Load carrying characteristics of sand coated Pile Raft Foundation: An Experimental

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Abstract: Pile raft foundation is relatively new approach for design of pile group in which pile cap was considered in contact with soil and designed as raft that transfer partial load of superstructure to soil. The design of pile raft foundation is not a simple problem as many interaction effect as pile to pile, pile to soil, pile to raft and raft to soil are involved and effect the design considerable. In this study, an experimental investigation has been carried out on a sufficiently large model in laboratory to observe the effect of various parameters such as effect on load carrying capacity of pile raft on diameter, length of piles and pile to pile spacing for piles coated with sand.

***IndexTerms*–Pile Raft, Soil Structure interaction, Sand coated piles, parametric study.**

I. INTRODUCTION

High rise structures and skyscrapers are considered as the indicator of development of a country. Every developed and developing countries are encouraging the construction of skyscrapers as burj khalifa, Taipei etc. To transfer the load of such a hedge structure to earth very strong foundations are required. Concept of pile raft foundation was advocated by many researchers [1-4] to economize the construction cost. Most of the studies are based on Finite Element Methods [5-12] and few studies have been reported with small scale model in laboratory [13-18]. The response of small scale pile raft model based on laboratory studies may not be the same as the behavior of prototype pile raft foundation. Although the results of small scale tests have added important insights into the behavior of pile raft foundation, but in view of the difficulties in accurately modelling full-scale behavior within small scale laboratory models, practicing engineers do not adopt the results as published in the literature. Therefore these test results cannot be relied to predict the exact behavior of a particular prototype pile raft foundation. Field tests on prototype foundations give more realistic results in any geotechnical engineering problems. However, economic considerations and other practical difficulties either eliminate the prototype tests completely or restrict their scope to greater extent. Authors have yet to encounter any report in the literature where the behavior of large scale pile raft model has been reported based on laboratory study. Keeping these facts in view, relatively large scale pile raft model tests were conducted in the laboratory. Several parameters which can influence the load carrying capacity and settlement characteristics of pile raft model like length of pile, diameter of pile and center to center spacing of pile were considered as variables in the study. The experiments were performed with wooden piles coated with sand.

II. VARIABLES OF STUDY

The behavior of pile raft foundation system was studied by varying the parameters like length of pile, diameter of pile and center to center (c/c) spacing of piles. The thickness and dimension of raft were kept constant as 20mm and 750x750mm respectively. The variables used in the study are tabulated in Table 1. Altogether 48 experiments were carried out in laboratory to observe the effect of length, pile diameter and c/c spacing of smooth and rough pile raft system on load carrying capacity.

Table 1: Variables of study

Size of Raft(mm)	Pile dia (mm)	Pile length		C/C pile spacing to dia. Ratio (s/ d)
		Length (mm)	Length to diameter ratio (l/d)	
750x750	15	300,450,600,750	20,30,40,50	2,4,6,8
	25	300,450,600,750	15,18,24,30	2,4,6,8
	35	300,450,600,750	8.57,12.86,17.14,21.43	2,4,6,8

III. EXPERIMENTAL SET UP AND MATERIAL

The pile raft model test was conducted in a tank having dimension 2500mm × 2500mm in plan and 1.0m in depth. The tank was fitted with a 12mm thick perplex sheet on front side and was made sufficiently rigid with vertical and horizontal stiffeners. The tank was filled with sand in layers of 100 mm each through hopper using rain fall technique. The sand was poured from a constant height of 400mm. Piles and rafts were inserted in the sand by applying gradual load, a loading frame with 500 kN capacity jack was used for applying the load to pile raft foundation. To measure the load and settlement, load cell (500kN capacity and 1.0N least count) and Linear Variable Differential Transformers (LVDTs) of 0.001mm least count were used. Systematic view of loading frame and experimental setup are shown in Figures 2.

All the laboratory tests were performed using local sand. Preliminary properties like specific gravity, gradation of sand, unit weight, void ratio, relative density and angle of internal friction of sand were determined as relevant Indian standards and results are tabulated in Table 2. Unit weight of sand was determined by allowing the sand to fall in a cubical calibrated container through a hopper from different heights. Several trials were done by changing the height of fall from 0cm to 60cm with an increment of 10cm i.e. 0cm, 10cm, 20cm, 30cm, 40cm, 50cm and 60cm. In the present study a medium dense sand condition was selected keeping the height of fall 40cm and the corresponding relative density was 56% as reported in Table2.

Table 2: Properties of sand

S.No.	Description ant Units	Value
1	Specific gravity	2.66
2	Uniformity coefficient C_u	2.59
3	Coefficient of curvature C_c	0.94
4	Classification of sand	poorly graded sand (SP)
5	Unit weight (kN/m^3)	15.2
6	Relative density	56%
7	Angle of internal friction	31°
8	Modulus of Elasticity (MN/m^2)	13.24
9	Coefficient of cohesion (kN/m^2)	0.02
10	Poisson ratio	0.3

IV. PILE RAFT MODEL FOUNDATION

Piles and raft were made of wood and in another experiments piles were coated with same sand by applying epoxy, making the surface rough as shown in Figure 2.

Fig. 1: piles (coated with sand)

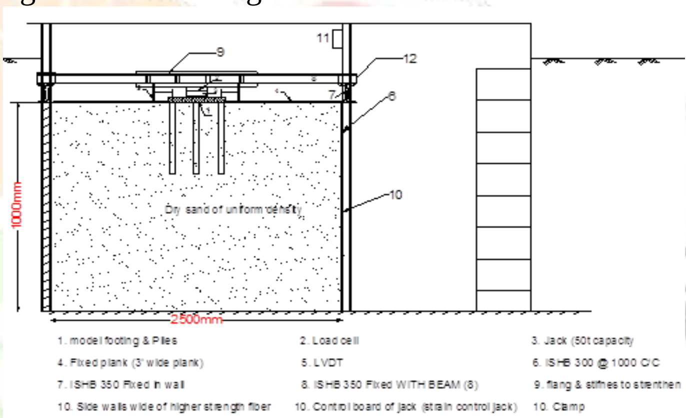


Fig. 2: Schematic view of loading arrangements used in the study

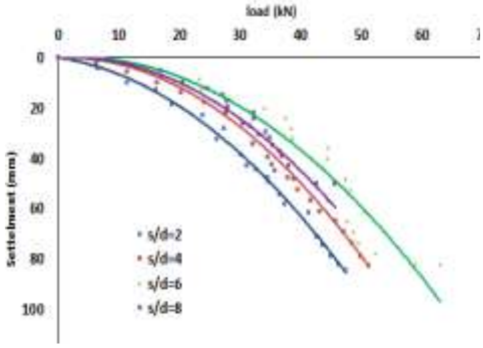
V. RESULT AND DISCUSSION

Load settlement curves were obtained by changing the geometric parameters as listed in table 1 and keeping other parameters as constant to observe the effect of these parameter on ultimate load carrying capacity of pile raft system. The ultimate load carrying load of pile raft foundation was determined cross ponding to 40mm settlement in sand. The load is divided by area of raft (0.75x0.75mm2) to get bearing capacity of pile raft foundation.

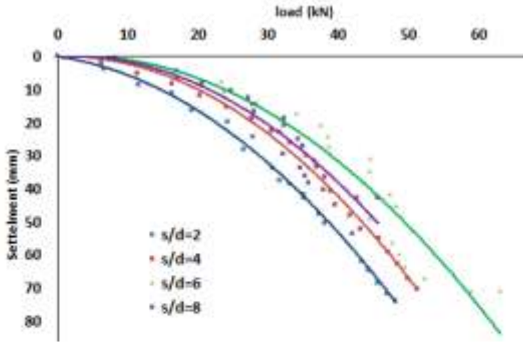
5.1 Effect of c/c pile spacing on load carrying capacity

To observe the effect of c/c pile spacing, 9 piles of 15, 25 and 35mm diameter and 300 to 750mm long piles were arranged in 3x3 group. Raft size is 750x750 mm and 40mm thick was used. The sand bed was prepared by falling it from a height of 40cm so that it sand bed might achieved a uniform density of 15.2 kN/m2. Piles were inserted in the sand bed and a vertical point load was applied with a rate of 1 mm/min on the raft, Load and corresponding settlement on two opposite corners of raft were started recording. These readings were processed and load settlement curve was obtained as shown in Figure 3. Experiments are performed by varying the pile c/c spacing from 2d, 4d, 6d and 8d for the same size of piles and raft. The combined results of 25mm diameter piles with 300, 450, 600 and 750mm long piles in the form of load settlement graphs were shown in Figure 3(a) to Figure 3(d).The load settlement graphs are also plotted for other diameters of piles. Ultimate load were determined crossponding to 40mm settlement.

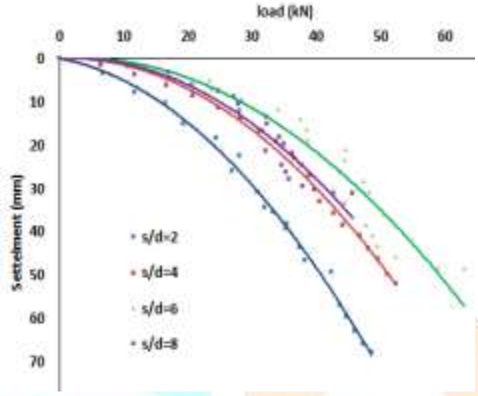
The effect of c/c pile spacing were shown in Fig 4(a) to (c) for 15, 25 and 35mm diameter piles respectively. It was observed from Figure 4 (a) to (c) that as c/c pile spacing increases from 2d to 6d, Load carrying capacity of pile raft system increases and with further increase in c/c pile spacing, it decreases for rough piles.



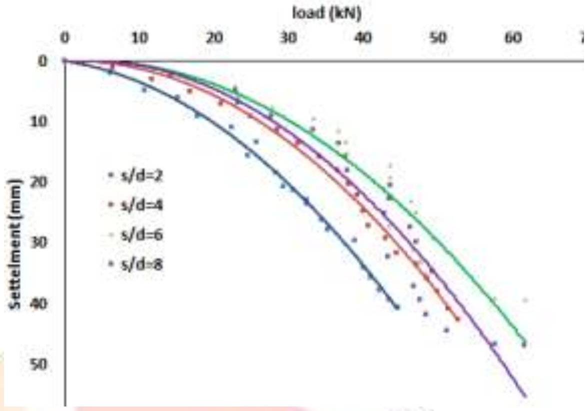
(a) d 25mm, L=300mm



(b) d 25mm, L=450mm

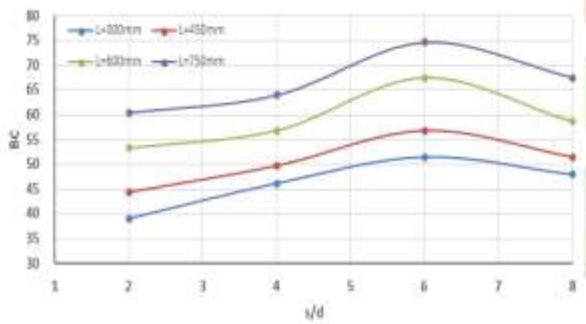


(c) d 25mm, L=600mm

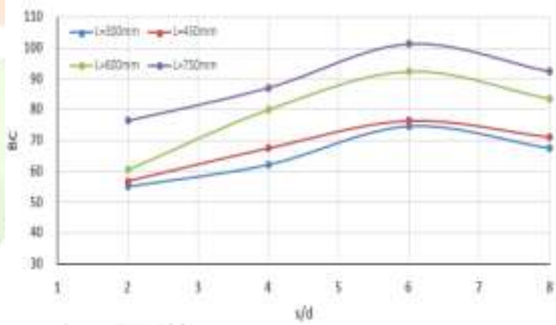


(d) d 25mm, L=750mm

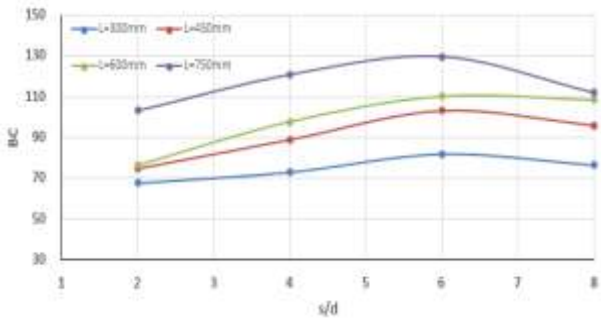
Fig.3: Experimental Load-Settlement response of pile raft: Rough Pile



(a) dia 15mm



(b) dia 25mm



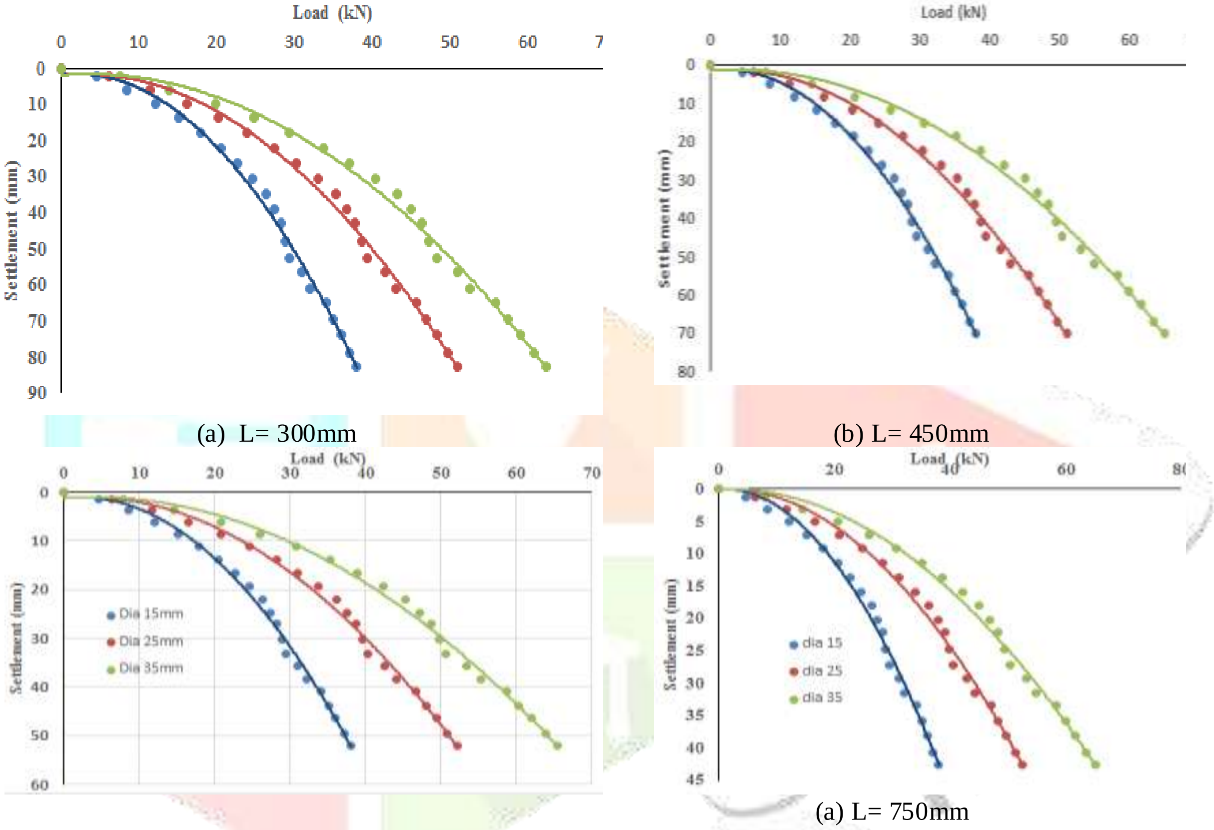
(c) dia 35mm

Fig. 4: Bearing capacity vs s/d graphs

The same trends were observed for all cases with other pile diameters and length. The maximum load carrying capacity were obtained at 6d for all diameter piles with different pile lengths. It is observed that % increase in load carrying capacity varies 22% to 40% for different diameter and pile length as c/c pile spacing increases from 2d to 6d in case of rough piles i.e. wooden piles coated with course sand. It may be because at c/c pile spacing 2d, the stress bulb generated along the pile due to vertical load overlap and soil in between became overstressed, hence failure of pile raft foundation occurs earlier. As pile spacing increases from 2d to 4d and then 6d, the stresses developed along pile get separated and interaction between pile to pile decreases, hence load carried by pile raft foundation increases. Again c/c pile spacing increases from 6d to 8d, ultimate carrying capacity decreases in spite of stress bulb generated get separated completely and pile to pile interaction is very less but as soil in-between consecutive piles may flow laterally and hence soil may fail in shear earlier. This decreases ultimate load carrying capacity of pile raft system. The trend of load carrying capacity with increase c/c pile spacing, obtained for different length (300mm to 750mm) and different pile diameter (15mm, 25mm and 35 mm) is similar for all cases. It may be concluded that optimum pile to pile spacing is 6d in case of rough pile raft foundation.

5.2 Effect of diameter of pile on Load carrying Capacity of pile raft system

To observe the effect of diameter of pile on load carrying capacity, experiments are conducted on different diameters of piles, keeping the length, raft thickness and size constant. These experiments are repeated for all lengths of piles as tabulated in table 1 so that effect of diameter may be observed for each length of piles. The load settlement response of rough piles obtained for 300, 450, 600 and 750mm pile lengths were represented in fig 5(a) to (d) respectively for 25mm diameter piles at s/d=6. The effect of diameter on Load carrying capacity of pile raft system is represented in Fig.6. It was found that for load carrying capacity of pile raft system increases with increase in pile diameters. When diameter of piles increases from 15mm to 25mm, BC increases 45 to 36% for different length of piles and if diameter increases from 25mm to 35mm, Load carrying capacity increases 10 to 26% for different length of piles.



(a) L= 300mm (b) L= 450mm

(a) L= 600mm (a) L= 750mm

Fig.5: Load-Settlement response of pile raft at s/d=6: Rough pile

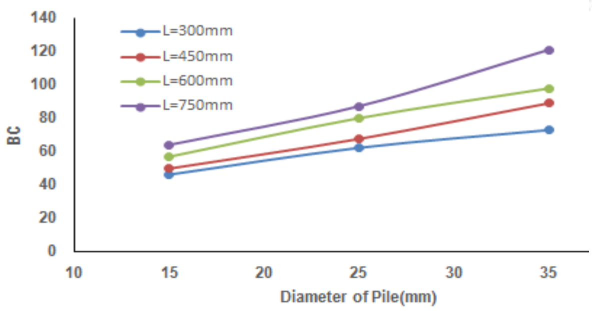


Fig.6: Effect of diameter of pile on Load carrying Capacity of pile raft system for s/d=6

5.3 Effect of length on Load carrying Capacity of pile raft system

Experiments were conducted on 3x3 set of piles with varying length of piles as 300, 450, 600 and 750mm. All other variables as raft size and thickness are constant. The same sets of experiments were conducted for all the diameters as tabulated in Table 1. In case of rough piles, load settlement response for 15mm, 25mm and 35mm diameter piles at s/d=6 may be observed from Fig 7 (a) to (c) respectively.

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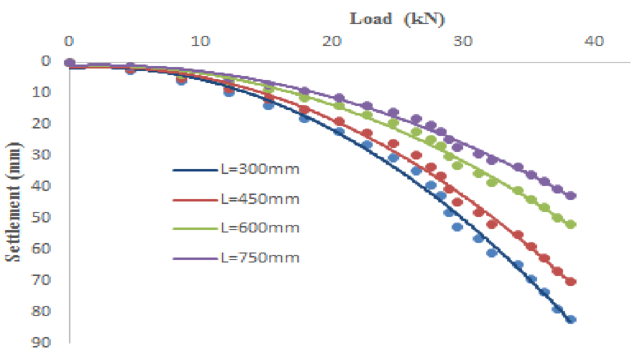
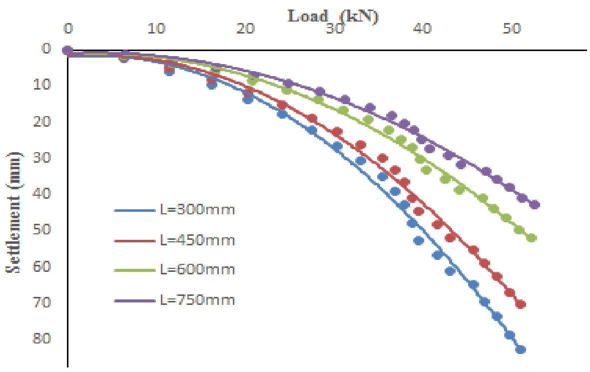
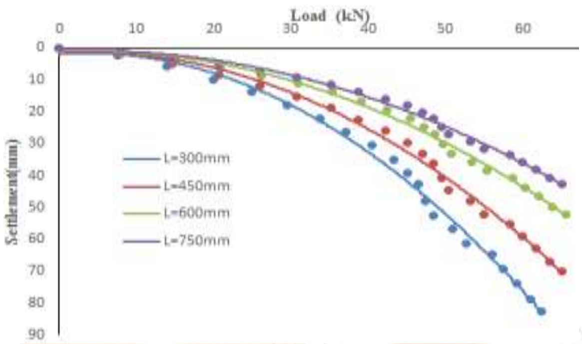


(a) d= 15mm



(b) d= 25mm



(c) d= 35mm

Fig.7: Load-Settlement response of pile raft at s/d=6: Rough pile

It is observed that if length of piles increases from 300 to 450mm, Load carrying capacity of pile raft system increases about 2% to 26% for different diameter of piles. With further increase of length upto 600mm the increase in load carrying capacity increases about 6 to 18% and if length increases from 600 to 750 mm, the increase in load carrying capacity was observed as 9 to 17%.

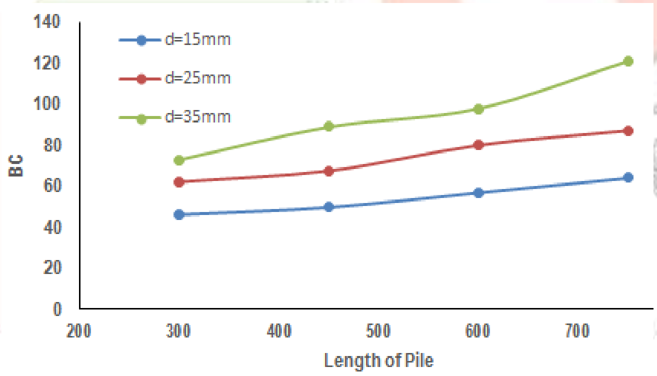
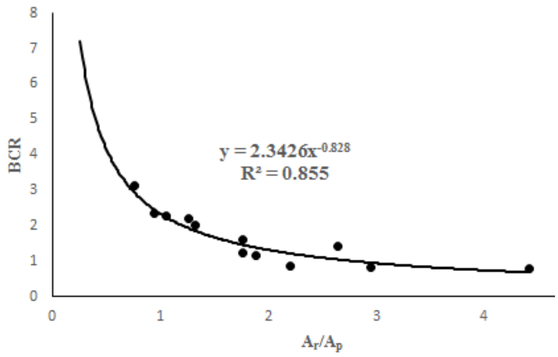


Fig.8: Effect of length of pile on Load carrying Capacity of pile raft system at s/d=6

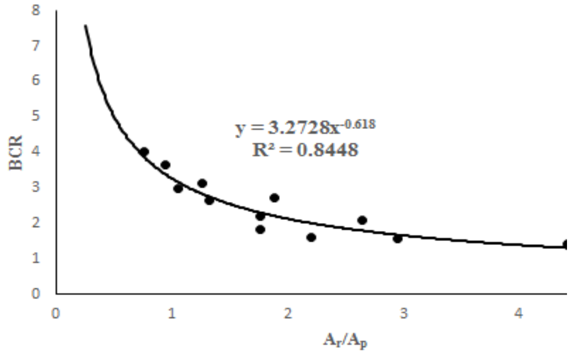
In case of smooth piles, if length of piles increases from 300 to 450mm, Load carrying capacity of pile raft system increases about 4% to 12% for different diameter of piles. With further increase of length upto 600mm the increase in load carrying capacity increases about 6 to 20% and if length increases from 600 to 750 mm, the increase in load carrying capacity was observed as 10 to 16%. The increase may be due to increase in surface area of piles with length and load carried through skin friction increases and hence over all load carrying capacity of pile raft system increases

VI.EFFECT OF PILE RAFT AREA RATION ON BCR

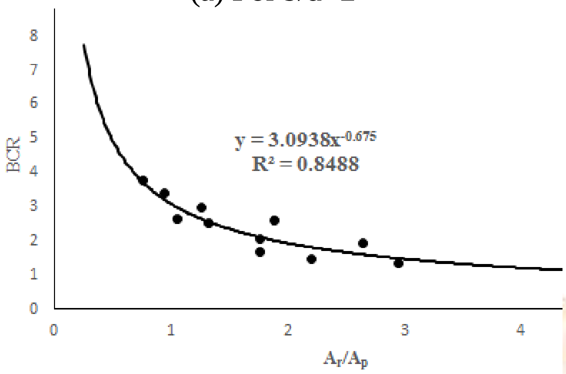
A number of soil, raft and piles parameters are responsible which affect the load carrying capacity of pile raft system. The major parameters of piles are length diameter of piles, c/c spacing of piles and roughness of piles. From the above Figures it is observed that with increase in the length and diameter of pile, the load carrying capacity of pile raft increases so the ratio of area of raft to total surface area of piles (Ar/Ap) is co-related with Bearing capacity ratio (BCR) i.e. ratio of load carrying capacity of pile raft to that of raft only as shown in Fig. 9(a-d).From the figures, it was observed that with decrease in (Ar/Ap) area ratio of raft and piles, BCR (increases in load carrying capacity) increases.As area of raft was kept constant throughout experiment, decrease in Ar/Ap means, increase in area of raft, it may be due to increase in diameter of pile or length of pile or increase in number of piles.



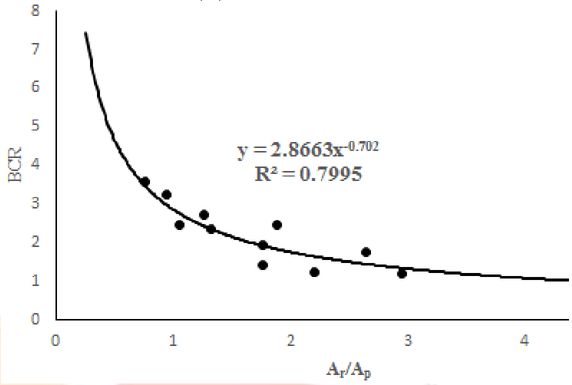
(a) For s/d=2



(b) For s/d=4



(c) For s/d=6



(d) For s/d=8

Fig.9: Correlation of BCR and Ar/Ap for Rough Pile

Correlation between BCR and Ar/Ap are represented Table 3. The correlation coefficient varied from 80% to 92% for different piles roughness at different c/c pile spacing to pile diameter ratio and may be adopted for calculating increase in load carrying capacity with respect to raft to pile area.

Table 3: Numerical correlation of BCR with raft pile area ratio

Pile Raft with	Rough Pile	
s/d=2	$Q_r = 2.91x(A_r/A_p)^{-0.487}$	$R^2 = 0.897$
s/d=4	$Q_r = 3.451x(A_r/A_p)^{-0.535}$	$R^2 = 0.930$
s/d=6	$Q_r = 3.92x(A_r/A_p)^{-0.518}$	$R^2 = 0.938$
s/d=8	$Q_r = 3.581x(A_r/A_p)^{-0.519}$	$R^2 = 0.918$

VII. CONCLUSION

A series of experiments on pile raft foundation were conducted, taking c/c spacing of piles, length, diameter and roughness of piles as variables and size and thickness of raft constant. About 48 number experiments were conducted. The results of experiments are concluded:

1. The center to center spacing of piles has a great impact on load carrying capacity of pile raft system. The optimum c/c spacing of pile raft foundation is 6d. Load carrying capacity increases from 7-18% if c/c pile spacing increases from 2d to 4d and if the spacing increases from 4d to 6d, load carrying capacity increases to 22-40%. With further increases in c/c pile spacing, load carrying capacity decreases about 2-14% depending upon pile diameter and length.
2. Pile diameter has also significant impact on load carrying capacity of pile raft foundation. Load carrying capacity increases from 45-52% and 28-39% if diameter increases from 15 to 25 and further increases from 25 to 35mm respectively.
3. Load carrying capacity also increases with increase in length of piles. It increases to maximum of 59%.
4. Slenderness ratio of pile also a significant factor to design pile raft system. Load carrying capacity of pile raft increases upto l/d as 32 afterwards load carrying capacity start decreasing.

VIII. ACKNOWLEDGMENT

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References

[1] Davis, E.H. and Poulos, H.G. (1972). "The Analysis of Piled Raft Systems", Aust. Geomechs. J., G2: 21-27

[2] Poulos, H.G. and Davis, E.H. (1980). "Pile Foundation Analysis and Design", Wiley, New York

[3] Poulos, H.G. (1994). "An Approximate Numerical Analysis of Pile-Raft Interaction", Int. J. NAM Geomechs., 18 pp. 73-92

[4] Van Impe W.F. (2001) "Methods of Analysis of Piled Raft Foundation" A Report prepared on behalf of Technical Committee TC18 on Piled Foundation, International Society of Soil Mechanics and Geotechnical Engineering.

[5] Cooke, R. W. (1986) " Piled Raft Foundations on Stiff Clays: A Contribution to Design Philosophy", Geotechnique, Vol 36 (ii),pp. 169-203

[6] Liu. W. and Novak, M. (1991), "Soil-pile-cap static interaction analysis by finite and infinite elements", Canadian Geotechnical Journal, Vol.28, pp.771-783.

[7] Lee J.H, Kim Y and Jeong S., (2010) "Three-dimensional analysis of bearing behaviour of piled raft on soft clay", Computers and Geotechnics, 37 pp.103-114

[8] Dr. Mosa Jawad Al-mosawe, Dr A'amal Abdul Ghani Al-Saidi, Dr. Faris Waleed Jawad (2013) "Experimental and Numerical Analysis of Piled Raft Foundation with Different Length of Piles Under Static Loads" Journal of Engineering Vol 19, pp. 543-549

[9] Maharaj, D. K. (1996) "Application of elastic and elasto-plastic analysis for piled raft foundation, Ph.D. Thesis, IIT, Madras, Chennai

[10] Trochanis, A. M., J. Bielak, and P. Christiano (1991) "Three-dimensional nonlinear study of piles", Journal of Geotechnical Engineering, ASCE, Vol.117, No.3, pp. 429-447

[11] Poulos, H. G. (1993). "An Approximate Numerical Analysis of Pile Raft interaction", Int. Jnl. Num. Anal. Meths. in Geo-mechs., 18, pp. 73-92.

[12] Ta, L. D., & Small, J. C. (1996). "Analysis of Piled Raft Systems in Layered Soil. International Journal of Numerical and Analysis Methods", Geomechanics, 20, pp. 57-72.

[13] Fraser, R. A., & Wardle, L. J. (1976). "Numerical analysis of rectangular rafts on layered foundations" Géotechnique 26(4), pp. 613-630.

[14] Kuwabara, F. (1989). "Elastic analysis of piled raft foundations in a homogeneous Soil". Soils and Foundation, 29(1), pp. 82-92.

[15] Prakoso, W. A., & Kulhawy, F. H. (2001). "Contribution to piled raft foundation design". J Geotech Engng Div, ASCE, 127(1), pp.1-17.

[16] Maharaj, D. K. (2003) "Load-Settlement Behaviour of Piled Raft Foundation by Three Dimensional Nonlinear Finite Element Analysis", Electronic Journal of Geotechnical Engineering. Vol. 8, Bundle C, Paper 0334

[17] Horikoshi and Randolph M.F. (1996). "Design methods for pile groups and piled rafts." S.O.A report, 13 ICSMFE, New Delhi, vol. 5; 1994. pp. 61–82.

[18] Cunha, R. P., Polous, H.G. and Small, J.C. (2001), "Investigation of Design Alternatives for a Piled Raft Case History." Journal of Geotechnical and Geoenvironmental Engineering Vol. 127. No. 8. pp. 635-641.

[19] Poulos, H.G. (2001) "Piled Raft Foundations Design and Applications". Geotechnique, Vol.50, (2): pp. 95-113.

[20] Horikoshi, K. and Randolph, M.F. (2003). "A Contribution to the Optimum Design of Piled Rafts". Geotechnique, Vol. 48(2), pp. 301-317.

[21] Dang Dinh Chung Nguyen, Dong-Soo Kim, Seong-Bae Jo,(2014)," Parametric study for optimal design of large piled raft foundations on sand", Computers and Geotechnique, Vol (55),pp. 14-26

[22] Lee Junhwan, Park Donggyu, Choi Kyujin,(2015)," Analysis of load sharing behaviour for piled rafts using normalized load response model", Computers and Geotechnique, Vol (57),pp. 65-74

[23] Bourgeois E., P. Buhan de, Hassen G.,(2012)"Settlement analysis of piled-raft foundations by means of a multiphase model accounting for soil-pile interactions", Computers and Geotechnique, Vol (46),pp. 26-38

[24] Basuony El-Garhy, Ahmed Abdel Galil, Abdel-Fattah Youssef, Mohamed Abo Raia,(2013),"Behavior of raft on settlement reducing piles: Experimental model study",Journal of Rock Mechanics and Geotechnical Engineering Vol(5), pp. 389–399

[25] 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

[26] El Sawwaf, M. (2010), "Experimental Study of Eccentrically Loaded Raft with Connected and Unconnected Short Piles". Journal of Geotechnical and Geoenvironmental Engineering. ASCE. Vol. 136. No. 10. pp. 1394-1402.

[27] Poulos, H. G (1993) "Piled raft in swelling or consolidating soils, Journal of Geotechnical Engineering", ASCE, Vol.119, No.2, pp.374-380

[28] Poulos, H. G. (2001) "Piled raft foundations: Design and applications", Geotechnique, Vol.51, No.2, pp.95-113

[29] Poulos, H. G., and Davis, E. H. (1980). "Pile foundation analysis and design". New York: Wiley.

[30] Randolph, M. F. (2003). "Science and empiricism in pile foundation design". Geotechnique, 53(10), pp. 847-875.

[31] Zhang, H. H. and Small, J. C. (2000)."Analysis of Capped Piled Groups Subjected to Horizontal and Vertical Loads", Computers and Geotechnics, 26,pp. 1-21

[32] Clancy, P. and Randolph, M. F. (1993). "Analysis and Design of Piled Raft Foundations", Int. Jnl. Num. Methods in Geomechs., 17, pp. 849-869.