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An experimental investigation on behavior of piled raft foundation

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ABSTRACT

An experimental program in laboratory is conducted on model piled rafts in sand soil. The aim of the experimental program is to study the behaviour of piled raft foundation system subjected to vertical load. The experimental program includes the model test on unpiled raft, raft supported by single pile, (2x2) and (3x3) pile groups. The model piles used in this test are non displacement piles. In the laboratory test, model mild steel piles of diameter 10mm and length 200mm were used, represents slenderness ratio, L/D of 20. The raft was made of mild steel plate with plan dimensions of 160mm x 160mm with different thicknesses of 5mm, 10mm and 15mm. The refinement in the bearing capacity is represented by load improvement ratio and the reduction in settlement is represented by settlement reduction ratio. The influence of number of piles and raft thickness on load improvement ratio and settlement reduction ratio are presented and discussed. The results of the tests show that as the number of piles underneath the raft increases, load improvement ratio and settlement reduction ratio increase and percentage of load carried by the raft decreases. Also, there is a negligible effect on load improvement ratio and settlement reduction ratio with increase in raft thickness, while raft thickness has a minimal effect on the load carried by the raft.

Key words: Raft, piles, piled raft, model test, sand soil.

1. Introduction

The piled raft foundation system has recently been widely used for many countries to support different types of structures like bridges, buildings and industrial plants in different types of soil. The Piles in combination with raft plays an important role in settlement reduction and thus can lead to economical design without compromising the safety of the structure. The concept of using piles as settlement reducers was first proposed by Burland et al. 1977. Several reports were published on the used of piles as settlement reducers (Poulos and Davis 1980; Clancy and Randolph 1993; Randolph 1994; Horikoshi and Randolph 1996; Kim et al. 2001; Poulos 2001; Cunha et al. 2001). Cooke et al. 1986 compared the behaviour of piled raft foundation system with that of the free standing pile group and unpiled raft, through model tests on piled raft foundation. Horikoshi et al. 1996 performed a centrifuge test on piled raft foundation system on clayey soil, to study the settlement of piled raft foundation. Horikoshi et al. 2003 performed centrifuge test on piled raft foundation system on sandy soil subjected to horizontal and vertical loading, to study the load-settlement behaviour and load sharing between pile and raft in piled raft foundation system. Conte et al.2003 conducted a centrifuge test on piled raft foundation system to determine the stiffness of piled raft foundation due to effect of variation in piles and raft geometry. Lee et al. 2005 carried out an experimental test on piled raft foundation system in sandy soil, to investigate the behaviour of piled raft foundation due to the effect of pile installation and interaction between the raft and pile. Bajad et al.2008 conducted 1 g model test on a piled raft foundation on soft clay with raft having different thicknesses on 4,9 and 16 piles, to study the effect of pile length and number of piles on load sharing between pile and the raft and settlement reduction.

Fioravante et al. 2008 conducted a centrifuge test on unpiled rigid circular raft and raft on 1, 3, 7 and 13 piles on sandy soil, to study the role of piles as a settlement reducer and load sharing between the raft and piles. Fioravante et al. 2010 conducted centrifuge test on piled raft foundation model to study the load transfer mechanism between the raft and the pile in sand soil and observed that load sharing mechanism is related to pile-soil stiffness. EI Garhy et al. 2013 performed experimental test on model piled raft foundation on sandy soil to investigate the behaviour of raft on settlement reducing piles, due to influence of raft-soil stiffness. In this paper, the load-settlement behaviour and the load sharing mechanism between the piles and raft is investigated through a model test on piled raft foundation system on sand.

2. Experimental Program

The main purpose of the experimental work was to study the load-settlement behaviour of piled raft foundation system and load transfer mechanism between the raft and piles with different raft thicknesses and different pile configurations. Total twelve tests were conducted in the laboratory. Three tests were carried out on unpiled raft and nine tests were carried out on piled rafts. The program of laboratory model test on unpiled raft and piled raft foundations are presented in Table 1.The pile configurations and dimensions of a model raft of piled raft are shown in Figure1.The dimensions of model pile and raft were chosen to ensure no stress concentration at the boundary of the tank. The height of soil was two times greater than the pile length to avoid the effect of a rigid base of the soil tank on the behaviour of piles (Horikoshi & Randolph, 1999).

Table 1: Summary of the model tests on unpiled and piled rafts**.**

Test Explanation	Model Raft dimensions (mm x mm x mm)	L/D	S/D	Number of Test Performed
Unpiled raft	160x160x5 160x160x10 160x160x15	-	-	1 1 1
Raft + 1 pile	160x160x5 160x160x10 160x160x15	10	-	1 1 1
Raft + 4 piles	160x160x5 160x160x10 160x160x15	10	3	1 1 1
Raft + 9 piles	160x160x5 160x160x10 160x160x15	10	3	1 1 1

2.1 Tested soil

A dry sand sample was used as foundation soil in this research. The specific gravity of sand was found to be 2.65.The minimum and maximum dry unit weights of sand were found to be 14.40 kN/m^3 and 16.90 kN/m^3, respectively. The particle size distribution was determined using the dry sieving method and results are shown in fig 2. The uniformity coefficient (C_u)

and coefficient of curvature (C_c) for the sand were 1.36 and 1.03, respectively. According to the Indian standard soil classification, the soil is classified as poorly graded sand, SP.The sand was poured in the tank at a unit weight of 15.80 kN/m^3 i.e. at 60% relative density. The angle of internal friction at a unit weight of 15.80 kN/m^3 was found to be 36.5^0. The secant modulus (E_{50}) at unit weight 15.80 kN/m^3 was found to be 10.725 MPa, determined from triaxial test.

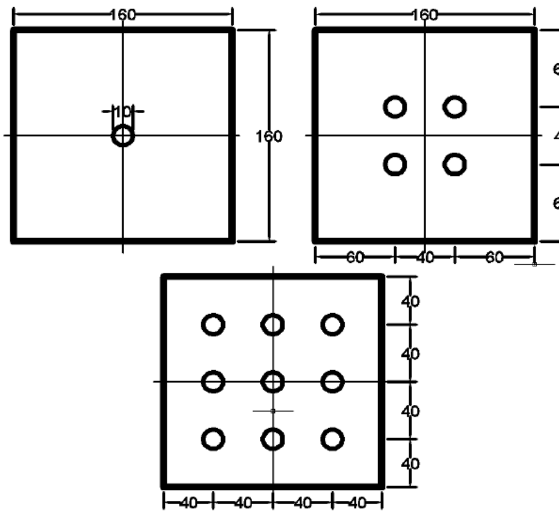

Figure 1: Studied cases of piled raft foundation (unit: mm)

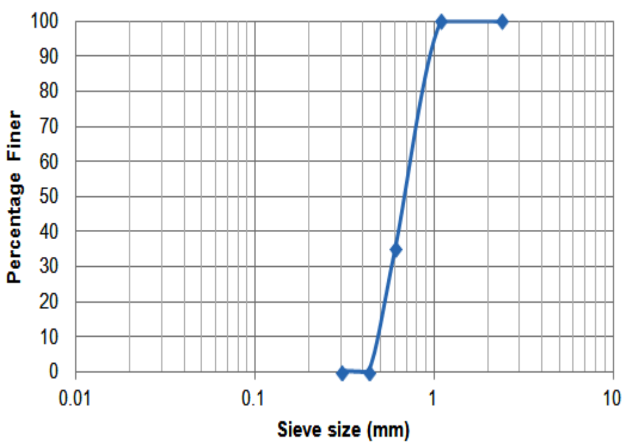

Figure 2: Particle size distribution curve

2.2 Piled raft model

The model raft was made up of mild steel plates having a square shape with different thicknesses. The dimensions of rafts were 160mm x 160mm x 5mm, 160mm x 160mm x 10mm and 160mm x 160mm x 15mm, respectively. The model piles were made up of the mild steel of diameter 10mm.The pile length of 200mm were used in the experiments, represents slenderness ratio of 20. The modulus of elasticity and Poisson's ratio of mild steel raft and pile were 1.8 x 10^5 MPa and 0.2 respectively. To ensure rigid connection between the pile and raft, top head of each pile was provided with a bolt of 6mm diameter and 25mm long to connect the pile to the raft through nuts.

3. Experimental setup

The tank is made from steel, having dimension 850 mm x 850 mm in plan and 500 mm in depth. The loading frame consists of four vertical columns of 1.0 m height, two on each side and two horizontal beams. The beam consists of hand operated hydraulic jack fixed at the centre as shown in Figure3.Calibrated load cell of 10 kN capacity was attached to the jack to measure the load. Two linear displacement transducers (LVDTs) of 0.01 mm accuracy were located at the middle side of the raft, to measure vertical displacement. Figure 4 shows the strain gauges mounted along the pile shaft, to measure the distribution of forces along the shaft.

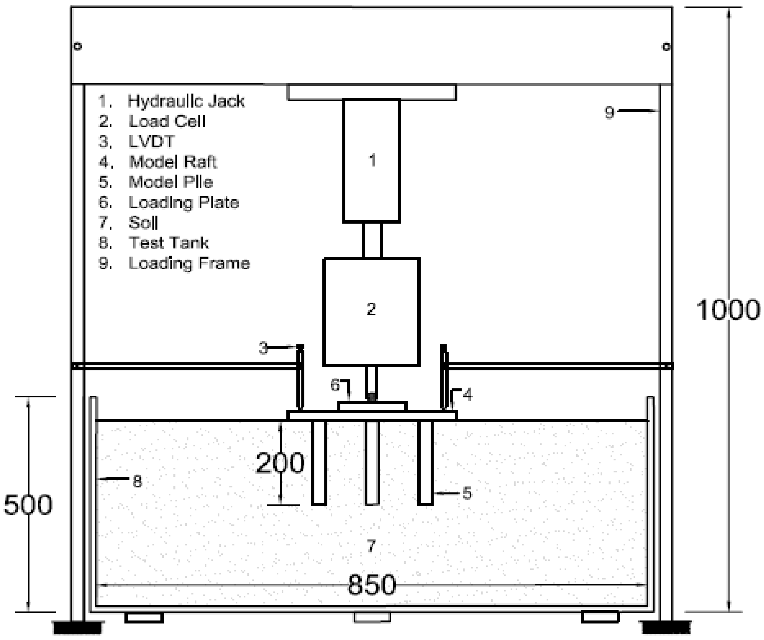

Figure 3: Model test set up (unit: mm)

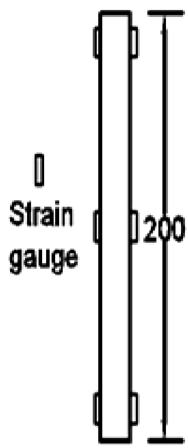

Figure 4 : Instrumented pile

3.1 Test procedure

1. Sand was poured in tank by rainfall method, Inorder to achieve required density in all the tests. The total height of the tank was divided into intervals of 50 mm. The sand was poured in tank up to a height of 450mm with height of fall 600mm, to achieve a unit weight of 15.80 kN/m^3.
2. As the piles are non-displacement piles, at first, sand was poured up to a height of 260 mm from bottom of tank, then piles having length 200mm, were placed in vertical position with 10mm penetration into sand, to ensure proper seating. The sequence of pile installation starts with inner pile, followed by corner piles and finally edge piles. The piles are held in position till the tank is filled up.
3. After installation of model piles, model raft was placed and connected to each pile by nuts.
4. The load was transferred to model raft through loading plate, placed on the raft. Then, two LVDTs were placed at the middle side of the raft, to measure vertical displacement.
5. A calibrated load cell of 10 kN capacity was connected to hydraulic jack. The model raft was loaded incrementally and at the end of each load increment vertical settlement was measured. The rate of loading was 0.1 kN/min. The loading was continued till the raft settlement reaches 20mm.

4. Results and discussion

The model tests results obtained from laboratory tests are analyzed and discussed in this section. The settlement equal to 10% of pile diameter or raft width is often adopted to define the ultimate load capacity in foundation design (cerato et al. 2006, Lee et al. 1999, Lee et al.2005). In this model tests, loading was continued till the raft settlement reaches 20mm.

4.1 Unpiled raft

Figure 5 shows the load-settlement curves for the unpiled raft models of different raft thicknesses. It can be noted that the load carrying capacity of the unpiled raft slightly increase with the increase in raft thickness. (e.g. at 20mm settlement, the increase of raft thickness from 5mm to 10mm causes an increase in the raft load by 5.9% and the increase of raft thickness from 5mm to 15mm causes an increase in the raft load by 12%).

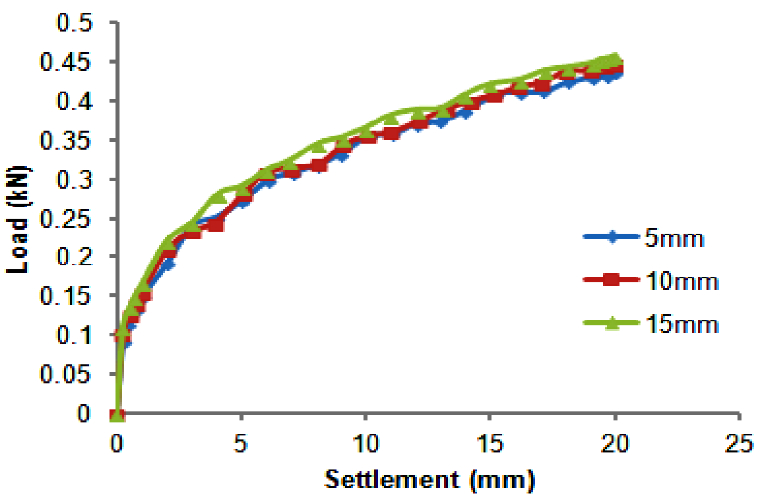

Figure 5: Load-settlement curves for unpiled rafts

4.2 Piled raft

In this section, the effects of number of piles and raft thickness, on the behaviour of piled raft are analyzed and discussed. In the following figures, symbols R, R+1, R+4, R+9are used which represents unpiled raft, raft supported by 1 pile, raft supported by 4 piles and raft supported by 9 piles, respectively. Figures 6-8 show the load-settlement curves of unpiled raft and raft supported by 1, 4 and 9 piles for raft thicknesses 5mm, 10mm and 15mm, respectively. As shown in these figures, the load carrying capacity of piled raft increases as the number of piles supporting the raft increases. This increase is mainly due to the increase of proportion of load shared by the piles due to the increase of the number of piles. In this study, due to the presence of piles under the raft, the improvement in load capacity of raft, at 10mm and 20mm settlements is represented by non-dimensional parameter called Load improvement ratio, which was define as the ratio of load carried by the piled raft and unpiled raft at 10mm and 20mm settlement.

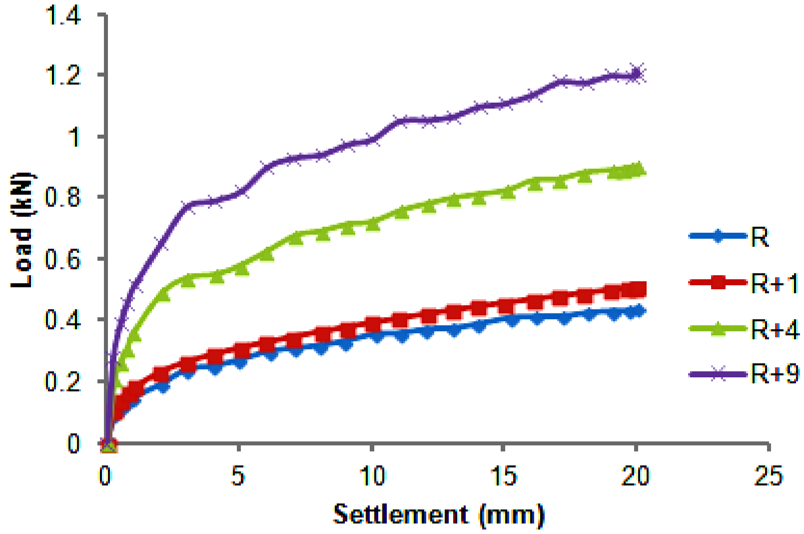

Figure 6: Influence of number of piles on load settlement curves of piled raft (t=5mm)

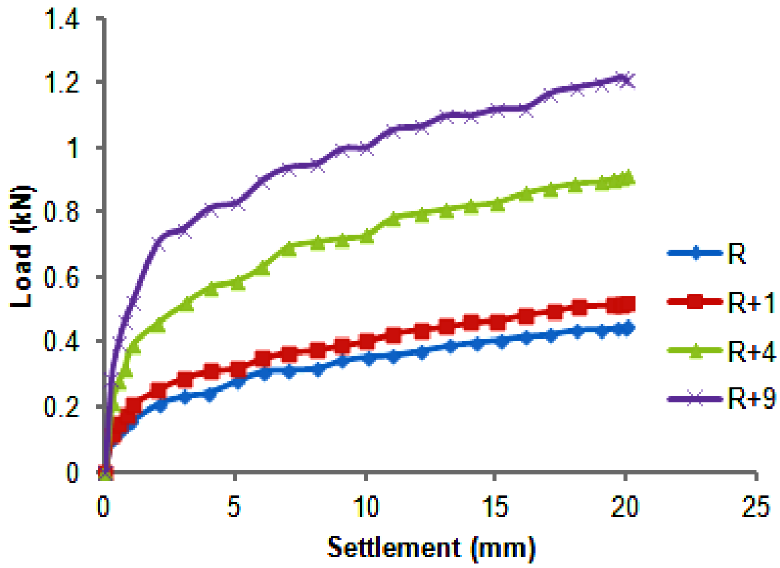

Figure 7: Influence of number of piles on load settlement curves of piled raft(t=10mm)

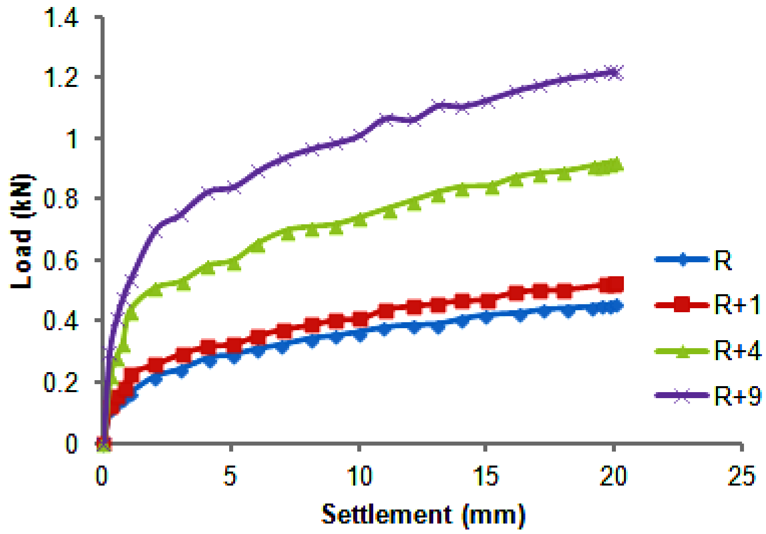

Figure 8: Influence of number of piles on load settlement curves of piled raft(t=15mm)

Figures 9 and 10 show the variation of the load improvement ratio with the number of piles at 10mm and 20mm settlements, respectively. From these figures, it can be observed that for the given raft thickness, the value of load improvement ratio increases as the number of piles beneath the raft increases (e.g. at 20mm settlement, for raft thickness 5mm, the value of load improvement ratio increases by 33%,while installing 4 piles to 9 piles).

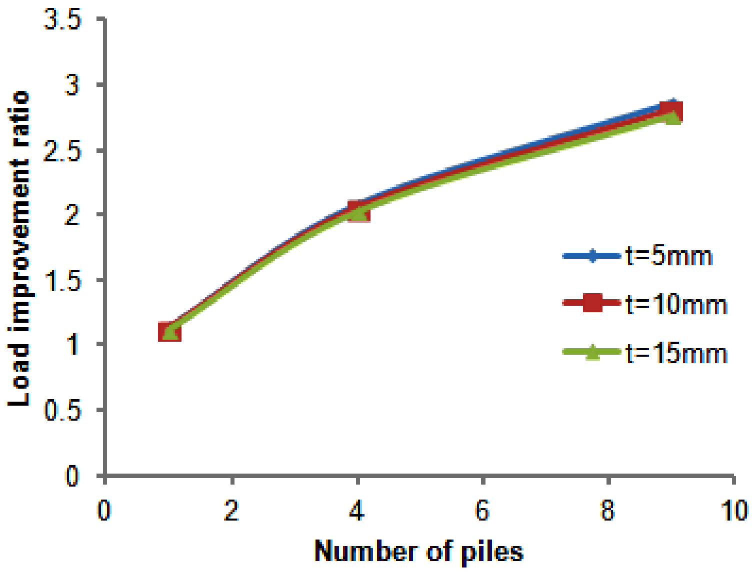

Figure 9: Variation of load improvement ratio with the number of piles at 10mm settlement

Figure 11 shows the variation of the load improvement ratio with the raft thickness for 1, 4 and 9 piles underneath the raft. It can be observed that load improvement ratio at 10mm settlement is greater than that at 20mm settlement. A similar observation has been reported by Phung, 2010 from experimental test results on piled rafts. This explains the mechanism of load sharing between the raft and piles (i.e. at the beginning of piled raft loading, the piles carry a major portion of the load, and with the increasing settlement, the load is transferred to the raft).

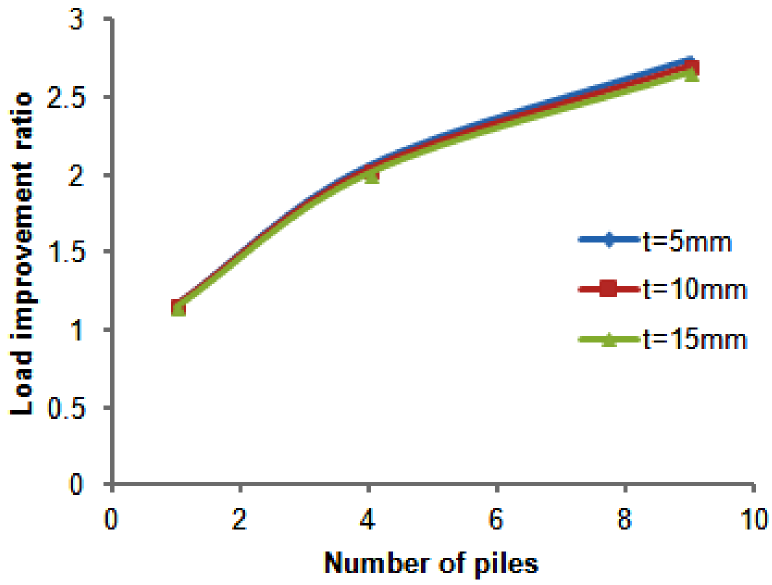

Figure 10: Variation of load improvement ratio with the number of piles at 20mm settlement

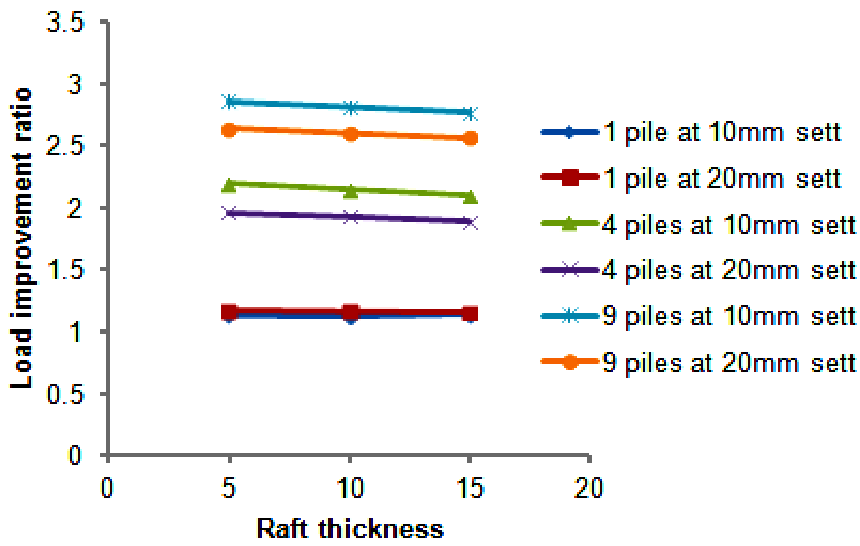

Figure 11: Variation of load improvement ratio with raft thickness

Figure12 shows the variation of proportion of load shared by piles with the number of piles for model raft with raft thicknesses of 5mm, 10mm and 15mm.From these figure, it can be observed that the proportion of load shared by the piles increases as the number of piles beneath the raft increases (e.g. for raft thickness 5mm, the proportion of load shared by piles increases from 8.8% to 41.5% of the total load, while installing 1 central pile to 4 piles).

Figure 13 shows the variation of proportion of load shared by the piles with the increase in raft thickness. From these figure, it can be observed that the change in thickness doesn't affect the proportion of load shared by the piles. Similar observations were obtained by Poulos, 2001 and Singh and Singh, 2011 from numerical analyses of piled raft with different numbers of piles.

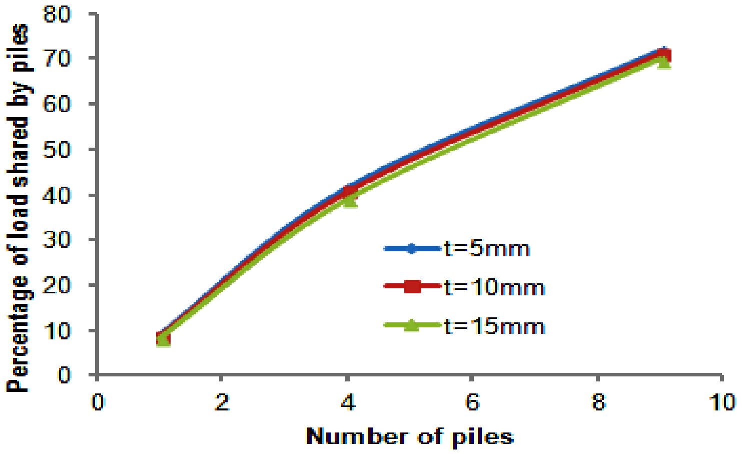

Figure 12: Influence of number of piles on load sharing between raft and piles

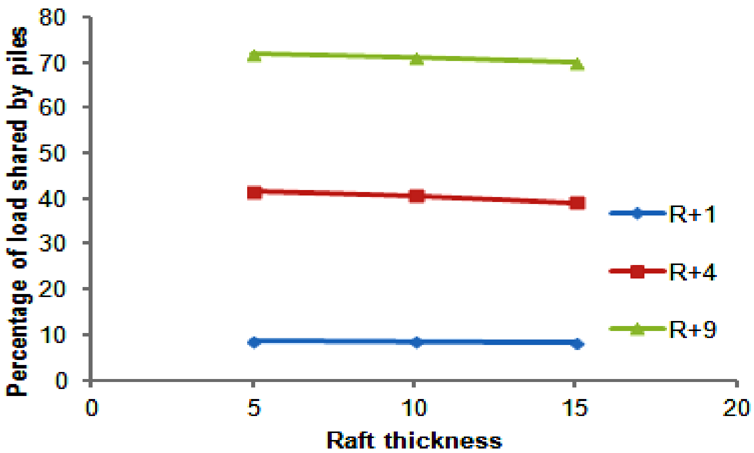

Figure 13: Influence of raft thickness on load sharing between raft and piles

The reduction in settlement of raft due to the presence of piles are represented by a non dimensional factor, called settlement reduction ratio, which was define as defined as the ratio of settlement of piled raft and unpiled raft at a given load.

$$\text{Settlement reduction ratio} = \frac{\delta r - \delta pr}{\delta r} \qquad [1]$$

where, δ_r and δ_{pr} represents settlement of unpiled raft and piled raft for a given load.

Figure14 shows the variation of settlement reduction ratio, with the number of piles for rafts with thickness of 5mm, 10mm and 15mm.From these figure, it can be observed that:

1. as the number of piles underneath the raft increases, the settlement reduction ratio increases.

2. The rate of increase of settlement reduction ratio decreases as the number of piles underneath the raft increases (e.g. For raft thickness 5mm, settlement reduction ratio increases by 42.7%, while installing 1 pile to 4 piles underneath the raft, while installing 4 piles to 9 piles settlement reduction ratio increases by 19.0%).

Therefore, it can be concluded that the efficiency of piled raft foundation system in reducing settlement is minimal beyond a certain number of piles.

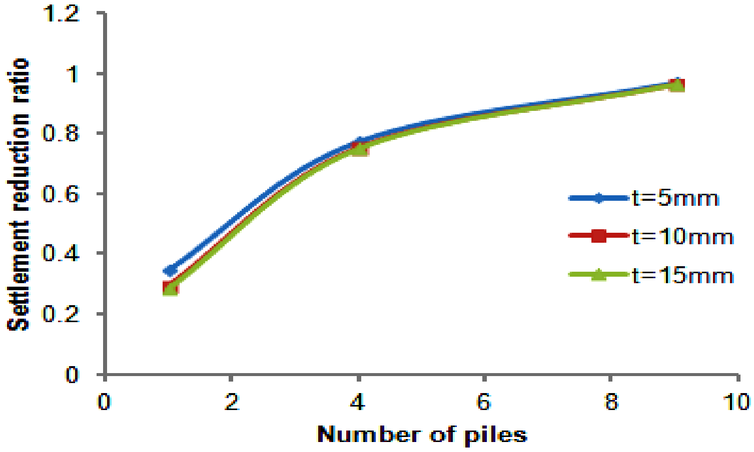

Figure 14: Variation of settlement reduction ratio with number of piles

Figure15 shows the variation of settlement reduction ratio with raft thickness for 1, 4 and 9 piles underneath the raft. It can be observed that the raft thickness has little effect on settlement of piled raft.

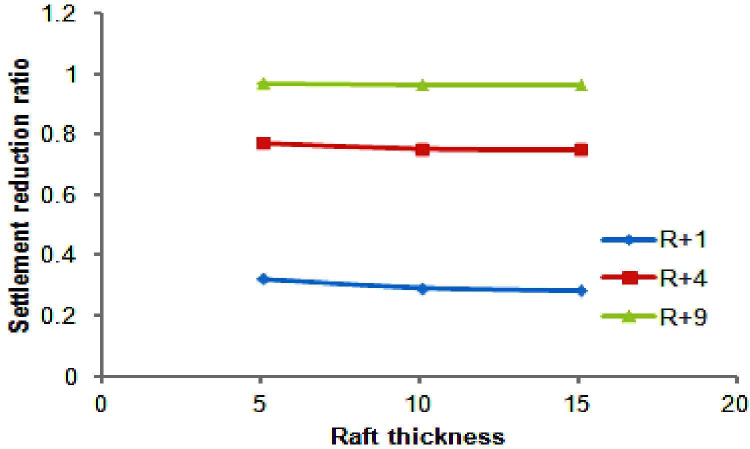

Figure 15: Variation of settlement reduction ratio with raft thickness

5. Conclusions

This paper has presented experimental results of small scale laboratory model test on sand, to investigate the load-settlement behaviour and load sharing between the piles and raft. From the results of this study, the following conclusions can be drawn

1) The load bearing capacity of piled raft increases as the number of piles beneath the raft increases.
2) Load improvement ratio increases at 10mm and 20mm settlement, as the number of pile increases.
3) The raft thickness has insignificant effect on the settlement and the loading sharing between piles and raft.

4) The efficiency of piled raft foundation system in reducing settlement is minimal beyond a certain number of piles.

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6. References

1. Burland J.B., Broms B.B., and de Mello, V.F.B., (1977), Behavior of foundations and structures, Proc.9 ICSMFE, Tokyo 2, pp 495-546.

2. Bajad S.P., and Sahu R.B., (2008), An experimental study on the behaviour of vertically loaded piled raft on soft clay, The 12th Intl. Conf. of International Association for Computer Methods and Advances in Geomechanics (IACMAG), pp 84–90.

3. Cooke R.W., (1986), Piled raft foundations on stiff clays, Contribution to design Philosophy. Geotechnique, 35(2),pp 169-203

4. Clancy P., and Randolph, M.F.,(1993),An approximate analysis procedure for piled raft foundations, Internatonal Journal of Numerical and Analytical Methods in Geomechanics, 17(12),pp 849–869.

5. Cunha R.P., Poulos H.G., and Small, J.C.,(2001),Investigation of design alternatives for a piled raft case history, Journal of Geotechnical and Geoenvironmental Engineering, 127(8),pp 635–641.

6. Conte G., Mandolini A., Randolph M.F.,(2003),Centrifuge modelling to investigate the performance of piled Rafts, Proceedings of the 4th international Geotechnical seminar on deep foundations on bored and auger Piles, Van Impe, W F Ed, Millpress, Rotterdam, pp 359-366.

7. Cerato A.B., Lutenegger A.J.,(2006),Bearing capacity of square and circular footings on a finite layer of granular soil underlain by a rigid base, Journal of Geotechnical and Geoenvironmental Engineering, 132(11), pp 1496–501.

8. El-Garhy B., Galil A.A., Youssef A.F., Raia M.A.,(2013),Behavior of raft on settlement reducing piles: Experimental model study, Journal of Rock Mechanics and Geotechnical Engineering, pp 389–399.

9. Fioravante V., Giretti D., Jamiolkowski M., (2008),Physical modelling of raft on settlement reducing piles, From research to practice in Geotechnical Engineering, Reston, pp 206–39.

10. Fioravante V., and Giretti D.,(2010), Contact versus Noncontact Piled Raft Foundations, Canadian Geotechnical Journal, 47(11), pp 1271-1287.

11. Horikoshi K., and Randolph M.F., (1996), Centrifuge modelling of piled raft foundation on clay, Geotechnique, 46(4), pp 741–752.

12. Horikoshi K., Randolph M.F.,(1999), Estimation of overall settlement of piled rafts, Soils and Foundations, 39(2), pp 59–68.

13. Horikoshi K., Matsumoto T., Hashizume Y., Watanabe T., Fukuyama H.,(2003), Performance of piled raft foundations subjected to static horizontal loads, International, Journal of Physical Modelling in Geotechnics, 3(2), pp.37–50.

14. Kim K.N., Lee S.H., Kim K.S., Chung C.K., Kim M.M., and Lee H.S.,(2001), Optimal pile arrangement for minimizing differential settlements in piled raft foundations, Computational Geotechniques, 28(4),pp 235–253.

15. Lee J., Salgado R.,(1999),Determination of pile base resistance in sands, Journal of Geotechnical and Geoenvironmental Engineering, 125(8), pp 673–83.

16. Lee S.H., and Chung C.K.,(2005),An experimental study of the interaction of vertical loaded pile groups in sand, Canadian Geotechnical Journal, vol 42, pp 1485-1493.

17. Lee J., Salgado R.,(2005),Estimation of bearing capacity of circular footings on sands based on cone penetration test, Journal of Geotechnical and Geoenvironmental Engineering, 131(4), pp 442–52.

18. Poulos H.G., and Davis E.H.,(1980),Pile foundation analysis and design, Wiley, New York.

19. Poulos H.G.,(2001),Piled raft foundations: Design and applications, Geotechnique, 51(2), pp 95–113.

20. Phung D.L.,(2010),Piled raft–a cost-effective foundation method for high-rises, Geotechnical Engineering Journal of the SEAGS and AGSSEA, 41(3), pp.1–12.

21. Randolph M. F.,(1994),Design methods for pile groups and piled rafts,Proc., 13th Int. Conference on Soil Mechanics and Foundation Engineering, 5, pp.61–82.

22. Singh N.T., and Singh B.,(2008),Interaction analyses for piled rafts in cohesive soil, The 12th International Conference of International Association for Computer Methods and Advances in Geomechanics (IACMAG), Goa, India, pp 3289-3296.