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Studying the Effect of Cushion Properties on the Behavior of Unconnected Piled Raft Foundation

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Abstract At the last decades, the design of piled raft foundation has been evolved in order to provide sufficient bearing capacity and reduction in settlement. While, minimum number of piles should be used for economical design. For this purpose, the concept of settlement reducer piles was presented. This system depend on using a few number of pile for reducing the settlement of raft to an allowable value. When these piles are structurally connected to the raft, a high axial stress develop in the pile heads. Therefore, the load-carrying capacity of these settlement reducing piles may be governed by their structural capacity mere than by their geotechnical capacity. In order to conquer problem of high stresses at connected point between piles and raft, unconnected piled raft foundation is a new developed system. Where the piles and raft are separated by granular cushion. The granular cushion is used as load redistribution between piles and soil in between. This system is a hybrid of shallow and deep foundation. In this system pile isn't acting as a structural element, but as a soil reinforcement. In this study, finite element software (plaxis 3D) was employed to investigate the effect of cushion properties (thickness and material properties) and raft thickness on the distribution of load through piles lengths, raft settlement, and the portion of load carried by piles. The results showed that, the maximum settlement of raft increases as cushion thickness increases or raft thickness increases. While, it decreases as cushion density increase. Moreover, carried loads by piles decrease as cushion thickness increases but, it decrease as cushion density increases. Raft thickness almost hasn't significant effect on redistribution of carried loads by piles.

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1. Introduction

The concept of a piled raft system was introduced by *Davis* and *Poulos* in 1972 [1]. When using traditional piled foundation, the number of piles is usually large and the load carried by each individual pile is relatively small. There is a high safety boundary before the piles reach their ultimate geotechnical bearing capacity or structural failure load, which lead to uneconomical design.

The application of piles as settlement reducers only was first suggested by *Burland et al. [2]*. The basic concept of this system is to use a number of piles for reducing the settlement of raft to an allowable level. These piles also carry a fraction of the structural loads. At system of settlement reducer piles, pile is designed to reach the fully geotechnical capacity. making it more economical compared to piled foundation. However, when these piles are structurally connected to the raft, high axial stresses develop in the pile. This make the load-carrying capacity of these piles are governed by their structural capacity not geotechnical capacity.

Clency and Randolph [3] suggested that so as to effectively design the raft foundation with settlement reducer piles, the bearing capacity of piles should be accounted for 80% of the service load. In most design codes (ASTM 1969, British Standard 1986, Singapore Code 2002), high safety factor have been considered for the allowable stresses in the piles that may be lead to uneconomical design of the foundation. In order to conquer problem of high stresses at connected point between the raft and pile, *Cao et al. [4]* and *Wong et al. [5]* suggested that piles should be dis-connected with the raft, in which the raft and pile are speared by a granular cushion, and unconnected piles cannot be considered as the structural element and are applied as soil reinforcing elements.

The *Rio–Antirrio bridge* in Greece [6] is an application of unconnected piled raft system, which consists of vertical piles used to improve the shear strength of soil and limit the danger of unsymmetrical settlements. The granular layer restricts the transition of shear forces and moments between the foundation and piles. *Liang et al. [7]* presented an unconnected piled raft system with cushion. In this system, short piles made of flexible material in order to increase the strength of the soil near the surface. Moreover, long piles made of rigid material were used to reduce raft settlement. The used of mid layer (cushion) was to redistribute the stress to the piles and soil underneath raft. The main results of this study showed that, as cushion modulus of elasticity increases, the axial load in long piles and short piles increases. Moreover, as cushion thickness increases, the axial stress through long piles decreases obviously, while that for short piles keeps almost constant. *Ata et al. [8]* investigated the load sharing capacity of unconnected piled raft under static loads in which several parameters such as number, diameter, and length of piles as well as raft thickness were analyzed. The results of this study can be summarized as, in the connected piled raft the maximum value of axial load through piles occurs at pile head. While, at unconnected system, the maximum value of axial load through piles shifted down. Moreover, axial load through pile decreases as cushion thickness increases.

Eslami and Malekshah [9] carried out 3-D analyses to illustrate the behavior of connected and unconnected piled raft foundation. This analysis indicated that, axial stress along piles occurs at different depths depending on the thickness and stiffness of the cushion. Morover, the result showed that, Increasing in the raft thickness has a little effect on the maximum settlement. But, its effect on the differential settlement. *Tradigo et al. [10, 11]* carried out three dimensional finite element analyses to present that an increase in cushion thickness will reduce the overall settlement. *Saeedi et al. [12]* used experimental centrifuge models to study the effect of connected and unconnected piled raft systems on the relationship between load and settlement. They showed that the existence of granular cushion is important for reduction the settlement of unconnected piled raft system while the function of piles is to reduce the settlements.

Although, the available information in the literature about unconnected piled raft foundations is valuable, a few researchers studied the behavior of cushion type. Moreover a few papers take into account the raft thickness and rigidity. This analysis was carried out by using a three dimensional finite element commercial software (PLAXIS 3D). This study investigate the effect of cushion properties and raft thickness on the distribution of load through piles lengths, raft settlement, and the portion of load carried by piles.

2. Methodology and Developed Model.

The properties of soil used in this analysis were taken from a study carried out by *Abd-Alaziz. et al. [13]* and are given in Table 1.

In this analysis, raft and piles are modeled as elastic materials. The soil layers and granular cushion are modeled by elastic plastic constitutive model following Mohr–Coulomb yield.

A vertical stress of 50, 100, 150, 200, 250, 300, and 350 kPa is applied on the raft, as an uniform distributed load. The schematic diagram of unconnected piled raft and cushion is shown in Fig. 1. The finite element mesh for the unconnected piled raft foundation system (UCPR) is shown in Fig.2, which is composed of the raft, cushion, soil and piles.

Where:-

t_C: thickness of granular cushion.
L_R: length of raft foundation.
t_R: thickness of raft.
L_p: pile length.
D_p: pile diameter.
S: spacing between piles. (center to center).

3. Parametric Study

The main purpose of the parametric study is to investigate the performance of the unconnected piled raft system with different cushion thickness and material properties. Also, the effect of raft thickness was investigated. The studied cases are listed in Table3. The influence of these parameters on maximum settlement of raft foundation, settlement along the raft foundation, axial load through the pile length and pile load ratio (α_{PR}) are presented.

4. Result and Discussion

4.1. Effect of cushion thickness, t_c (Cases 1, 2, 3, 4, 5, 6 and 7)

The relationship between applied stress on raft and the corresponding maximum settlement of UCPR system is shown in Fig.3. From this figure, it can be noted that, the un-piled raft curve has the highest gradients. In contrast the connected piled raft (CPR) curve has the lowest gradients. Also it can be seen that, the maximum settlement increases as the cushion thickness increases. Based on the results of this study, it was found that the optimum thickness of the cushion layer is 1m then increasing in cushion thickness hasn't significant effect. Fig.4 shows the settlements through the raft which subjected to 350 kPa vertical stress. From this figure, it can be seen that, compared to the raft without piles, the maximum settlement of connected piled raft foundation system (CPR) has decreased by 61%, while the maximum settlement of the unconnected piled raft with cushion thickness 0.25m and 0.5m have decreased by 57% and 51%, respectively, and decreased by 35% for cushion thickness of 1, 1.5, and 2m.

Fig.5 presents pile load ratio (α_{pr}) for CPR and UCPR foundation system with different cushion thickness. The portion of load carried by piles can be expressed by pile load ratio (α_{pr}) where,

$\alpha_{pr} = \sum P_{pile} / P_{total}$

Where $\sum P_{pile}$ is the all pile head loads summation and P_{total} is the total applied load on the raft. From this figure it can be seen that, pile load ratio decreases as cushion thickness increases, until reaches the minimum value of $\alpha = 33\%$ at 1m cushion thickness then increasing in cushion thickness has not significant effect.

Figs. 6, 7 and 8 present axial loads through central pile, exterior pile and corner pile, respectively, versus pile length for CPR and UCPR systems. These figures show that, the axial load through pile length at unconnected system is smaller than that in the connected system. The maximum axial load in the connected system occurs at the head of pile, and then decreases along the length of the pile. However, in the unconnected system, the position of maximum axial load is shifted downwards to a certain point below the pile head (approximately half pile length in the studied model). The decrease of the axial load at the pile head is due to the load shared by the cushion. Some of the vertical load carried by the cushion is then gradually transferred again to the lower parts of the pile by skin resistance. It also can be seen that the axial load on pile decrease as cushion thickness increased. This result show a good agreement with that obtained by *Zhu. [14]*

4.2. Effect of cushion type (Cases 8, 9, 10, 11, and 12)

Figure 9 presents the stress-settlement behavior of the UCPR foundation with different cushion type. This figure shows that, when very loose sand is used as cushion, the stress-settlement curve has maximum gradient, however minimum gradient is occurred for crushed stone cushion. This is attributed to the increasing of both elastic modulus and density of crushed stone cushion. Fig. 10 shows the settlement along the raft. From this figure, it can be seen that, compared to the unconnected piled raft foundation with very loose sand cushion, the maximum settlement of the loose sand cushion has decreased by 19%, the maximum settlement of the dense sand cushion decreased by 35%, the maximum settlement of the very dense sand and crushed sandstone cushion decreased by 38% and 35% respectively. Fig.10 presents the settlement along the raft, from this figure it can be seen that, the density of cushion hasn't significant effect in differential settlement along the raft. Fig.11 shows the pile load ratio at different cushion type, it can be seen that increasing in cushion density leads to increasing in pile load ratio.

Figs 12, 13 and 14 present axial loads through central pile, exterior pile and corner pile respectively versus pile length for UCPR systems with different cushion type. These figures show that, the axial load along the length of pile in case of very loose sand cushion is the minimum and in the case of crushed sandstone is the maximum. It also shows, that the axial pile loads increase as cushion density and stiffness increase.

4.3. Effect of raft thickness (Cases 13, 14, 15, 16, 17 and 18)

Model analysis is performed for a square raft having dimension 10×10 m with thickness varies from 0.25 m to 3m and supported on 25 unconnected piles with dense sand cushion of thickness 0.5m**.** Fig.15 presents the stress-settlement behavior of UCPR with different raft thickness**.** It can be seen that, as raft thickness increases, maximum settlement increased because the own weight of raft increased when its thickness increases. Fig.16 shows the settlement along the raft for UCPR with different raft thickness. The raft–soil relative stiffness (Krs) is a main factor influencing the differential settlement of the unconnected raft foundation system. *Horikoshi* and *Randolph* [15] estimated the raft–soil relative stiffness (Krs) of rectangular raft using the following equation.

$$K_{rs}=5.57\,\frac{Er}{Es}\left(\frac{1-\mu_s{}^2}{1-\mu_r{}^2}\right)(B/L)^{0.5}\,(t_r/L)^3 \qquad (1)$$

Where
Er = Modulus of elasticity of raft,
E_s = Modulus of elasticity of soi,
μ_s = Poisson's ratio of soil,
μ_r = Poisson's ratio of raft,
B = Width of the rectangular raft,
L = the length of the rectangular raft,
t_r = the raft thickness.

Fig. 17 shows that the differential settlement between center and edge of raft, from this figure it can be seen that decrease as the soil-raft stiffness (Krs) increase. The differential settlement reduces with the increasing of the raft thickness up to 1.5 m. then increasing in raft thickness has not significant effect on relative settlement of raft. Fig.18 shows the pile load ratio in variable raft thickness. From this figure it can be noted that, the pile load ratio decrease as raft thickness increased. Figs.19, 20 and 21 present axial loads through central pile, exterior pile and corner pile respectively versus pile length for UCPR systems with different raft thickness. These figures show that, for raft thickness less than 1m by applying equation No.1 (Krs<1) (flexible raft) the axial load through central pile decreased as raft thickness increased. These figures also presented, for thickness greater than 1.5m (Krs<10) (rigid raft) the axial load through pile length is not effect as raft thickness increased. Contrariwise, axial load through exterior and corner pile length increase with raft thickness. The previous results can be illustrated as, at flexible unconnected piled raft foundation the stresses concentrated at central zone of raft, and this stresses redistributed with raft rigidity increases.

Table 1. Soil parameters used in modeling

Soil type	Fill loamy sand	soft sandy clay	Dense silty sand	Very dense sand and silt
Model	.Mohr-col	.Mohr-col	Mohr-col.	Mohr-col.
E, kN/m^2	3.50E+04	2.00E+04	1.20E+05	2.80E+05
Poisson	0.3	0.35	0.3	0.3
$C_{u,KPa}$	10	30	24	25
φ	36	15	42	44
γ_{unsat}	15.9	15.9	17.4	17.4
γ_{sat}	17	17	18.5	18.5
R_{inter}	0.67	0.5	0.67	0.7
ψ	6	0	12	14
Layer thickness	4	2	13	14

Table 2. Cushion material properties

Soil type	very loose sand	loose sand	Dense sand	very dense sand	crushed sandstone
Model	.Mohr-col	.Mohr-col	Mohr-col.	Mohr-col.	Mohr-col.
E, MPa	11.96	20.79	53.76	75.32	250
Poisson	0.3	0.35	0.4	0.4	0.25
$C_{u,KPa}$	0	0	0	0	1
φ	26	30	36	42	40
γ_{unsat}	15	17	19	21	19
γ_{sat}	16	18	20	22	20

Table 3. The general plans of the parametric study

Case of study	Case No	Cushion type	t_c (m)	Raft dimension		Pile group geometry			
				$L_R \times B_R$ (m)	t_R (m)	L_p (m)	D_p (m)	S	Number of piles
Effect of cushion thickness	1	No pile	0	10×10	0.5	0	0	0	
	2	CPR	0			10	0.5	$4D_p$	5×5
	3	Dense sand	0.25						
	4		0.5						
	5		1						
	6		1.5						
	7		2						
Effect of cushion Type	8	Very loose sand	0.5	10×10	1	10	0.5	$4D_p$	5×5
	9	loose sand							
	10	Dense sand							
	11	Very dense sand							
	12	Crushed sandstone							
Effect of raft Thickness	13	Dense sand	0.5	10×10	0.25	10	0.5	$4D_p$	5×5
	14				0.5				
	15				1				
	16				1.5				
	17				2				
	18				3				

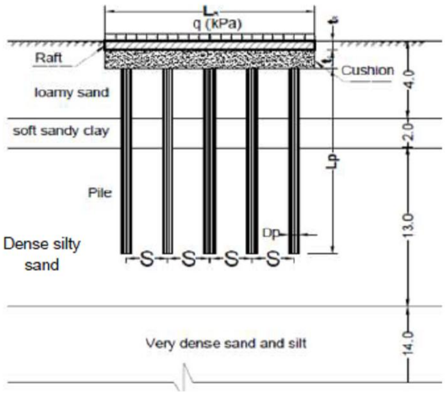

Fig.1 Schematic diagram of unconnected piled raft and cushion

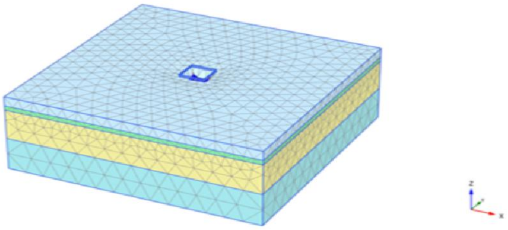

Fig.2 Finite element for unconnected piled raft foundation system

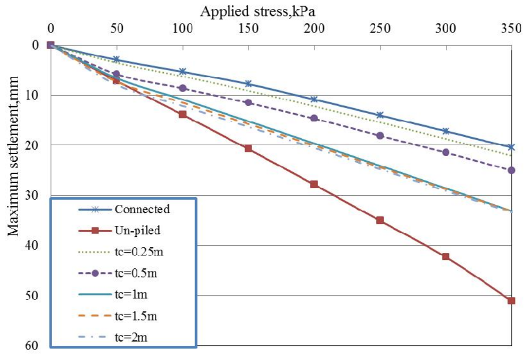

Fig.3 Maximum settlement of raft for un-piled, CPR and UCPR systems (t_R=0.5m)

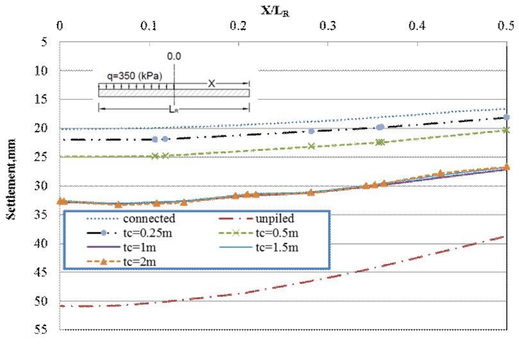

Fig.4 Settlement along the raft for un-piled, CPR and UCPR systems (t_R=0.5m)

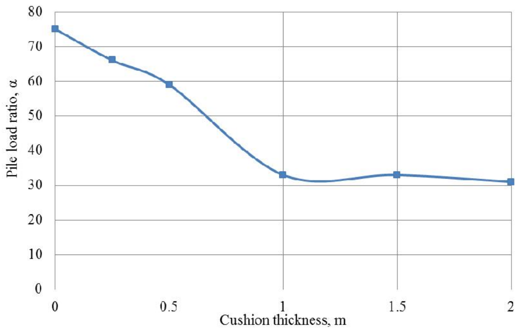

Fig.5 Pile load ratio for connected and unconnected system. (t_R=0.5m)

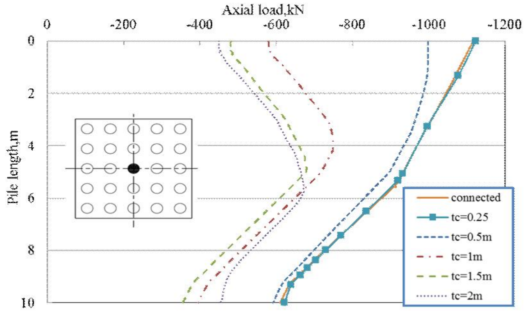

Fig.6 Vertical load through central pile length for connected and unconnected system, (q=350 kPa, t_R=0.5m)

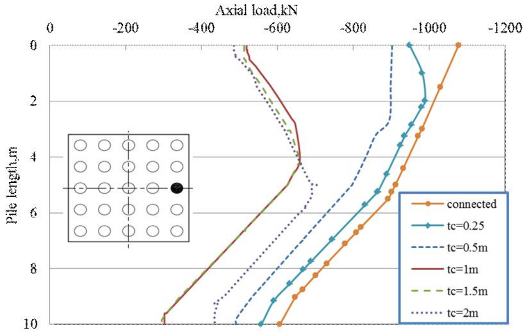

Fig. 7 Vertical load through exterior pile length for connected and unconnected piled raft system, (q=350 kPa, t_R=0.5m)

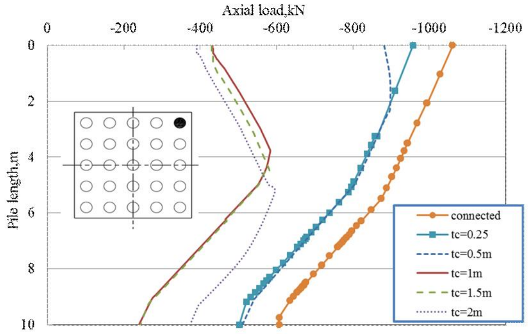

Fig. 8 Vertical load through corner pile length for connected and unconnected piled raft system, (q=350 kPa, t_R=0.5m)

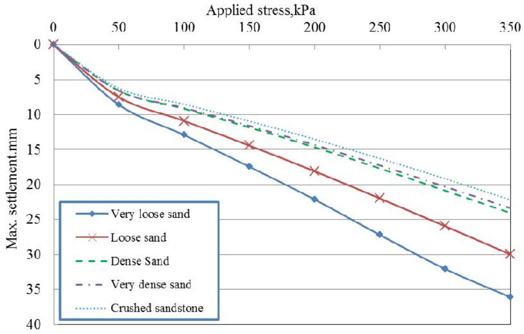

Fig. 9 Maximum settlement of raft for UPRF with different cushion type (t_R=1m)

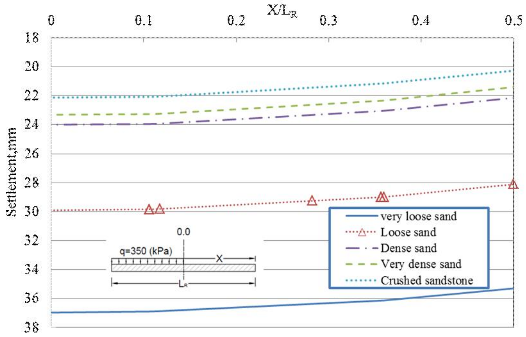

Fig. 10 Settlement along the raft for UPRF with different cushion type (t_R=1m)

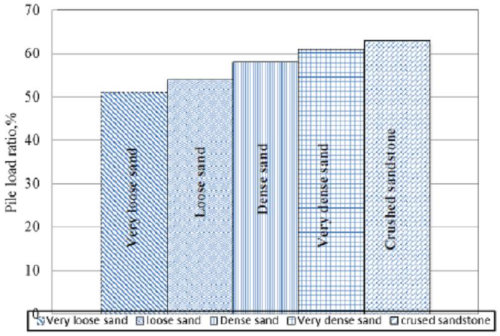

Fig. 11 Pile load ratio for different cushion type (t_c=0,5m, t_R=1m)

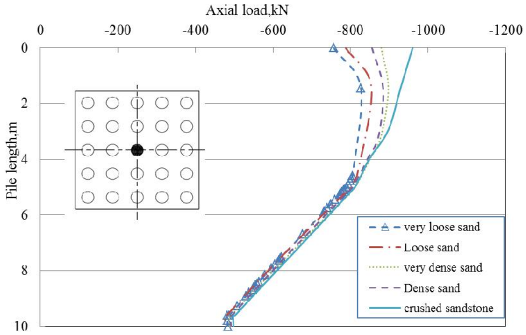

Fig. 12. Vertical load through central pile length for different cushion type, (q=350 kPa, t_c=0.5m, t_R=1m)

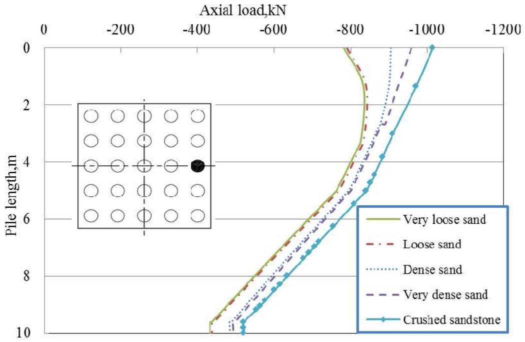

Fig. 13. Vertical load through exterior pile length for different cushion type, (q=350 kPa, t_c=0.5m, t_R=1m)

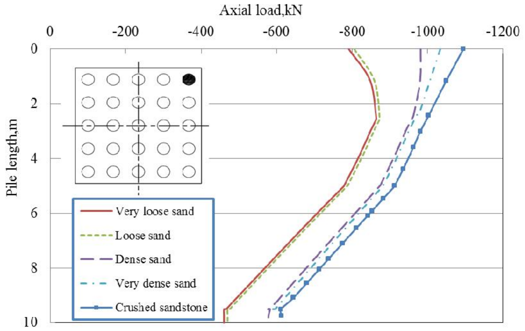

Fig.14 Vertical load through corner pile length for different cushion type, (q=350 kPa, t_c=0.5m, t_R=1m)

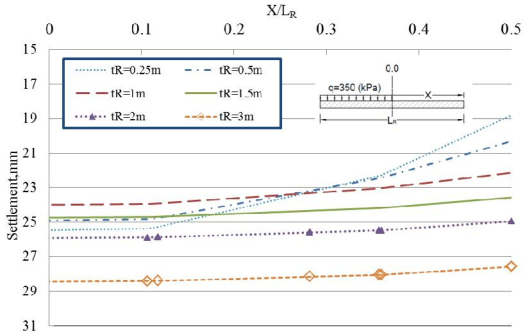

Fig.15 Maximum settlement of UCPR system for different raft thickness

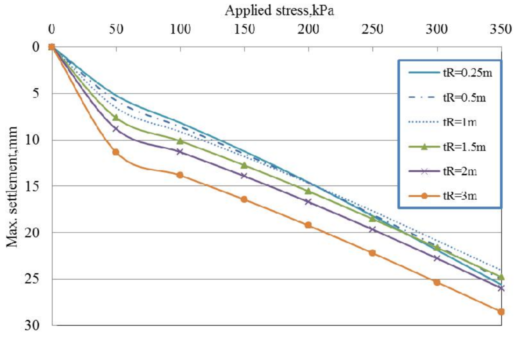

Fig.16 Settlement along the raft for different raft thickness (for UCPR)

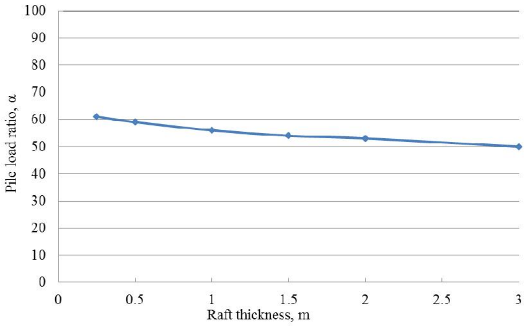

Fig.17 Relation between differential settlement and raft-soil stiffness ratio (Krs)

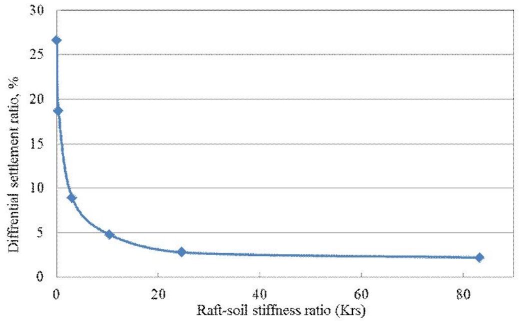

Fig.18 Pile load ratio at different raft thickness for UCPR system (t_c=0.5m)

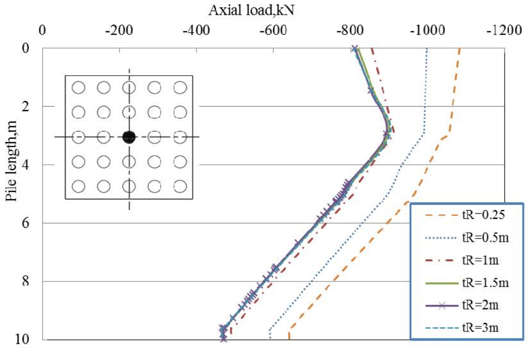

Fig.19 Vertical load along central pile length for various raft thickness, (q=350 kPa, t_c=0.5m)

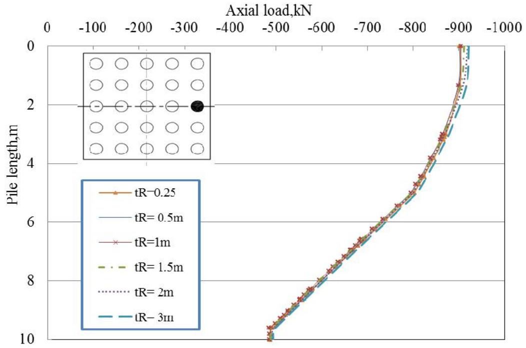

Fig.20 Vertical load along external pile length for various raft thickness, (q=350 kPa, t_c=0.5m)

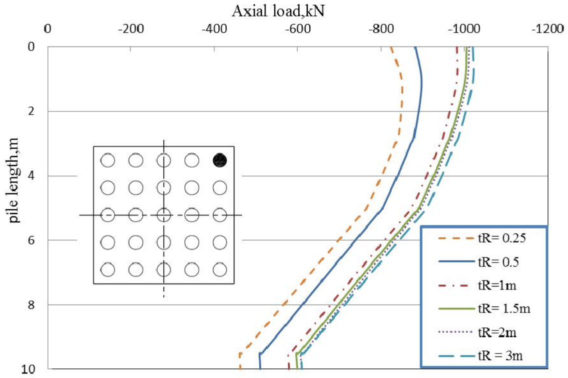

Fig.21 Vertical load along corner pile length for various raft thickness, (q=350 kPa, tc=0.5m)

5. Summary and conclusion

Based on this numerical study, following conclusion can be obtained.

(1) Compared to the raft without piles, the maximum settlement of the connected piled raft has decreased by 61%, while the maximum settlement of the unconnected piled raft with cushion thickness 0.25m has decreased by 57%.

(2) The axial load along the length of pile in the unconnected system is smaller than that in the connected system. The maximum axial load in the connected system occurs at the head of pile, and then decreases along the length of the pile. However, in the unconnected system, the position of maximum axial load is shifted downwards to a certain point below the pile head (approximately half pile length in the studied model.

(3) Axial load on pile and pile load ratio increase as cushion modulus of elasticity and density increased.

(4) In the studied model it is noted that increasing in cushion modulus of elasticity more than 80Mpa is not effective.

(5) Relative settlement of raft decreases as (K_{rs}) increases.

References

1. Davis E, Poulos H. "The analysis of pile raft systems", Australian Geomechanics Journal, 1972, No. 1, Vol. 62, pp. 21-27.
2. Burland J, BB B, De Mello VFB. "Behavior of foundations and structures", Proceeding 13th International Conference on Soil Mechanics and Foundation Engineering, 1977, Tokyo, pp. 495-546.
3. Clancy P, Randolph M. "An approximate analysis procedure for piled raft foundations", International Journal for Numerical and

Analytical Methods in Geomechanics,1993, No. 12, Vol. 17, pp. 849-869.

4. Cao, X. D., I. H. Wong, and M.-F. Chang, “Behavior of model rafts resting on pile-reinforced sand,” Journal of Geotechnical and Geoenvironmental Engineering, vol. 130, no. 2, pp. 129–138, 2004.
5. Wong I, Chang M, Cao X. 17. "Raft foundations with disconnected, Design Applications of Raft Foundations", 2000, pp. 469.
6. Giretti D." Modelling of piled raft foundations in sand": Università degli Studi di Ferrara, 2010.
7. Liang FY, Chen LZ, Shi XG. "Numerical analysis of composite piled raft with cushion subjected to vertical load” Computers and Geotechnics, 2003, No. 6, Vol. 30, pp. 443-453.
8. Ata, A., E. Badrawi, and M. Nabil." Numerical analysis of unconnected piled raft with cushion" Ain Shams Engineering Journal, Vol. 6 (2), (2015) pp 421-428.
9. Eslami A. and S. S. Malekshah, “Analysis of non-connected piled raft foundations (NCPRF) with cushion by finite element method,” Computational Methods in Civil Engineering, vol. 2, no. 2, 2011.
10. Tradigo, F., F. Pisan`o, C. Di Prisco, and A. Mussi, “Non-linear soil-structure interaction in disconnected piled raft foundations,” Computers and Geotechnics, vol. 63, pp. 121–134, 2014.
11. Tradigo, F., F. Pisan`o, and C. di Prisco, “On the use of embedded pile elements for the numerical analysis of disconnected piled rafts,” Computers and Geotechnics, vol. 72, pp. 89–99, 2016.
12. Saeedi, A. A., Baziar, M. H., Rasouli, H., Modarresi, M. and Shahnazari, H. “Centrifuge modeling of non-connected piled raft system,” EJGE. 18: 2417-2432,2013.
13. Abd Alaziz, T. M., A. M. Ragheb And W. M. Arafa. "Numerical simulation of single Pile Capacity Using plaxis". the 9th International Conference on Soil Mechanics and Geotechnical Engineering, Alexandria, Egypt, December 2016.
14. Zhu, X. J. “Analysis of the load sharing behaviour and cushion failure mode for a disconnected piled raft,” Advances in Materials Science and Engineering, 2017.
15. Horikoshi K, Randolph MF." On the definition of raft–soil stiffness ratio" Geotechnique 1997;47(5):1055–61.

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