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Numerical study of load carrying capacity of piled raft foundation embedded in sand

Etude numérique de la capacité de charge de la fondation à chevrons incorporés dans le sable

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ABSTRACT: In this study, three-dimensional finite element (FE) analyses of piled rafts embedded in sand are performed to investigate the effects of various geometric parameters of piles on the performance of piled raft under vertical load using PLAXIS 3D. A verified 3-D piled raft model is used for the parametric study by varying certain geometric parameters of pile i.e. normalized pile length (L/d = 20, 40, 60) and the configuration of piles (single, 2 × 2, 3 × 3). The diameter of the pile '*d*' is considered 0.5 m and size of the raft is considered 6 m × 6 m. In this present study, the load carrying capacity of piled raft is quantified through a factor namely Load Capacity Improvement Factor (LCIF) which is defined as the ratio of the load carrying capacity of piled raft to the load carrying capacity of un-piled raft at the same settlement. Results confirm that the geometric parameters of pile affect the load response of piled raft significantly. Bearing capacity of piled raft is found to increase with increase of pile length. The LCIF is found higher when pile length (L/d) changes from 20 to 40 as compared to when it changes from 40 to 60. The increase in the number of piles under the raft also contributes to enhance the load capacity of piled raft.

RÉSUMÉ: Dans cette étude, des analyses par éléments finis tridimensionnels (FE) des radeaux empilés incorporés dans le sable sont effectuées pour étudier les effets de divers paramètres géométriques des pieux sur la performance du radeau empilé sous charge verticale en utilisant PLAXIS 3D. Un modèle de radeau empilé 3D vérifié est utilisé pour l'étude paramétrique en faisant varier certains paramètres géométriques de pieu, à savoir la longueur de pieu normalisée (L/d = 20, 40, 60) et la configuration des pieux (simple, 2 × 2, 3 × 3). Le diamètre de la pile «*d*» est considéré comme étant de 0,5 m et la taille du radeau est considérée comme étant de 6 m × 6 m. Dans la présente étude, la capacité de charge du radeau empilé est quantifiée par un facteur, à savoir le facteur d'amélioration de la capacité de charge (LCIF), défini comme le rapport entre la capacité de charge du radeau empilé et la capacité de charge du radeau non empilé. le même règlement. Les résultats confirment que les paramètres géométriques du pieu affectent la réponse de charge du radeau empilé de manière significative. La capacité portante du radeau empilé augmente avec l'augmentation de la longueur du pieu. La LCIF est plus élevée lorsque la longueur de pieu (L/d) passe de 20 à 40 par rapport à 40 à 60. L'augmentation du nombre de pieux sous le radeau contribue également à augmenter la capacité de charge du radeau empilé.

Keywords: Piled raft; Load response; Settlement; Finite element; Geometric parameter

1 INTRODUCTION

Piled raft foundations are widely used for the high-rise buildings in modern world because of the facility of utilizing the bearing capacities of both raft and piles. Piled rafts can limit the settlements to acceptable values. The load responses of piled rafts are greatly affected by the interaction among raft, pile and the surrounding soil. The load sharing mechanism between raft and piles depends on different geometric factors i.e. pile length, pile configurations etc.

Burland et al. (1977) pioneered the idea of using piles under the raft foundation. Since then, a number of different methods and approaches have been reported by several researchers to study the performance and evaluate the load bearing capacity of piled raft (Poulos and Davis 1980; Clancy and Randolph 1993; Poulos 2001). Many experimental as well as numerical studies on piled rafts have also been documented to study the load transfer mechanism (Phung 1993; Horikoshi and Randolph 1996; Prakoso and Kulhawy 2001; Sinha and Hanna 2017).

In this paper, 3D finite element (FE) analyses of piled rafts embedded in sand are carried out to investigate the effects of geometric parameters of pile i.e. pile length and pile configurations on the performance of piled raft under vertical load using PLAXIS 3D. A comprehensive assessment of the load carrying capacity of piled raft is presented by introducing a factor namely Load Capacity Improvement Factor (LCIF).

2 MODELLING IN PLAXIS

The details of the 3D FE model and its validation with literature are presented in this section.

2.1 Boundary conditions and FE mesh

The horizontal boundaries of soil domain, fixed at a distance of 2.5 times the width of the raft (*B*) from the raft edge on either side, are restrained against horizontal movement but allowed to move vertically as shown in Figure 1.

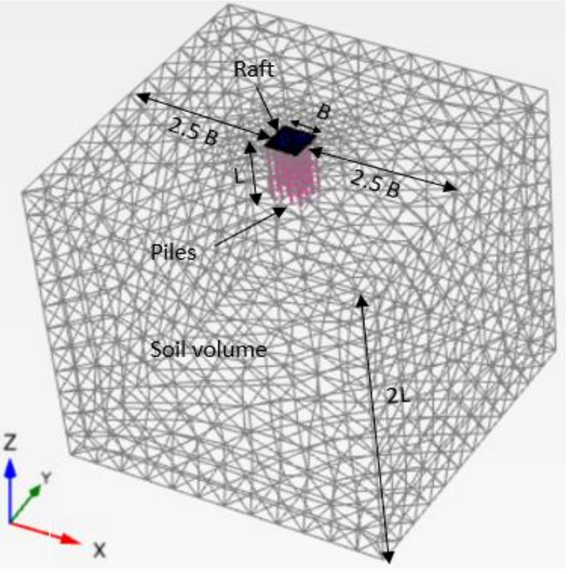

Figure 1. Finite element model of piled raft system

The bottom boundary, placed at a distance of twice the pile length (*L*) from the raft, is restricted from both vertical and horizontal translations.

A mesh convergence study is performed using the non-dimensional average element lengths to find out the optimal mesh size for the FE model. Figure 2 represents the result of the convergence study which shows that beyond the fine mesh, the results are almost identical. So, the fine mesh option has been selected for the FE model.

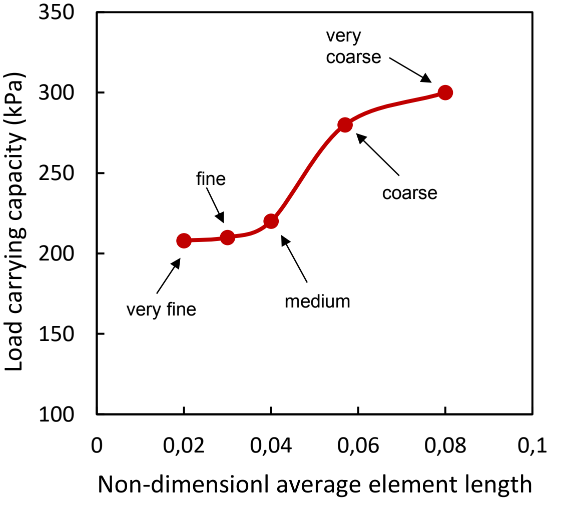

Figure 2. Mesh convergence study for mesh selection

2.2 Material models

The soil volume is modelled using 10-node tetrahedral elements. For sand, the liner elastic-perfectly plastic Mohr-Coulomb model is used. The raft is modelled using the plate element and the piles are modelled with embedded beam element having special interface element.

The geotechnical properties of medium sand, pile and raft are presented in Table 1.

Table 1. Properties of soil, pile and raft

Parameters	Soil	Pile and Raft
Elastic modulus, E (kN/m^2)	35×10^3	28×10^6
Friction angle, ϕ (Degree)	32	-
Cohesion, c (kN/m^2)	0	-
Poisson's ratio, ν	0.3	0.15
Unit weight, γ (kN/m^3)	17	24

2.3 Validation of FE model

Figure 3 shows the comparison of the load-settlement curves obtained from the centrifuge test (Lee et al. 2015) and present FE analysis. Close agreement can be found between the results obtained from the FE analysis and the centrifuge test data stated in the literature. So, this verified FE model is used for the parametric study.

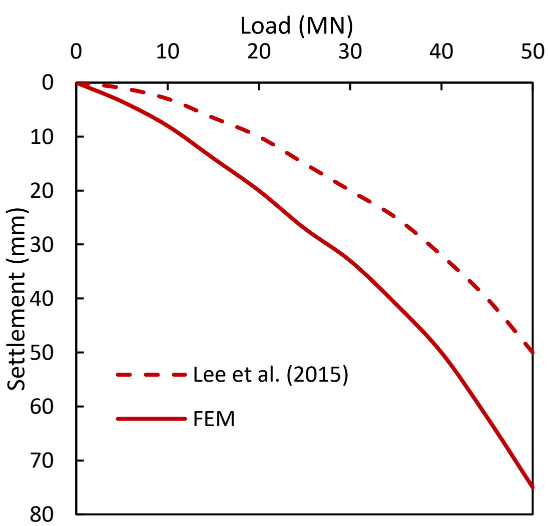

Figure 3. Comparison of load-settlement curves

3 RESULTS AND DISCUSSION

Results are presented in terms of a dimensionless quantity namely Load Capacity Improvement Factor (LCIF), defined as the ratio of load carrying capacity of piled raft to the load carrying capacity of un-piled raft at same settlement.

3.1 Influence of pile length to diameter ratio (L/d)

In this case, analyses are carried out for three L/d ratios i.e. 20, 40 and 60 keeping the pile spacing to diameter ratio (S/d) equals to 3. Figure 4 presents the load-settlement curves of piled rafts for different L/d ratios. It can be observed from Figure 4 that the capacity of the piled raft increases with increasing pile length at any settlement level. But, this increase is very small when the L/d ratio changes from 40 to 60. With the increase of pile length, the capacity of pile improves in the form of higher skin friction, hence, increase in overall load bearing capacity.

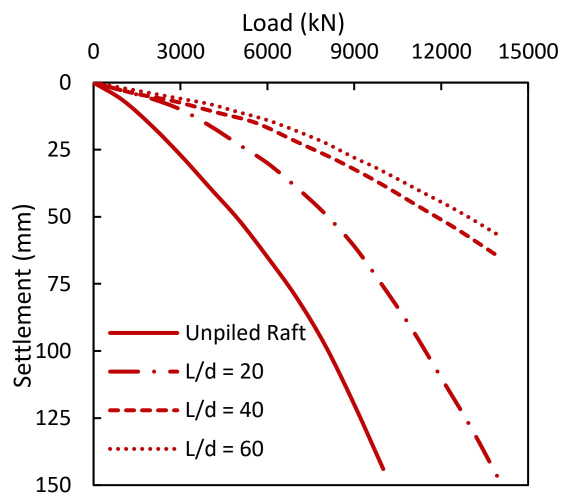

Figure 4. Load responses of piled rafts for different pile lengths (L/d) under the raft

Figure 5 shows the variation LCIF with normalized pile length at 50 mm settlement level of the raft. The improvement in the bearing capacity of piled raft is observed to be increasing with the increasing pile length.

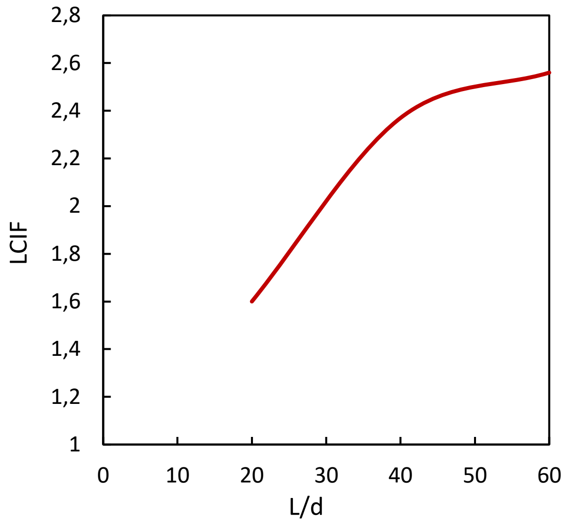

Figure 5. Variation of LCIF with different L/d ratios

The LCIFs are calculated as 1.6, 2.37 and 2.56 for *L*/*d* of 20,40 and 60 respectively. Improvement in capacity is found 48% when *L*/*d* changes from 20 to 40 and 8% when *L*/*d* changes from 40 to 60.

3.2 *Influence of pile configurations*

Here, analyses are performed for 3 pile configurations i.e. single, 2×2 and 3×3 keeping *L*/*d* ratio 20 and (*S*/*d*) ratio constant as 3.

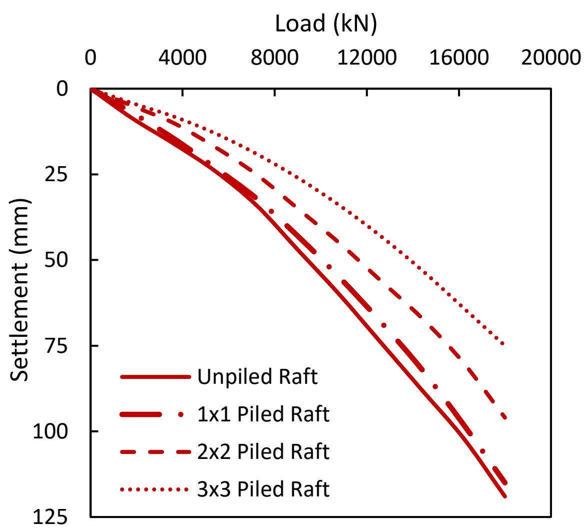

Figure 6. Load responses of piled rafs for various pile configurations under the raft

Figure 6 presents the load-settlement curves of piled rafts for different pile configurations considered in the present study. It can be seen that the capacity of piled raft is found increasing with increasing pile number. The improvement for the single piled raft case as compared to the unpiled raft is found marginal as compared to other cases. As the number of the pile increases, the load gets transferred to the piles mostly.

Figure 7 exhibits the variation of LCIF with normalized pile spacing at 50mm settlement level of the raft.

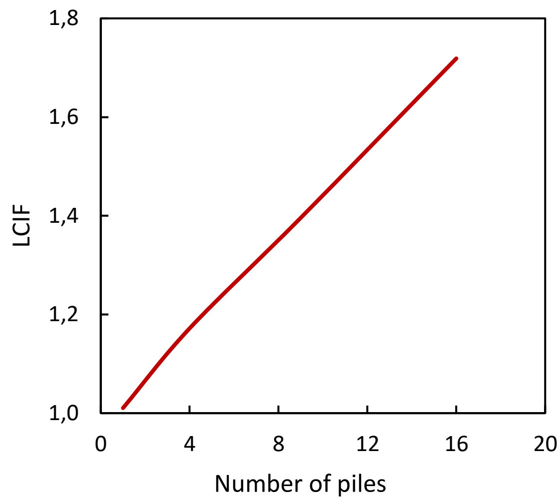

Figure 7. Variation of LCIF with number of piles

The improvement in the bearing capacity of piled raft is found to be increasing with increasing pile numbers under the raft. The LCIFs are calculated as 1.01, 1.17 and 1.40 for single, 2×2 and 3×3 piled rafts respectively. The improvement in bearing capacity is found 15.8% when pile configuration changes from single to 2×2 and almost 20% when pile configuration changes from 2×2 to 3×3 under the raft.

4 CONCLUSIONS

In the present study, three-dimensional finite element (FE) analyses of piled raft system are performed using geotechnical software PLAXIS. The prime objective is to investigate the effects of pile length and pile configurations under the raft on the load carrying capacity of piled raft foundation system under the action of static vertical loading. From the results found from the analyses, the following significant conclusions can be drawn:

- Mesh convergence study is essential for selecting the appropriate mesh size for the numerical model amongst the five different meshing options available in PLAXIS 3-D.
- The bearing capacity of piled raft is found to increase with increasing pile length under the raft due to enhancement of pile capacity in the form of higher skin resistance.
- The improvement in load carrying capacity of piled raft, presented in the form of LCIF, is found 48% when *L/d* changes from 20 to 40 and 8% when *L/d* changes from 40 to 60.
- The enhancement in bearing capacity of piled raft is found 15.8% when pile configuration changes from single to 2×2 and almost 20% when pile configuration changes from 2×2 to 3×3 under the raft.

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