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Analysis of Piled Raft by Geo-Structural Approach

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***Abstract*: Piled raft foundations provide an economical foundation option for circumstances where the performance of the raft alone does not satisfy the design requirements. In this study, an approximate method of analysis has been performed to estimate the settlement and load distribution of large piled raft foundation. A finite element method of analysis has been performed to estimate the settlement and load distribution of a large piled raft foundation. In this method, the raft is modelled as a thin plate and the piles are modelled as interactive springs. Both the resistance of the piles as well as raft base are incorporated into the model. Raft-soil-raft interaction are taken into account. The proposed method makes it possible to solve the problems of uniformly and large non-uniformly arranged piled rafts in a time saving way using computers. This paper focuses advantages of piled raft over conventional raft foundation and pile foundation. Also the focus is on the general effects of various parameters like raft thickness, soil stiffness, length and diameter of piles etc. on piled raft.**

***Keywords*: Pile foundation, piled raft foundation, axial deformation of piles, settlements, inelastic settlement of piles.**

1. Introduction

In past few years, the construction of tall structures has become increasingly common and with them new challenges strikes both the structural and geo technical engineers. For this purpose, immense research has been done and it has been recognized that the strategic use of piles can reduce raft settlement and differential settlement, and can lead to considerable economy without comprising the safety and performance of the foundation. Such a foundation makes use of both the raft and piles, and is referred to here as pile-enhanced raft or piled raft.

The use of piled raft foundations is considered to the situations that the raft alone cannot satisfy the design requirements, and the piles are needed to reduce the overall and differential settlements of the structures. Under these situations, the addition of limited number of piles may improve the ultimate load capacity, the settlement and differential settlement performance, and required thickness of the raft. When piles are used in conjunction with raft, the applied loads are transferred to the supporting soil through the pile. The different design philosophies of piled raft foundations are:

Piles are mainly designed to take up the foundation loads and raft only carries small proportion of loads. The raft is designed to resist foundation loads and piles carry small proportion of total load. They are placed strategically to reduce differential settlement. The raft is designed to take up majority of foundation loads. The piles are designed to reduce net contact pressure between raft and soils to a level below the pre-consolidation pressure of soil

The main advantages of piled raft foundations are:

- Settlements, differential settlements and tilts can be reduced.
- Increases overall stability of foundation.
- No. of piles required are reduced in comparison with conventional pile foundation where bearing effect of raft is not taken into consideration.
- Bending stresses in raft can be greatly reduced.
- Overall cost of the foundation is reduced.
- Piled raft is effective in stiff as well as soft clays.

2. Methodology

In this topic, the philosophy of modelling piled raft has been explained using combined structural-geotechnical approach. Initially to observe the behaviour of piled raft, piles are modelled as spring and raft as beam on elastic foundation as shown in Figure.

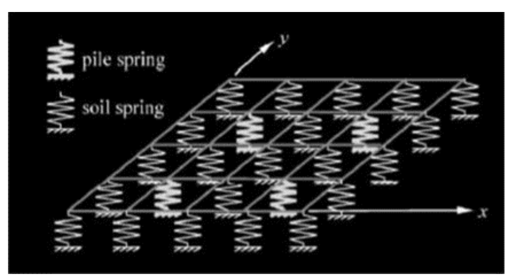

Fig. 1. Structural idealization for raft with pile and supporting soil

For this study, SAFE software is used for analysis of piled raft. The superstructure is first analyzed in ETABS software and following design parameters are considered:

- Floor Finish : 1.5 KN/m^2
- Live Load : 2 KN/m^2 (Live load of 3 KN/m^2 and 5 KN/m^2 are provided for passage and staircase slabs respectively)

- Siporex blocks of density 8 KN/m^2 are used as walls.
- No. of stories : 45
- Floor to floor height : 3.5m.
- Grade of concrete : M60
- Wind load is considered as per IS: 875-(Part III)
- Earth quake load is considered as per IS: 1893. (Moment resisting frame with response reduction factor of 4, zone factor 0.16 & 5% damping is provided.)
- The building is analysed for dynamic load using Response Spectrum Method.

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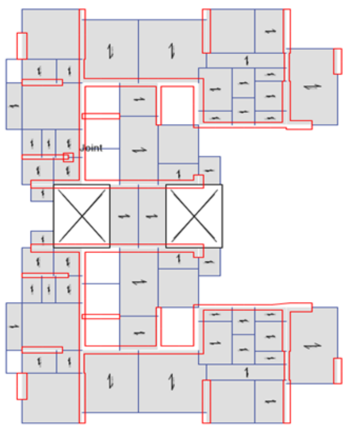

Fig. 2. Typical floor plan of g+45 storey building

The maximum top storey displacements for wind in X & Y directions are 61 & 63 mm respectively. The maximum top storey displacements for earth quake in X & Y directions are 69 and 67 mm respectively.

A. Modelling of raft foundation

All loads coming from superstructure are imported to SAFE from ETABS. First raft of thickness 2500mm is modelled in SAFE and upward pressure and displacement of raft is observed. Fig. 3 and Fig. 4 shows upward pressure and settlement in raft foundation respectively. It is observed that raft does not satisfy max upward pressure and permissible settlement requirements.

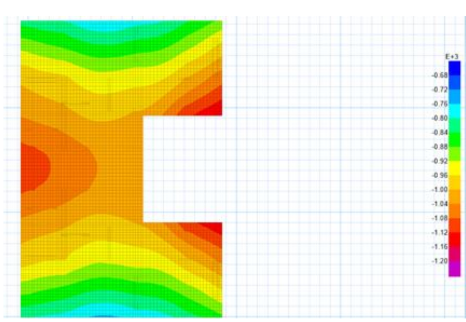

Fig. 3. Upward pressure in raft foundation (1168 KN/m^2)

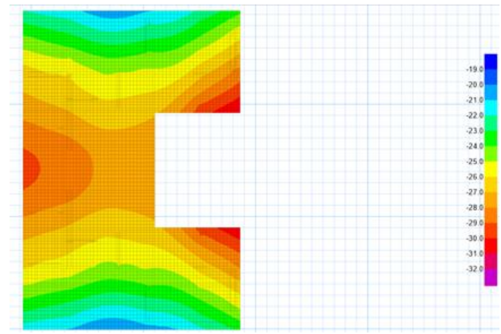

Fig. 4. Displacements in raft foundation (31.15 mm)

Determination of No. of Piles Required for Piled Raft

- Load from superstructure = 985735 KN
- Load taken by raft = Area of raft X SBC = 269262 KN
- Load to be taken by piles = Load from superstructure – Load taken by raft = 716473 KN
- No. of piles required = $\frac{716473}{10000}$

$= 71.64$

~ 72 Nos

However, considering geometry of figure and permissible settlement requirements,

Provide 84 No. of 1000mm Diameter piles.

- Stiffness of point spring

$$= \frac{\text{Capacity of one pile in KN}}{\text{Permissible Settlement in mm}} = \frac{10000}{8}$$

$= 1250$ KN/mm

To consider the effect of soil-structure interaction, piles are modelled as point springs. The spring stiffness value of 1250 KN/mm is applied to each spring. Fig. 5 shows layout of piled raft foundation. Fig. 6 and Fig. 7 shows upward pressure and displacement in piled raft foundation respectively.

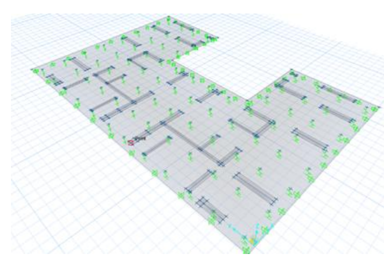

Fig. 5. Layout of piles in piled raft foundation

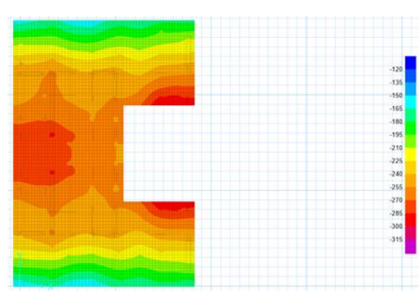

Fig. 6. Upward pressure in piled raft foundation (300 KN/m^2)

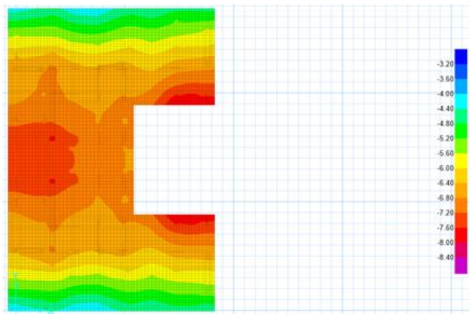

Fig. 7. Displacements in piled raft foundation (8.00 mm)

B. Parametric Study

Parametric study is carried out by changing different parameters of piled raft. The effect of varying raft thickness, spacing of piles, length of piles, diameter of piles and stiffness of soil are observed. Following aspects are considered for parametric study:

- Raft thickness is varied (1500mm, 2000mm, 2500mm and 3000mm) for soil stiffness of 37500 KN/m^3, pile length of 15m and pile diameter of 1000mm.
- Soil stiffness is varied (18750KN/m^3, 37500 KN/m^3, 56250 KN/m^3 and 75000 KN/m^3) for raft thickness of 2500mm, pile length of 15m and pile diameter of 1000mm.
- Spacing of piles is varied (3m, 4m, 5m and 6m) for soil stiffness of 37500 KN/m^3, pile length of 15m and pile diameter of 1000mm.
- Length of piles is varied (10m, 15m, 20m and 25m) for soil stiffness of 37500 KN/m^3, raft thickness of 2500mm and pile diameter of 1000mm.
- Diameter of piles is varied (600mm, 800mm, 1000mm and 1200mm) for soil stiffness of 37500 KN/m^3, raft thickness of 2500mm and pile length of 15m.

3. Results and Discussions

Comparison of Structural Forces, Settlements in Raft and Soil Pressure in case of Raft and Piled Raft. The following table shows variations between various structural forces, settlements and soil pressure.

Table 1
Comparison between Raft and Piled Raft Foundation

Type of Foundation	Raft	Piled Raft
Max Shear Force (KN)	18980	18825
Max Negative Bending Moment (KN-m)	26065	15635
Max Positive Bending Moment (KN-m)	39420	30210
Max Soil Pressure (KN/m^2)	1170	300.1
Max Settlement in Raft (mm)	31.15	8.00
Differential Settlement in Raft (mm)	11.05	3.95

It is also observed that piles which are located in centre of piled raft carry more load as compared to piles located at edge of piled raft. Therefore, it is beneficial to provide piles of small diameter or smaller length to make foundation more economical.

Effect of Varying Raft Thickness on Settlement of Raft, Settlement of Piles and Maximum Bending Moment. For a Forty-five storey building, increasing the raft thickness results in decrease in settlement in raft as well as piles up to certain extent, beyond which further increase in raft thickness doesn't affect the settlement at all. Also with the increase in raft thickness the differential settlement reduces considerably. It is also observed that with increase in raft thickness the dead load increases which results in increase in maximum bending moment. However, increase in raft thickness is advantageous for punching shear. Fig. 8 shows variation of max settlement and differential settlement in raft and piles with increase in raft thickness. Fig. 9 shows variation of max positive and negative bending moments with increase in raft thickness.

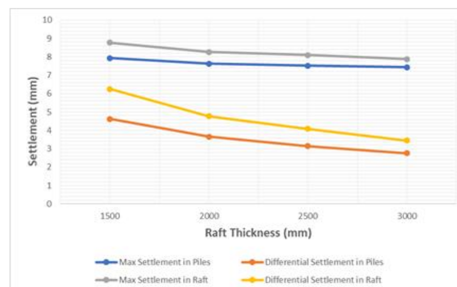

Fig. 8. Graph of raft thickness v/s pile settlement

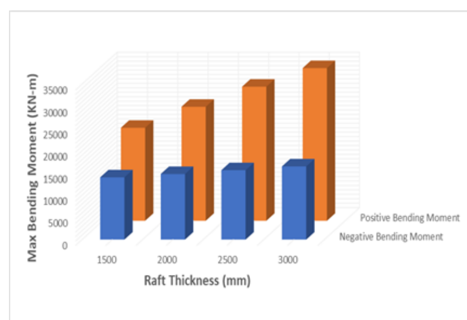

Fig. 9. Graph of raft thickness v/s max bending moments

Effect of Varying Soil Stiffness on Load Carrying Capacity of Piles and Raft. For a forty-five story building, increase in stiffness of soil below raft results in increase in load taken by the raft. Fig. 10 shows effect of soil stiffness on load carrying capacity of piled raft.

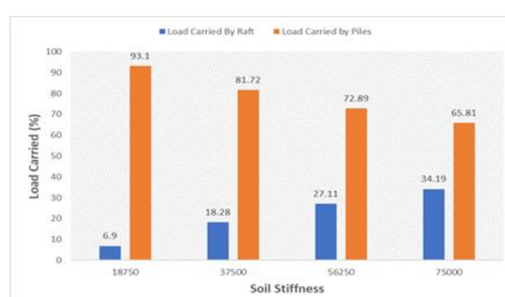

Fig. 10. Graph of soil stiffness v/s load carrying capacity of raft and piles

Effect of Varying Spacing of Piles on Load Carrying Capacity of Piles and Raft. For a forty-five story building, spacing is increased for given diameter of piles and it is observed that load carried by raft is also increased. Fig. 11 shows variation of load contribution of piles and raft with respect to spacing of piles.

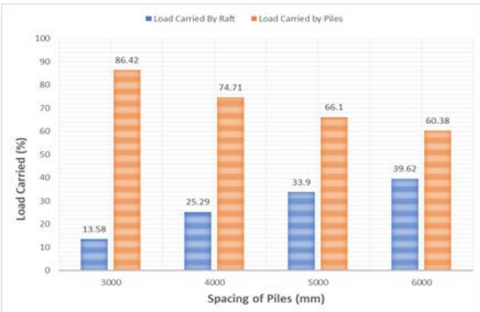

Fig. 11. Graph of spacing of piles v/s load carrying capacity of raft and piles

Effect of Varying Length of Piles on Settlement of Piles, Settlement of Raft, Load Carrying capacity and Maximum Bending Moment.

For determining effect of length of piles on different parameters, four different lengths of pile are considered. (10m, 15m, 20m and 25m). Spring stiffness is determined for each length. Spring stiffness of 975 KN/m^3, 1250 KN/m^3, 1562.5 KN/m^3 and 1812.5 KN/m^3 is applied for 10m, 15m, 20m and 25m length of pile respectively. It is observed that as length of piles increases, maximum settlement and differential settlement in raft and pile decreases. It is also observed that as length of piles increases, maximum bending moment decreases. With increase in length of piles, load carried by piles also increases. Fig. 12 shows variation of maximum settlement and differential settlement in raft and piles with increase in length of piles. Change in bending moment with respect to length of piles is shown in fig. 13. Whereas, change in load carrying capacity of piled raft with change in length of piles is shown in fig. 14.

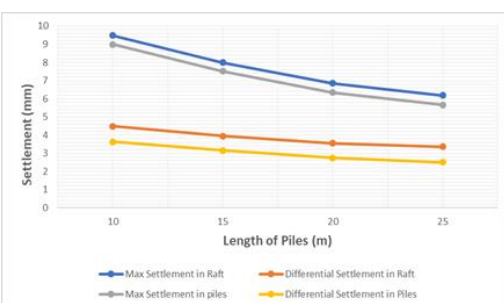

Fig. 12. Graph of length of piles v/s settlement of raft and piles

Effect of Varying Diameter of Piles on Settlement of Piles, Settlement of Raft, Load Carrying capacity and Maximum Bending Moment.

For determining effect of diameter of piles on different parameters, four different diameters of pile are considered. (600mm, 800m, 1000mm and 1200mm). Spring stiffness of 662.5 KN/m^3, 937.5 KN/m^3, 1250 KN/m^3 and 1625 KN/m^3 is applied for 600mm, 800mm, 1000mm and 1200mm diameter pile respectively. It is observed that as diameter of piles increases, maximum settlement and differential settlement in raft and pile decreases. It is also observed that as diameter of piles increases, maximum bending moment decreases. With increase in diameter of piles, load carried by piles also increases. Fig. 15 shows variation of maximum settlement and differential settlement with increase in diameter of piles. Change in bending moment with respect to diameter of piles is shown in fig. 16. Whereas, change in load carrying capacity of piles and raft with increase in diameter of piles is shown in fig. 17.

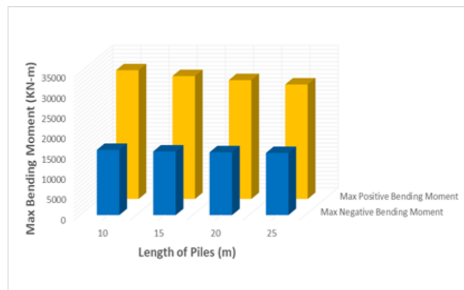

Fig. 13. Graph of length of piles v/s max bending moment

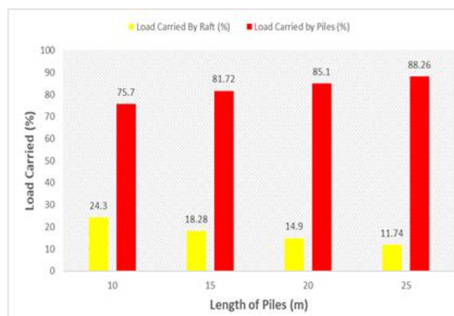

Fig. 14. Graph of length of piles v/s load carrying capacity of raft and piles

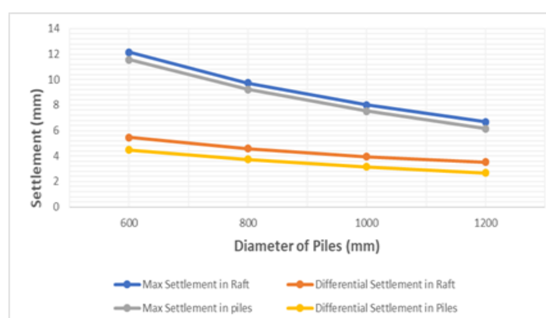

Fig. 15. Graph of diameter of piles v/s settlement of raft and piles

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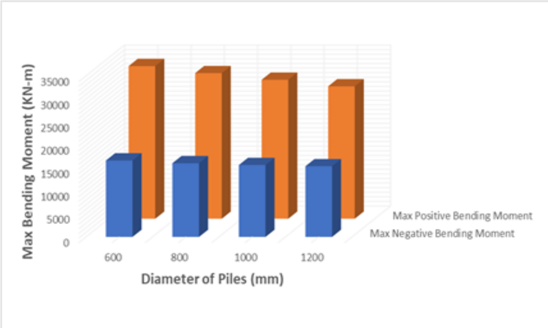

Fig. 16. Graph of diameter of piles v/s max bending moment

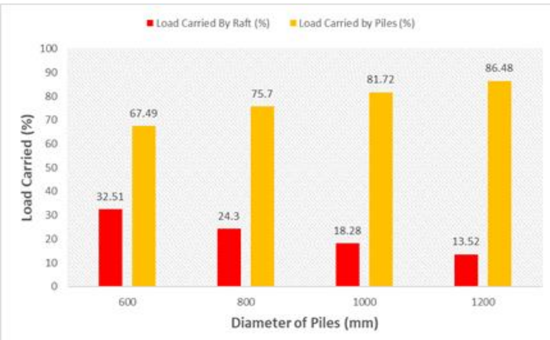

Fig. 17. Graph of diameter of piles v/s load carrying capacity of raft and piles

4. Conclusion

The studies indicate that piled raft foundation concept has significant advantages in comparison to conventional foundation for the available soil strata. From the studies, the following points have been observed.

- Piled raft foundation efficiently decreases settlements, differential settlements and bending moment compared to raft foundations.
- As thickness of raft increases, maximum settlement in raft as well as piles decreases up to certain extent, beyond which further increase in raft thickness doesn't affect the settlement at all.
- As thickness of raft increases, differential settlement in raft as well as piles decreases.
- Increase in raft thickness results in increase in bending moments in piled raft.
- It is observed that stiffer the soil, more will be the load shared by raft.

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