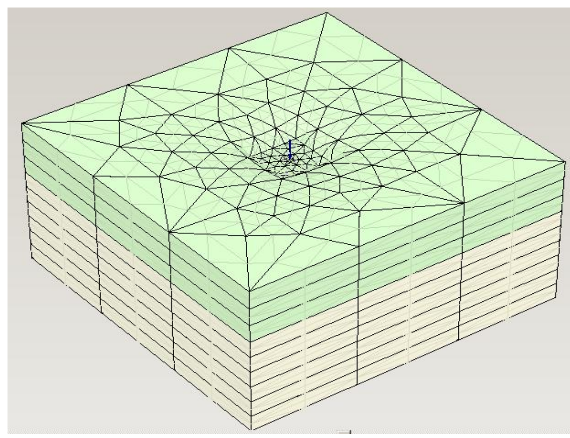

Figure-7. Deformation of 3-D mesh after final stage.

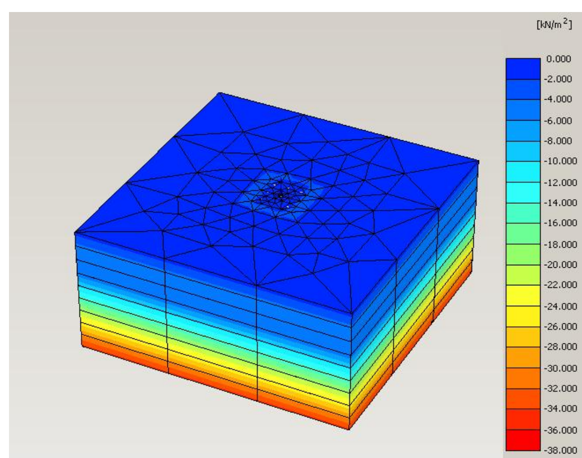

Figure-8. Normal stress of 3-D mesh after final stage.

DISCUSSION

As can be seen in Figure-5 that with the same maximum loading of 100 kN, Raft foundation has the significant settlement (103.52 x 10^{-3}m), while Short Piled Raft with concrete pile has a smaller settlement (62.74 x

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10^{-3}m) and Short Piled Raft with end closed steel pipe has the smallest one (45.73 x 10^{-3}m).

For the case of Raft foundation, it can be easily understood, because the concrete slab was thin enough (0.15 m) and just laid on the peat without any stiffener, something like a beam or other.

While for the case of Short Piled Raft foundation system, the use of closed end steel pipe has an advantage because the total weight of foundation much lighter than the use of concrete pile. It can be seen at the initial condition (loading = 0 kN), using end closed steel pipe produced settlement of 10.03 x 10^{-3}m, while using. concrete pile produced settlement of 24.47 x 10^{-3}m.

Moreover at peat land area, the ground water table usually high, in this study -0.5 m from the ground surface, it means that the closed end steel pipe is functioning as pontoon and this is another advantage.

CONCLUSIONS

Based on the result and discussion, it can be concluded that Raft foundation on peat has significant settlement, therefor need to be improved or modified in order to get a better performance related to settlement produced.

Short Piled Raft foundation system on peat is functioning effectively to reduce settlement produced.

The use of closed end steel pipe as pile showed better performance significantly than the use of concrete pile.

For applying of Short Piled Raft foundation system on peat, the use of structure part as light as possible but still in an adequate strength is reasonable.

ACKNOWLEDGEMENTS

The authors wish to express their gratitude to RECESS - UTHM for their supports.

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