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A PARAMETRIC STUDY ON BEHAVIOUR OF PILED RAFT FOUNDATION-STRUCTURE INTERACTION EFFECTS ON SEISMIC PERFORMANCE OF MULTI-STORY REGULAR RC MRF BUILDING

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ABSTRACT

Present studies show that the effects of Soil Structure Interaction (SSI) may be detrimental to the seismic response of structure and ignoring SSI in analysis may lead to un-conservative design. Despite this, the orthodox design procedure usually involves assumption of fixity at the base of foundation ignoring the flexibility of the foundation, the compressibility of soil mass and consequently the effect of foundation settlement on further redistribution of bending moment and shear force demands. The effects of SSI are analyzed for typical G+15 story regular building resting on raft foundation and piled raft foundation. Two different type of loading pattern (surface load and Point load) and varied raft thickness used for seismic demands evaluation of the target moment resistant frame building. Three-dimensional Finite Element (FE) model is constructed to analyze the effects of soil structure interaction in layered soil condition. Numerical results obtained using soil structure interaction model conditions are compared for surface loading and point loading conditions. The peak responses of maximum settlement, load sharing ratio, shear force in raft and piled raft foundation, bending moment in raft and piled raft foundation, axial force on pile are analyzed.

Key words: Soil Structure Interaction, Piled Raft Foundation, Raft Foundation, Plaxis 3D.

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1. INTRODUCTION

Recently with the increasing in economical development, rapid industrialization and decreasing availability of land for construction in thickly populated countries like India, Germany etc. scope for extending construction in horizontal direction is becoming increasingly lesser resulting in construction of high-rise building with increasing number of floors. In the design of foundations for large buildings on deep deposit of cohesive soils it is generally seen that raft foundation be chosen the foundation will have sufficient factor of safety against shear failure but corresponding settlement will be very high to permit. In such cases pile foundation are generally selected causing very large cost for such foundations. The settlements are successfully controlled in such foundations, however in the late, it has been recognized if few number of piles are installed at suitable locations below the raft foundation for such structures, the resultant settlement under such structure will be much smaller and will be within permissible limits compared to that below the raft without provision of piles. Use of raft in conjunction with some piles will be costlier than in case where only raft is used if possible but much less than the case when only piles are used. As a result in the past decades there has been increasing recognition to use some piles with raft to reduce the total and differential settlement of raft leading to considerable economy without compromising the safety and performance of the foundation structure system. Such a foundation system is called piled-raft. One of the most important buildings constructed with such system is for the foundation system of the world's tallest building the Burj Dubai. Similar foundations are also being adopted in India for twenty-five story building at Surat (Shukla S.J., Desai A.K., and Solanki C.H. 2013) [20]. The adoption of piled-raft foundation for high rise buildings is also very common in European cities. Thus it seems on the other countries, piled-raft foundation will be increasingly adopted as a most economic safe foundation system.

1.1. Concept of Piled Raft Foundation

The piled raft is a composite geotechnical foundation system, which acts as a composite construction consisting of the three bearing elements: piles, raft and sub soil. Figure 1 demonstrates the principle of piled raft foundation and different interaction (e.g. pile/ pile and pile/raft) that governs its behavior. In conventional design of pile foundations, it is assumed that the total applied load has to be carried only by the piles with a certain factor of safety against bearing failure. Considering the contribution of raft, this can lead to a more economic foundation in comparison with a pure pile foundation. The pile can be designed in such cases to carry loads to their ultimate capacity. The main criterion that governs the design of piled raft concerns the relative proportion of load carried by the raft and piles; and the effect of the additional pile support on foundation settlement. The pile is assumed to have a solid cross-section and is divided into a series of two nodded linear elements. The soil is divided into several layers which correspond to the pile elements. The skin friction along the pile shaft is treated as a series of ring loads acting on each soil interface and the force at the pile base is treated as a uniform circular load with the same diameter as the pile as shown in Figure 2.

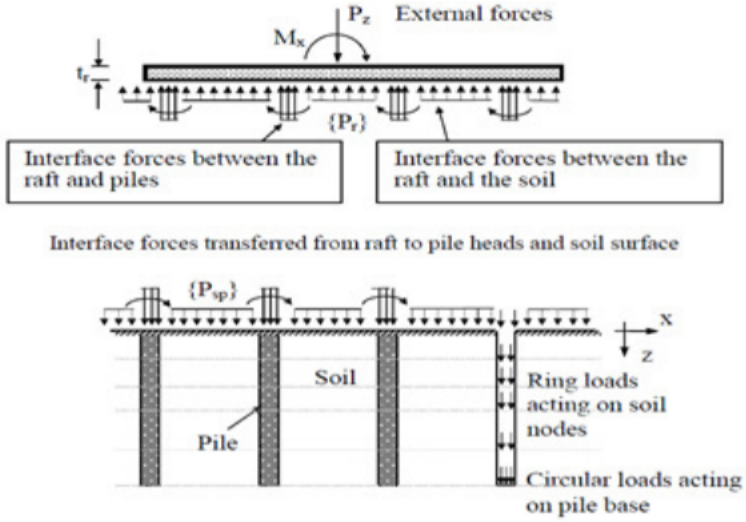


Figure 1 Raft and Pile group subjected to external forces and interface forces in all directions (J.C. Small & H.H. Zhang, 2002) [17]

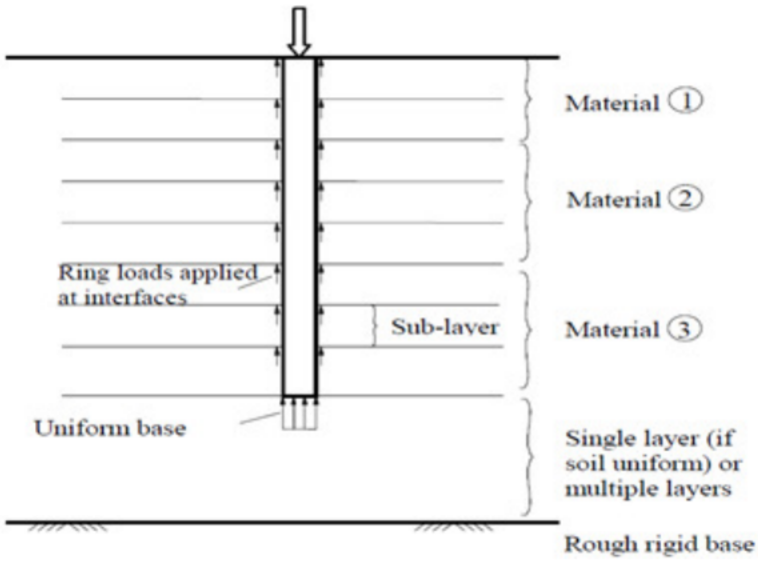


Figure 2 Single pile showing ring loads and uniform base load (J.C. Small & H.H. Zhang, 2002) [17]

1.2. Seismic Analysis Procedures

In the preliminary design process, equivalent static seismic forces are used to determine the design internal forces of structural members using linear elastic analyses of structure and in turn, determine the design member strength demands. Such static seismic forces are simply determined corresponding to the elastic design acceleration spectrum divided by a structural strength reduction factor particularly called: the response reduction factor R (IS 1893 (Part-1) 2016). The adopted strength reduction factor is thus intended to represent an expected inelastic response demand or expected damage level demand of the whole structure, which may be induced during earthquake excitation. For the analysis of G+15 story building two methods: Equivalent Static Load (ESL) and Response Spectrum (RS) method are used.

2. DATA USED AND RAFT AND PILED RAFT FOUNDATION MODELING

Identifying the important parameters which significantly affect the performance of piled-raft foundations can assist in optimizing the design of such foundations. Therefore, studying the effect of different design parameters on the behavior of piled-raft foundations was carried out. This study focused on the effect of some parameters on the load-settlement between the raft and piles of piled-raft foundations. The effect of the selected parameters on the load-settlement relationship will be investigated at small and large settlements. The tests in this study were carried out using the developed PLAXIS 3D model. One pile arrangements were considered in this study. Square piled-rafts 0.6 m diameter pile supported 4x4 piles and 4d spacing were studied. For analyzing the building G+15 story RC building with ESL and RS method are consider. After analyzing the G+15 story building considering the surface load as 321 kN/m^2 and two different point loads condition (ESL and RS) is taken for the study. The Plan of the G+15 Story building as shown in Figure 3.

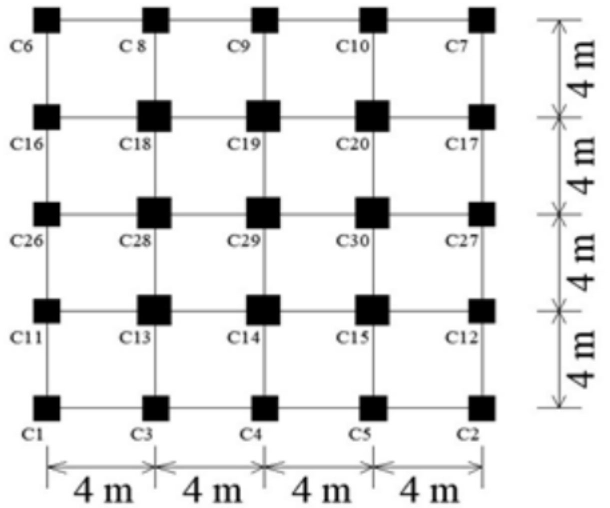


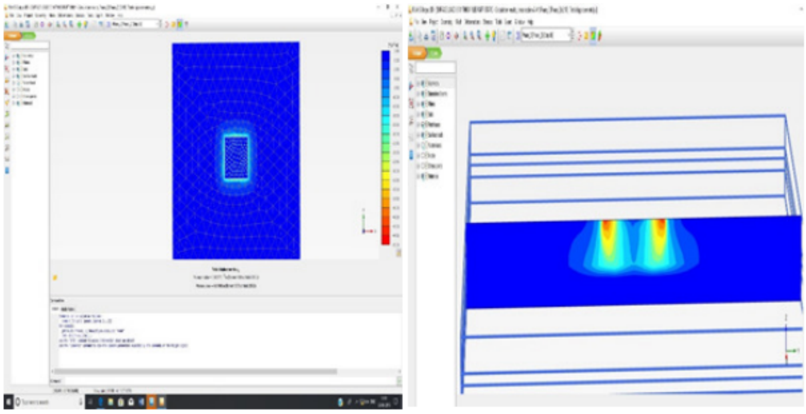
Figure 3 Plan of G+15 Story RC Building

Four different layer of soil is consider for the study which is existing at Puna Gam near Surat city. The Properties of different soil layer are as shown in Table 1. Thickness of raft is consider as 0.5 m, 0.8 m and 1.0 m.

Table 1 Properties of Soil adopted in Plaxis 3D software for study

Description	Silty clay with	Silty Sand with	Silty Sand	Silty Sand
Thickness (m)	4	1	1.5	3.2
Unit Weight, γ (kN/m^3)	16	17	17	18
C'	7	7	0.5	0.2
Friction Angle, ϕ, (deg.)	26	26	32	32
Dilatant Angle, ψ, (deg.)	0.1	0.1	0.01	0.02
Young's Modulus, Es ,(	134939.50	96889.70	13800.00	254973.00
Poisson's Ratio, υ	0.3	0.3	0.3	0.3

Figure 4 shows the Plaxis 3D software view for (a) raft foundation and (b) piled raft foundation respectively.



(a) (b)

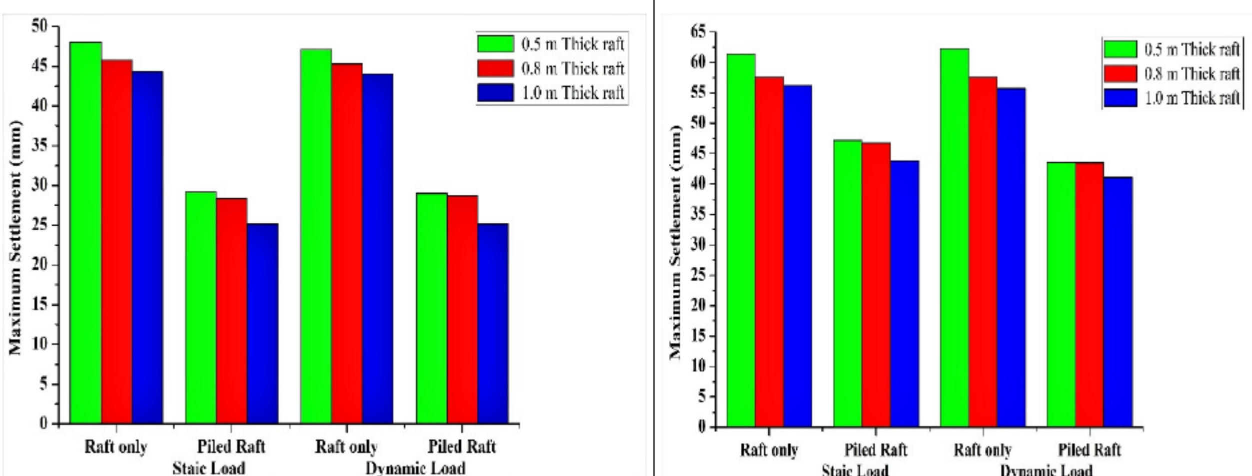
Figure 4 Plaxis 3D software view of (a) Raft Foundation (b) Piled Raft Foundation

3. RESULTS AND DISCUSSION

For the parametric study of raft thickness, the plan dimensions of raft taking constant as 18 m X 18m as square raft is assumed and the thickness of raft varying as 0.5m, 0.8m and 1.0m. The pile diameter taken as 0.6m and spacing between piles is taken as 4d, while 4X4 group of piles is assumed and static and dynamic load is considered for this parametric study.

3.1. Effect of Type of Loading on Maximum Raft Settlement

The effect of maximum settlement of raft thickness is presented in the Figure 5 for surface loading and point loading for two different loading condition. It can be stated that the effect of raft thickness on load-settlement relationship of piled-raft foundations is the same at small or large settlement levels.



Raft only (mm)	Piled raft (mm)	Raft only (mm)	Piled raft (mm)	Thickness of raft
48.01	29.2	47.1	29	0.5 m Thick
45.81	28.37	45.31	28.7	0.8 m Thick
44.32	25.16	44.03	25.15	1.0 m Thick

(a)

Raft only (mm)	Piled raft (mm)	Raft only (mm)	Piled raft (mm)	Thickness of raft
61.34	47.17	62.21	43.57	0.5 m Thick
57.58	46.77	57.57	43.48	0.8 m Thick
56.19	43.8	55.72	41	1.0 m Thick

(b)

Figure 5 Maximum settlement for raft foundation and piled raft foundation for static and dynamic load condition under (a) surface load (b) point load condition for different raft thickness

Within the range of raft thickness 0.5 m to 1.0 m considered in this study and it was found that as soon as raft thickness increases 0.5 m to 1.0 m then there is little decreases in settlement.

Maximum settlement in point load is more than surface load condition. As the thickness of raft increases from 800mm to 1000 mm, there is a minor difference in maximum settlement.

3.2. Effect of Load Sharing

The effect of load sharing by raft and pile raft foundation is shown in the Figure 6.

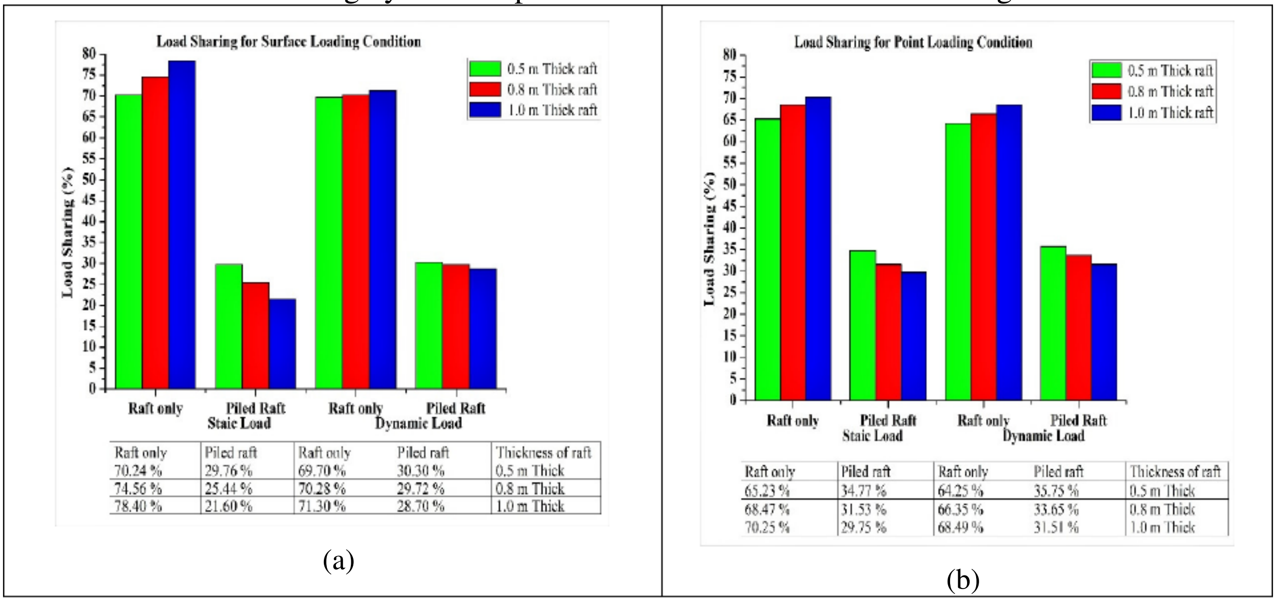


Figure 6 Load sharing ratio for raft foundation and piled raft foundation for static and dynamic load condition under (a) surface load (b) point load condition for different raft thickness

As soon as raft thickness increases 0.5 m to 1.0 m then there is little increases in load sharing by raft. Maximum load sharing in point load is less than surface load condition.

3.3. Shear Force in Raft Foundation and Piled Raft Foundation

The effect of surface loading and point loading for shear force of static and dynamic loading consider for this parametric study shown in Figure 7.

As the raft thickness increases from 0.5m to 1.0 m it was found that shear force is decreases.

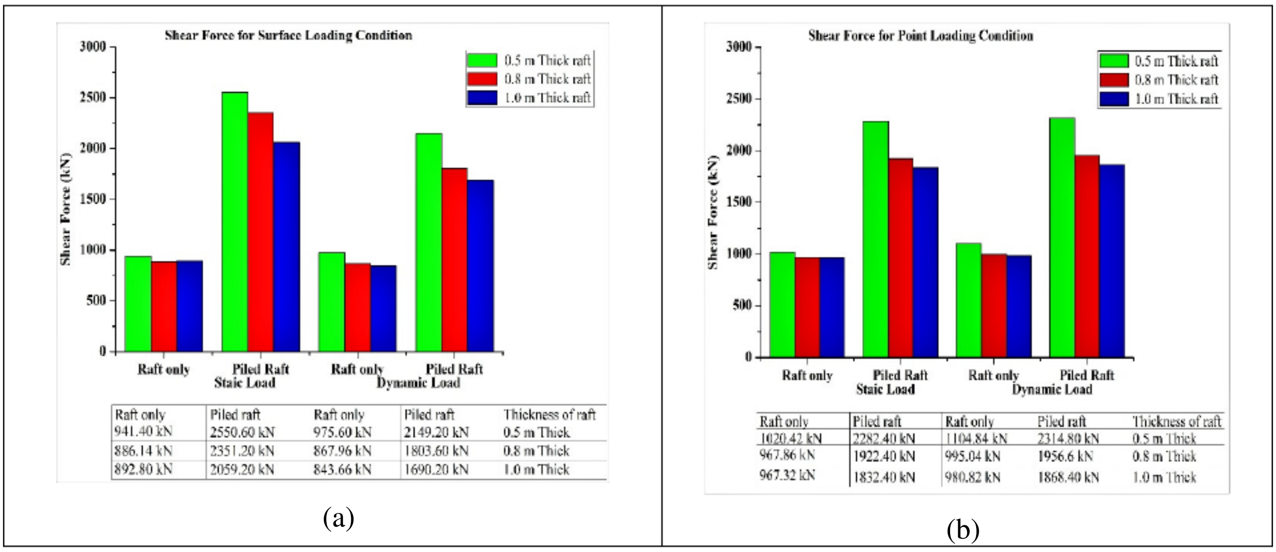
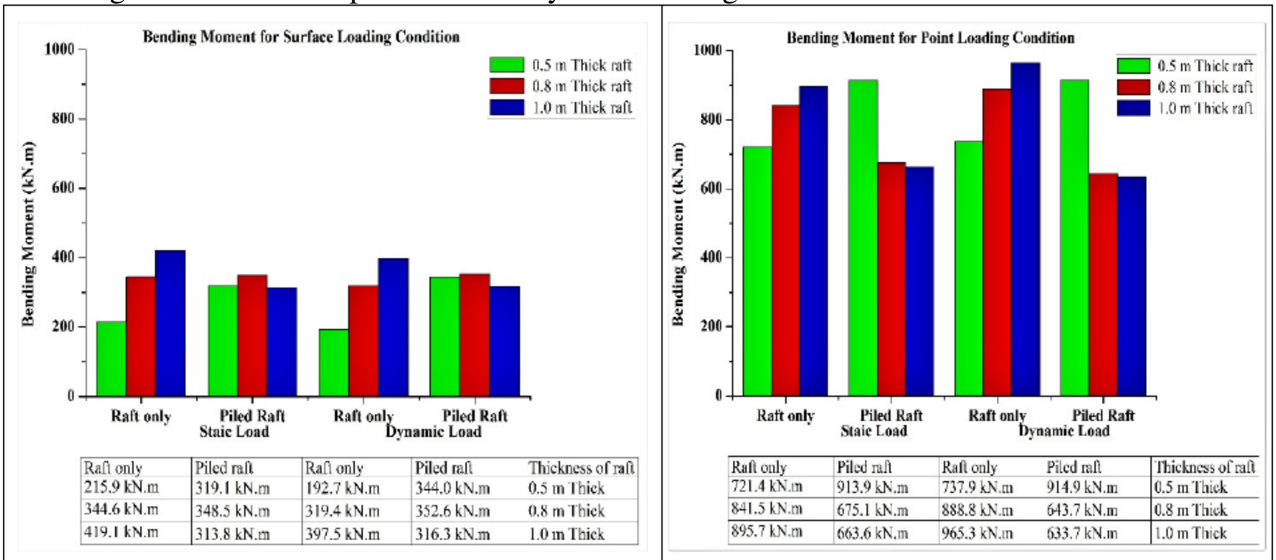


Figure 7 Shear force for raft foundation and piled raft foundation for static and dynamic load condition under (a) surface load (b) point load condition for different raft thickness

3.4 Bending Moment in Raft Foundation and Piled Raft Foundation

The effect of surface loading and point loading for bending moment of static and dynamic loading consider for this parametric study shown in Figure 8.



(a) (b)

Figure 8 Bending moment for raft foundation and piled raft foundation for static and dynamic load condition under (a) surface load (b) point load condition for different raft thickness

As raft thickness increases from 0.5 m to 1.0 m bending moment is increases in raft foundation for surface loading and point loading condition.

3.5. Effect of Axial force on Pile

For the parametric study of raft thickness, the plan dimensions of raft taking constant as 18 m X 18m as square raft is assumed and the thickness of raft varying as 0.5m, 0.8m and 1.0m. The pile diameter taken as 0.6m and spacing between piles is taken as 4d, while 4X4 group of piles is assumed. The effect of surface loading and point loading for axial force of static and dynamic loading consider for this, results of parametric study as shown in Figure 9.

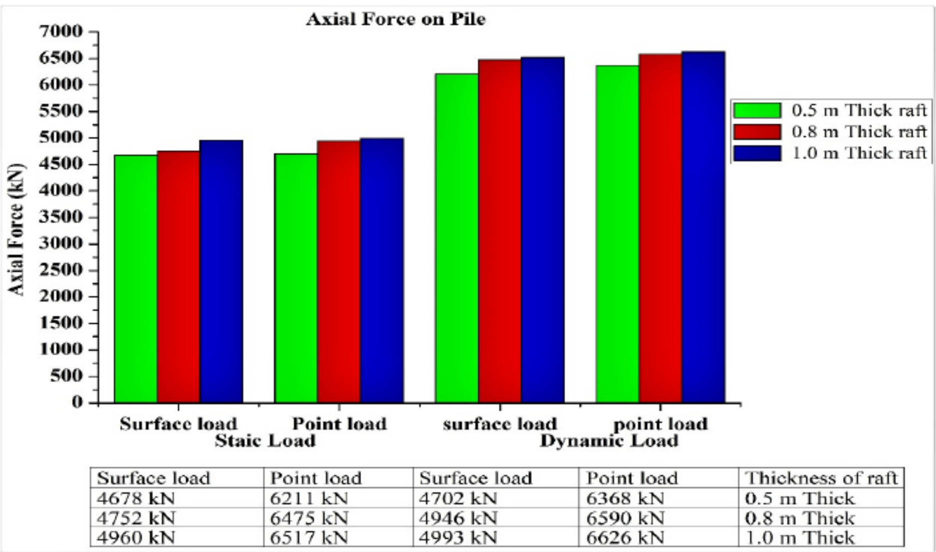


Figure 9 Axial Force on Pile for Static and Dynamic Load condition under Surface load and point load condition for different Raft Thickness

As raft thickness increases from 0.5 m to 1.0 m axial force on pile increases from 4678 kN to 4960 kN and 4702 kN to 4993 kN for surface load and 6211 kN to 6517 kN and 6368 kN to 6626 kN for point load under static load and dynamic load condition respectively.

4. CONCLUSION

- Average maximum settlement in raft foundation for static loading are 46.04 mm and 58.37 mm and for dynamic loading are 45.48 mm and 58.50 mm under surface load and point load condition.
- Average maximum settlement in piled raft foundation for static loading are 28.57 mm and 45.91 mm and for dynamic loading are 28.61 mm and 42.68 mm under surface load and point load condition.
- As the raft thickness increases the settlement decreases.
- Average maximum load sharing for raft foundation under static loading are 74.40 % and 67.98 % and 70.43 % and 66.36 % under under dynamic loading for surface load and point load condition.
- As the raft thickness increases the load sharing by raft is increases.
- The load sharing ratio in point load condition is laser than the surface load condition for raft foundation.
- The load sharing ratio in point load condition is greater than the surface load condition for piled raft foundation.
- As the raft thickness increases the shear force decreases.
- Average shear force in raft foundation for static loading are 906.78 kN and 985.20 kN and 975.60 kN and 1026.90 kN for Dynamic loading under surface load and point load condition.
- Average shear force in piled raft foundation for static loading are 2320.33 kN and 2012.4 kN and 2821.50 kN and 2046.60 kN under surface load and point load condition.
- As the raft thickness increases the bending moment increases.
- Average bending moment in raft foundation for static loading are 326.53 kN.m and 819.53 kN.m and 303.20 kN.m and 864.00 kN.m under surface load and point load condition.
- Average bending moment in piled raft foundation for static loading are 327.13 kN.m and 750.77 kN.m and 337.63 kN.m and 730.76 kN.m under surface load and point load condition.
- As the raft thickness increases the axial force on pile increases.
- Average axial force on pile for static loading are 4796.67 kN and 6401.00 kN and 4880.33 kN and 6528.00 kN for dynamic loading under surface load and point load condition.

It is observed that as the raft thickness increases the settlement decreases, load sharing ratio increases, shear force decreases, bending moment increases and axial force on pile increases.

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