ANALYSIS OF PILED RAFT FOUNDATIONS IN CLAYEY SOILS USING FINITE ELEMENT AND ANALYTICAL METHODS

P. WULANDARI*

Department of Civil Engineering, Petra Christian University, Indonesia

ABSTRACT

Raft foundations are usually used as a foundation on soft or variable ground for commercial, industrial or residential building. They have the advantage of providing the adequate bearing capacity and also reducing differential settlements of structure. Unfortunately, raft foundation may cause excessive settlement although it has an adequate bearing capacity. Considering that foundation building must have adequate bearing capacity but the total or differential settlements of the foundation should not exceed the allowable value, the combination of raft and pile foundation as named piled raft foundation system may be considered as the good alternative solution for this problem. The contribution of a group of pile under raft could acts as a settlements reducer.

This study analysed the settlement of piled raft foundation by considering the various number of piles using finite element method and analytical method. In this study, the finite element method were conducted using a PLAXIS-2D software and the analytical method was carried out using simplified calculation method by Poulos and Davis.

In order to obtain the appropriate comparison of piled raft settlement for both methods of analysis, it might be used a parameter called settlement reduction factor, since a number of piles in piled raft system acts as a settlement reducer. Both methods also performed that addition of piles beyond the optimum number of piles does not have significant effect in the reduction of piled raft settlement. So, for economic design, it needs to determine the optimum number of piles based on the allowable settlement. In this case study, by considering the settlement reduction factor, both methods of analysis showed the optimum number of piles in this piled raft system is approximately 15 x 15 piles.

Keywords: piled raft foundation, settlement, clayey soils, finite element, analytical method

1. INTRODUCTION

Raft foundations are usually used as a foundation on soft or variable ground for commercial, industrial or residential building. They have the advantage of providing the adequate bearing capacity and also reducing differential settlements of structure. Unfortunately, raft foundation may cause excessive settlement although it has an adequate bearing capacity. Considering that

* Corresponding author and presenter: Email: paravita@petra.ac.id

foundation building must have adequate bearing capacity but the total or differential settlements of foundation should not exceed the allowable value, by choosing the combination of raft and pile foundation as named piled raft foundation system may be considered as the good alternative solution for this problem. The contribution of a group of pile under raft could acts as a settlements reducer. There are many researches on piled raft foundations to investigate the performance of piled raft system (Poulos 2001; Prakoso and Kulhawy 2001; Leung et al. 2010).

This study analysed the settlement of piled raft foundation by considering the various number of piles using finite element method and analytical method. In this study, the finite element method were conducted using a PLAXIS-2D software and the analytical method was carried out using simplified calculation method by Poulos and Davis (Poulos and Davis 1980; Poulos 2002).

2. GEOMETRY OF MODEL

In this study, the piled raft foundation supported vertical loading of 71.24 kN/m^2 were analyzed. The soil profile is shown in Figure 1. The stratigraphy of the soil layers are given as following:

- Layer 1: Stabilized soil 2 m thick with static water table at 1 m below ground surface.
- Layer 2: Clay with thickness from depth of 2 to 13 m.
- Layer 3: Sandy clay with thickness 7 m.
- Layer 4: Sandy silt 2 m thick.
- Layer 5: Stiff clay with thickness from depth of 24 to 35 m.

Generally, the soil has adequate bearing capacity at the surface so it is reasonable for using raft foundation. However, the highly compressive clay can cause excessive settlements for building constructed on it. The square raft of 42 m width (B) with a thickness of 1.2 m was used with variation of a square group of piles as a piled raft system. Piles with a diameter of 0.4 m and a length of 15 m are considered with various numbers of piles and acts as a settlement reducer.

3. MATERIAL PROPERTIES

In this study, an undrained condition was assumed and the properties of various soil layers are tabulated in Table 1.

Table 1: Soil Properties

Parameter	Stabilized soil	Clay	Sandy Clay	Sandy Silt	Stiff Clay
Thickness (m)	2	11	7	4	11
Unit weight, γ (kN/m^3)	13.33	12.33	12.86	17.5	15
Saturated unit weight, γ_{sat} (kN/m^3)	18	15	18	20	18
Young's modulus, E_s (kN/m^2)	7500	2000	10000	25000	10000
Poisson's ratio, υ_s	0.35	0.35	0.35	0.3	0.3
Undrained cohesion, c_u (kN/m^2)	80	20	100	20	120
Friction angle, ϕ (deg)	0	0	12	32	5
Dilatancy angle, ψ (deg)	0	0	0	2	0

In the finite element analysis, the raft was modeled as a plate element, while the piles are modeled as beam elements with modulus of elasticity, E, as 2.1 x 10^7 kN/m^2.

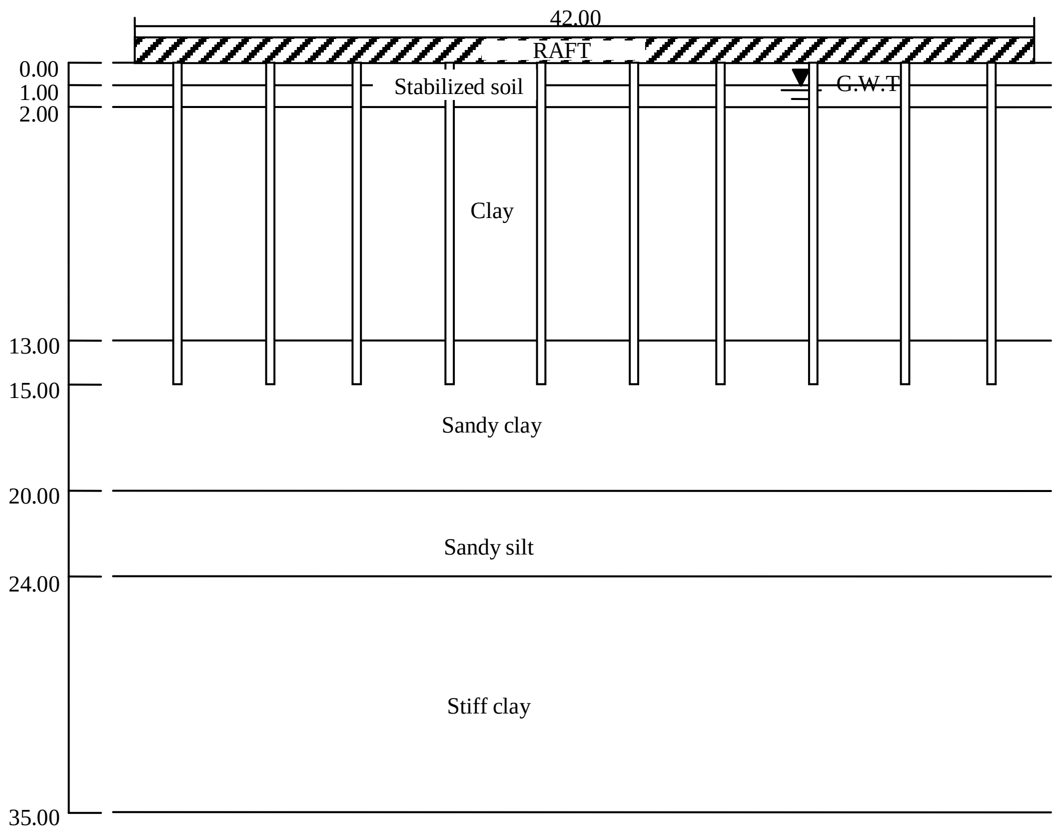

Figure 1: Geometry of model

4. METHOD OF ANALYSIS

The piled raft system was analyzed using a two dimensional plane strain analysis finite element software (PLAXIS 2D). The raft and piles were assumed to be linearly elastic. Based on the materials, the Mohr Coulomb model was used as a simple analysis.

The simplified hand computation of piled raft system was carried out based on Poulos-Davis method (Poulos and Davis 1980). Considering the total final settlement (ρ_{TF}) under the working load (P), for a rigid square raft alone,

$$\rho_{TF} = 0.947 \frac{P}{B} \left[\frac{(1-\nu_s^2}{E_s} \right] \tag{1}$$

As the settlement is excessive, then piles must be added to the raft to reduce the settlement.

For a square rigid raft B x B with m piles, the overall undrained settlement (ρ_w) of the pile raft system at a working load (P_w) and the ultimate load (P_A) is given by,

$$\rho_w = P_A R_{G0.5}\rho_1 + \frac{0.947(P_w - P_A)(1-\nu_s^2)}{BE_u} \quad (2)$$

where $R_{G0.5}$ is the value of the group reduction factor for $\upsilon_s = 0.5$ and ρ_1 is the total final settlement per unit load.

5. RESULT AND DISCUSSION

The comparison results by the Poulos-Davis analytical method and finite element method are presented in the Table 2 and Figure 2.

Table 2: The comparison results from Poulos method and PLAXIS 2D analysis

Numbers of piles (m^2)	Settlement (mm)		Numbers of piles (m^2)	Settlement (mm)	
	POULOS	PLAXIS		POULOS	PLAXIS
0	1369	127	13	557	41
1	1103	127	14	500	40
2	1061	109	15	475	39
3	1037	95	16	464	38
4	1009	84	17	452	38
5	955	72	18	452	38
6	918	64	19	441	37
7	876	58	20	441	38
8	831	53	21	441	36
9	780	49	22	430	36
10	733	46	23	429	35
11	680	43	24	429	36
12	621	42	25	429	37

For both methods, it can be seen in Figure 2 that increasing pile number will reduce settlement of the piled raft but beyond some point the settlement tends to be constant. Those both methods showed the different results. Settlements calculations by analytical method (Poulos and Davis 1980) showed the greater value than by two dimensional finite element method using PLAXIS 2D. It showed that the approach used in Poulos-Davis method (1980) probably is not same with the adjustment applied on finite element analysis.

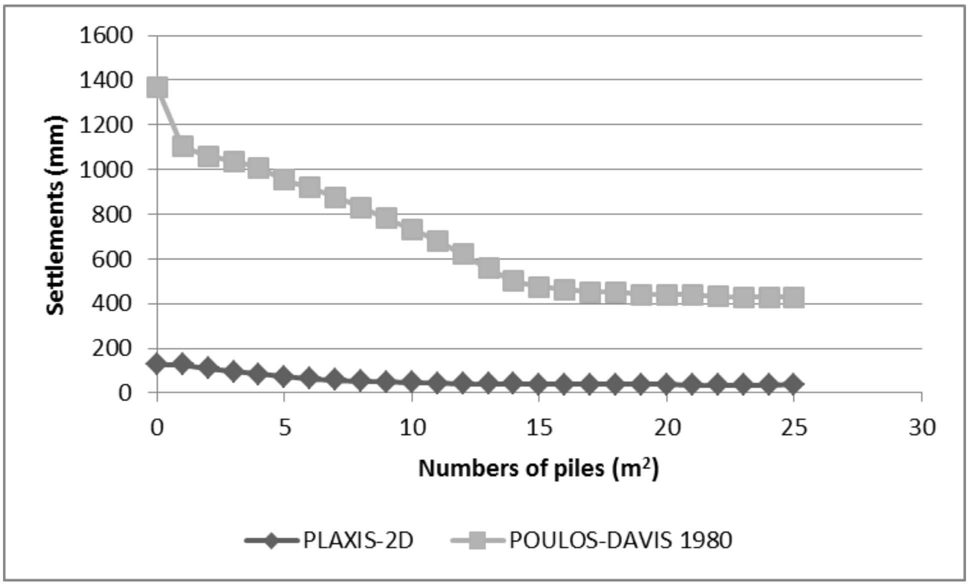

Figure 2: Settlements considering number of piles

In order to obtain the appropriate comparison of piled raft settlement for both methods of analysis, it might be used a parameter called settlement reduction factor, F_{sr}, since a number of piles in piled raft system acts as a settlement reducer.

$$F_{sr} = \frac{\rho_{piled-raft}}{\rho_{raft}} \tag{3}$$

where $\rho_{piled\text{-}raft}$ is the total settlement of the piled raft system and ρ_{raft} is the settlement of the raft alone.

As shown in Figure 3, for both methods, it can be seen that beyond an optimum number of piles, the settlement reduction factor almost kept constant, which means there is no longer decreases. By these results, it is not necessary to use an excessive numbers of piles for an economic design solution. In this case study, by considering the settlement reduction factor, both methods of analysis showed the optimum number of piles in this piled raft system is approximately 15 x 15 piles.

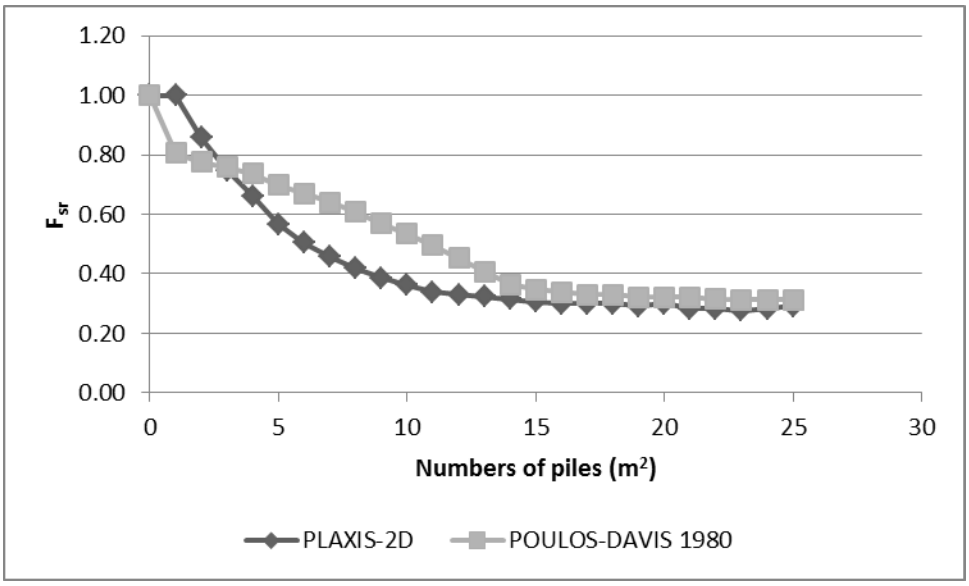

Figure 3: Settlement reduction factors considering numbers of piles

6. CONCLUSIONS

In this paper, two analysis methods, finite element method (PLAXIS 2D) and Poulos-Davis simplified analytical method, were carried out to investigate the settlement of piled raft foundation. Settlements calculations by analytical method (Poulos and Davis 1980) showed the greater value than by two dimensional finite element method using PLAXIS 2D. In order to obtain the appropriate comparison of piled raft settlement for both methods of analysis, it might be used a parameter called settlement reduction factor, since a number of piles in piled raft system acts as a settlement reducer. Both methods also performed that addition of piles beyond the optimum number of piles does not have significant effect in the reduction of piled raft settlement. So, for economic design, it needs to determine the optimum number of piles based on the allowable settlement. In this case study, by considering the settlement reduction factor, both methods of analysis showed the optimum number of piles in this piled raft system is approximately 15 x 15 piles.

REFERENCES

Poulos HG (2001). Methods of Analysis of Piled Raft Foundation. A Report Prepared on Behalf of Technical Committee TC18 on Piled Foundations, International Society of Soil Mechanics and Geotechnical Engineering.

Prakoso WA and Kulhawy FH (2001). Contribution to piled raft foundation design. Journal of Geotechnical and Geoenvironmental Engineering, 127(1), pp. 1024-1090.

Leung YF, Klar A, and Soga K (2010). Theoretical Study on Pile Length Optimization of Pile Groups and Piled Rafts, Journal of Geotechnical and Geoenvironmental Engineering, 136(2), pp. 319-330.

Poulos HG and Davis EH (1980). Pile Foundation Analysis and Design. John Wiley & Sons Australia.

Poulos HG (2002). Simplified Design Procedure for Piled Raft Foundations. Deep Foundations, pp. 441-458.