Study of Piled Raft Foundation with Consideration to Soil Structure Interaction

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Abstract

Analysis of combined piled raft foundation proves to be an effective tool to bear the stresses and reduce the settlement of the foundation. Efforts have been made to optimize the parameters of pile raft foundation. In order to find economical solution various parameters like spacing of piles and the load imposed on foundation are varied to obtain optimum results. A finite element model of combined piled raft foundation is simulated in SAP-2000 to examine the performance of foundation under various loading conditions. Springs are assigned by discretising the model to simulate soil properties. The model is being validated by comparing result with standard book. This study could be helpful and serve as a guideline for the variation in other parameters like pile length, pile shape, raft thickness and several soil properties.
Keyword- Piled Raft Foundation, SAP – 2000, Spacing of Piles, Loads, springs, Modulus of Subgrade Reaction

I. INTRODUCTION

A piled raft is used when the soil at a shallow depth is highly compressible and the water table is high. Piles under raft help in reducing settlement and provides resistance against buoyancy. Piles are deep foundations. They are formed by long, slender, columnar elements typically made from reinforced concrete. A foundation is described as 'piled' when its depth is more than three times its breadth. Pile foundations can help transfer loads through weak, compressible strata or water onto stronger, more compact, less compressible and stiffer soil or rock at depth. The addition of piles to a raft increases the effective size of a foundation and can help resist horizontal loads. This can improve the performance of the foundation in reducing the amount of settlement and differential settlement, as well as improving the ultimate load capacity. Piled raft foundations are typically used for large structures, and in situations where soil is not suitable to prevent excessive settlement. They are an increasingly popular choice for high-rise buildings. During the design process, the optimum number and position of piles, as well as their diameter, reinforcement and length, is determined to ensure the stability of the structure while providing an economical solution, with the raft and piles acting together to ensure the required settlement is not exceeded. Typically, the piles provide most of the stiffness while the raft provides additional capacity at the ultimate loading.

Poulous H. G. (2002) tells about the simplified design procedure for piled raft foundation. Various issues like ultimate load carrying capacity of piles for vertical loading, maximum settlement, differential settlement, raft shear and moments, pile loads and moments and their analysis. H.A Sadeq (2009) has given analysis and design of unpiled raft foundation by modelling in SAFE (csi). Design concepts and load sharing mechanism of piled raft foundation is summarized by Nurullah Sonmez (2013) in his thesis. The circumstances involved in selecting piled raft foundations were summarized by Sinha (2013). The model accounts for pile-to-pile, raft-to-pile, pile-to-soil, and raft-to-soil interactions.

II. MODELLING

A. General Model Procedure

The model of combined piled raft is simulated using software SAP 2000. Piles are discretised and modelled as 2 noded beam elements and raft panel is modelled as thick shell element. Figure 1 shows the sketch of modelled piled raft foundation in SAP 2000. Properties of soil like dry density, modulus of elasticity, angle of internal friction, poisson's ratio and properties of concrete like grade of concrete and steel are as shown in Table 1.

Parameter	*Soil*	*Pile*	*Raft*
Density	*17 kN/m³*	*25 kN/m³*	*25 kN/m³*
Modulus of elasticity	*20 N/mm²*	*25000 N/mm²*	*25000 N/mm²*
Poisson's Ratio	*0.3*	*0.2*	*0.2*

Table 1: Material Properties

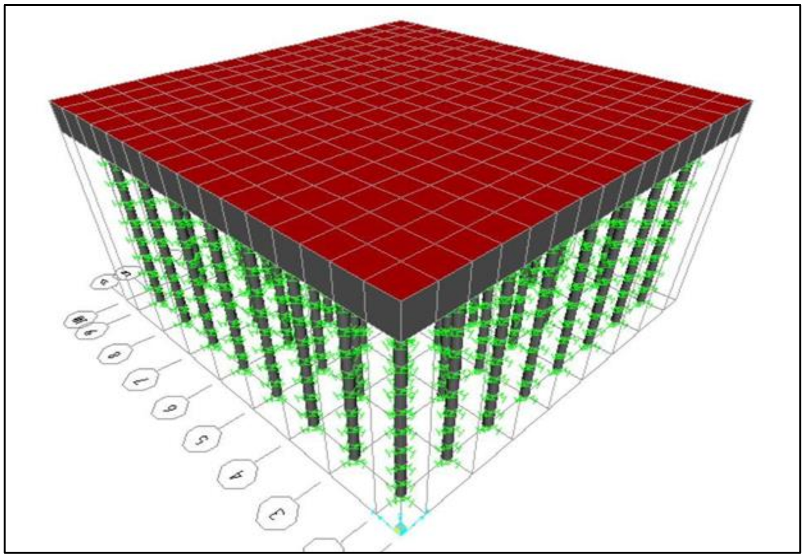

Fig. 1: Schematic Model of Pile Raft foundation

B. Simulation of Soil

Soil continuum is modelled by assigning springs at nodes of piles and by assigning area springs on the membrane of raft. Modulus of subgrade reaction are calculated as per Vesic's Theory. The modulus of subgrade reaction is a conceptual relationship between soil pressure and deflection that is widely used in the structural analysis of foundation members. It is used for continuous footings, mats, and various types of piling.

$$k_s = \frac{q}{\delta}$$

Vesic proposed that the modulus of subgrade reaction could be computed using the stress-strain modulus Es as

$$ks = 0.65 * \sqrt[12]{\frac{Es}{Ef*If}} * \frac{Es}{1-\mu 2} \qquad (1)$$

Where

E_s, E_f = modulus of soil and footing, respectively, in consistent units,

B, I_f = footing width and its moment of inertia based on cross section (not plan) in consistent units.

Since the twelfth root of any value times 0.65 will be close to 1, for all practical purposes the Vesic's equation reduces to

$$ks = \frac{Es}{1-\mu 2} \qquad (2)$$

C. Numerical Validation

Same model has been verified by using the settlement analysis of Terzaghi's primary consolidation. Settlements are computed using the relevant formulae and compared with the SAP Modelling. It was observed that the deviation of settlement result is found to be 2.5% only. Hence the validation results are found to be appropriate.

D. Dimensioning and Calculation of other Parameters

Various models of piled raft are prepared varying the spacing of piles as 2D, 3D, 4D, 6D, 7D and all these models are compared with unpiled raft foundation for variation in loads from 100 kPa to 400 kPa at and interval of 100 kPa applied at nodes above piles attached to the raft panel. Length of pile is considered as 15m. Dimensional properties of modelled piled raft are as shown in table 2.

<table>
<tr><th>Spacing of piles</th><th>Size of raft</th><th>No. of piles</th><th>Load applied</th></tr>
<tr><td>Un-piled Raft</td><td>24 x 24 x 2</td><td>0</td><td rowspan="6">Apply Loads 100kPa to 400kPa</td></tr>
<tr><td>2D</td><td>24 x 24 x 2</td><td>144</td></tr>
<tr><td>3D</td><td>24 x 24 x 2</td><td>64</td></tr>
<tr><td>4D</td><td>24 x 24 x 2</td><td>36</td></tr>
<tr><td>6D</td><td>24 x 24 x 2</td><td>16</td></tr>
<tr><td>7D</td><td>28 x 28 x 2</td><td>16</td></tr>
</table>

Table 2: Dimensions of pile raft foundation model

Springs are assigned at every node of pile in there directions viz. springs in global x and y direction to account for lateral earth pressure and a spring in z direction to account for skin friction. Modulus of Subgrade reaction is calculated as per equation (ii) stated above.

III. RESULTS

Load vs deflection curves are plotted considering the deflection at the centre of the raft for spacing of piles varying from 2D to 7D and also considering unpiled raft for load intensity varying from 100kPa to 400kPa. Results are as shown in table 3.

Load (kPa)	*Deflections at the center (mm)*					
	Unpiled	*2D*	*3D*	*4D*	*6D*	*7D*
0	*0*	*0*	*0*	*0*	*0*	*0*
100	*-35.67*	*-23.44*	*-22.3*	*-29.54*	*-43.76*	*-58.54*
200	*-76.45*	*-47.86*	*-54.55*	*-64.74*	*-92.87*	*-98.66*
300	*-140.65*	*-81.86*	*-96.32*	*-115.87*	*-175*	*-182.76*
400	*-238.67*	*-127.75*	*-158.36*	*-176.87*	*-314.76*	*-328.65*

Table 3: Deflections under various loadings

Above table is plotted and analysed to have a clear picture of optimum spacing between the piles that must be provided in order to achieve economy.

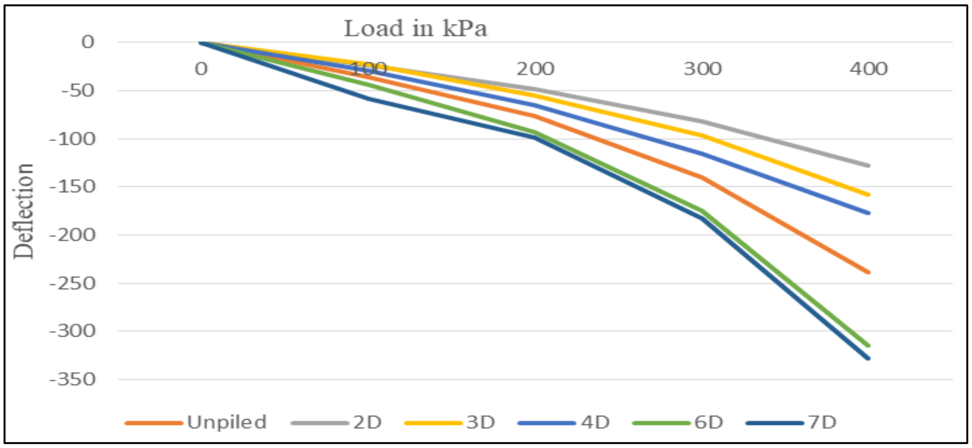

Fig. 2: Load vs Deflection curve for piles raft foundation with different spacing

Settlements for various spacing for a particular set of loads is plotted as below:

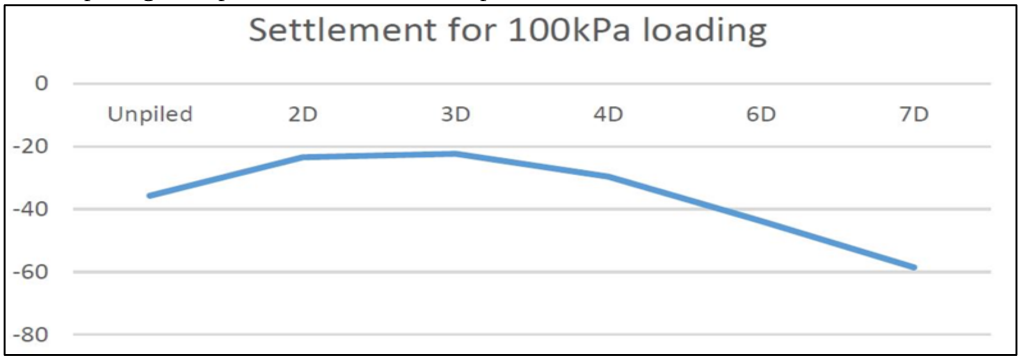

Fig. 3: Settlement for 100 kPa loading

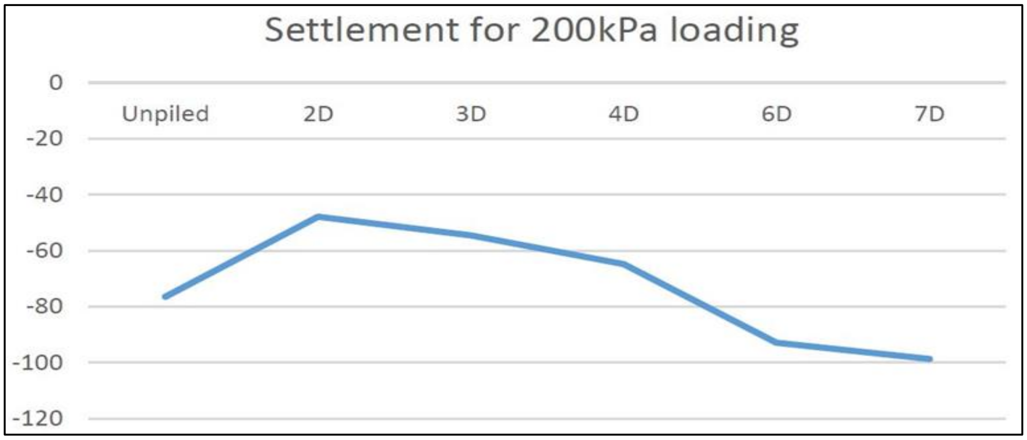

Fig. 4: Settlement for 200 kPa loading

IV. Conclusions

1) The capacity of the piled raft system decreased with the increase of the pile spacing up to 4D, beyond which the raft carried almost the full load of the building.
2) Least settlement is observed for the raft having pile spacing equal to 2D.
3) Un- piled raft foundation is found to behave as an average of piled raft having pile spacing equal to 4D and 6D.
4) Beyond a point increase in pile spacing yields no productive spacing; optimum spacing suggested is 2D to 4D, where D is the diameter of the pile.

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