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Experimental and Analytical Study of connected and non-connected piled raft foundations

M. J. Malekkhani, J. Bolouri Bazaz

Civil Engineering Department, Ferdowsi University of Mashhad, Mashhad, Iran

ABSTRACT: In the piled raft foundation, in contrast to the pile group, both raft and piles transfer the imposed load to the foundation soil. The concentration of shear stresses and bending moments at the connection point of the pile and raft in the piled raft may cause a structural collapse in the pile while the geotechnical bearing capacity of the pile has not fully mobilized. This problem may be solved by disconnecting the piles from raft and inserting a soil layer between the piles and the raft. This layer in non-connected piled rafts is called cushion. In a non-connected piled raft, the cushion plays an important role to mobilize the bearing capacity of the foundation soil, adjusting the load transfer mechanism, and changing the system stiffness. The behavior of a connected and non-connected piled raft is too complicated to easily estimate the load sharing ratio and stiffness for the preliminary design. In the present research, based on the test results of the pile group and the unpiled raft, an analytical approach is introduced to calculate the load sharing ratio and the stiffness of the connected and non-connected piled rafts. To verify the proposed analytical model accuracy, 21 small scale tests on the unpiled raft, pile group, connected and non-connected piled rafts were conducted. According to the results increasing the number and length of piles, increases the bearing capacity. In a non-connected piled raft, increasing the cushion thickness decreases the load sharing ratio of piles, stiffness, and bearing capacity of the system.

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1- Introduction

In a piled raft foundation, both raft and piles transfer the imposed load from the structure to the subsoil. In the piled raft, for a specific imposed load, less number of piles is needed to reach the same settlement in comparison to the pile group [1-3]. At the connection points of pile and raft, high moment and shear forces are transferred to the pile head and structural collapse may occur, while the geotechnical capacity of the pile is not fully mobilized [4, 5].

By disconnecting the piles from the raft and interposing a compacted granular soil layer between the raft and pile heads, the mentioned problem can be resolved. This system is known as a non-connected piled raft foundation [6-10]. The interposed layer which is called cushion, distributes vertical stress between the subsoil and the pile heads uniformly and prevents structural damages at the pile head. The physical properties and the shear strength parameters of the cushion influence the mechanism of load carrying and load sharing of piles and subsoil in non-connected piled raft foundations. In a non-connected piled raft system, due to the increase of the subsoil stiffness, the raft settlement is reduced and the bearing capacity of the piled raft is enhanced [11, 12].

In a non-connected piled raft foundation, the stiffness difference between piles and the subsoil and also the compressibility of the subsoil cause to produce the relative settlement at the piles head elevation and develops the negative skin friction at the upper part of the piles [13].

The aforementioned literature review indicates that interposing the cushion between the piles head and the raft in a non-connected piled raft foundation creates a complicated system with various interactions. Also, the cushion plays an important role in the load transfer and distribution mechanism, mobilizing negative skin friction and the bearing capacity of the subsoil. In the current study, an analytical model is developed to determine the stiffness of the non-connected piled rafts and the load sharing ratio of piles according to the stiffness of the unpiled raft and the pile group. To verify the proposed analytical model accuracy and validity, 21 small-scale tests were conducted.

2- Methodology

To estimate the stiffness of a non-connected piled raft, the settlement of the piled raft is needed. In a non-connected piled raft, the total applied load is shared between the piles and the subsoil. The piles and raft can be considered independent springs. In a non-connected piled raft, the settlement of the raft is equal to the sum of pile settlement and the compression of the cushion above the pile head.

In this study, to calculate the compression of the cushion, as depicted in Fig. 1, the cushion with a thickness of h_c is interposed between raft and piles and divided into

*Corresponding author's email: bolouri@um.ac.ir

a column above the pile head and a hollow cylinder above the subsoil in section A-A. The internal friction angle and elasticity modulus of the cushion are φ_c and E_c, respectively. The differential settlement, which occurs at the pile head elevation, mobilizes shear stress within the cushion. On the other hand, due to the high rigidity of the raft in comparison with the cushion, no differential settlement occurs in the cushion at the raft bottom [14]. In this model, to express the force equilibrium in the cushion, a unit element of the inner column with height dz is considered (Fig. 1-c). By solving the obtained equations, first, the transferred vertical stress on the pile head (Pi(0)) and then the compression of the cushion above the pile head (Si) can be derived as:

$$P_i = \frac{(-D_{pile}\gamma_c \cot\varphi_c) + e^{\frac{4k_0(h_c+z)\tan\varphi_c}{D_{pile}}}(4k_0 q_0 + D_{pile}\gamma_c\cot\varphi_c)}{4k_0} \quad (1)$$

$$S_i = \int_{-h_c}^{0} \frac{P_i}{E_c}dz = \frac{(D_{pile}\cot\varphi_c)}{16k_0^2 E_c} \times \frac{(-4k_0 q_0 - 4h_c k_0 \gamma_c - D_{pile}\gamma_c\cot\varphi_c + e^{\frac{4k_0 h_c \tan\varphi_c}{D_{pile}}}(4k_0 q_0 + D_{pile}\gamma_c\cot\varphi_c))}{16k_0^2 E_c} \quad (2)$$

While the stiffness of the non-connected piled raft (kpr) is the combination of the unpiled raft and group pile stiffness, it can be expressed as:

$$k_{pr} = k_r + \frac{k_p w_p}{w_{pr}} = k_r + \frac{k_p w_p}{(w_p + S_i)} \quad (3)$$

The load sharing ratio of a non-connected piled raft as the portion of the load taken by the piles can be derived as:

$$\alpha_{pr} = \frac{Q_p}{Q_{pr}} = \frac{k_p w_p}{(k_r + \frac{kp\,wp}{wp+si})(w_p + s_i)} = \frac{w_p}{\frac{k_r}{k_p}(w_p + s_i) + w_p} \quad (4)$$

To conduct the experimental tests, the dimensions of the square steel plate as the model raft was 200 mm×200 mm×10 mm, and to model the piles, solid steel pipes with 10 mm diameter were used. The soil container was a steel cubic tank with 1000 mm dimension. Firouzkouh No. 161 dry sand was used to model the cushion and the subsoil. The relative densities of subsoil and cushion were 50% and 96%, respectively. A new air pluviation system, developed at Ferdowsi University of Mashhad [15], was used to prepare reproducible and homogenous specimens and deposit the sand into the soil container.

3- Results and Discussion

According to the load-settlement curves, by increasing the length of the connected or non-connected piles, the load sharing ratio of the piles, which is defined as the portion of the carried load by the piles, is increased and the bearing capacity of the raft is enhanced. Increasing the number and the length of piles increases the resistance of the pile against the imposed vertical load and the stiffness of the piled raft as well. In the non-connected piled rafts, the thicknesses of 5, 10, and 20 mm for cushion were used. The stiffness of the cushion is much less than the rigid piles and by increasing the cushion thickness the stiffness and the load-bearing

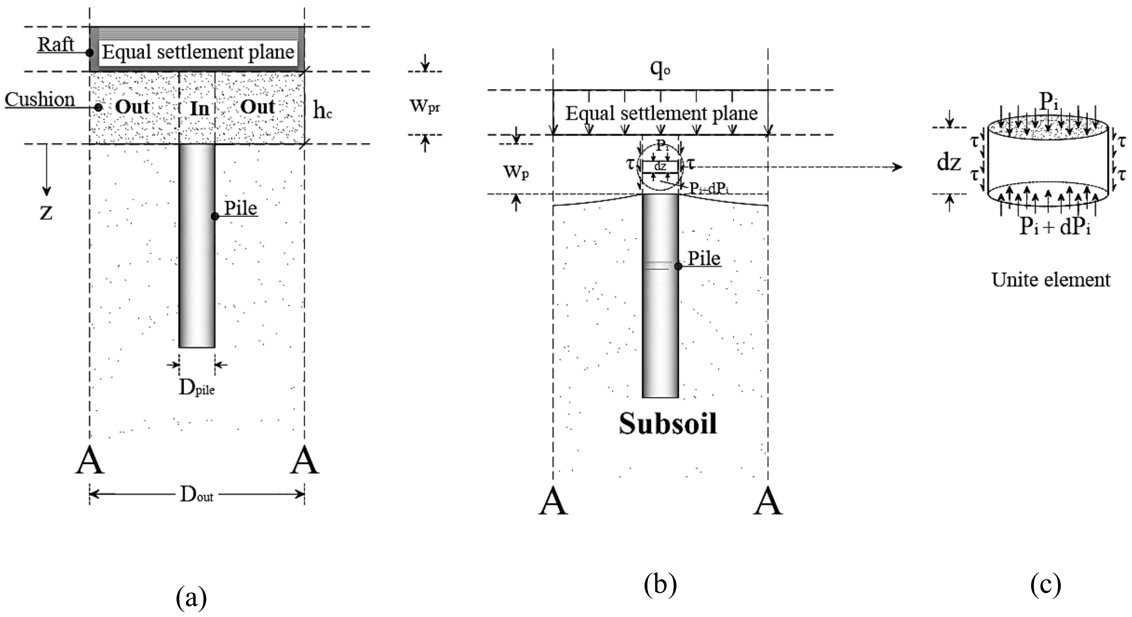

Fig. 1. Schematic view of the cylindrical unit cell for the cushion. (a) Before settlement. (b) After settlement. (c) Unit element in cushion

capacity of the non-connected piled raft were both reduced. On the other hand, the differential settlement at the pile head elevation is the result of the compressibility of the cushion and the stiffness difference between the piles and the subsoil. Any increase in the cushion thickness causes to affect more length of the piles by the down drag force of the negative skin friction and reduces the load sharing ratio of the piles and increases the settlement of the raft.

The stiffness of the connected and non-connected piled rafts was also measured according to the load-settlement results. At the initial loading stages, the stiffness of the piled raft foundations increases and after reaching the maximum amount, by increasing the interaction effects among pile-raft-soil, the stiffness of the piled rafts reduced. The magnitudes of the connected and non-connected piled raft stiffness predicted by the analytical model are in good agreement with those measured experimentally and the maximum differences are within an acceptable range.

4- Conclusions

In the present research, an analytical model is developed to calculate the stiffness and the load sharing ratio of piles in non-connected piled rafts. Also, experimental tests were carried out to study the behavior of non-connected piled rafts and to provide a verification tool for the analytical model. According to the test and model results, the following conclusions can be drawn briefly:

(1) The bearing capacity of the non-connected piled raft is considerably more than the pile group. Increasing the number or length of the piles reduces the settlement of the piled raft.

(2) In non-connected piled rafts, by disconnecting the piles from the raft the geotechnical bearing capacity of the piles can be fully mobilized.

(3) In non-connected piled rafts, the role of the cushion is to distribute the vertical stress beneath the raft almost uniformly. Increasing the cushion thickness decreases the load sharing ratio of piles and the stiffness and the bearing capacity of the non-connected piled rafts.

(4) The compressibility of the cushion and the stiffness difference of pile and subsoil mobilize negative skin friction at the upper part of the non-connected piles.

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