Computers and Geotechnics 55 (2014) 14–26

Contents lists available at ScienceDirect

Computers and Geotechnics

journal homepage: www.elsevier.com/locate/compgeo

Parametric study for optimal design of large piled raft foundations on sand

Dang Dinh Chung Nguyen, Dong-Soo Kim *, Seong-Bae Jo

Department of Civil and Environmental Engineering, KAIST, 291 Daehakro, Yuseong-gu, Daejeon 305-701, Republic of Korea

ARTICLE INFO

Article history:
Received 5 February 2013
Received in revised form 30 July 2013
Accepted 31 July 2013
Available online 23 August 2013

Keywords:
Piled-raft
Centrifuge modeling
Pile arrangement
Bending moment
Total settlement
Differential settlement

ABSTRACT

In designing piled raft foundations, controlling the total and differential settlements as well as the induced bending moments of the raft is crucial. The majority of piled raft foundations have been designed by placing piles uniformly. In such a design method, the settlements of the piled rafts are likely to be large, which leads to an increase of the pile length and/or number of piles required to reduce the settlements. However, this increase does not satisfy the requirement for economical design. On the basis of a parametric study, this paper contributes a framework for considering an economical design methodology in which piles are placed more densely beneath the column positions when the piled raft is subjected to column loads. The analysis uses PLAXIS 3D software, and the validity of the parametric study is examined through the results of centrifuge model tests conducted by the authors. The study shows that the concentrated pile arrangement method can help to considerably reduce the total and differential settlements as well as the induced bending moments of the raft. Moreover, the effects of parameters, such as pile length, pile number, raft thickness and load types, on the piled raft behavior are investigated. This study can help practicing engineers choose pile and raft parameters in combination with the concentrated pile arrangement method to produce an economical design.

1. Introduction

Piled rafts have been widely adopted as an effective foundation method for designing high-rise buildings because of their efficiency in controlling the total and differential settlements and improving bearing capacity. Furthermore, in the past few years, there has been increasing recognition that, with optimal design, piled rafts can achieve the most effective conditions and lead to minimization of the total and differential settlements; thus, optimal design can help to achieve optimal cost effectiveness. This advantage is mainly derived from the piles, which play an important role in the reduction of total and differential settlement.

For large piled rafts where the width of the raft exceeds the length of the piles [10] and the piles are employed as a settlement reducer, the piles need to be designed not only in terms of optimal size and number of piles but also with the optimal arrangement method according to the subjected load type. Kim et al. [4] proposed three methods for optimally placing the piles according to three load types: uniform, column and line loads. By placing the piles according to these methods, the differential settlement of a piled raft can be minimized. Moreover, Leung et al. [6] suggested that implementing an optimized pile length configuration can both increase the overall stiffness of the foundation and reduce the total and differential settlements. Horikoshi and Randolph [3] proposed an optimum design method by investigating the effects of changing several parameters, such as pile spacing, pile length and soil depth, on the behavior of the piled raft. Poulos [9] suggested that increasing the raft thickness can considerably reduce the differential settlement. Moreover, he proposed that increasing the number of piles, while is generally beneficial, does not always produce the best foundation performance and that there is an upper limit to the number of piles beyond which very little additional benefit is obtained. Nevertheless, there have only been a few studies on the effects of combining pile arrangements with changes in the parameters of the piles and raft on the piled raft behavior, which employs the piles to reduce settlements.

Nguyen et al. [8] examined the feasibility of the concentrated pile arrangement for reducing the total and differential settlements and verified it through comparisons between centrifuge test results and calculated results obtained from numerical simulations (finite element method using PLAXIS 3D). The centrifuge test results showed that the concentrated pile arrangement method can result in lower total and differential settlements by approximately 30–40% compared to the uniform pile arrangement method. Moreover, it also helps to reduce the bending moment and restrict the development of the maximum bending moment of the raft. The

* Corresponding author. Tel.: +82 423503619.
E-mail addresses: chungbk2002@gmail.com (D.D.C. Nguyen), dskim@kaist.ac.kr (D.-S. Kim), siderique@kaist.ac.kr (S.-B. Jo).

0266-352X/$ - see front matter
http://dx.doi.org/10.1016/j.compgeo.2013.07.014

reliability of the numerical simulation by PLAXIS 3D was verified by centrifuge tests.

Based on these results, this paper presents a parametric study for investigating the optimum design for a large piled raft that employs piles as settlement reducers. The large piled raft model is considered to be subjected to vertical, horizontal and moment loads, but earthquake loading is not considered in this study. By investigating the effects of changing the parameters of the piles (pile length and number of piles) and raft (raft thickness and applied load types) on the settlements and induced bending moments of the raft, and by comparing the optimally arranged piled raft model with the commonly designed piled raft model, this paper may help practicing engineers in recognizing the preeminent and economical qualities of optimizing pile arrangement in designing piled rafts. Then, a series of numerical simulations for different piled raft models are performed to make comparisons of the settlements and induced bending moments between these piled raft models. The compared results may contribute to a more economical design process for large piled raft foundations.

2. Measured and computed settlements of piled raft foundation in centrifuge models

This section presents the results of the centrifuge test performed to verify the advantages of the concentrated pile arrangement method for a large piled raft subjected to column loads as well as comparisons between the measured results and the calculated results obtained by numerical simulation via PLAXIS 3D. The model tests were performed using the KOCED 240 g-ton geotechnical centrifuge at Korea Advanced Institute of Science and Technology, Korea (details can be found in Kim et al. [5]). The centrifuge tests were performed with two piled raft models, one model with a uniform pile arrangement and the other with a concentrated pile arrangement. For these two models, the piles and raft, which is flexible (raft thickness is approximately 0.542 m of reinforced concrete on the prototype scale), are the same size. The number of piles is 16, and the pile length and pile diameter are 12.5 m and 0.6 m on the prototype scale, respectively (the centrifugal acceleration is 50 g). Fig. 1 shows the model test layout. The settlements of the rafts are monitored using eight linear displacement transducers (LVDTs) along two cross-sections, A–A and B–B. The bending moments of the rafts are monitored along section A–A by strain gages attached to the bottoms of the rafts. Four columns were used to reproduce the point loads on the foundation models. The external load is unsymmetrically applied to the raft to create differential settlement along the A–A and B–B sections. The soil is loose silica sand with a relative density D_R of approximately 40%. The details of these centrifuge tests can be found in Nguyen et al. [8]. Fig. 2 shows the test model set-up.

Fig. 3 presents the settlements measured along the A–A and B–B sections. It can be seen that the centrifuge test data show a general trend that the total and differential settlements of the piled raft increase with the increase of the total applied load. In addition, the centrifuge results show that the total and differential settlements of the piled raft with a concentrated pile arrangement are much smaller than those of the piled raft with a uniform pile arrangement when the applied load is large. There are several ways to explain how the optimal pile arrangement scheme can considerably reduce the total and differential settlements. First, by placing nine piles at column C1, the maximum settlement is reduced. Second, when the pile spacing has a reasonable value, the interaction among the piles increases, which causes an increase in the supporting capacity of the pile group and therefore reduces the settlement of the raft in the region of the pile group. Third, it can utilize the capacity of the raft in regions that are subjected to small applied loads. In these regions, with or without the presence of piles, the raft can support the amount of loads subjected to it, and its settlement will remain at an acceptable value.

In comparing the centrifuge results and the results calculated by PLAXIS 3D, the same trend arises during the development of the differential settlement with an increase of the total load. The results of the model with a uniform pile arrangement obtained from PLAXIS 3D match those from the centrifuge tests fairly well, whereas the maximum settlements of the model with a concentrated pile arrangement calculated by PLAXIS 3D are found to be larger than those from the centrifuge tests. This phenomenon may be related to the confinement effect which occurs in the centrifuge tests of the concentrated pile arrangement case. The confinement effect contributes to increase the capacity of each pile in the pile group and this makes the measured settlements be smaller than the computed settlements.

Fig. 4 presents the induced bending moments of the two piled raft models along section A–A. It can be seen that the concentrated pile arrangement can also reduce the induced bending moment of the raft. However, there are differences between the values

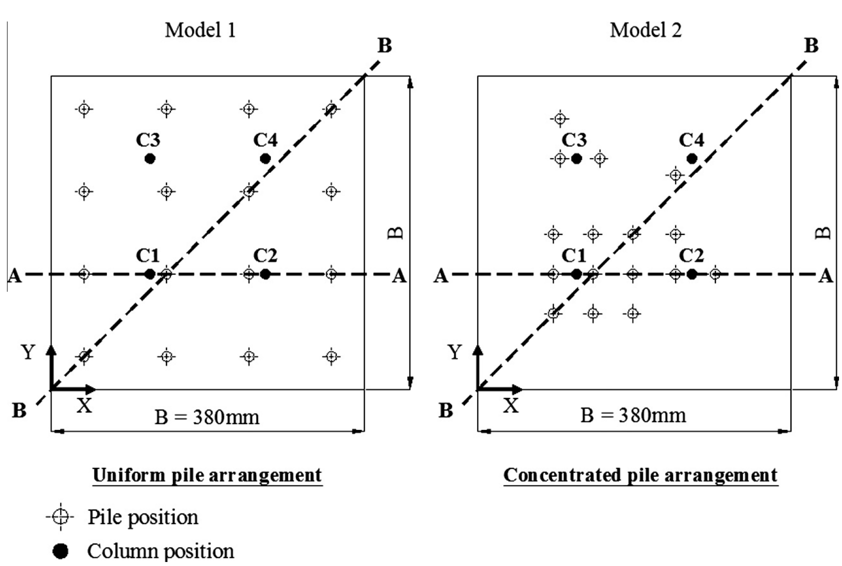

Fig. 1. Pile, column, cross section arrangement [8].