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Load sharing characteristics of piled raft foundation in clay soil

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Abstract— In an elastic analysis of piled raft foundation in clay soils, the load sharing behaviour of piles and raft has been studied by varying soil modulus, pile spacing, pile length and raft thickness. Increase in raft thickness has no significant effect on load sharing in soft soil. Unit skin friction developed along the pile length increases with depth as well as pile spacing.

Keywords— Piled raft, soil modelling, load sharing, relative stiffness, soil interaction, unit skin friction.

I. INTRODUCTION

Nowadays in urban areas, people are more concentrating on building expansion vertically in place of horizontal expansion due to higher cost of land, limited space & scarcity of land. Use of raft foundation is being increasingly used for multi-storied buildings, with or without basement, in subsoil conditions such as thick clay deposits even with a high water table. If the clay shear strength is very low, long load-bearing piles are introduced to transfer the entire load to deeper and stiffer soil layers. Even if the clay shear strength is adequate for giving the required bearing capacity of a raft foundation, the settlement may be very large. For such situations, where it becomes necessary to reduce settlements, a piled raft foundation can be opted for. The total and differential settlements can be minimized by providing the piles at specific locations under the raft.

Various methods for the analysis of piled raft foundations have been described by several authors, including Randolph (1994), Chow et al. (2001), Poulos (2001), Small and Zhang (2002), Reul (2004), and Maharaj & Gandhi (2004).

II. MODELING OF PILED RAFT

Modeling of piled raft was carried out considering the soil, pile and raft as 8-noded brick elements solid 185, and volume meshing of the top raft as 1x1x0.6 units, piles as 0.4x0.4x1 units and surround soil as 1x1x1 units. The degree of tolerance and merged distance of the meshing was set to 0.01. Regarding boundary condition, YZ plane is allowed to move in all the direction except UX, YX plane is also allowed to move in all the direction except UY and XY plane at the bottom of the model is fixed as shown in Fig.1.1. Finally a varying pressure load of 50, 100, 150, 200, 250 and 300 kPa was applied on the top of raft.

Analysis and design of piled raft foundations and its interaction effects is a complex solution and this complex behaviour can be solved using the FEM numerical software. The results present in this paper was carried out in ANSYS which provide approximate acceptable solution and involves complex material properties, boundary conditions, irregular geometry of the complete model etc.

The present analysis is carried out in a single pile with different pile spacing (S), length (L) assuming variation of soil modulus as given in Table 1. The Poisson's ratio of soil and concrete is taken as 0.45 and 0.15 respectively. Both the pile and raft will be represented by the concrete and the surround medium of pile and below the raft is modeled as soil.

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Table 1. Parameters of piled raft foundation

T in m	0.4	0.8	1.2			
S in m	1.2	1.6	2.4	3.2	4	6
L in m	4	6	8	10	12	
E_c kN/m^3	$2x10^7$					
E_s kN/m^2	$2x10^5$	$1x10^5$	$5x10^4$	$3.3x10^4$	$2.5x10^4$	
T/d	1	2	3			
S/d	3	4	6	8	10	15
L/d	10	15	20	25	30	
E_c/E_s	100	200	400	600	800	

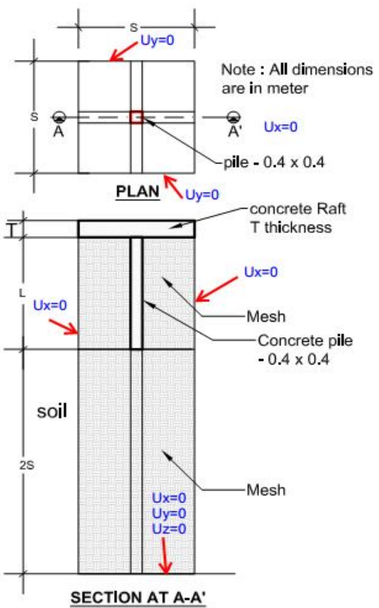

Fig. 1 Discrete model of a piled raft

For idealization of the model, it is assumed that a 4x4 m^2 raft of 1.2 m thickness with a centrally located square pile of 0.4x0.4 m^2 upto a depth of 4, 6, 8, 10, 12 m respectively was considered and a uniformly distributed pressure load of 50, 100, 150, 200, 250 and 300 kPa was applied on the top of the pile raft as shown in Fig. 1.

III. RESULTS & DISCUSSION

A. Axial Load Distribution

Five different cases of pile length such as 4, 6, 8, 10 and 12 m and pile spacing of square dimension whose L/d and S/d values are given in the Table 1.

Figs. 2(a-e) show the variations of axial load distribution along the pile length. and maximum at few depths from the top of pile and proportionately decrease with increase of pile depth.

The minimum load shared of the pile occurs at the bottom of the pile and 60 to 70% of the total applied pressure load is being shared to the pile in case of soft soil whereas 30 to 40% of the total applied load in case of hard soil. It is because of the raft takes the initial load and dispersed to the hard soil instantly before transferring to the pile. Further increase of loading intensity, the raft & soil cannot bear the increased load and the remaining load will be transferred to the soil through pile. There is proportionate increase in axial load with increase in depth of the pile.

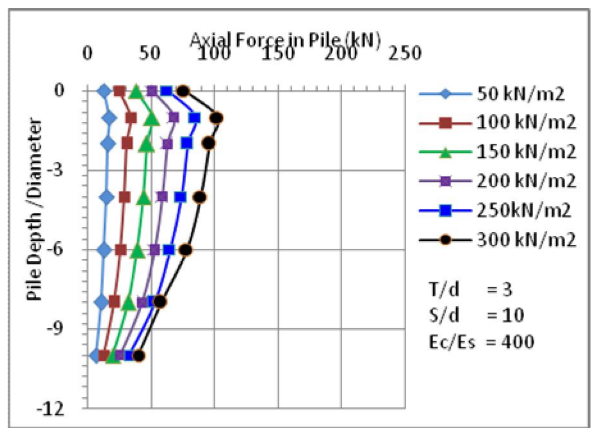

Fig. 2(a) Variation of axial force in pile, L/d = 10

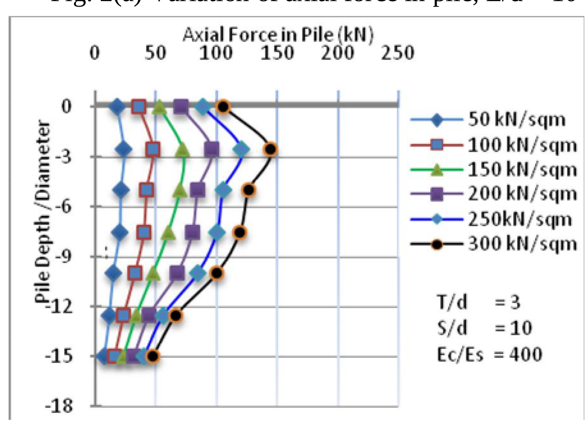

Fig. 2(b) Variation of axial force in pile, L/d = 15

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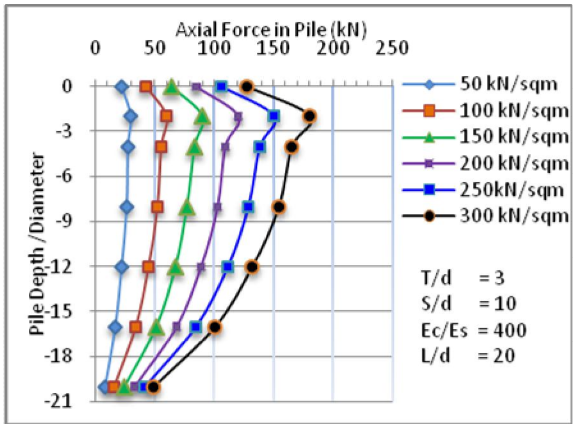

Fig. 2(c) Variation of axial force in pile, L/d = 20

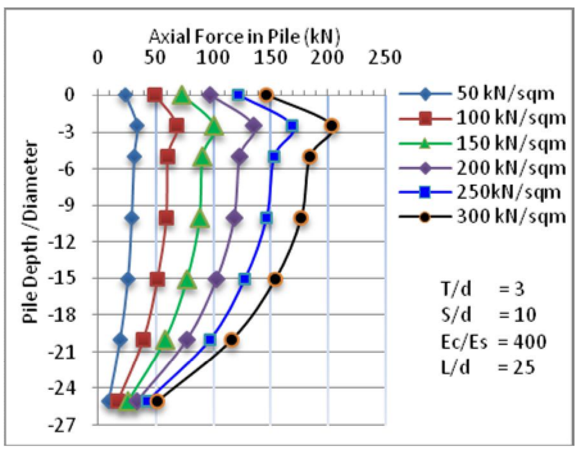

Fig. 2(d) Variation of axial force in pile, L/d = 25

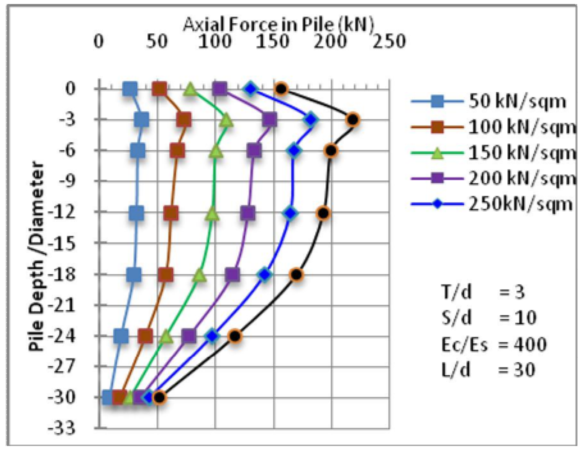

Fig. 2(e) Variation of axial force in pile, L/d= 30

B. Load Sharing of Pile and Raft

Influence of Raft Thickness: Load sharing between the raft & pile for different raft thickness and pile spacing are indicated in Fig. 3. The percentage of load shared by the raft decreases with increase of raft thickness and thinner the raft share more load than the thicker raft due to bending action which is not significant in case of thicker in raft. Further, it is also seen that thicker in raft does not have any significant advantage on load sharing as a whole. On the basis of the above result, further analysis of the piled raft, a constant value of ratio of raft thickness (T) to diameter of pile (d) is kept constant at 3 (three) in all cases.

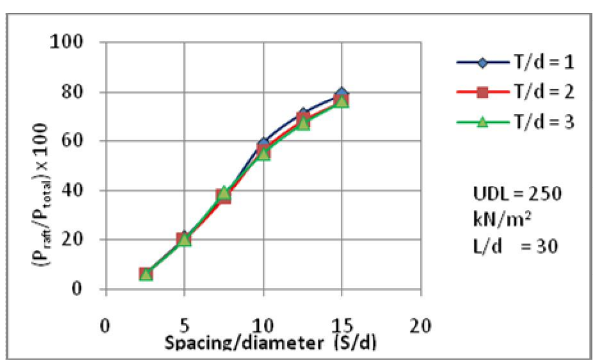

Fig. 3 Effect of raft thickness and pile spacing

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Influence of Pile Length and Spacing: While observing the result as shown in Fig. 4, the effect of pile length and spacing under the constant pressure load of 250 kN/m^2 may be summerised as increase in pile length, smaller the pile spacing (S) does not show any improvement in the percentage of load carried by the pile. It is because of no relative motion between the pile and surrounding soil. It means that they are moving as a single unit and the pressure bulb of each pile falls one above the other and interference to each other resulting the piles are not fully utilised. It seems that whatever load comes from the superstructure, 90% to 98% of the load is possibly transferred to the piles. Even with increase in pile length, there is not showing any significant improvement of load taken by raft or soil. Whereas, increase in pile length with larger in pile spacing (S), shows improvement in the percentage (100 x P_{pile}/P_{total}) of load carried by the pile. It is because of complete utilization of a pile behaviour such as bearing due to skin friction. Thus, the load transfer from the superstructure are being more taken care by the longer piles due to skin friction than the shorter pile and the percentage of load transferred to the pile also decreases.

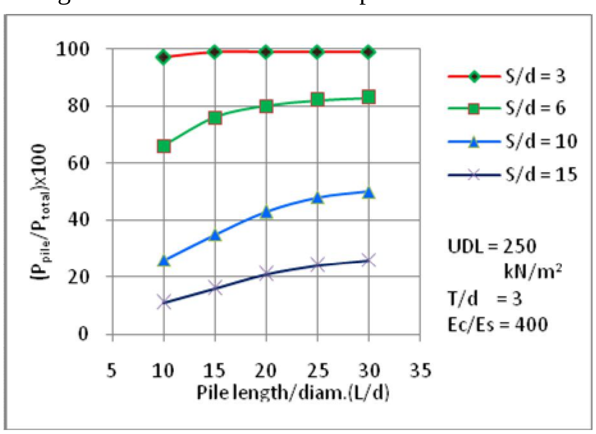

Fig. 4. Effect of pile length and spacing to pile load

It is also observed that increase in pile spacing, percentage of load shared to piles decreases.

Influence of Soil Modulus: Fig. 5 shows the effect of soil modulus and pile spacing on load shared by the pile. Further observing the plot, it can be stated that load shared by pile inversely proportional to the soil modulus i.e decrease in soil modulus increases in load sharing value to piles.

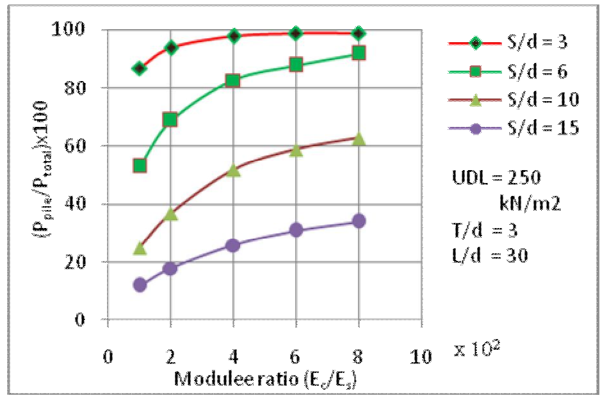

Fig. 5 Effect of modulus and pile spacing to pile load

Stiffer the soil (i.e E_c/E_s value decreases), there is lesser in load sharing to pile. This is because of load transfer mechanism in to the soil and maximum of the load coming from the superstructure is getting transferred to the deeper soil through contact surface of pile, i.e. skin friction. Thus, in soft soil, whatever load comes to the raft is taking care by the pile through skin friction and alternatively, if the soil is hard soil, whatever load comes to the raft is taking care by the underneath raft soil, thus minimum effect in the pile.

C. Development of Unit Skin Friction

The unit skin friction is developed around the circumference of the pile along the pile length. Fig. 5 shows the development of unit skin friction for different pile spacing. With increase of pile spacing, mobilization of skin friction along the pile length is increased and lesser the pile spacing there is proportionally decrease in development of unit of skin friction along the pile length.

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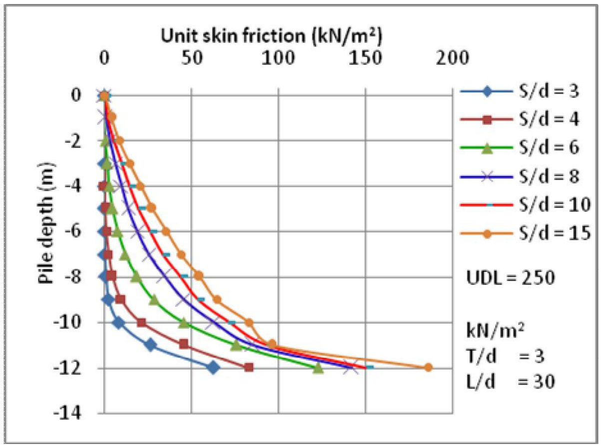

Fig. 6 Effect of pile spacing and skin friction

It shows that a fully developed unit skin friction of a pile in piled raft foundation can only be achieved when the piles are placed at larger spacing. Further examined that development of unit skin friction along the pile is found very less on the top portion of the piles as the soil just below the raft is taking initial load. After fully mobilized, the load is being transfer to the bottom of the soil through skin friction there by amount of unit skin friction increases.

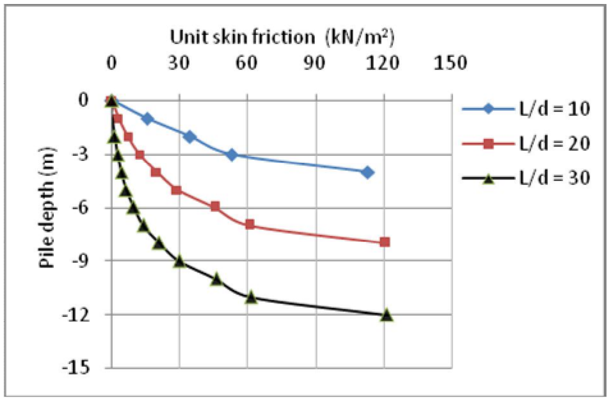

Fig. 7 Development of skin friction for different pile lengths

Fig. 6 above shows the effect of pile length on development of skin friction along the pile length. It show that development of skin friction is higher in case of shorter pile, because the total load applied to the pile raft reaches its maximum value by pile instantly than the raft. Whereas, for longer pile, unit skin friction will reach latter after fully mobilization of raft first and the load will be dispersed to pile.

IV. CONCLUSION

Load sharing behaviour of pile and raft is found to vary according to the stiffness of soil considering the stiffness of the raft and pile at constant. Stiffer the soil, lesser in load sharing and softer the soil, more in load shared by the pile. There is not much significant effect of increase in raft thickness in case of soft soil beyond which they are almost similar characteristic. However, unit skin friction plays a very important role on load sharing between piles and raft in piled raft foundation. Above all, there is significant effect of pile spacing for every analysis result thereby advised to keep the pile in larger spacing than the smaller spacing.

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