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Optimization of piled-raft foundation compound system by evaluation of the effect of pile length variation on performance this system

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ABSTRACT: Piled-Rafts are frequently designed with equal or similar pile length. However, the significant interaction effects among equal-length piles imply that this may not be the optimized configuration. In this paper with notice in cases of piled-raft foundation under non-uniform loading, using of non-similar piles can improve system performance, this parameter effect and other effective parameters have been considered. Behavior of piled-raft foundation assessed with non-similar piles by using APRILS software. We used finite element method for analysis piled-raft foundation system and finite layer method for analysis layered soil. The most important factors considered of system behavior are full interaction between piles, raft and soil that have been analyzed. Interaction between no similar piles under non-uniform horizontal and vertical loading was examined. We drew conclusion that by using non-similar piles can improve system performance. For piled-raft under non-uniform vertical loading with notice of differential loading, it is preferred to piles put with more length under central area of raft and for horizontal loading; put piles with bigger diameter in this area.

1 INTRODUCTION

Piled-raft can be a suitable solution when using only raft is led as a foundation to extreme settlement and is high-priced using of pile group. The use of a piled-raft as the foundation for buildings has proven to be an effective and economic way to control total and differential settlements as well as improving bearing capacities. The performance of a piled-raft can be influenced by several factors such as the conditions of the supporting soil, relative stiffness between pile and soil, loading conditions, size and length of the piles, and pile arrangement. In the design of piled-raft foundations, it is necessary to take account of these factors to achieve the objective of economic construction with satisfactory performance. Optimized design of piled-raft has been addressed by several researchers (Tandjiria et al., 1999, Valliappan et al., 1999, Kim et al., 2001, Bezerra et al., 2005, El-Mossallamy et al., 2006). Based on distribution of contact pressure at the raft-soil interface, Randolph (1994) stated that by placing piles under the Centre region of a raft, the differential settlement could be reduced substantially. When a raft is subjected to non-uniform loadings, the overall and differential settlements and the titling of the building are of a special importance (Reul and Randolph 2004). In this paper, the effect of some factors mentioned above such as pile diameter and length on the performance of piled-rafts will be examined. The results will be presented in term of the (i) overall and differential settlements of the raft, (ii) horizontal displacement of piles.

2 SOIL-STRUCTURE INTERACTION

Soil-structure interaction refers to the interaction between a structure, its foundation and the subsoil. As the term soil-structure interaction covers a broad field, the work presented in this paper will be restricted to the analysis of piled-raft foundations under static load. Traditionally, the design work for structure has been separated from that of the foundations by the structural and geotechnical engineers, thus the stiffness of the superstructure is neglected. However, the structural stiffness can have effects on the distribution of column loads and bending moments transmitted from the structure to the foundation, therefore interaction analysis which accounts for the structural stiffness has to be considered. Piled-rafts are composite structures which are comprised of three elements: the piles, raft and the supporting soil. Loads applied to the raft are transferred to the soil through the piles; therefore, it is necessary to take into account the interaction among the three elements. Four different types of interaction have to be considered in the analysis. In this paper, the interaction mechanism for piled-raft foundations is discussed and the use of finite layer technique to compute the interaction factors is presented.

The concept of interaction factors has been widely adopted for the analysis of pile groups and piled-rafts since its introduction by Poulos (1968). Davis and Poulos (1972) suggested that the analysis of piled-raft involves the interaction between the piles and the cap. In their analysis, the interaction of the Mindlin solution. Finite layer techniques developed by Small and Booker (1986) were used to compute the interaction factors by Ta and Small (1995) and Zhang and Small (1999) for the analysis of pile groups in layered soils and then extended to piled-rafts (Ta, 1996) and Zhang (2000). In their analyses, piles used to support the raft have to be identical. In this section, four different interactions (i) pile-pile, (ii) pile-soil, (iii) soil-pile, (iv) soil-soil as shown in Figure 1 for a layered system are calculated by finite layer method. The piles considered in the calculation can be of different diameters and lengths.

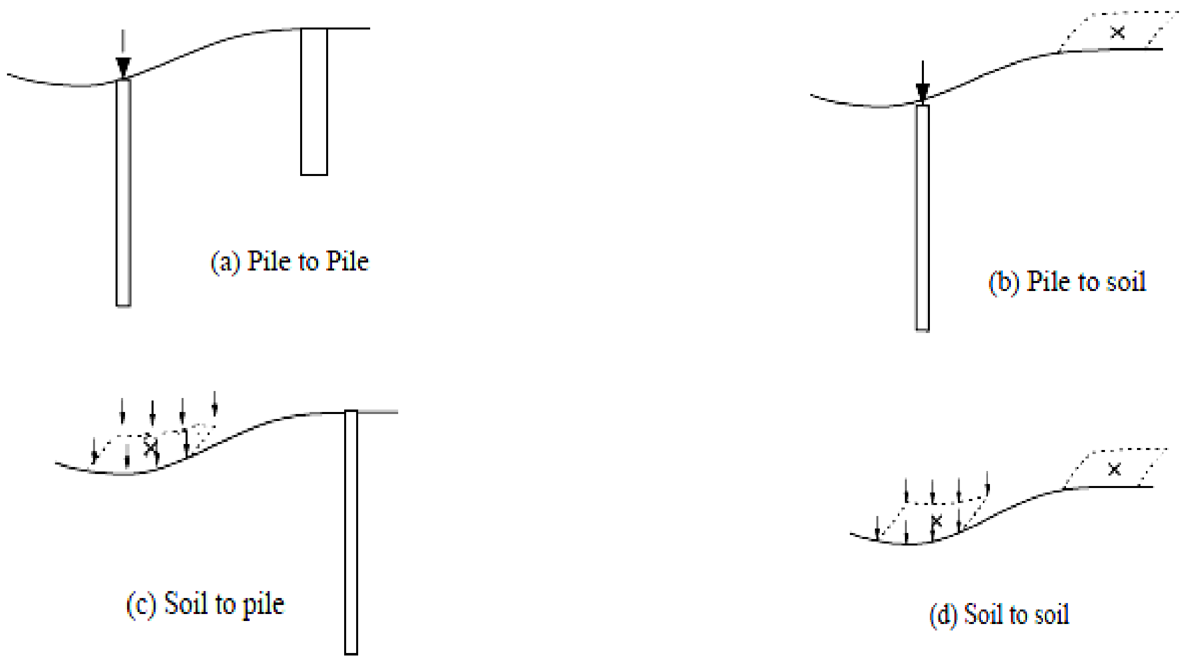


Figure 1. Types of interaction in piled-raft foundation.

3 PARAMETRIC STUDIES

In the following examples, the results are presented in terms of dimensionless parameters: (i) normalized vertical displacement $I_{rz,}$ and vertical differential displacement, I_{dz} in the raft, (ii) normalized horizontal displacement I_{rx} in the raft, (iii) normalized vertical displacement along the pile I_{pz}, (iv) normalized horizontal displacement along the pile I_{px}.

3-1 Effect of pile length

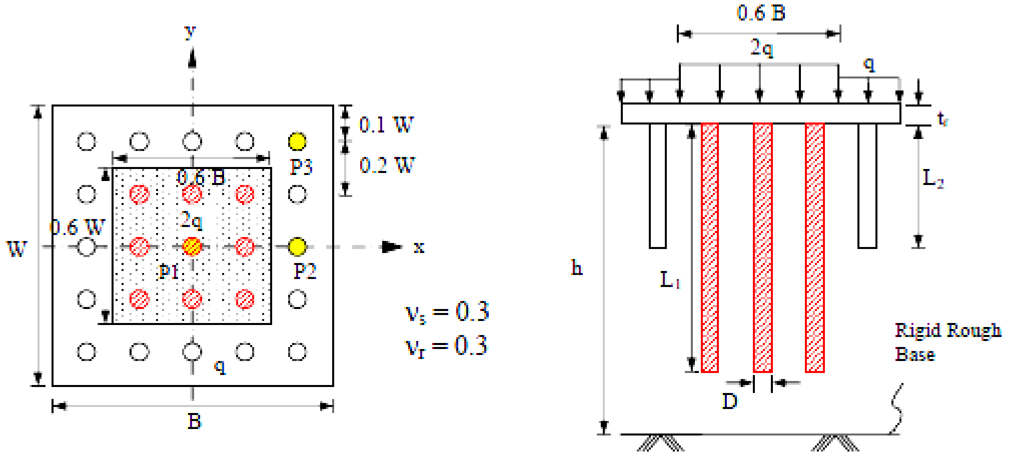
When a piled-raft is subjected to non-uniform loadings, the use of piles with different lengths may help to reduce the differential and overall settlement. This example shows the effect of pile length on the behaviour of a piled-raft subjected to non-uniform loadings. A square piled-raft supported by 25 piles was subjected to uniform pressures of q and 2q at the edge and central regions of the raft respectively as shown in Figure 2. These uniform pressures were applied vertically or horizontally to the raft. The piles underneath the central and edge regions of the raft have lengths of L_1 and L_2 respectively as shown in Figure 2. The Poisson's ratios of the raft and the soil were taken as 0.3 and the ratio of pile modulus E_p/E_s was taken as 2500. Analyses were carried out for pile length ratios (L_1/L_2) that varied from 1 to 3.5 for vertical load and from 1 to 1.5 for horizontal load.
For a vertically loaded piled-raft, results are presented in Figures 3 for behaviour of the raft and in Figures 4 for the behaviour of the piles. The differential displacement between the centre and the corner of the raft decreases with increasing L_1/L_2 ratio as shown in Figure 3.a. Figure 3.b shows that the overall vertical displacement along the centre line of the piled-raft reduced by 40% as L_1/L_2 increased from 1 to 3.5. The vertical displacements along the piles located at the centre (P1), edge (P2) and the corner (P3) are shown in Figures 4. The centre pile (P1) has the maximum displacement which decreases significantly as L_1/L_2 increases. However, the effect becomes less significant for the piles located further from the centre (i.e. Pile P3).
For a horizontally loaded piled-raft, the results for different L_1/L_2 ratios are shown in Figure 5 for horizontal displacement of the raft. From the results, it can be seen that an increase in the length (L_1) of the piles underneath the central region of the raft has no significant effect on the behaviour the piled-raft.

3-2 Effect of pile diameter

The piled-raft as shown in Figure 6 is used to demonstrate the effect of using larger piles underneath the heavily loaded (central) region of the raft on the behaviour of the piled-raft. The properties of the soil and piles and the applied loads are the same as in the above example. The piles underneath the central and edge region have diameters of D_1 and D_2 respectively with an identical length of L. analyses were carried out for pile diameter ratios D_1/D_2 that vary from 1 to 3. The ratios of the thickness to D_2 (t_r/D_2) and the pile length to D_2 (L/D_2) were taken as 1 and 20 respectively.
Figures 7 and 8 show the behaviour of a vertically loaded piled-raft supported by piles of different diameters. The variation of the differential displacement with different D_1/D_2 ratios is shown in Figure 7. The differential displacement was computed from the displacement at the centre with reference to the displacement at the corner of the raft. The differential displacement decrease with increasing D_1/D_2 ratios, however, the contribution of increasing D_1 to the differential displacement becomes less at $D_1/D_2 >2$. The overall vertical displacement along the centre line of the raft is show in Figure 8. By increasing the diameter of the piles underneath the heavily loaded region, the vertical displacement of the raft especially at the heavily loaded region has been reduced.
Figures 9 and 10 show the variation of the behaviour of a horizontally piled-raft with different D_1/D_2 ratios. By increasing the diameter of piles underneath the heavily loaded region of the raft, the horizontal displacement of the raft reduces slightly. Figures 10 show the horizontal displacement along the piles. For the horizontal displacement of the piles as shown in Figure 10, there is a small change as the ratio of the D_1/D_2 increases from 1 to 2 but vertically no change for larger D_1/D_2 values. It can be seen in this example, the optimum ratio of D_1/D_2 is where the diameter of centre

piles is twice of the diameter of the edge and corner piles (i.e. D_1/D_2 =2) for both horizontal and vertical loading of a piled-raft.

4 FIGURES



$$\frac{E_p}{E_s} = 2500 \quad \frac{E_p}{E_r} = 1, \quad \frac{t_r}{D} = 1, \quad \frac{h}{L_2} = 5, \quad \frac{B}{W} = 1 \quad \frac{L_2}{D} = 20$$

Figure 2. Configurations of the piled-raft.

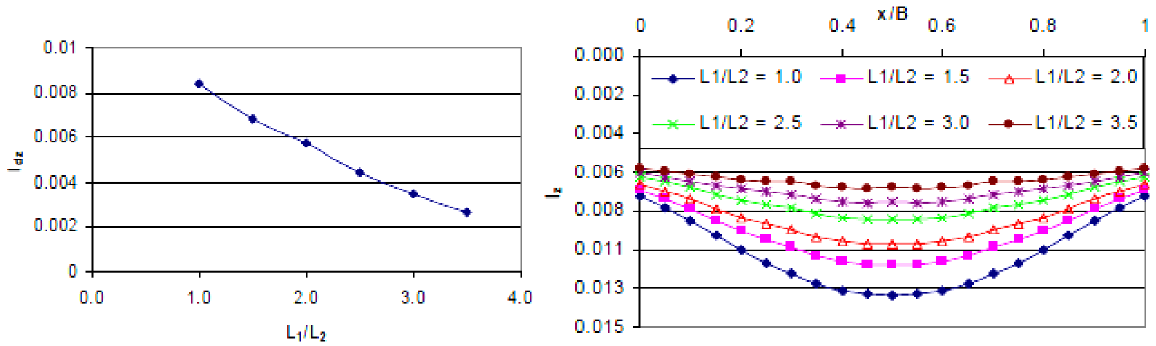
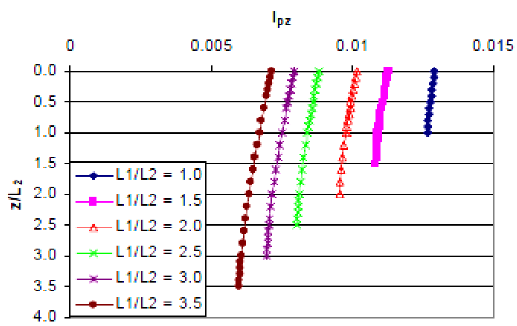
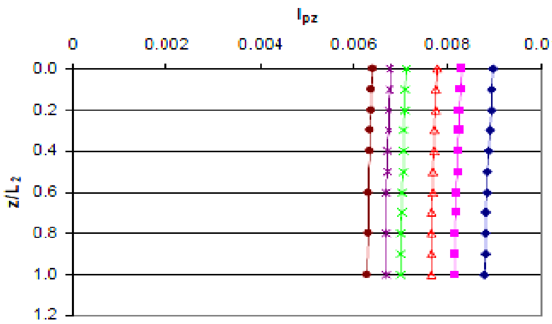


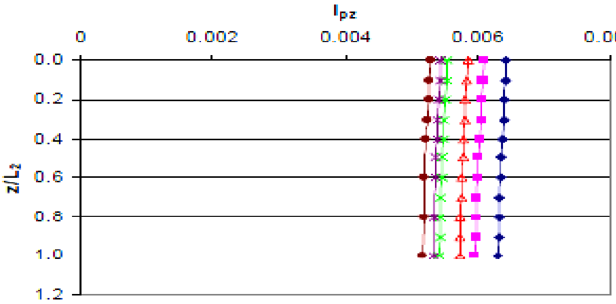
Figure 3. Variation of normalized differential and vertical displacement of the piled-raft with L_1/L_2 ratios.



(a) center pile



(b) edge pile



(c) corner pile

Figure 4. Normalized vertical displacement along the pile at different pile locations for different L_1/L_2 ratios.

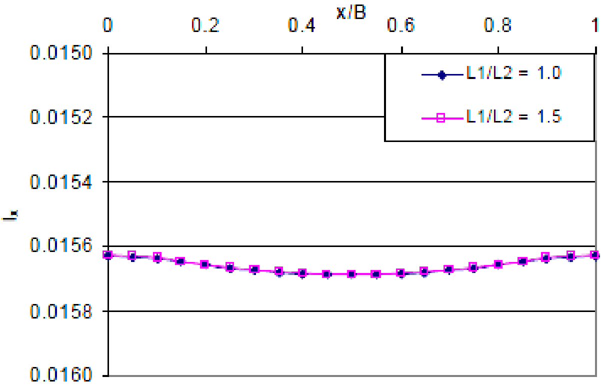
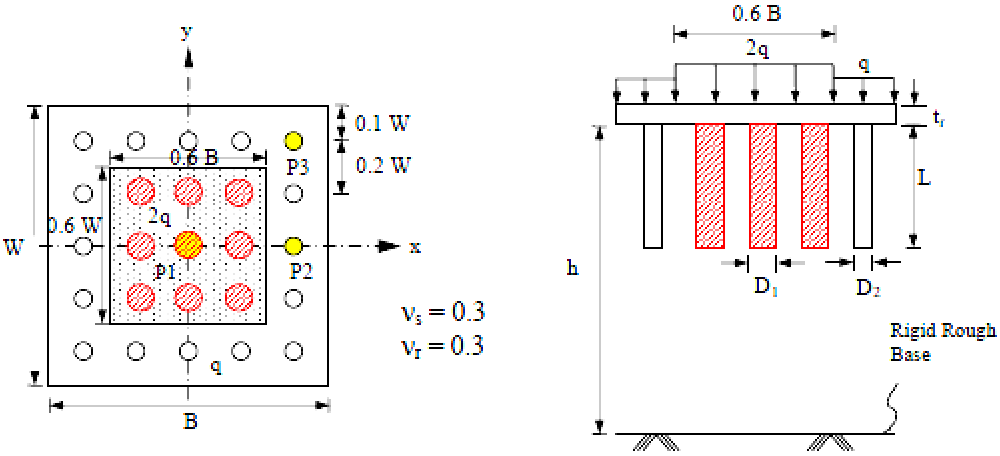


Figure 5. Normalized horizontal displacement of the piled-raft for different L_1/L_2 ratios.



$$\frac{E_p}{E_s} = 2500 \quad \frac{E_p}{E_r} = 1, \quad \frac{t_r}{D_2} = 1, \quad \frac{h}{L} = 5, \quad \frac{B}{W} = 1 \quad \frac{L}{D_2} = 20$$

Figure 6. Configuration of the piled-raft.

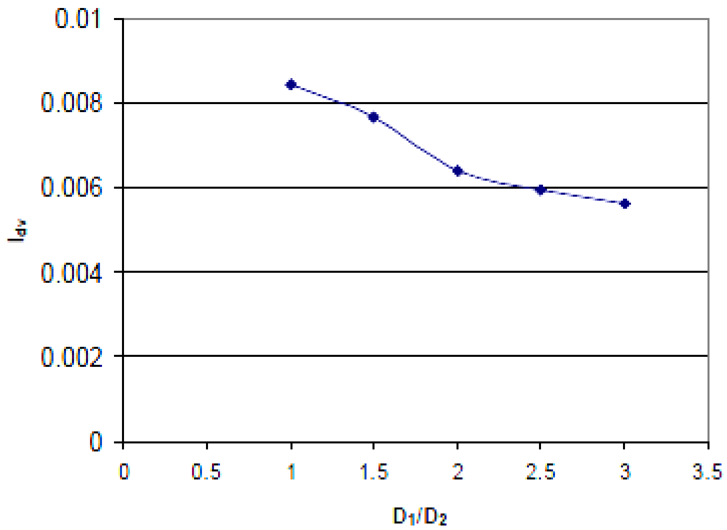


Figure 7. Variation of normalized differential displacement of the piled-raft with D_1/D_2 ratios.

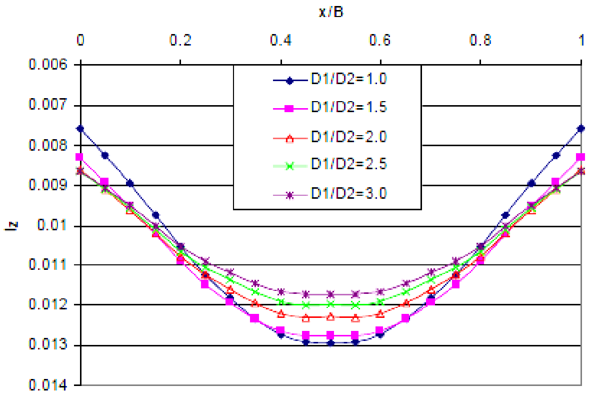


Figure 8. Normalized vertical displacement of the piled-raft for different D_1/D_2 ratios.

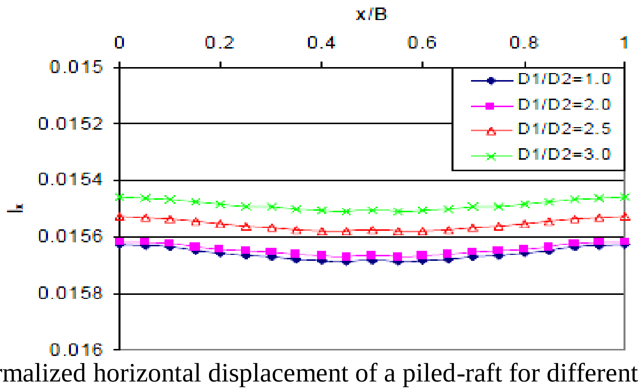
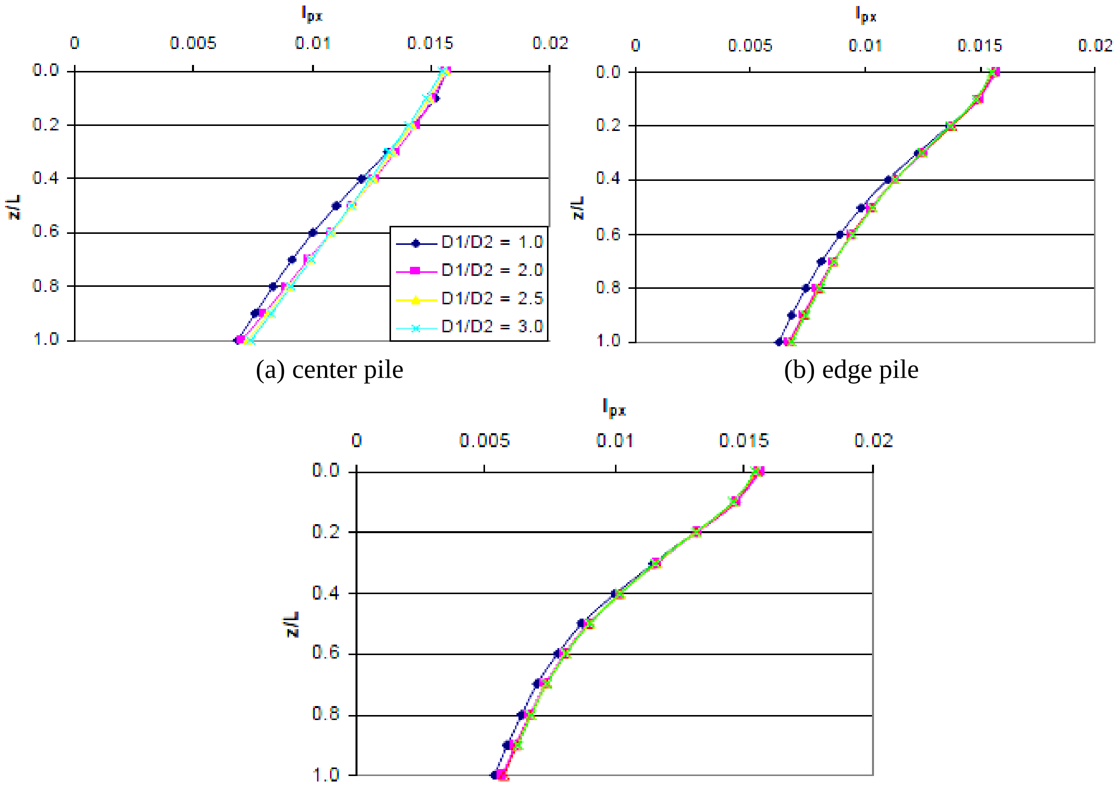


Figure 9. Normalized horizontal displacement of a piled-raft for different D_1/D_2 ratios.



(a) center pile (b) edge pile

(c) corner pile

Figure 10. Normalized horizontal displacement along the pile at different pile locations for different D_1/D_2 ratios.

5 FORMULAE

$$I_{rz} = \frac{u_{rz}E_sD}{q_zBW} \quad I_{px} = \frac{u_{px}E_sD}{q_xBW} \quad I_{pz} = \frac{u_{pz}E_sD}{q_zBW} \quad I_{dz} = \frac{\Delta u_{rz}E_sD}{q_zBW} \quad I_{rx} = \frac{u_{rx}E_sD}{q_xBW}$$

u_{rx} and u_{rz} are the horizontal and vertical displacements in the raft

Δu_{rz} is the differential vertical displacement in the raft

u_{px} and u_{pz} are the horizontal and vertical displacements in the pile

E_s is the modulus of the soil

D is the diameter of the pile

B and W are the length and width of the raft

q_x and q_z are the uniform horizontal and vertical applied loads on the raft

6 CONCLUSIONS

In this paper, the use of piled-raft foundations and pile dimensions on the performance of a piled-raft has been discussed through the examples presented above. The following conclusions can be reached:

(1) For vertical loads, piled-raft can be used to minimize the overall and differential displacement of the raft. For horizontal loads, the piles underneath the raft can help to resist the lateral movement of the raft; however, these piles will induce bending moment into the raft.

(2) For horizontally loaded piled-raft, the proportion of the load carried by the piles is lower than that of subjected to vertical loading. This showed that the contribution of the soil to resist movement for horizontally loaded piled-raft is more than that of for vertically loaded piled-raft.
(3) For piled-raft subjected to vertical non-uniform loadings, the use of longer piles underneath the heavily loaded region leads to a significant reduction in the overall and differential displacement of the piled-raft. The effect of longer centre pile is more significant than the corner pile.
(4) The effect of using larger diameter piles on a vertically loaded piled-raft is less significant compared with the effect of using longer piles. However, the effect is more significant for a horizontally loaded piled-raft.

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