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"Analysis of Piled Raft by Geo-Structural Approach"

Submitted By

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ABSTRACT

Piled raft foundations provide an economical foundation option forcircumstances 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 loaddistribution of large piled raft foundation. A finite element method ofanalysis has been performed to estimate the settlement and loaddistribution of a large piled raft foundation. In this method, the raft ismodelled 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 problemsof 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.

INTRODUCTION

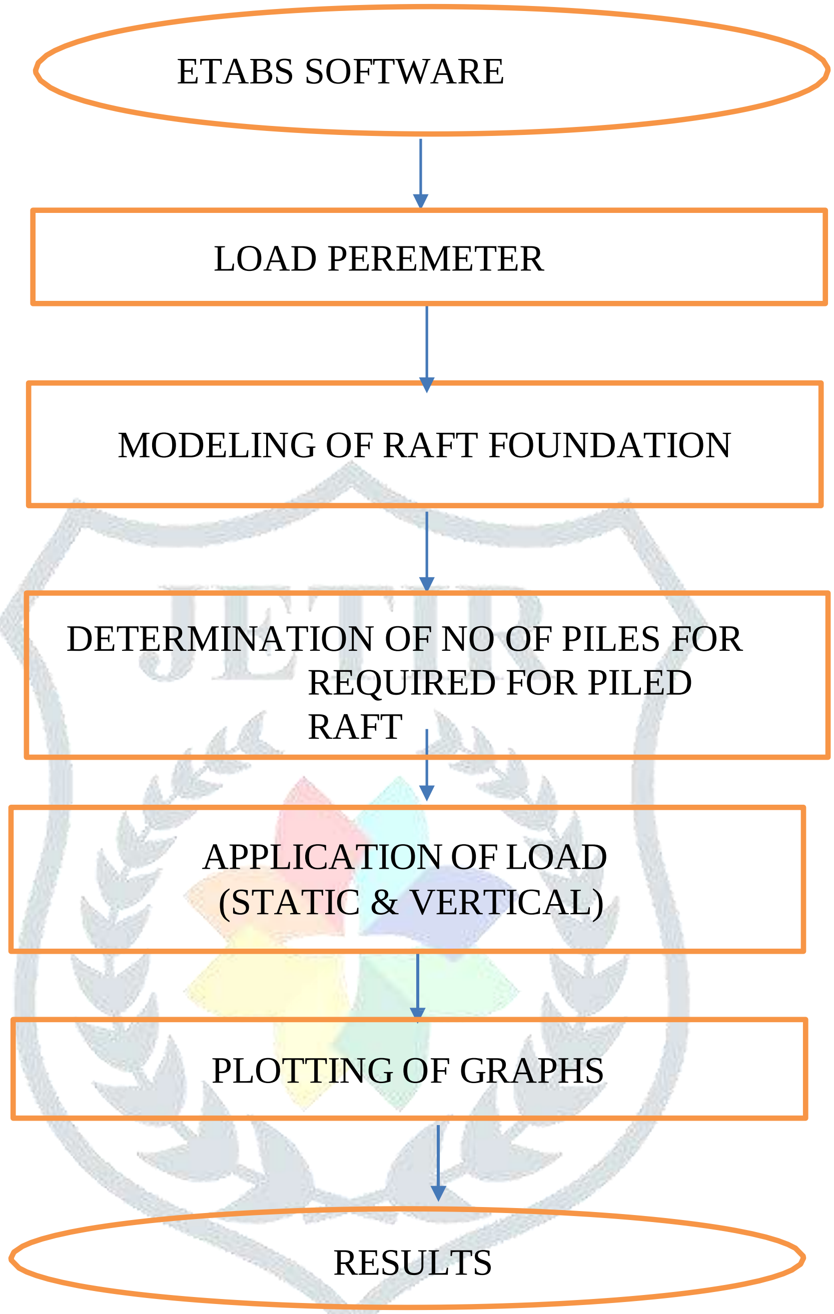
In past few years, the construction of tall structures has become increasingly common and with them new challenges strikes both the structural and geo technical engineers. For this purpose, immense research has been done and it has been recognized that the strategic use of piles can reduce raft settlement and differential settlement, andcan 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 piledraft.

The use of piled raft foundations is considered to thesituations that the raft alone cannot satisfy the design requirements, and thepiles 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 andraft 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 withconventional 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.

THODOLOGY



1. LITERATURE REVIEW ON COMBINED PILE RAFT FOUNDATION (CPRF)

- **Nitin Nandwani, Prof P.J.Salunke, Prof N.G.Gore et. al.** reported that the use of piled raft foundations has become more popular in recent years, as the combined action of the raft and the piles can increase the bearing capacity, reduce settlement, and the piles can be arranged so as to reduce differential deflection in the raft. Piled raft foundation is a new concept in which the total load coming from the superstructure is partly shared by the raft through contact with soil and the remaining load is shared by piles through skin friction. A piled raft foundation is economical compared to the pile foundation. Because piles do not have to penetrate the full depth of clay layer but it can be terminated at higher elevations. Such piled raft foundation undergoes more settlement than the pile foundation and less settlement than the raft foundation. In this paper the study of different parameters like size of the raft, thickness of the raft(500mm, 750mm, 1000mm), diameter of the piles(600mm, 800mm, 1000mm), length of piles(12m), spacing of piles(4D and 5D) etc., which affect the behaviour of piled raft foundation. And its interdependency is also reviewed for G + 20 storey building. This study is useful to decide the various parameters like that maximum settlement of the raft decreases as the diameter of the pile increases, as spacing between the piles increases, settlement increases, the ultimate bearing capacity of Piles will be increased as the Pile diameter increases. To reduce the differential settlement and moment the piles should be place strategically using some trial and error or using parametric study, required in the design of piled raft foundation and suggest the suitable combination of Pile Raft Foundation MATERIALS AND SPECIFICATIONS

- **Aleena Tom, Sindhu A R et. al.** reported that Combined piled raft foundation is an efficient foundation for medium rise buildings in which the superimposed load is transferred to the soil by the combined action of pile and raft and facilitates settlement reduction. Raft and pile are combined in a view to reduce the overall settlement of the structure. In this paper, 1g model study is conducted on piled raft foundation subjected to vertical axial loading. The foundation medium adopted is a layered soil profile. As a result of experimental model study, load- settlement graphs are plotted for various configurations of piled raft where the arrangement, length and spacing of piles are varied. The thickness of raft is kept constant as it has less influence on the capacity. Numerical modelling is done in PLAXIS 3D software to validate the results. The major parameter used in this study to identify the best piled raft configuration is the settlement ratio. As a result of the study, when the number of piles increases settlement ratio decreases and becomes negligible beyond a 4x4 pile arrangement, where the spacing between the piles is 3.75D, where 'D' is the diameter of the pile. Based on the conducted model tests, following conclusions have been obtained, Comparing the load-settlement response of plain raft and piled raft, it is seen that at any given settlement the load taken by the piled raft is greater than that of plain raft, When the number of piles increases, the settlement ratio decreases gradually from 0.929 and becomes 0.032 when the number of piles is increased from 1 to 16, for L/D of 15cm, When the L/D ratio increases from 15 to 25, Settlement Ratio, SR decreases gradually and becomes zero for R + 16P configuration of length 25cm, It can be concluded that as the spacing between piles beyond a value of 3.75D has no effect in reducing settlement, Maximum percentage reduction in settlement occurs at this spacing. This study focused on study of settlement characteristics of combined pile-raft foundation with various arrangements of pile groups using experimental and numerical models. The work can be extended as follows: This study can be extended by the application of lateral loads instead of axial loads. In this study 'Static Loading' was given. Instead of that 'Dynamic Loading' can be given and its effects can be studied. The study can be extended by using 'Bulb Piles' instead of Circular piles.

- **Jaymin. D. Patil, Prof. S. A.Vasanvala, Prof. C. H. Solanki et. al.**[3] reported that with increasing in urbanisation in last three decades all over the world led to rapid increase in number and height of buildings even on problematic subsoil conditions. Piled raft system proves to be more effective on such problematic subsoil conditions. It takes the high vertical load and used to bring the settlement, differential settlement and tilting of structure within the permissible limit. Piled raft system proves to be cost effective than the conventional pile foundation system. Piled raft foundation accounts for complex soil-structure interaction, which needs interaction between structure engineer and geotechnical engineer for giving most economical and safe design of the system. This paper reveals the performance of piled raft foundation in sandy soil, clayey soil and, layered soil carried through experimental and numerical analysis.

- **Shukla S.J., Desai A.K., Solanki C.H. et. al.**[4] reported that a piled raft foundation is a combination of a shallow foundation and a deep foundation with the best characteristics of each of its components. The piled raft foundation is a composite construction consisting of three bearing elements, piles, raft and subsoil. Unlike the traditional design of foundation where the load is carried either by the raft or by the piles, in the design of a piled raft foundation the load share between the piles and the raft is taken into account. In this foundation the piles usually are not required to ensure the overall stability of the foundation but to reduce the magnitude of settlements, differential settlements and the resulting tilting of the building and guarantee the satisfactory performance of the foundation system. The bearing behaviour of a piled raft foundation is characterized by complex soil- structure interactions (Katzenbach et al. 1998). The modelling of these interactions requires a reliable and powerful analysis tool, such as the Finite Element Method in combination with a realistic constitutive law. Different researches have been realized investigations about the numerical modelling of piled rafts with FE analysis and different constitutive models. The present research combines the 3D modelling with a modern and realistic constitutive model. An increasing number of structures, especially tall buildings are founded on piled rafts (O'Neil et al. 1996; Katzenbach et al. 2000, Poulos 2001). For this reason, it is important to develop a methodology to study the bearing behaviour of piled rafts. In this paper different parameters of piled raft foundation like diameter of the piles, thickness of rafts, are discussed. It is incorporated with computational modelling of piled raft foundation. In this research work the analysis was carried out for 25 storey building with 3 different types of sub soil: medium dense sand (ϕ-soil), clayey sand(c- ϕ soil) and clayey soil(c-soil). The FEM modelling was carried out with Winkler's approach with different elasto-plastic spring which represents soil elements with different modulus of sub-grade reaction and study was carried out for time history analysis. In area of research work for static gravitational loading, it was observed that for the first 3 modes, c soil gives highest time period and ϕ soil gives lowest time period. As c soil reflects more flexibility and structure behaves with more flexibly. In case of dynamic analysis, three time histories were applied at the base of the footing with different duration and PGA. In which Bhuj time history was with highest time period and highest PGA where as El-centro time history was with lowest duration and lowest PGA.

- **Nirmal John Joy, Hashifa Hassan et. al.** [7] reported that the Combined pile raft foundations provide an economical foundation option for circumstances where the raft foundation can satisfy the bearing capacity requirement but fails to keep differential as well as maximum settlement below the maximum allowable limit. It had been established that augmenting features like thickness of raft, length of piles etc has decreased the settlement of raft and on other hand: decreasing ‘spacing/depth’ of piles has increased settlement of raft. In this paper permuted arrangement of piles were adopted rather than a uniform arrangements; such that an improved performance of CPRF system can be envisioned. In this paper CPRF is analysed using Finite Element Software PLAXIS 3D with permuted arrangement of piles. Three different Pile diameters and its combinations were modelled and analysed. For the study a 10 storey building founded on Medium Dense Sand was analysed in STAAD.Pro Software to determine the loads to be transferred, after fixing dimensions of raft and settlement analysis of raft PLAXIS 3D work programme was composed. Piled Rafts with various combinations of piles were modelled and analyzed. From the comparison of results, it has been found out that; installing high capacity piles at region with maximum load concentration and reinforcing the rest of the raft with medium capacity piles have the most important effect on significantly reducing maximum settlement and the differential settlement. A few general trends in the behaviour of piled rafts have been studied during this investigation. Thus, from our study on settlement characteristics of combined pile raft foundation founded on sand with various arrangements of piles using Plaxis-3D following points can be concluded, from the results obtained, it is advisable to provide piles with different diameter than with equal diameter irrespective of soil type, from all the possible diameters, it is best to provide larger diameter piles in the interior region to reduce the maximum settlement and the differential settlement. The piles configurations in raft have the most important effect on significantly reducing maximum settlement and the differential settlement, particularly by concentrating the piles in the centre of raft.

LOAD PARAMETER WITH ETABS SOFTWARE ANALYSIS

In this topic, the philosophy of modelling piled raft has beenexplained using combined structural-geotechnical approach. Initiallyto observe the behavior of piled raft, piles are modelled as spring andraft as beam on elastic foundation as shown in **Figure**.

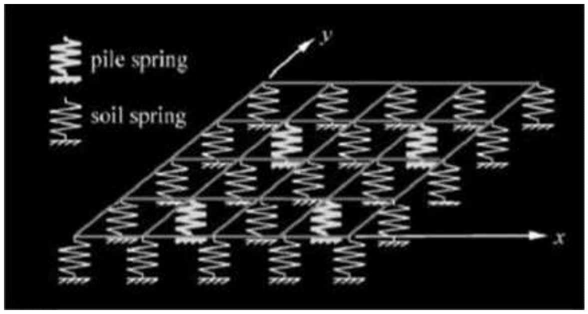


Fig. 1. Structural idealization for raft with pile and supporting soil

For this study, **SAFE** software is used for analysis of piled raft. Thesuperstructure 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 areprovided 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 analyzed for dynamic load using ResponseSpectrum Method. The building is analyzed for dynamic loadusing Response Spectrum Method.

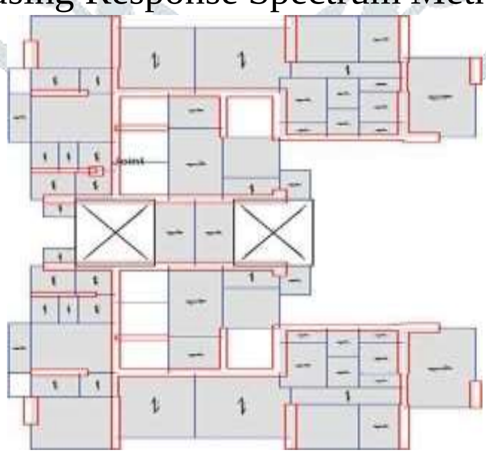


Fig. 2. Typical floor plan of g+45 storey building.

The maximum top storey displacements for wind in X & Y directions are 61 & 63 mm respectively. The maximum top storey displacementsfor 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.

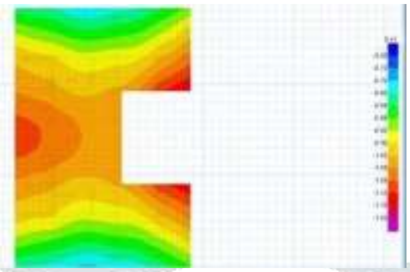


Fig. 3. Upward pressure in raft foundation (1168 KN/m^2)

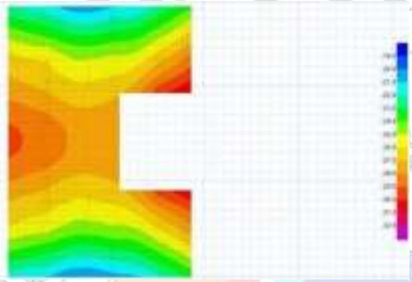


Fig. 4. Displacements in raft foundation (31.15 mm)

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 = 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

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

$$= 1250 \text{ KN/mm}$$

To consider the effect of soil-structure interaction, piles are modelledas 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 piledraft foundation respectively.

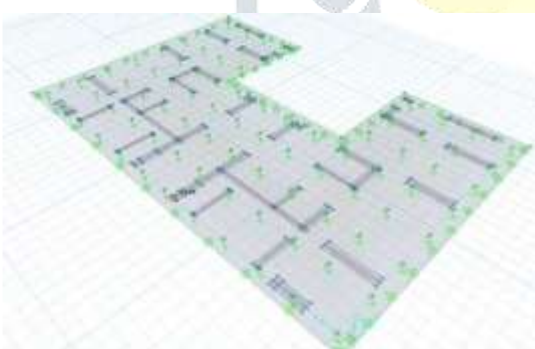


Fig. 5. Layout of piles in piled raft foundation

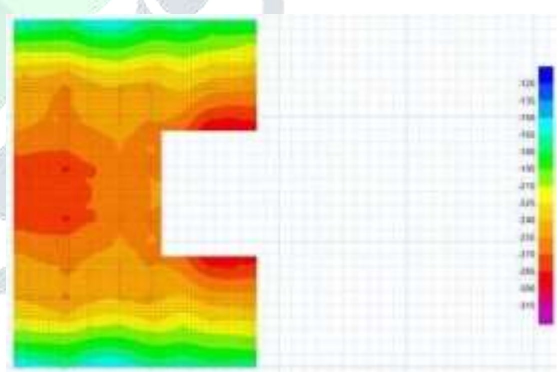


Fig. 6. Upward pressure in piled raft foundation (300 KN/m²)

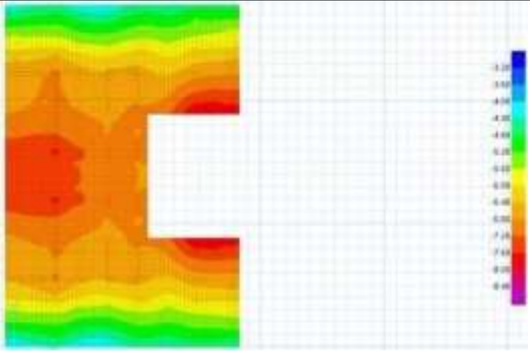


Fig. 7. Displacements in piled raft foundation (8.00 mm)

B. Parametric Study*:*

Parametric study is carried out by changing different parameters of piled raft. The effect of varying raft thickness, spacing of piles, lengthof piles, diameter of piles and stiffnessof soil are observed. Followingaspects are considered forparametric 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 stiffnessof 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.

RESULTS AND DISCUSSIONS

Comparison of Structural Forces, Settlements in Raft and Soil Pressure in case of Raft and Piled Raft. The following tableshowsvariations 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 raftcarry more load as compared to piles located at edge of piled raft.

Therefore, it is beneficial to provide piles of smalldiameter or smallerlength to make foundation more economical.

Effect of Varying Raft Thickness on Settlement of Raft, Settlementof Piles and Maximum Bending Moment. For a Forty-five storey building, increasing the raft thickness results in decrease in settlementin raft as well as piles up to certain extent, beyond which further increase in raft thickness doesn’t affect the settlement at all. Also withthe increase in raft thickness the differential settlement reduces considerably. It is also observed that with increase in raft thickness the dead loadincreases 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 raftthickness.Fig. 9 shows variation of max positive and negative bending momentswith increase in raft thickness.

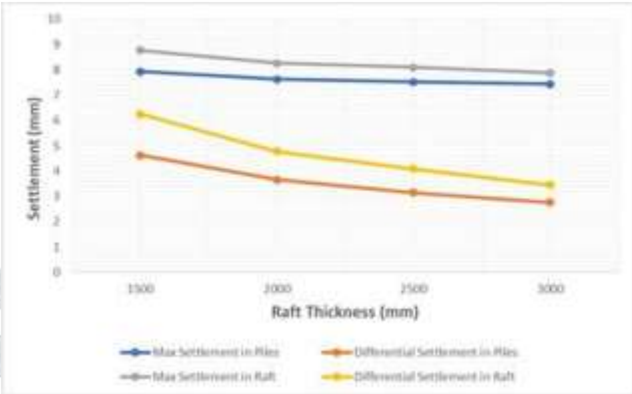


Fig. 8. Graph of raft thickness v/s pile settlement

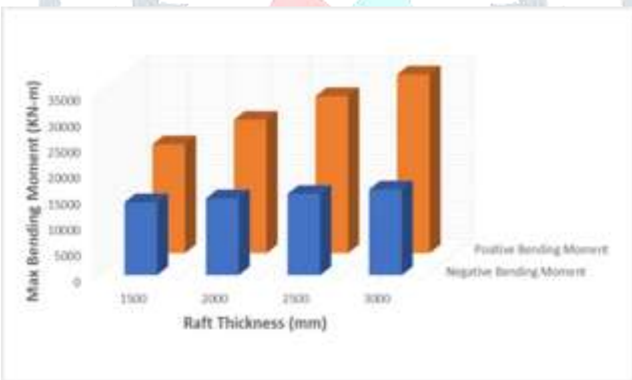


Fig. 9. Graph of raft thickness v/s max bending moments

Effect of Varying Soil Stiffness on Load Carrying Capacity of Pilesand 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 showseffect of soil stiffness on load carrying capacity of piled raft.

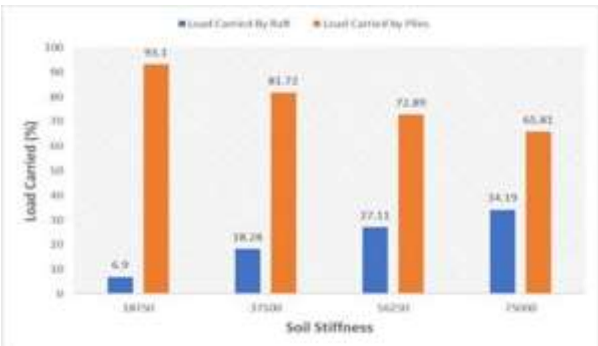


Fig. 10. Graph of soil stiffness v/s load carrying capacity of raft and piles

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.

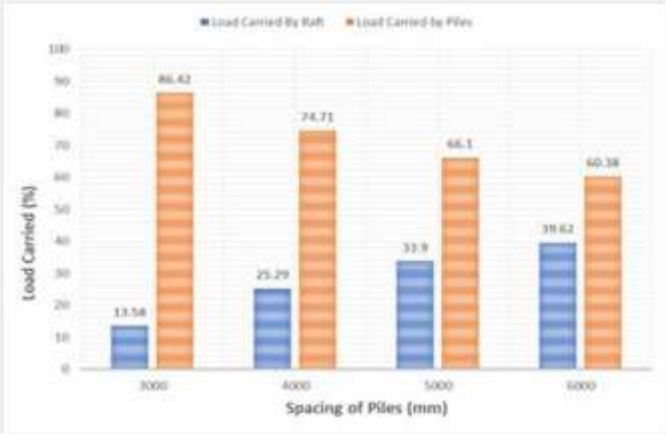


Fig. 11. Graph of spacing of piles v/s load carrying capacity of raft and piles

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 settlementin raft and pile decreases. It is also observed thatas 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 inbending moment with respect to length of piles is shown in fig. 13. Whereas, change in load carrying capacity ofpiled raft with change inlength of piles is shown in fig. 14

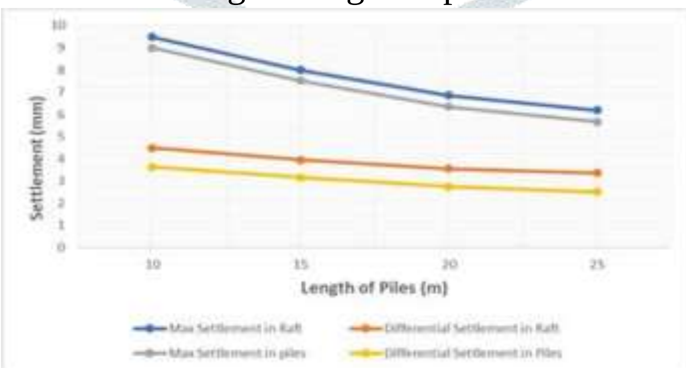


Fig. 12. Graph of length of piles v/s settlement of raft and piles

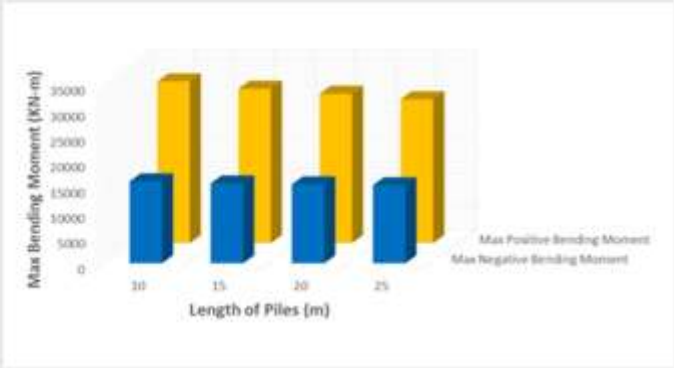


Fig. 13. Graph of length of piles v/s max bending moment

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 withincrease in diameter of piles is shown in fig. 17.

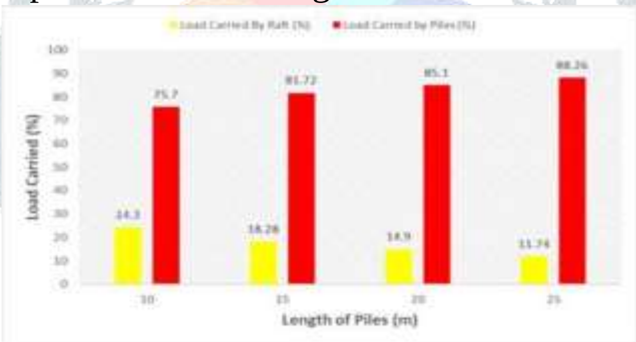


Fig. 14. Graph of length of piles v/s load carrying capacity of raft and piles

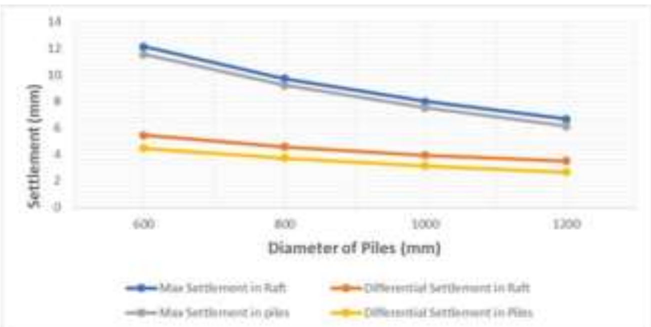


Fig. 15. Graph of diameter of piles v/s settlement of raft and piles

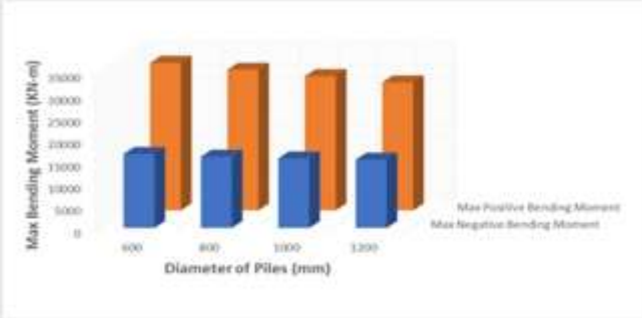


Fig. 16. Graph of diameter of piles v/s max bending moment

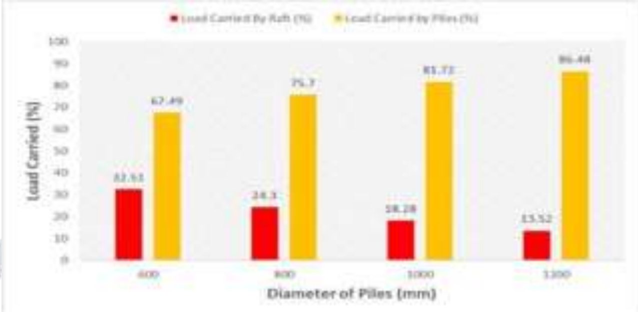


Fig. 17. Graph of diameter of piles v/s load carrying capacity of raft and piles

CONCLUSION

The studies indicate that piled raft foundation concept has significantadvantages in comparison to conventionalfoundation for the availablesoil strata. From the studies, the following points have been observed.

- Piled raft foundation efficiently decreases settlements, differentialsettlements 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 momentsin piled raft.
- It is observed that stiffer the soil, more will be the load shared byraft.
- As thickness of raft increases, maximum settlement inraft as wellas 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 momentsin piled raft.
- It is observed that stiffer the soil, more will be the load shared byraft.

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